Managing Water in the face of Growing Scarcity, Inequity and Declinging Returns: Exploring Fresh Approaches

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IWMI TATA Water Policy Research Program

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IWMI-TATA Water Policy Research Program (IWMI-TATA Program)

The IWMI-TATA Water Policy Research Program (ITP) was launched in 2000 as a collaborative program of International Water Management Institute (IWMI) and Sir Ratan Tata Trust, Mumbai. ITP emerged in response to widely articulated problems of growing water stress in many parts of India, with several detrimental consequences to the society.

The program aims at evolving new perspectives and practical solutions derived from the wealth of research done in India on water resources management. The objective of ITP is to help policy makers at the central, state and local levels to address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations.

ITP engages Indian scientific/academic institutions in addition to in-house researchers in a practical agenda to identify, analyze and document relevant water-management approaches and current practices. This program is seen to fill critical gaps in India's water sector research by bringing in multi-disciplinary perspectives in the analysis of water related problems.

Since its inception, ITP has worked on 18 themes in the water sector and brought out three books, over 80 research papers in national and international journals and nearly 300 discussion papers. In addition, ITP had initiated two major field interventions aimed at improving water resources management and enhancing water-based livelihoods of rural communities.

International Water Management Institute (IWMI)

The International Water Management Institute is a non-profit scientific research organization specializing in improving water and land resources management for food, livelihoods and nature.

IWMI targets water and land management challenges faced by poor communities in the developing world/or in developing countries and through this contributes towards the achievement of the UN Millennium Development Goals (MDGs) of reducing poverty, hunger and maintaining a sustainable environment. These are also the goals of the CGIAR.

IWMI is one of 15 international research centers supported by the network of 60 governments, private foundations and international organizations collectively known as the Consultative Group of International Agricultural Research (CGIAR). IWMI has staff of about 350 and offices in 12 countries across Asia and Africa.

Sir Ratan Tata Trust (SRTT)

Set up in 1919, the Sir Ratan Tata Trust situated in Mumbai, is one of the oldest philanthropic intuitions in India, and has played a pioneering role in changing the traditional ideas of charity. Through its grant making, the trust supports efforts in the development of society in areas of rural livelihoods & communities, education, enhancing civil society & governance, health, arts & culture.

Annual Partners' Meet

ITP's Annual Partners' Meet (APM) is one of the largest event focusing on water issues in India with the aim to disseminate the findings of the studies conducted by ITP, its partners and other researchers to a large group of stakeholders including government officials, policy makers, development professions, leading water scientists and representative of international organizations from across the globe. Substantial participation from central and state governments is of this meet.

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FOREWORD

"Managing Water in the Face of Growing Scarcity, Inequity and Declining Return" is not a new topic for discussion by the water fraternity. But, it is perhaps the first time it has been adopted as a theme for a conference and examined in a comprehensive manner. **"Exploring Fresh Approaches"** is one of greatest challenges that water professionals face and is both complex and profound. It is for this reason that we bring together renowned individuals to the IWMI-Tata Annual Partners Conference - which is considered as a major gathering of water professionals in the country - to think, innovate, debate, motivate and recommend what concrete steps we can take that will help meet the challenges facing the water sector of India.

This volume brings together papers presented and deliberated at the 7th annual conference held on 2-4 April, 2008 at ICRISAT campus, Patancheru, Andhra Pradesh. The papers offer new perspectives and practical solutions derived from research carried out under the IWMI-Tata Policy Research Program and those done by other scholars on water issues in India. Papers included in this volume cover five key topics: subsidizing micro-irrigation systems in India; groundwater depletion and its socio-economic impacts; water policies and legal frameworks; water harvesting and groundwater recharge; water, economic growth and human well-being. The aim of ITP is to help policy makers at the central, state and local levels to address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations.

The holding of the conference was possible through the funding from Sir Ratan Tata Trust (SRTT). We acknowledge the support and encouragement received from the Program Manager of SRTT Mr. Arun Pandhi. We also express our appreciation to Dr. Colin Chartres, Director General of IWMI, Dr. Peter McCornick, Director for Asia and Dr. Debbie Bossio, Theme Leader for their support and encouragement.

Dr. Dinesh Kumar, Head of the IWMI-Tata Policy Research Program provided the inspiration and Leadership for the conference. It is because of his efforts that the papers in this volume were peer reviewed and published in time for the conference. Dr. Kumar was ably supported by his colleagues, Kairav Trivedi, Vidhya Ramesh, Nidhi Ladha, Sacchidananda Mukherjee, Nitin Bassi and Dr. M.V. K. Sivamohan. Finally, a special word of thanks goes to Navanith, Judy, Aparna and many others for their productive contributions.

Madar Samad
Head, South Asia
International Water Management Institute

ACKNOWLEDGEMENTS

We owe our thanks to many individuals and institutions in bringing this work to fruition. First of all, I, personally and also on behalf of the IWMI-Tata water policy research program, would like to express my deep sense of gratitude to all the contributors to this volume. I appreciate their sincerity in responding to our queries and requirements promptly, in completing all the formalities relating to finalization of the papers and printing.

We would also like to thank Sir Ratan Tata Trust, and its Senior Programme Manager, Shri Arun Pandhi for having provided the generous support for making the Annual Partners' meet of this collaborative program and publication of this volume possible.

Dr. Madar Samad, Principal Researcher and Head, IWMI-India, has provided invaluable suggestions and advices on varied issues, from design of the partners' meet to setting up the norms and quality standards for selection of papers and deciding the themes and topics to be discussed in the conference. We are indebted to him for these inputs.

The scientific Committee, which reviewed the papers, consisted of six scholars working in the water sector. They are Dr. Narayanamoorthy, Reader, Gokhale Institute of Politics and Economics, Pune, Prof. R. Parthasarathy, Director, Gujarat Institute of Development Research (GIDR), Ahmedabad, and Dr. P. K. Vishwanathan, Reader, GIDR, Dr. L. Venkitachalam, Reader, Madras Institute of Development Studies, Chennai, Dr. V. Ratna Reddy, Professor, Centre for Social Studies, Hyderabad, and Dr. M. V.K. Sivamohan, Consultant, IWMI. We are also indebted to them for having meticulously gone through the draft versions of the papers which were selected for this volume, for giving very specific, targeted and constructive comments, which I believe, had immensely helped improve the quality of the papers.

Ms. Nidhi Ladha, development consultant, Hyderabad had painstakingly and meticulously edited more than 90 per cent of the papers included in this volume. We are extremely thankful to her for having accepted this task on a short notice, and completed it on a war footing without compromising on the quality.

To be sincere, it would be difficult to include 'in extenso' the very large number of people, whom I am indebted to, for this work.

M. Dinesh Kumar

Researcher and ITP Leader

PREFACE

India is facing a major water crisis. But, the origin of this crisis is in the increasing realization that very little is known about the nature and magnitude of water scarcity, and the causes for such scarcity situation. At the fundamental level, there is little understanding of the probable ways in which the major factors driving water situation such as economy, society, environment, demography, technology and governance forms could unfold in future. Uncertainty exists about the type, nature and magnitude of water problems that India is likely to face in the coming decades due to lack of consensus on the approaches and methodologies for forecasting water scenarios.

On the civil society front, there were intense debates on the approaches to deal with water scarcity. These debates are by and large characterized by polarized positions. Many from within water bureaucracies and outside believe that solution to avert an impending future water crisis lies in mega water transfer projects that could take water in bulk from well-endowed to poorly endowed regions. They believe that the future social tensions and ecological crisis that can be perpetuated by water scarcity would be enormous and widespread that they would justify the localized negative social and ecological impacts of major water transfer projects.

On the other hand, many have mooted water demand management to avert a crisis, some focusing mainly on improving water productivity in agriculture to make more water available for environment. They argue that significant improvements in productivity of both rainwater and irrigation water is possible through farm management and on-farm water management. Though over the past 25 years, there have been significant improvements in efficiency of water use in irrigation globally leading to leveling off of water use, it has mostly been in developed countries.

Globally, many advocate rainwater harvesting not only as a means to augment the supplies, but often as a source of irrigation supplement to enhance the productivity of rainwater. In India, it mainly concerns runoff harvesting in rural areas, and artificial groundwater recharge to create buffer for drought-proofing. Voluntary organizations strongly advocate the need to exercise control on the use of water in agriculture, domestic sector and pollution assimilation, and lobby for stringent regulations on water withdrawal and use.

On the implementation front, decentralization and participation of stakeholders at different levels are often discussed as institutional alternative in water development and management actions, to circumvent the evils in the conventional approaches. NGO involvement is strongly being argued as a catalyst for fostering community participation. The underlying assumption is that NGOs represent the voice of the poor and could be used to deliver the services, which governments fail to provide. Whereas in certain other situations, the need for involving Panchayat Raj Institutions (PRIs) in water management is emphasized. A few experiments are underway in irrigation and drinking water sector for participatory management.

Many scholars believe that the huge stock of groundwater and plenty of surface water resources in the Ganga-Brahmaputra-Meghna basin could be tapped to meet India's future water needs. Such propositions have ignored the low demand for water in the region, due to poor availability of arable land, ecological factors, and poor socio-economic and volatile political situation inhibiting farmers from investing in irrigation infrastructure. Suggestions for policy interventions often made to boost the demand for water in agriculture had looked at the ways to overcome economic constraints, ignoring the agro-hydrological, ecological, political, and sociological features.

Often, projections of India's irrigation growth by both government agencies and scholars harp heavily on the official figures of untapped groundwater stock, purely on hydrological considerations of recharge and abstraction. They hardly factor in the regional and local resource dynamics and trends. Part of the problem is the "hydro-schizophrenia", where the contribution of groundwater to maintaining the lean season flows in rivers is ignored in resource assessment methodologies, leading to over-estimation of the utilization potential from either surface water or groundwater. So is the case with contribution of canal water to augmenting groundwater supplies in command areas.

On the other hand, governments are investing mammoth sums in rehabilitating tanks, especially in South India. But, there have been limited attempts to understand the functioning of tanks as part of an integrated hydrological system comprising groundwater, surface water and catchments. In many situations, tanks are situated in regions which have experienced dramatic increase in groundwater use, and major land-use changes. The governments are also simultaneously investing in watershed development in the upper catchments of tanks. Groundwater development in command areas and upper catchment watershed interventions, often have major negative impacts on the tank inflows. Understanding these interactions is crucial for deciding investment priorities in water resources in such regions.

In India, the proponents of rainwater harvesting have been successful in projecting "local water harvesting solutions" as a significant alternative to the conventional water projects that involve large engineering interventions, huge capital investments, and having major social and environmental imperative. The World Commission on Dams report also advocates local water harvesting solutions for the said reasons. NGOs, civil society organizations and local governments alike had implemented local water harvesting and groundwater recharge projects on a large scale in many arid and semi-arid parts of the Indian country-side.

But, very little systematic and scientific analysis exists on the potential of rainwater harvesting and groundwater recharging in water-scarce regions. More importantly, very little analysis is available on the comparative economics of rainwater harvesting projects, against large water resource projects. The scientific accuracy of certain claims about rainwater harvesting such as improved runoff collection efficiency is often subject to questioning. Another big issue to be resolved is how many local interventions would be required to achieve the same productive impact as a single large intervention, and their social and downstream environmental impacts.

While the concept of water productivity and "more crop per crop" have gained acceptance in policy circles in India, the complex concepts underlying it are poorly understood. Very little understanding exists on the drivers of change in water productivity, and the opportunities and constraints in enhancing the same. On-farm water management and farm management can improve crop water productivity. But, farmers' ability to carry out on farm water management depends on the quality and reliability of irrigation water supplies. Further, their ability to carry out agronomic practices also depends on the quality and reliability of irrigation.

Drip irrigation is advocated by the government of India (GoI) as a panacea for all water problems in water-scarce regions. The Task Force on Micro Irrigation (MI) estimated that a total area of 97 m. ha could be brought under MI systems. But, little attention has been paid to the constraints facing the farmers in adopting this system such as: erratic power supply conditions; and lack of clear economic incentives for saving water and energy due to inefficient pricing of electricity and water; the existing cereal dominated cropping systems; and the small size of farm holdings. A recent ITP study shows that a total of only 5.8m.ha could be brought under drip systems considering the existing cropping pattern, climatic conditions, water availability and rural power supply situation in different regions.

The issues relating to poor-targeting of subsidies in MI are even more serious. The whole basis for public subsidies in micro irrigation is the social benefits their adoption brings about. But, there is hardly any analysis in India looking at the social costs and benefits of micro irrigation systems. Social benefits of water saving can be over-estimated at least in regions with shallow groundwater, whereas the social costs of talking labour out of agriculture could be ignored in areas where labour is already in short supply. Such analysis would help judicious allocation of public funds. Having said that, there are regions where MI adoption is picking up fast like wild fire in India. It is important to know the social conditions under which MI is being adopted by farmers like higher risk taking ability, entrepreneurship and degree of exposure to modern farming practices. The social changes it brings about in rural areas, needs to be carefully analyzed.

Within the larger questions of "more crop per drop", there are questions of how water productivit (Rs/ET) varies from crop to crop; how does water productivity of a rain-fed crop change with supplementar irrigation; between rain-fed crop and irrigated crop, which one generates more biomass and income; hov important is rain-fed production when compared to irrigated production in terms of enhancing basin wate economy? There were very few attempts to evaluate productivity of water in agriculture, most of which focu on productivity of diverted water and its contribution to water economy. Not much information and knowledge exists about the use of rainwater for crop production, and the economy it generates in Indian agriculture.

Finally, research on water productivity had its accent on "more crop per crop". Transposing the findings of the research from the west to Indian situations would be meaningless. The distinct features of India that make the conventional "more crop per drop" approach less versatile are: smaller land holdings; relatively lower volume of water handled by farmers; inefficient pricing and zero marginal cost of water, or the energy used for pumping groundwater; uncontrolled water deliveries from public systems; and lack of institutional regimes governing access to groundwater.

There is a need to examine how the various considerations involved in assessing water productivity should be different in India from those for the west. Generally, farming systems in India are composite, with crops and dairying practiced together. Employment generation in rural areas and food security are still major public concerns, and can run into conflict with the private interest of enhancing water productivity as some of the cereals, which feed our granary and generate wage labour, have low water productivity. Hence, trade offs between realizing economic objectives and social objective need to be understood.

The use of economic concepts such as the "value of water in its use" for managing water allocation decisions is extremely limited. Historically, projects that involve transfer of water from abundant regions to scarce regions had their basis in increasing the effective utilization of water, rather than enhancing its economic value. But, the concept of incremental economic value would have great relevance in managing water economies in the Indian context.

The present institutional and policy regimes governing the use of water in agriculture include power tariff in agriculture; pricing of canal water; and property rights in water, particularly groundwater. Many states follow flat rate tariff for electricity supplied in agriculture, and some states offer free power to farmers. No Indian state charges for canal water on volumetric basis as a rule. Due to these, the farmers are not concerned with enhancing the productivity of water unless they help them maximize the returns from land. Even in situations of physical scarcity of water, where farmers are confronted with the opportunity cost of using water, productivity enhancement might not lead to reduced use, and resource reallocation. The reason is farmers want to maximize their returns. This is due to lack of well defined property rights in water. Institutional and policy interventions for water allocation have to be designed. But, discussions on these aspects are scanty.

Water users associations are the only institutional innovation which had been tried out in India's irrigation sector during the past several decades. Their management regime had not extended beyond the secondary level in the hydraulic system hierarchy, apart from having very low scale of implementation. Also, questions are often raised about the transaction costs of creating these institutions against the real benefits derived from their existence, and of late, the very sustainability of these institutions. While government and policy makers provide lip services to options such as water pricing, water laws, registration of users, issuing of licenses and "quotas" to draw water, researchers and practitioners have debated on enabling legal framework, water rationing, and water rights. But, hardly any research exists on the institutional processes involved in instituting and enforcing water rights in Indian situations, and the benefits against the transaction costs.

In the past few years, a great deal of government response to groundwater over-draft problems and the huge revenue losses in electricity subsidies has fallen on regulatory measures such as regulating the supply of electricity to farm sector, and state regulation of groundwater use. On the other hand, recent past had seen remarkable increase in the price of diesel, a major fuel for running the rural economic engine, which uses water as another key input. The impacts of these on the rural water economy and livelihoods, especially equity, have not been studied in a comprehensive manner.

The past decade has seen some legal and policy reforms in water sector in several Indian states. Also many Indian states have drafted their own water policies. The cornerstone of these state level policy reforms is the National Water Policy-2002, although few States have put policies and laws in place to implement the policy objectives. In most cases, where legal reforms have happened, it has been before the adoption of the national water policy. But, very little thinking seems to have gone into implementing policy choices. The biggest gap is the institutional and administrative mechanism for implementing them. Over and above, the likely outcomes and impacts of these policy choices are little known.

In this backdrop, the IWMI-TATA Water Policy Research Program (ITP) aims at contributing to improved agricultural livelihoods in India through research on improved management of water resources. The IWMI-Tata program by joining IWMI and the TATA-Trust brings a unique and powerful partnership of research and development investment to bear on these problems. The Program tackles policy relevant issues in water management which have direct bearing on the livelihoods of the rural poor, and provides advice for investment and policy interventions to improve those outcomes. ITP had identified some of the issues discussed above for research during this year. Following are the three major topics we have focussed: 1] enhancing water productivity in agriculture: physical, institutional and policy alternatives; 2] changing groundwater socio-ecology and its impact on agriculture and rural livelihoods; and, 3] water policies and legal frameworks in India.

The theme of this year's meet is "Managing Water in the Face of Growing Scarcity, Inequity and Declining Returns: Exploring Fresh Approaches". The meet is being hosted by the South Asia Sub-regional office of International Water Management Institute in Hyderabad, India. A total of 56 papers were included in the conference proceedings, after peer reviews. Of these, more than half are from ITP researchers and ITP-commissioned studies. The rest are contributions from young and senior researchers from other institutions. Most of the papers deal with the topics selected for this year's research, while a few are on topics like issues in water harvesting/groundwater recharge in India; and water and economic growth. These are also topics on which ITP has been working in the recent past. These papers are organized under five major themes and eight sub-themes. This volume contains these research papers, which would be discussed during the 3 days of the meet from 2-4 April, 2008.

We hope the papers in this volume would be of immense interest to the researchers, practicing managers and policy makers engaged in water sector in India.

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WATER SAVING AND YIELD ENHANCING MICRO-IRRIGATION TECHNOLOGIES IN INDIA : WHEN AND WHERE CAN THEY BECOME BEST BET TECHNOLOGIES?

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Abstract

A systematic attempt to determine the conditions under which, micro irrigation (MI) systems become the "best bet technology" in terms of realizing the potential benefits, and extent of reduction in crop water requirement possible through such systems is crucial for assessing our ability to address future water scarcity at the regional and national level. The ultimate objective of this research is to find out under what conditions micro irrigation system offer the best bet technology, and what benefits it can yield. The research aims at determining the potential benefits from the use of MI systems in India. This is done through assessing: a] the conditions that are favourable for MI system adoption; b] the field level and aggregate level impacts of the systems on water use; and c] the yield and economic benefits from adoption. The research also aims at assessing the potential future coverage of MI systems in India, and the potential reduction in aggregate water requirement in crop production.

The research used extensive review of published and unpublished literature on the feasibility, and physical and economic impacts of various MI systems; results from field experiments carried out by IWMI in one location in Gujarat on the techno-economic viability of some MI devices; data from field-based research carried out by IWMI researchers on the economic viability of MI systems; and statistics on MI adoption in India.

The constraints in MI system adoption are: i] lack of independent source of water and pressurizing device for many farmers; ii] poor quality of groundwater in many semi arid and arid regions; iii] the mismatch between water delivery schedules and irrigation schedules required in MI systems in surface irrigation systems; iv] cropping systems that dominate field crops in semi arid regions; v] dominance of small and marginal farmers, and small plot sizes; vi] low opportunity costs of pumping groundwater due to lack of well-defined water rights; vii] negative technical externalities in groundwater use; viii] poor extension services; and viii] poor administration of subsidies.

The other findings are: 1] the extent of real water-saving and water productivity gains at the field level from adoption of MI systems varies across crops, climate, geo-hydrology and type of MI devices used; 2] the potential benefits of MI systems in terms of real field level water saving are likely to be realized in semi arid and arid areas with deep water table conditions, for widely spaced row crops; 3] the economics of pressurized MI systems depend on the capital cost of the system, size of the plot, type of crop irrigated, extent of water and energy saving and the market value of the produce; 4] being capital intensive, the economic viability of MI systems is sound for high valued cash crops and orchards, especially in areas where groundwater availability is extremely limited; and 5] in many areas, due to flat rate system of pricing and heavy subsidy in electricity, zero opportunity cost of using groundwater, energy and water saving does not result in cost saving and improved economic returns from MI.

The future potential of MI systems to improve basin water productivity is primarily constrained by the physical characteristics of the basins vis-à-vis the opportunities they offer for real water-saving at the field level and basin water productivity improvements, and area under crops that are conducive to MI in those basins. Preliminary analysis shows a very modest potential of MI systems to the tune of 5.6 million ha, with the impact of drip systems in reducing aggregate water requirement for crop production to the tune of 44.46 BCM. Creating appropriate institutions for technology extension, designing water and electricity pricing and supply policies apart from building proper irrigation and power supply infrastructure would play a crucial role in facilitating large-scale adoption of different MI systems. The subsidies for MI promotion should be targeted at regions, people and technologies level, where MI adoption results in real water and energy saving at the aggregate level, and maximize welfare impacts.

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1. INTRODUCTION

Demand management becomes the key to the overall strategy for managing scarce water resources (Molden et al., 2001). Since agriculture is the major competitive user of diverted water in India (GoI, 1999), demand management in agriculture in water-scarce and water-stressed regions would be central to reducing the aggregate demand for water to match the available future supplies (Kumar, 2003a and 2003b). Improving water productivity in agriculture is important in the overall framework for managing agricultural water demand, thereby increasing the ability of agencies and other interested parties to transfer the water thus "saved" to economically more efficient or other high priority domestic and industrial use sectors (Barker et al., 2003; Kijne et al., 2003).

Three dimensions of water productivity include: physical productivity, expressed in kg per unit of water consumed; combined physical and economic productivity expressed in terms of net return per unit of water consumed, and economic productivity expressed in terms of net income returns from a given amount of water consumed against the opportunity cost of using the same amount of water (Kijne et al., 2003). The discussion in the present paper would be largely on the first parameter, i.e., physical productivity. There are two major ways of improving the physical productivity of water used in irrigated agriculture. First: the water consumption or depletion for producing a certain quantum of biomass for the same amount of land is reduced. Second: the yield generated for a particular crop is enhanced without changing the amount of water consumed or depleted per unit of land. Often these two improvements can happen together with an intervention either on the agronomic side or on the water control side (for discussion on other aspects of water productivity, see Kumar et al., 2007).

There are several conceptual level issues in defining the term "water saving" and irrigation efficiency. This is because with changing contexts and interests, the "unit of analysis" changes from field to farm to irrigation systems to river basins. With the concepts of "dry" and "wet" water saving", which capture the phenomena such as "return flows from field" and "depleted water", becoming dominant in irrigation science literature in the last one decade, the old concepts of "water saving" and irrigation efficiencies have become obsolete. The real water saving or "wet water" saving in irrigated production at the field level can come only from reduction in depleted water and not the water applied (Molden et al., 2001). But, there are methodological and logical issues involved in estimating the depletion fraction of the water effectively applied to the crop. Complex considerations, including agronomic, hydrologic, geo-hydrological and geo-chemical, go into determining the "depletion" fraction. Nevertheless, for the limited purpose of analysis, throughout this paper, "water saving" refers to "wet" water saving.

Water productivity is an important driver in projecting future water demands (Amarasinghe et al., 2004; Kijne et al., 2003). Efficient irrigation technologies help establish greater control over water delivery (water control) to the crop roots, reduce non-beneficial evaporation and non-recoverable percolation[1] from the field, and return flows into "sinks" and often increases beneficial ET, though the first component could be very low for field crops. Water productivity improves with reduction in depleted fraction and yield enhancement. Since at the theoretical level, water productivity improvements in irrigated agriculture can result in saving of water used for crop production, any technological interventions, which improve crop yields, are also, in effect, water saving technologies. Hence, water saving technologies in agriculture can be broadly classified into three: water saving crop technologies; water saving and yield enhancing irrigation technologies; and, yield improving crop technologies.

There are several technologies and practices for water-saving in irrigation. They include: 1) broad beds or small border irrigation; 2) improved furrow irrigation (surge, cutback, proper management) 3) laser leveling of fields; 5) plastic mulches and tunnels; 6) improved soil moisture retention sub-surface barriers; 7) alternative wetting and drying for rice; 8) system of rice intensification; 9) direct seeding of rice; 10) aerobic rice; 11) on-farm storage; and, 12) allowing better control and timing of surface irrigation (micro-irrigation, sprinklers and their variants). But, only micro irrigation technologies, which are based on plastics, are dealt with in this report.

India stands 27th in terms of scale of adopting water-saving and yield enhancing micro irrigation devices (Source: www.oznet.ksu.edu/sdi/News/Whatisnew.htm). There are several constraints to adoption of MI

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[1] See Allen et al., (1997) for definitions of non-beneficial evaporation, non-recoverable deep percolation.

devices. These are physical, socio-economic, financial, institutional—pricing, subsidies, extension service and policy-related related (Narayanamoorthy, 1997; Sivanappan, 1998; Kumar, 2002a). Nevertheless, a systematic attempt to find out the conditions under which MI systems become a best bet technology, and assess the magnitude of reduction in water requirement possible through them is hardly ever made. Such efforts are crucial for assessing our ability to address problems of water scarcity in the future at the regional and national level.

The ultimate objective of this research is to find out under what conditions micro irrigation system offer the best bet. It aims at determining the potential benefits from the use of MI systems. This includes assessing: a] conditions that are suitable or unsuitable for MI systems; b] field level and aggregate level impacts of the systems on water use; and c] yield and economic benefits due to adoption of MI system. The research also aims at assessing the potential future coverage of MI systems in India, and the reduction in aggregate water requirement in crop production.

The scope of the report is as follows. First, it provides an over-view of the benefits of "MI technologies. It then covers the present spread of MI systems in India. It deals with the potential physical and economic impacts of MI systems in India. This is based on analysis of: i] physical, socio-economic and institutional constraints for its adoption in the country; ii] field level water saving, and impacts on drivers of water demand; iii] and cost-benefit analysis of MI systems for different crops under different socio-economic conditions, and policy environments. A macro level analysis of the potential future impact of drip systems on agricultural water requirements in India is provided. This is done by: a] assessing the actual cropped areas that can be brought under drip systems in the basins which would benefit from them in terms of water productivity improvements; and b] potential future reduction in water requirement of selected crops through drips. The fifth section deals with the impact of existing water and energy related policies in India, and discussions on institutional and policy alternatives for spreading MI system adoption.

2. AVAILABLE WATER-SAVING AND YIELD IMPROVING IRRIGATION TECHNOLOGIES IN INDIAN AGRICULTURE AND THEIR POTENTIALS

Water-saving and yield enhancing irrigation devices which are in use in India and the crops for which they can be used are given in Table 1. While listing these devices, we have considered their technical feasibility for the crop in question and their actual preference by farmers, and are not based on their analysis of the social costs and benefits of using them. Synthesizing the information provided in the last column, it is clear that highest growth in water productivity would be possible with green house, which reduces the consumptive use of water and enhances the yield substantially.

3 CONTRIBUTION OF MICRO-IRRIGATION TECHNOLOGIES IN INDIAN AGRICULTURE

3.1 Present Spread of Micro-irrigation Technologies in Indian Agriculture

There were no systematic attempts in the past to assess the spread of water-saving irrigation technologies in India. Sivanappan and Lamm (1995) reported that the area under drip irrigation is a mere 7000 ha in 1994. The most recent data shows that nearly 1.3 m ha of irrigated land is under drip irrigation (see Narayanamoorthy, 2004b).

They cited high initial cost (including mis-targetted subsidies), clogging of drippers and cracking of pipes, lack of adequate technical inputs, damages done by rodents; high cost of spare components; and insufficient extension education effort as the major problems in the slow rate of adoption of drips. The National Committee on Irrigation and Drainage also added factors such as salinity hazards to the list of problems (GoI, 1994). Shiyani and others (1999) found difficulty in inter-cultivation another reason for non-adoption, while Palanisamy and others (2002) cited joint ownership of wells as additional reason for non-adoption based on their study in Coimbatore (Tamil Nadu). However, some of the problems listed above such as clogging, lack of adequate technical inputs and high cost of spare components, to a limited extent, are being bypassed with the introduction of low cost micro irrigation systems in India, pioneered by International Development Enterprises.

The recent data released by the Task Force on Micro Irrigation in India shows that during the past four years, peninsular India had recorded highest growth in adoption of drip systems. Maharashtra ranks first, followed by Andhra Pradesh and Karnataka. Table 2 presents the data of adoption of drip irrigation systems under various programmes, viz., macro management plan; technology mission on horticulture; cotton development programme and oil palm development programme. The major crops for which drip systems are currently adopted are: cotton, sugarcane; banana, orange, grapes, pomegranate, lemon, citrus, mangoes, flowers, and coconut.

Table 1: Nature of Water Saving for Different Crops under Different Types of Efficient Irrigation Devices

Sl. No	Name of water-saving and yield enhancing micro irrigation technology	Names of crops for which the technology can be used ideally	Nature of Saving in Applied Water
1.	Pressurized drip systems (inline and on-line drippers, drip tape)	All fruit crops; cotton; castor; fennel; maize; coconut; arecanut; chilly; cauliflower; cabbage; ladies finger; tomatoes; egg plant; gourds; mulberry; sugarcane; water melon1 ; flowers	1. Reduces non-beneficial evaporation (E) from the area not covered by canopy 2. Reduces deep percolation 3. Water saving also comes from reduction in evaporation from fallow after harvest 4. Extent of water saving higher during initial stages of plant growth 5. Significant yield and quality improvement.
2.	Overhead (movable) sprinklers (including rain guns)	Wheat; pearl millet; sorghum; cumin; mustard; cow pea; chick pea, grasslands and pastures, tea estates	1. Reduces conveyance losses 2. Improves distribution efficiency slightly 3. Reduces deep percolation 4. Marginal yield growth
3.	Micro sprinklers	Potato; ground nut; alfalfa; garlic and onion, herbs and ornamentals	1. Reduces seepage and evaporation losses in conveyance 2. Reduces deep percolation over furrow irrigation and small border irrigation 3. Yield growth and quality improvement significant
4.	Plastic mulching	Potato; ground nut; cotton; castor; fennel; brinjal; chilly; cauliflower; cabbage; ladies finger; flowers; maize	1. Keeps complete check on the evaporation component of ET 2. Stops non-beneficial evaporation (E), kills weeds and pests 3. Extent of water saving higher over drip irrigation 4. Faster germination and significant yield growth

[2]Watermelon is often grown in intercropping with orchard crops, reducing the capital cost of drips significantly.

Sl. No	Name of water-saving and yield enhancing micro irrigation technology	Names of crops for which the technology can be used ideally	Nature of Saving in Applied Water
5.	Green houses	All vegetables, high valued fruits such as strawberry; and exotic flowers, nurseries, vegetative propagation	1. Controls the ambient temperature and humidity, 2. Checks the wind, thereby reducing transpirative demand of plant. 3. The water-saving is highest as compared to other technologies 4. Substantial yield growth, quality improvement and nutrient savings.
6.	Micro tube drips	All horticultural and plantation crops	1. Reduces non-beneficial evaporation 2. Distribution uniformity is poor and depends on number of micro tubes on a lateral

Table 2: Rate of Adoption of MI Systems during 2001-05 under various programmes

		Area Under Micro Irrigation Systems (in ha)				
Sr. No.	Name of State	2001-02	2002-03	2003-04	2004-05	Total
1	Andhra Pradesh	9117	4227	12	4200	17556
2	Arunachal Pradesh	110	100	248	500	958
3	Assam	22	16	17	350	405
4	Bihar	500	141	0	0	641
5	Chhatisgarh	444	227	0	100	771
6	Goa	70	48	0	305	423
7	Gujarat	2130	2109	1035	3650	8924
8	Haryana	226	0	236	230	692
9	Himachal Pradesh	111	85	0	0	196
10	Jammu and Kashmir	0	5	30	0	35
11	Jharkhand	179	0	0	0	179
12	Karnataka	9480	397	2635	4219	16731
13	Kerala	939	457	180	489	2065
14	Madhya Pradesh	1190	1007	200	375	2772
15	Maharashtra	14391	6875	248	844	22358
16	Manipur	10	20	25	100	155
17	Meghalya	28	0	55	60	143
18	Mizoram	0	50	20	450	520
19	Nagaland	60	55	100	50	265
20	Orissa	250	0	285	650	1185
21	Punjab	0	80	0	0	80
22	Rajasthan	1400	1000	1700	1200	5300
23	Sikkim	30	30	0	50	110
24	Tamil Nadu	814	635	25	1986	3460
25	Tripura	118	0	278	300	696
26	Uttar Pradesh	454	264	0	235	953
27	Uttaranchal	100	100	0	0	200
28	West Bengal	0	0	0	99	99
	Total	42173	17928	7329	20442	87872

Source: Task Force on Micro Irrigation, Ministry of Agriculture, Government of India

Though exact state level wise data on the spread of sprinkler systems are not available, it is found that sprinkler systems are in vogue in regions where conditions are unfavourable for traditional method of irrigation such as loose sandy soils and highly undulating fields. These areas are irrigated by wells. Farmers in other (well-irrigated) areas have also procured the system under government subsidy programme, but were using HDPE pipes for water conveyance in the field except during droughts when they use them for providing supplementary irrigation to kharif crops.

In India, sprinkler systems are mainly used for field crops such as wheat, sorghum, pearl millet, groundnut and mustard. But the use of sprinklers is often limited to certain part of the crop season when farmers face severe shortage of water in their wells. Normally, this is just before the onset of monsoon when the farmers have to sow these crops, or when there is a long dry spell during the monsoon season. Sprinkler for groundnut is common in Saurashtra in Gujarat; sprinkler for mustard is common in Khargaon district of Madhya Pradesh and Ganga Nagar district of Rajasthan. In the high ranges of Kerala and Tamil Nadu, sprinklers are used for irrigating tea and coffee plantations. However, recently, farmers have started using micro sprinklers and mini micro sprinklers for potato, groundnut and alfalfa.

3.2 Potential Contribution of Micro-irrigation Technologies in India

3.2.1 Physical impact of micro-irrigation technologies on water demand for crop production

Analyzing the potential impact of MI systems on the aggregate demand for water in crop production involves three important considerations. The first concerns the extent of coverage that can be achieved in MI system adoption at the country level. The second concerns the extent of real water saving possible with MI system adoption at the field level. The third concerns what farmers do with the water saved through MI systems, and the changes in the cropping systems associated with adoption. But, most of the past research on physical impacts of MI systems had dealt with the issue of changes in irrigation water use, crop growth and crop yield.

There is limited analysis available on the potential coverage of MI systems in India, and the water saving possible at the aggregate level. These analyses suffer from severe limitations. *First:* the analyses of potential coverage of MI systems are based on simplistic considerations of the area under crops that are amenable to MI systems, and do not take into account the range of physical, socio-economic and institutional factors that induce severe constraints to adoption of these technologies. *Second*: they do not distinguish between saving in applied water and real water saving, while the real water saving that can be achieved through MI adoption could be much lower than the saving in applied water. *Third*: there is an inherent assumption that area under irrigation remains the same, and therefore the saved water would be available for reallocation. But, in reality, it may not be so. With introduction of MI systems, farmers might change the very cropping system itself, including expansion in irrigated area. Therefore, all these assumptions result in over-estimation of the potential coverage of MI systems and the extent of water-saving possible with MI adoption. These complex questions are addressed in the subsequent sections of this paper.

3.2.1A Physical constraints and opportunities for adoption of MI Systems

Determining the potential coverage that can be achieved in MI system adoption require a systematic identification of the conditions that are favourable or un-favourable for adoption and a geographical assessment of areas where such conditions exist. Such conditions can be physical, socio-economic or institutional. These physical, socio-economic and institutional constrains in the adoption of MI systems are discussed below.

If we do not consider the difficult options of shifting to less water intensive crops and crops having higher water productivity, there are two major pre-requisites for reducing the overall demand for water in agriculture in the region. They are: i] reducing the non-beneficial evapo-transpiration from crop land; and ii] maintaining the area under irrigation. The second issue is not being dealt with here. The time-tested and widely available technology for increasing water productivity is pressurized irrigation systems such as sprinklers and drips (or trickle irrigation). (Consider removing)

Micro Irrigation adoption is very low in India. This includes even areas where the capital investment needed for creating irrigation sources is very high such as Kolar district in Karnataka, Coimbatore district in Tamil Nadu and alluvial north and central Gujarat. While, there are several constraints at the field level, which limit the adoption of this technology by the farmers, some of the very critical ones that are physical in nature are analyzed here.

First of all, MI systems need reliable daily water supply. But, nearly 41.24% of the net irrigated area in the country gets their supplies from surface sources such as canals and tanks (source: GoI, 2002). Drips and sprinklers are not conducive to flow irrigation due to two reasons. First is the mismatch between water delivery schedules followed in canal irrigation and that required for MI systems use. Normally, in surface command areas in India, farmers get their turn once in 10-15 days at flow rates ranging from 0.5 to 1 cusec. But, for drips and sprinklers to give their best, water should be applied to the crop either daily or once in two days with lower flow rates which are equal to the evapo-transpiration. This means, intermediate storage systems would be essential for farmers to use water from surface schemes for running MIs. Storage systems are also required as settling tanks for cleaning large amounts of silt contents in the canal water supplies. Second, there is a need for pumps for lifting water from the storages and running the MI systems. These two investments reduce the economic viability of MI.

Therefore, in the current situation adoption of MI would be largely limited to areas irrigated by wells. Having said that, an increasingly large number of farmers in groundwater irrigated areas manage their supplies from water purchase. This also includes areas where groundwater over-draft is not a concern like Bihar and western Orissa, and where economic access to water is a problem. It is difficult for these farmers to adopt any MI devices.

Need for pressuring devices limits the adoption of MI systems. In groundwater over-exploited areas such as north and central Gujarat, Coimbatore district in Tamil Nadu and Kolar district of Karnataka, ownership of wells mostly does not remain with individual farmers but with groups. Also, a large number of farmers have to depend on water purchase. They get water through underground pipelines at almost negligible water pressure (head). In order to use the conventional sprinkler and drip systems, high operating pressure (1.0-1.2 kg/cm^2) is required. Unless the systems are directly connected to the tube well, the required amount of "head" to run the sprinkler and drip system cannot be developed. The need for a booster pump and the high cost of energy required for pressurizing the system to run the sprinklers and drips reduce the economic viability. But, there are new MI technologies, which require very low operating head such as sub-surface irrigation systems and the micro-tube drips. Farmers who are either water buyers or share wells can store the water in small tanks, lift it to small heights to generate the required head for running the sub-surface drip system or micro tube systems.

Another important constraint is the poor quality of groundwater. Due to the high TDS level of the pumped groundwater (the TDS levels are as high as 2000 ppm (parts per million) in many parts of India where groundwater is still being used for irrigation), the conventional drippers that are exposed to sunlight get choked up due to salt deposition in the dripper perforations. The saline groundwater areas include south western Punjab, north and central Gujarat, parts of Rajasthan, and many parts of Haryana. This needs regular cleaning using mild acids like the hydrochloric acid. This is a major maintenance work, and farmers are not willing to bear the burden of carrying out this regular maintenance. However, in limited cases, rich farmers in South West Punjab use large surface tanks for storing canal water when it is available, and blend it with brackish groundwater, and use for drip irrigating *kinnow* (a citrus fruit) orchards to prevent problems of clogging.

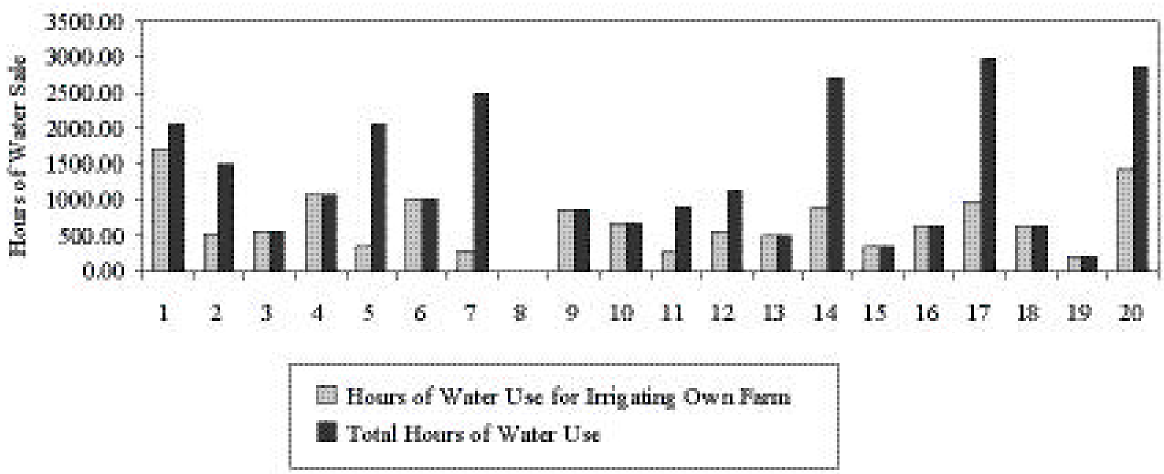
In addition to areas irrigated by groundwater, there are hilly areas of the western and eastern Ghat regions, north-western Himalayas (Himachal Pradesh, Jammu and Kashmir and Uttaranchal) and states in north-eastern hill region, where surface streams in steep slopes could be tapped for irrigating horticulture/plantation crops. Such practices are very common in the upper catchment areas of many river basins of Kerala, which are hilly. Farmers tap the water from the streams using hose pipes and connect them to sprinkler systems. The high pressure required to run the sprinkler system is obtained by elevation difference in the order of 30-40 mts. Such systems are used to irrigate banana, vegetables and other cash crops such as vanilla. With the creation of an intermediate storage, drips can irrigate crops such as coconut, aracnut and other fruit crops during the months of February to June.

Geological setting has a strong influence on MI adoption in well-irrigated areas. In hard rock areas, farmers will have strong incentive to go for MI systems. The reason is dug wells and bore wells in hard rock areas of Maharashtra, Madhya Pradesh, Tamil Nadu, Karnataka and Andhra Pradesh have very poor yield and well owners leave a part of their land fallow due to shortage of water. In most of these areas, farmers have to discontinue pumping after 2-3 hours for the wells to recuperate. When pressurized irrigation systems (drips, sprinklers) are used, the rate at which water is pumped will reduce. This gives enough opportunity time for wells to recuperate. Since, pump will eventually run for more number of hours, the same quantity of water could be pumped out, and the command area can be expanded. This factor provides a great economic incentive for farmers to go for water-saving micro irrigation systems.

3.2.1B Socio-economic and institutional constraints for MI adoption

Another major constraint in adopting conventional MI technologies is the predominant cropping pattern in the water-scarce regions. MI systems are best adaptable for horticultural crops from an economic point of view (Dhawan, 2000). The analyses presented in Table 11 and 12 also substantiate this point. Saving in input costs are not very significant, the additional investment for drips has to be offset mainly by better yield and returns (Kumar et al., 2004). But, percentage area under horticultural crops is very low in these regions, except Maharashtra1. Though the low cost drip irrigation systems appear to be a solution, they have low physical

Figure 1: Total Water Use Vs Own Irrigation



efficiency when used for crops in which the plant spacing is small (chilly, vegetables, groundnut and potato) (Source: IWMI research in Banaskantha). In such situations, they also score low on the economic viability. Low cost systems can be used for some of the row crops such as castor, cotton and fennel. However, to use the system for these crops, it is very important that the farmers maintain a fixed spacing between different rows and different plants. So far as maintaining the spacing between rows is concerned, farmers pay sufficient attention. But, spacing between plants is not maintained. Due to this un-even (un-favourable) field conditions, designing and installing drippers becomes extremely difficult. Therefore, for adoption of these water saving technologies, the farmers' agricultural practices need major changes.

For crops such as paddy, neither drips nor sprinkler irrigation systems are feasible. Paddy is an important crop in many arid and semi arid regions where water levels are falling. Certain studies at ICAR (Patna) have

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The total area under horticultural crops and vegetables is only 5.04 per cent of the net irrigated area in the country in 2001-02. It is highest in Maharashtra, both in percentage (19.04%) and aggregate terms (0.75 M ha).

developed Low-Energy Water Application (LEWA) systems which apply regulated water supplies to paddy and have demonstrated potential to save water. But the technology is still in its infancy and requires large scale testing before field scale adoption. Adopting suitable cropping patterns that would increase the adoptability of water saving technologies is one strategy. But, as mentioned in the beginning of the section, “crop shift” is a harder option for farmers.

The socio-economic viability of crop shifts increases with the size of the operational holding of farmers. Given that small and marginal farmers account for large percentage of the operational holders in India, the adoptability of horticultural crops by farmers in these regions cannot be high. This is because these crops need at least 3-4 years to start yielding returns, (except for pomegranate, papaya). It will be extremely difficult for these farmers to block their parcel of land for investments that do not give any returns after a season. Market is another constraint. Large-scale shift to fruit crops can lead to sharp decline in the market price of these fruits. Labour absorption is another major issue when traditional crops such as paddy, which are labour-intensive, get replaced by orchards. Orchards require less labour, it is also seasonal, and the chances for mechanization are higher.

Plot size also influences farmers’ choices. Conventional MI systems will be physically and economically less feasible for smaller plots due to the fixed overhead costs of energy, and the various components of these irrigation systems such as filters, overhead tanks (Kumar, 2003).

The following equation calculates the pressure “head” required to pump water for running pressurized irrigation systems.

$$P_{req} = \frac{(P_2 + P_L)}{(w + Z)}$$

Where P_{req} is the residual pressure required at the well outlet. P_2 is the pressure required at the sprinkler nozzle or dripper and P_L is the pressure loss during conveyance of water from the tube well to the sprinklers or the drips. Z is the difference in elevation. If the sprinkler/drip systems are located at a higher elevation than the pump outlet, then ‘Z’ will be negative. The equation shows that the additional energy required for running the system will reduce with every additional sprinkler, the reason being that only the pressure loss increas es with increase in number of sprinklers/drip irrigated area. However, organizations like International Development Enterprises (IDE) have developed and promoted MI systems for very small landholders, which use small storage cisterns for providing the required pressure.

Poor rural infrastructure, mainly power connections to agro wells and the quality of power supply, is another major constraint for adoption of MI systems. Difficulty in obtaining power connections for farm wells, and poor quality of power supply forces farmers to use diesel pump sets for irrigating their crops. Use of diesel pump increases the cost of abstraction of well water. Regions such as Bihar, eastern UP and Orissa are examples. Here, many cash-starved farmers do not own wells, and depend on water purchased from well owners for irrigation. Drips and sprinklers are energy intensive systems, and installing such systems would mean extra capital investments for installing higher capacity pump sets as well as recurring expenses for buying diesel. These factors act as deterrents for adopting MI systems.

The current water pricing and energy pricing policies that exist in most states[4] also reduce the economic incentives for MI adoption. Due to these policies, the water-saving and energy-saving benefits from the use of MI systems do not get converted into private benefits.

Un-scientific water delivery schedules followed in surface irrigation systems, and power supply restrictions for farm sector also induce constraints for MI adoption. It is common in surface irrigation systems that while plenty of water is released for the crops for certain part of the season, in the last leg of the crop season the crops are subject to moisture stress. Poor reliability of water delivery services or lack of adherence to a standard delivery schedules and poor control over volumetric supplies force farmers to adopt crops that are less sensitive

[4]They are: 1] crop area based pricing of surface water for irrigation; 2] flat rate system of pricing of electricity or free electricity followed by many Indian states for farm sector. Only Gujarat and Orissa had partially introduced metering of electricity for farm wells.

to water stress such as paddy and sugarcane and resort to flood irrigation. Regulated power supply in agriculture is also reducing the economic incentive for adoption of MI systems that are energy-intensive. Many states including Punjab, Madhya Pradesh, Tamil Nadu, Gujarat and Karnataka had consistently reduced the duration of power supply to farm sector, due to growing power crisis. In future, this would emerge as a major impediment for large-scale MI adoption.

Poor extension services offered by concerned agencies pose another major constraint. It is not common for the extension wings of Agricultural Universities to set up demonstration of new technologies in farmers' fields. This is applicable to companies which manufacture and sell MI devices. Because of this, there is very little knowledge about MI technologies among the farmers in water-scarce regions. The existing knowledge is filled more with misconceptions. Many farmers believe that MI systems have severe limitations vis-à-vis crops for which they could be used. Another misconception is that coverage of sprinklers being circular leaves a lot of dry spots in the irrigated fields. This belief has mainly come from the experience of farmers who have used the system with improper designs.

The administration of subsidies in MI devices also works against the promotion of MI systems. In many states, the governments continue to pay the subsidy directly to the manufacturers. Many farmers purchased MI systems just to avail the subsidy benefits, and do not maintain them. The suppliers do not offer any after-sales services to the farmers and hence are not interested in ensuring quality control. The systems supplied are often of sub-standard quality. Over and above, as the amount funds available for subsidies are limited, the smarter influential farmers take benefit. On the other hand, the government officials, who come and inspect the systems installed, only check the amount of materials supplied, and work out the subsidy that has to be paid to the irrigation company. Since the manufacturers had the hassle of doing the entire documentation for obtaining the subsidy, they keep the price (without subsidy) high enough to recover their interests on capital and transaction costs.

The present institutional framework governing the use of groundwater, which puts no limit on the amount of water farmers can pump from aquifer, does not provide clear economic incentives to use water efficiently. This is particularly so for well owners, who have good sources of water supply. Examples are the Indo-Gangetic alluvium and alluvial areas of Gujarat. Though the opportunity cost of using water influences farmers' decision-making, the opportunity costs are not felt clearly. This is in spite of the prevalence of water markets[6] in these regions. The reason is that the demand for water from the water buyers and for ones own irrigation use, is much less than the number of hours for which the farmers could run their pumps[6] (see Figure 1). In such cases, the direct additional financial returns farmer gets by introducing MI systems are from the increased crop yield. This will not happen unless the farmer adopts new agronomic practices.

Due to this reason, the well owners would rather pump for extra hours to sell water to the needy farmers than trying to use water more efficiently by making substantial capital investments. The economic efficiency of water use for irrigated crops in the area even with the current inefficient practices is much higher than the price at which water is traded (Kumar and Singh, 2001).

Negative externalities in groundwater pumping pose a serious constraint for MI adoption. Well interference is very common in hard rock areas. Under such conditions, pumping by one farmer will have effect on the prospects of pumping by another farmer. Due to this reason, the efforts to cut down pumping rates by a farmer may not result in increased future availability of groundwater for the farmer. Efforts to save water from the system by an individual farmer might mean increased availability of groundwater for pumping by the neighboring farmers. Under such situations, the farmers do not have any incentive to invest in MI systems. The technical externality becomes negative externality for well irrigators in the absence of well-defined water rights in groundwater.

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[5] These are not formal water markets, but pump rental markets. Here the well owners are not confronted with the opportunity cost of tapping water from the aquifer.

[6]For instance, a survey of 19 tube well owners carried out in Daskroi taluka of Ahmedabad district showed that the total hours of pumping including that for providing irrigation services to the neighbouring farmers is in the range of 80 hours and 2930 hours. Most of them are found to be in the range of 1000 hours. But, the hours for the farmers could run the pump is as high as 3600.

3.2.1C Real Water Saving and Water Productivity Impacts of MI Systems in the Field

The real water saving impact of MI systems at the field level depends on improvements in water use efficiency. All the available data on the efficiency impact of micro irrigation systems are on application efficiency[7]. The classical definition of irrigation efficiency is the ratio of amount of water consumed by the crop to the amount of water applied. Sivanappan (1998) provides the data on application efficiencies at various stages such as conveyance efficiency, field application efficiency and soil moisture evaporation (see Table 3). These figures do not take into account two factors:1] in certain situations, water will have to be applied in excess of the ET requirements for the purpose of leaching if the irrigated soils have salts; and 2] the actual field performance in the irrigation systems is not as good as that shown in experiments and demonstrations.

In estimating water-saving, what matters is the amount of depleted water, rather than the amount of water applied. The depleted water includes moisture evaporation from the exposed soil and non-recoverable deep percolation. It would be less than the applied water so long as the un-consumed water is not lost in natural sinks like saline aquifer or swamps (Allen *et al*., 1997). This means, the application of the concept of irrigation efficiencies are no longer useful in analyzing the performance of irrigation systems, with greater understanding of agro-hydrology and appreciation of deep percolation from irrigated fields[8] as a component of the available water resources (Keller *et al*., 1996), except in situations where the groundwater is saline or deep or the unconsumed water goes into swamps.

Water use efficiency improvements through MI adoption, and therefore the field level water-saving impacts, depend on three major factors: 1] the geo-hydrological environment, including the depth to groundwater table and the nature of aquifer, whether freshwater or saline; 2] the type of crops; and 3] the agro-climate.

In regions where water table is deep and showing declining trends, MI adoption can lead to real water saving at field level. The reason is deep percolation that occurs under traditional method of irrigation, does not reach the groundwater table. This can be explained in the following way. The depth of groundwater table is in the range of 20 m to 135 m. The 20-135 m thick vadose zone holds the vertically moving water as hygroscopic water and capillary water. Some of the water from the soil profile within or below the root zone, having higher levels of moisture, also can move up due to differential hydraulic gradients (Ahmed *et al*., 2004). All this water would eventually get evaporated from the crop land after the harvest if the fallow period is significant depending, on the climate. The depth of soil below the surface from which evaporation could take place can be up to 2-3m in semi arid and arid regions (Todd, 1997). Some water in the deep vadoze zone would get sucked away by the deep-rooted trees around the farms during the non-rainy season.Since, under MI system, water is applied daily in small quantities to meet the daily crop water requirements, deep percolation is prevented.

Such regions include alluvial tracts of north and central Gujarat, central Punjab, hard rock areas of northern Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Madhya Pradesh and many parts of Rajasthan. Though deep percolation could be quite significant in paddy irrigation, so far no water-saving irrigation devices are being tried in paddy, though many water saving practices have evolved over time in paddy irrigation.

Nevertheless, in areas where groundwater levels are still within 20 m below ground level, the saving in applied water achieved through MI devices would mostly result in saving in pumping cost, but no real saving in water from the system. The reason is that a good share of the excess water used in irrigation under the traditional irrigation practices finally goes back to the groundwater system through return flows. It is important to note that areas with high water table coincide with areas with low level of aridity or mostly sub-humid or humid climate where evaporation losses from soil would be low even in summer months.

The real water saving that can be achieved through MI system would be high under semi arid and arid climatic conditions. This is because the non-beneficial depletion of moisture from the exposed soil could be high under such situation due to high temperature, wind speed and low humidity. Such losses would be significant during initial stages of crop growth when canopy cover is small[9].

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[7]It refers to total amount of water diverted from the source for irrigation and not the amount of water applied in the field.

[8]Deep percolation is due to the drainage below the root zone, which can find its way to perched water table or true groundwater table. Deep percolation is common in all surface methods of irrigation such as border irrigation (both leveled and unleveled small and large border), furrow irrigation and flooding.

Real water saving would be more for row crops, including orchards, cotton, fennel, castor, and many vegetables, where the spacing between plants is large. The reason is the area exposed to solar radiation and wind between plants would be large, and as a result the non-beneficial evaporation would be a major component of the total water depleted, under traditional method of irrigation. With drip irrigation, water could be directly applied to plants, preventing this loss. Such row crops are widely grown with drips and sprinklers in arid and semi arid regions of India. Examples are mulberry in Karnataka; cotton, sugarcane, banana, groundnut, coconut and vegetables in Tamil Nadu; chilly and mangoes in Andhra Pradesh; orange, banana, pomegranate, mangoes, grapes, flowers, sugarcane and vegetables in Maharashtra; cotton, mustard, rapeseed and wheat in Madhya Pradesh; oil seed crops such as cotton, groundnut, castor, mustard and fennel, and wheat, potato and alfalfa in Gujarat; mustard and chilly in Rajasthan; and wheat and potato in Punjab. Hence, the reduction in non-beneficial evaporation from soils and non-recoverable deep percolation, and hence actual water saving through micro irrigation could be in the range of 10-25% depending on the type of crops and the natural environment (soils, climate and geo-hydrology).

There are no scientific data available in India on the actual impact of MI systems on water use efficiency, which estimates the depleted water against the water consumed by the crop, or which takes into account the amount of water available for reuse from the total water applied. The figures provided by Sivanappan (1998) do not give figures of "real water saving", the extent of which would be determined by the climate (arid, semi arid or sub-humid or humid), depth to groundwater table and groundwater quality, and the amount of water available for deep percolation.

Table 3: Relative Irrigation Efficiencies (per cent) under Different Methods of Irrigation

Irrigation Efficiencies	Method of Irrigation		
Conveyance Efficiency[1]	Surface 40-50 (canal) 60-70 (well)	Sprinkler	Drip
Application Efficiency[10]	40-70	60-80	90
Surface water moisture evaporation	30-40	30-40	20-25
Overall efficiency	30-35	50-70	80-90

Source: Sivanappan (1997)

[1] This is for open channels

There is effectively no research in India quantifying the real water saving and water productivity impacts of water saving irrigation technologies on various crops, at the field level. An extensive review of literature shows that all the data on water-saving are based on applied water, and within that more reliable ones are on experimental farms, for limited number of crops and system types and for a few locations. Table 4 presents experimental data on water-saving, yield rise and water use efficiency improvements with drip irrigation over flood irrigation in several crops from different research stations across India. The reduction in water consumption varies from a mere 12% for ash gourd and bottle gourd to 81% for lemon.

[9] For instance, direct dry seeded rice in wet season and direct wet seeded rice in dry season were found to be effective ways of saving water in rice irrigation over transplanted rice (Tabbal *et al*., 2002). Similarly, large amount of research in India has demonstrated the benefits of applying irrigation after 2-3 days of disappearance of applied and ponded water. Field studies conducted on System of Rice Intensification (SRI) also showed significant reduction in applied water use owing to reduction in the duration for which the field remains under submerged conditions (Satyanarayana, 2004; Tiyagarajan, 2005). Majority of this reduction could have possibly come from reduction in deep percolation of water from the paddy field. However, the area under SRI, aerobic rice and other methods of improved irrigation is still very small in India.

[10] Here, application efficiency is defined as the ratio of volume of water retained in the RZ at application against the total water applied.

As seen from the data, some of the figures on water saving are quite high. But, it is important to remember here that the condition of flood irrigation system chosen for comparison influences the findings on water saving and yield improvements in DMI (drip method of irrigation). Poorly managed flood irrigation systems used for comparison could significantly affect the result in favour of DMI. However, to obtain high efficiencies, surface methods (furrow, border, and basin) generally demand operating skills and a high degree of flexibility in water supply. In contrast, much of the complexity of drip and sprinkler irrigation systems is in their design rather than their operation, and they can more easily be operated (but are not always) with low losses. Generally, the natural environment imposes constraints on realistically achievable efficiency levels (Carter *et al.*, 1999),[11] and therefore in what environments the comparisons are made is also important. With the same technology, and with the same crop, the water saving and yield impacts of these irrigation technologies would depend on the agro climate.

One major limitation of the database is that they are generated for a single location. Another limitation is that it compares DMI with one traditional method only. But, the extent of field level water saving through DMI would be heavily influenced by the conventional irrigation method practiced for that crop in the region under consideration, and the precision irrigation followed in drip irrigation. Flooding is just one of the many traditional irrigation methods used by Indian farmers. Its use is generally limited to canal irrigated fields, and fields irrigated by wells in canal command areas due to high flow rates from canals. Well irrigators generally use other methods viz., small border irrigation, trench irrigation and furrow irrigation. On-farm efficiencies are much higher under furrow, trench and small border irrigation as compared to flooding. Another limitation is that data obtained from experimental farms are for ideal conditions, and using such data can lead to over-estimation of field level water saving and water use efficiency impacts of DMI. The reason is it is difficult to simulate the ideal conditional of experimental farms in farmers' fields.

The rest of the data on field level water savings and yield improvements through MI systems are from socio-economic studies based on respondent surveys involving adopters and non-adopters. The results from such studies are summarized in Table 5. The data on water saving are arrived at using figures of total applied water. The available data from the experimental farms do not enable analysis of reduction in depleted water under various treatments. Based on the earlier discussions, it is reasonable to assume that for traditional methods of irrigation, the "applied water" would be very close to the depleted water for row crops, under semi arid and arid climatic conditions, there are no hard empirical data obtained from experiments to prove this. Here, deep percolation is one unknown parameter.

While MI systems are expected to have likely impact on deep percolation from the fields, such deep percolation can be treated as loss into the sink because of the following reasons: 1] drip irrigation is normally used in well-irrigated fields; 2] the amount of water percolating in non-paddy irrigated fields would normally be low (source: based on Ahmed *et al*., 2004;) especially for well irrigation, as the dosage per watering is generally low ; 3] depth of vadoze zone in which the percolating water could be held as hygroscopic water or capillary water would be high in arid and semi arid areas which depend on groundwater; and, 4] part of the water going into the vadoze zone can get lost in soil evaporation during fallow period (based on Todd, 1997). Hence, applied water saving which the available literature refer to can be treated as real water saving.

But, these studies are not complete in themselves, as they cover only a few crops, and a few MI devices. Also, these studies have limitations. First, they are mostly based on data obtained from respondent surveys, which capture relative benefits of the technology from the farmers' perspective. Second, they are also likely to be influenced by respondents' bias. In order to understand the extent to which the water productivity of crops could be enhanced through MI technologies, it is crucial to get realistic data on potential changes in irrigation water use and crop yield, the two determinants of water productivity, with different technologies.

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[11]Soil types, climate and hydrology can affect water losses. Surface irrigation is likely to be more efficient on vertisols than sandy soils. Undulating or sloping land may dictate the use of drip or sprinkler irrigation which can then be managed with less water loss than surface techniques. Unpredictability complicates management and normally reduces efficiency. Total irrigation is easier to schedule and manage than supplementary irrigation because of the unpredictability of natural rainfall (Carter et al., 1999).

Field experiments were conducted in Banaskantha district of Gujarat with different MI devices on various crops to analyze the impact of the technology on irrigation water use, crop yield and water productivity. Banaskantha district falls in semi arid to arid climatic conditions. The mean annual rainfall for the location (Palanpur) was 682mm (source: authors' own analysis based on data provided by Gujarat Agriculture University, Anand). The annual reference evapo-transpiration (ET_0) for the nearest location (Radhanpur) was estimated to be 1750mm. 32% of this evapo-transpirative demand is during the four months of July-October when the region receives monsoon rains (source: Indian Meteorological Department, Ahmedabad as cited in Figure 6 of Kumar, 2002b: page 17). The soil type in the area varies from sandy to sandy loam and loamy sand.

Table 4: Saving in Applied Water and Productivity Gains through Drip Irrigation

Name of the crops	Water consumption (or application?) (mm/ha)		Yield (ton/ha)		Water saving over FMI (%)	Yield increase overFMI (%)	Water consumption per ton of yield (mm/ton)	
Vegetables	FMI	DMI	FMI	DMI			FMI	DMI
Ash gourd	840	740	10.84	12.03	12	12	77.49	61.51
Bottle gourd	840	740	38.01	55.79	12	47	22.09	13.26
Brinjal	900	420	28.00	32.00	53	14	32.14	13.13
Beet root	857	177	4.57	4.89	79	7	187.53	36.20
Sweet potato	631	252	4.24	5.89	61	40	148.82	42.78
Potato	200	200	23.57	34.42	Nil	46	8.49	5.81
Lady's finger	535	86	10.00	11.31	84	13	53.50	7.60
Onion	602	451	9.30	12.20	25	31	64.73	36.97
Radish	464	108	1.05	1.19	77	13	441.90	90.76
Tomato	498	107	6.18	8.87	79	43	80.58	12.06
Chilly	1097	417	4.23	6.09	62	44	259.34	68.47
Ridge gourd	420	172	17.13	20.00	59	17	24.52	8.60
Cabbage	660	267	19.58	20.00	60	2	33.71	13.35
Cauliflower	389	255	8.33	11.59	34	39	46.67	22.00
Fruit Crops								
Papaya	2285	734	13.00	23.00	68	77	175.77	31.91
Banana	1760	970	57.50	87.50	45	52	30.61	11.09
Grapes	532	278	26.40	32.50	48	23	20.15	8.55
Lemon	42	8	1.88	2.52	81	35	22.34	3.17
Watermelon	800	800	29.47	88.23	Nil	179	27.15	9.07
Sweet Lime*	1660	640	100.0	150.00	61	50	16.60	4.27
Pomegranate*	1440	785	55.00	109.00	45	98	26.18	7.20
Other Crops								
Sugarcane	2150	940	128.00	170.00	65	33	16.79	5.53
Cotton	856	302	2.60	3.26	60	25	329.23	92.64
Groundnut	500	300	1.71	2.84	40	66	292.40	105.63

*: Yield in 1000 numbers;

Source: INCID (1994) and NCPA (1990) as cited in Narayanamoorthy (2004): pp 122

Note: FMI and DMI refer to flood method of irrigation and Drip Method of Irrigation, respectively.

Table 5: Results available from past studies on water saving and yield impacts of drip irrigation

Name of researchers	Location	Nature of study	Results on	
			Saving in Applied Water	Crop Yield
Jadhav *et al.* (1990)	Haryana	Socio-economic	31 per cent saving in water use in tomato	Yield increase by 50 %
Hapase *et al.* (1992)	Maharashtra	Socio-economic	50-55 per cent saving in water in sugarcane crop	Yield increase in the range of 12-37%
Muralidharan and others (1994)	Kolar, Karnataka	Socio-economic	Water-saving benefits highlighted, not quantified	
Narayanamoorthy (1996)	Nashik, Maharashtra	Socio-economic (respondent survey)	41 per cent water saving for banana and 59 per cent for grapes	Productivity higher under DMI for both crops
Reddy and Thimmegowda (1997)	Bangalore, Agricultural University Research Station	Experimental farm measurements	Water-saving benefits not quantified	Seed cotton yield increased by 13% under drip tap; 16% under emitter drip
Reddy and Thimmegowda (1997)	Bangalore, Agricultural University Research Station	Experimental farm measurements	Water-saving benefits not quantified	Seed cotton yield increased by 13% under drip tap; 16% under emitter drip Ratoon yield by 3% under drip tape; and 6% under emitter drip
Dahake and others (1998)	Akola district of Maharashtra (Orange)	Socio-economic survey	Uniform distribution and conservation of water in orchards	
R. L. Shiyani and others (1999)	Four districts of Saurashtra in Gujarat viz., Junagadh, Rajkot, Amreli and Bhavnagar (Cotton)	Socio-economic survey	Socio-economic survey Water saving not quantified; but estimated reduction in irrigation cost as varying from 25% to 51%; increase in irrigation cost in Bhavnagar	Yield enhancement in cotton in all districts, averaging 22%
Palanisamy and others (2002)	Coimbatore (Coconut)	Socio-economic survey	50 % water saving in coconut	20-30 per cent increase in coconut yield
Kumar and other (2004)	Banaskantha, Gujarat (Alfalfa)	Techno-economic evaluation of drips in demo farms of alfalfa	Reduction in water application in the range of 7-43 per cent	Yield increase in the range of 5-10 per cent

Name of researchers	Location	Nature of study	Results on	
			Saving in Applied Water	Crop Yield
Kumar, Singh, Singh and Shiyani (2004)	Four districts in Gujarat (several crops)	Socio-economic survey	Extent of water saving varies from crop to crop and from system to system	Yield increase in all crops; but variation in yield benefits across crops
Waykar and others (2003)	Ahmednagar district of Maharashtra (Sugarcane)	Socio-economic survey	Data on water-saving not available	Higher yield of sugarcane (up to 27%) for adopters of drip systems.

Source: Synthesis of various studies by the authors

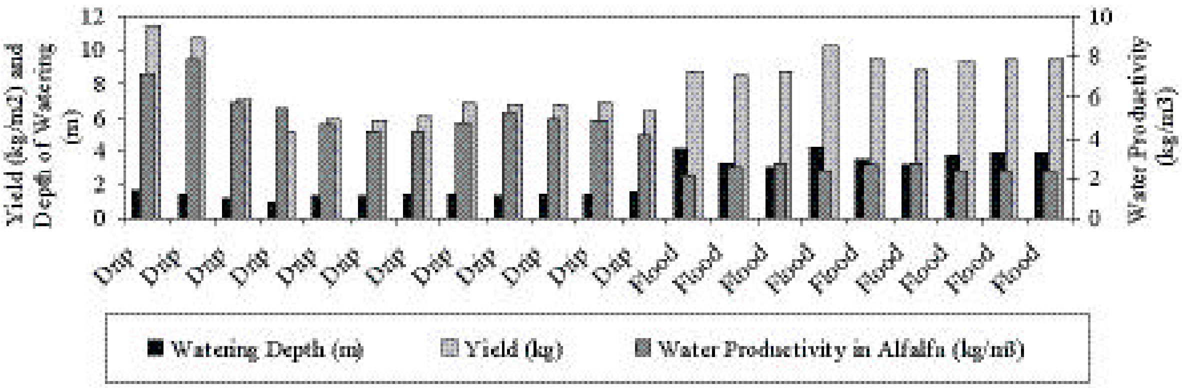
The crops covered are: alfalfa, castor, groundnut and potato. The technologies used are: inline drip system for alfalfa; micro tube drip with and without plastic and organic mulching, and flooding with and without plastic/organic mulching; micro tubes and inline drippers in groundnut; and inline drippers and micro tubes in potato. The results from these experiments are presented in Table 6-9.

The treatments used for alfalfa are: different spacing of drippers without changing the water delivery through drippers (30cm*40cm in F1 to 50cm*40cm in F4); maintaining the same spacing of drippers (30cm*30cm) with different intensities of daily irrigation (G1 to G4); maintaining same spacing of drippers with different intensities of irrigation, and with watering on alternate days; small level border irrigation with different intensities and with various irrigation schedules (from an average of 7-8 days in winter to 5 days in summer to an average of 6 days in winter to 4 days in summer). FYM was applied in all the plots in equal dozes, and no chemical fertilizers were used. The volume of water applied in the field was measured using water meters each time when irrigation is done, and output is weighted each time harvest/cutting is done.

The results are presented in Figure 2. It shows that the yield is highest for plot with a dripper spacing of 30 cm* 40 cm (11.36 Kg./m^2) of green matter, followed by one with a spacing of 35cm*40 cm (10.71 Kg./m^2). But, water productivity was highest (7.8 Kg./m^3 of water) for the plot which recorded second highest yield (F_2). Therefore, the highest yield corresponds to a depth of application of 1.6 m, while highest water productivity corresponds to a depth of 1.37 m. With flood irrigation, the yield values were highest for treatment I_5 in which the amount of water applied was 4.3 m. Though these are very high figures for small border irrigation, it can be attributed to sandy soils. Here, I1 is a case of over-irrigation with very heavy doses of irrigation (139 mm) and can be discarded. The figures are relevant since with such high dozes of irrigation no field run off was generated, meaning there are chances for farmers to actually apply such high doses in sandy soils under well irrigation.

The yield figure almost touched that obtained with daily irrigation through drips (F_1 and F_2). But, the amount of water applied was far higher than that under F type treatments-almost 3 times in most cases. The water productivity values were in the range of 1.47 Kg./m^3 and 2.79 Kg./m^3, which were only 20-30% of that obtained with drip irrigation under F_2 treatment. The results show that with drip irrigation, the water productivity could be enhanced significantly in alfalfa without compromising on the yield. As for economic viability, even if we compare the drip irrigated plots with some of the best plots under flood irrigation, the reduction in water use is substantial, with modest improvements in yield. Therefore, when water availability becomes a constraint, drip for alfalfa would be economically viable under a lateral spacing of 30cm*40 cm. This is because, one of the earlier analysis with similar type of drip system on alfalfa showed that even with 10% increase in yield, and 45% reduction in water use, drips could be economically viable, when the social benefits of water saving are taken into account. In this case, reduction in water use is much higher when F1 and F2 are compared with any of the flood-irrigation plots. Increase in yield is 10% when F2 is compared against the best flood irrigated plot, and much higher than 10% when compared against other flood-irrigated plots.

Figure 2: Impact of Drip on Applied Water Productivity in Alfalfa



The results (I_1 to I_{10}) also show that there are significant variations in water productivity levels of alfalfa under flood irrigation with changing irrigation intensity. Highest yield was obtained under second highest level of water application (4.33 m over the full crop year). Highest water productivity (2.79 Kg./m^3) was obtained with the lowest level of irrigation (3.15 m). The lowest water productivity (1.47 Kg./m^3) was obtained under highest level of irrigation (6.0 m).

Experiments carried out with micro tube drips with plastic and organic mulching and micro tubes with broad furrows as the control in Manka village of Vadgam in Banaskantha. There were four treatments followed. In the first three treatments, watering was done daily with daily irrigation water requirement estimated roughly on basis of the crop water requirement (K_c*ET_0), and daily dosage was adjusted on the basis of the field observations of soil moisture conditions. In the fourth case, the irrigation water dosage was determined by making provision for evaporative losses from the exposed soil in the crop land and deep percolation losses. The scheduling was same as that practiced in the area for castor for traditional method. While a total of 96 watering were done with C_1, C_2 and C_3, irrigation was applied nine times under C_4. The results showed that water application rate was lowest when micro tube drips were used with plastic mulching (treatment C_1), followed by micro tube with organic mulch (treatment C_2). The water application rate was highest for broad furrow treatment (C_4). The yield was highest for C_1, followed by C_4. The water productivity was highest for C_1, and second highest for C_2. The difference in water productivity was 100% between the first and the last treatment.

Table 6: Impact of Drip Irrigation on Applied Water, Yield and Applied Water Productivity in Castor in Manka

Plot No.	Method of Irrigation	Agro-nomic Practices	Plot Size (m^2)	No.of Watering	Water Application Rate (mm/ irrigation)	Per Sq. Meter Area		
						Water use (m^3)	Production (Kg.)	Water Productivity (Kg./m^3)
C - 1	Micro-tube	P M	1110	96	2.09	0.201	0.135	0.67
C - 2	Micro-tube	O M	1110	96	2.35	0.225	0.099	0.44
C - 3	Micro-tube		1110	96	3.14	0.302	0.113	0.37
C - 4	Flooding		1110	9	40.64	0.366	0.126	0. 34

PM = Plastic Mulching; OM = Organic Mulching
Source: Authors' own analysis

Experiments conducted on groundwater with inline drip systems and micro tube drips showed highest level of reduction in applied water use in case of inline drippers when compared against border irrigation. The treatment included daily application of water to the plot through inline drippers and micro tube drips. The fertilizer doses were same in all the plots which were of the same size. The reduction in water dosage was nearly 18 cm, while the yield was higher by 0.013 Kg./m^2, with a net effect on water productivity in the order of 0.18 Kg./m^3 of water (see Table 7). The micro tube irrigated plot gave same yield as that of furrow irrigated plot, but the applied water was less with micro tube. The study shows that inline drippers are physically more efficient than furrow method and inline drip irrigation.

Table 7: Impact of Drip Irrigation on Applied Water, Yield and Applied Water Productivity in Groundnut (Kumbhasan)

Plot No.	Method of Irrigation	Plot Size (m^2)	No. of Watering	Water Application Rate (mm/ irrigation)	Per Sq. Meter Area		
					Water use (m^3)	Production (Kg.)	Water Productivity (Kg./m^3)
G - 1	Inline Drip	192	49	6.54	0.320	0.130	0.41
G - 2	Micro-tube	192	49	7.05	0.345	0.117	0.34
G - 3	Furrows	192	8	62.85	0.503	0.117	0.23

Source: Authors' own analysis

Another interesting experiment was done with different types of MI devices to understand the physical productivity of applied irrigation water in potato. In this experiment, five different types of MI devices were used, viz., inline drippers; easy drips (or drip systems with flexible laterals having a thickness ranging from 125 microns to 500 microns and have perforations instead of drippers to emit water); micro tube drips; micro sprinklers; and mini sprinklers. The results are presented in Table 8. It can be seen that the yield and physical productivity of water is highest for field irrigated with micro sprinklers, followed by mini sprinklers. This is in spite of the fact that the water dosage was more than double in the case of treatments P4 and P5.

On the basis of the values of irrigation dosage and the corresponding yield and water productivity values under different treatments, one can infer that water dosage was much lower than required in the case of inline drip, easy drip and micro tube drip irrigated plots, resulting in water stress and significant yield losses. Also, another inference is that in all the treatments, water dosage was in the ascending part of the yield and water productivity response curves for irrigation water application, which also means that with higher dosage of irrigation, the chances for getting higher yield are higher. It can be seen that with micro tubes, though the amount of water applied was same as that with inline drips (P1), the yield (0.148 Kg./m^2) was much lower than that with P1. This could be due to poor distribution efficiency obtained with micro tubes.

Table 8: Impact of Drip Irrigation on Applied Water, Yield and Applied Water Productivity in Potato (Manka)

Plot No.	Method of Irrigation	Plot Size (m^2)	WST (cm)	No.of Watering	Water Application Rate (mm/ irrigation)	Per Sq. Meter Area		
						Water use (m^3)	Production (Kg.)	Water Productivity (Kg./m^3)
P - 1	Inline drip	304	52.5 x 30	56	7.50	0.420	0.375	0.893
P - 2	Easy drip	304	52.5 x 30	56	7.50	0.420	0.411	0.979
P - 3	Micro-tube drip	304	52.5 x 30	56	7.50	0.420	0.148	0.352
P - 4	Micro-Sprinkler	304	310 x 290	59	15.96	0.942	1.316	1.397
P - 5	Mini-Sprinkler	304	730 x 720	59	15.96	0.942	0.905	0.961

Source: Authors' own analysis

3.2.1D Potential aggregate impact of MI systems on water use for crop production

There is debate about the extent of water saving at system and basin level due to the widespread adoption of MI systems. This concerns: 1] whether there is real water saving in the first place, and 2] what users do with the saved water. We have addressed the first question in the earlier section. As regards the second question, many scholars believe that the aggregate impact of drips on water use would be similar to that on water use in unit area of land. While several others believe that with reduction in water applied per unit area of land, the farmers would divert the saved water for expanding the area under irrigation, subject to favourable conditions with respect to water and equipment availability, and power supplies for pumping water (Kumar, 2002),[12] and therefore the net effect of adoption of micro irrigation systems on water use could insignificant at the system level. At the same time, there are others who believe that with adoption of WSTs, there is a greater threat of depletion of water resources, as in the long run, the return flows from irrigated fields would decline, while area under irrigation would increase under WSTs.

These arguments have, however, missed certain critical variables that influence farmers' decision making with regard to area to be put under irrigated production, and the aggregate water used for irrigation. They are: groundwater availability vis-à-vis power supply availability; crops chosen; and amount of land and finances available for intensifying cultivation. The most important factor is the overall availability of groundwater in an area.

If power supply restrictions limit pumping of groundwater by farmers, then it is very unlikely that adoption of conventional WSTs would help farmers expand their area under irrigation. In the states of Punjab, Gujarat, Karnataka and Madhya Pradesh, power supply to agriculture sector is only for limited hours (GoI, 2002). It acts as a constraint in expanding the irrigated area, or increasing irrigation intensity, in those areas where groundwater availability and demand is more than what the restricted power supply can pump.

Since the available power supply is fully utilized during winter and summer seasons, farmers will be able to just irrigate the existing command with MI system. This is because the well discharge would drop when the sprinkler and drip systems connected to the well outlet start running, owing to increase in pressure developed in the system (please see equation below). In other words, the energy required to pump out and deliver a unit volume of groundwater increases with the introduction of MI system. The only way to overcome this is to install a booster pump for running the MI system. As electricity charges are based on connected load, farmers have least incentive to do this.

$$Q = \frac{\beta * 100 * \eta}{H}$$

Where, "BHP" is pump power in kilowatt/sec, "H" is the total head, "Q" is the discharge. ? = combined electrical and hydraulic efficiency of pump set.

Such outcomes are expected in the alluvial areas of north Gujarat and Punjab. In this area, even in situations of availability of extra land, it won't be possible for farmers to expand the area under irrigated crops due to restrictions on power supply.

The other factor is the lack of availability of extra arable land for cultivation. This is applicable to areas where land use and irrigation intensity is already high. Example is central Punjab. But, farmer might still adopt water-saving technologies for cash crops to raise yields or for newly introduced high-valued crops to increase their profitability. So, in such situations, adoption would result in reduction in aggregate water demand.

On the other hand, if the availability of water in wells is less than what the available power supply can abstract, with adoption of micro irrigation systems, the farmers are likely to expand irrigated area. This is the situation in most of the hard rock areas of peninsular India, central India and Saurashtra. Due to limited groundwater potential and over-exploitation, well water is very scarce in these areas. The available power supply is

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[12]If power supply is more than what is required to pump the available water from wells, then water saving can lead to expansion in irrigated area. Whereas, if power supply is less than what is required to pump the available water from wells, then water saving per unit area cannot result in area expansion (Kumar, 2002).

more than what is needed to abstract the water in the wells. Hence, farmers have strong economic incentive to go for MI systems other than yield enhancement (Dhawan, 2000). The reason is that the saved water could be used to expand the irrigated area and improve the economics of irrigated farming. In Michael region of central India, for instance, farmers use low cost drips to give pre sowing irrigations to cotton, before monsoon, when there is extreme scarcity of groundwater. This helps them grow cotton in larger area as water availability improves after the monsoon (Verma *et al*., 2005). In this case, there is no water saving at the aquifer level.

The third factor is the crops chosen. Often MI technologies follow a set cropping pattern. All the areas in the country where adoption of drip irrigation systems has increased, orchard crops are the most preferred crops (Dhawan, 2000; Narayanamoorthy, 2004b). Therefore, while farmers adopt MI systems, the crops also change, normally from field crops to fruits.[13] While for many fruit crops, the gestation period is very large extending from 3-10 years (for instance, citrus, orange and mango), for many others like grapes, pomegranate and banana, it is quite short extending from one to two years. Also, farmers can go for intercropping of some vegetables and watermelon, which reduces their financial burden of establishing the orchards. This flexibility enables small and marginal farmers also to adopt MI systems, as found in north Gujarat and Jalgaon and Nasik districts of Maharashtra.

Access to credit and subsidy further increases MI adoption among small and marginal farmers. The irrigation water requirement of the cropping system consisting of field crops such as paddy, wheat, pearl millet/ sorghum combinations is much higher than that of fruit crops such as pomegranate, gooseberry, sapota and lemon. Also for other orchard crops such as mango, the irrigation water requirements during the initial years of growth would be much less than that of these field crops. Therefore, even with expansion in cropped area, the aggregate water use would drop. Only in rare situations, the system design for one crop is adaptable for another crop. For example: the micro sprinklers that are used for winter potato, can also be used to irrigate summer ground nut and hence farmers opt for that crop.

Synthesizing, there is very little data across agro-climatic conditions on the yield impacts of micro irrigation systems for the same crop. The research is heavily skewed towards drip irrigation systems, and there is hardly any data on the economics of other WSTs. As we have seen early, for a given crop, the yield as well as water-saving benefits of MI system can change across systems, as can the capital costs. Also, it can change across crops. But, the research is also heavily skewed towards orchard crops (banana, sugarcane and cotton). These crops still occupy a small percentage of the irrigated area in the country. Further, these economic analyses were not contextualized for the socioeconomic and institutional environment for which they were performed. The socio-economic and institutional environments determine the extent to which various physical benefits get translated into private and economic benefits. We would explain it in the subsequent paragraphs.

Normally, it has been found that drip irrigation is economically viable for horticultural crops and orchards such as banana, grapes, orange, coconut, and sugarcane (Dhawan, 2000: pp 3775; Sivanappan, 1994; Narayanamoorthy, 2003).

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[13] Farmers bring about significant changes in the cropping systems of farmers with the adoption of drips. When drips are adopted for orchards, farmers permanently abandon cultivation of traditional crops such as paddy and wheat. A most recent example is Nalgonda district in Andhra. Farmers generally start with small areas under orchards and install drips. After recovering the initial costs, the general tendency of farmers is to bring the entire cultivated land under orchards, and put them under drip irrigation. This is because orchards require special care and attention and putting the entire land under orchards makes farm-management decisions easier. However, the same tendency of area expansion is not seen when MI systems are used for other cash crops such as cotton and sugarcane.

In the case of cotton, it is difficult for farmers to take up any crop that can be irrigated with drips after the harvest in the end of winter. This is due to the lack of flexibility in the design of the conventional MI systems. Due to the high capital cost, it is best suited to permanent plantings or crops having roughly the same planting space as frequent removal and rolling back can cause damage to online drips. Exceptions are porous pipes used for sub-surface irrigation. In the cotton growing areas, farmers normally roll back the system and cultivate the traditional crops in summer only if water is available. But, early sowing of cotton is found to be common among farmers who have installed drip irrigation, as they are able to manage their pre-sowing irrigation with very little water available from wells (Verma *et al*., 2004). With improved planting patterns (paired rows, pit system) farmers install almost permanent drip systems for sugarcane crop.

Table 9: Results available from past studies on economic viability of drip and sprinkler irrigation

Name of researchers	Location	Nature of study	Results on	
			Economic Viability	Remarks
Jadhav *et al.* (1990)	Pusa, Haryana	Socio-economic	5.16 and 2.96 for drip and furrow method, respectively, in tomato	
Muralidharan and others (1994)	Kolar, Karnataka	Socio-economic	B-C ratio not as good as in furrow irrigation for mulberry crop.	But, B-C ratio did not take into account the price at which water is traded in the region
Narayanamoorthy (1996)	Nashik, Maharashtra	Socio-economic (respondent survey)	Incremental return was Rs. 32400/ha in banana and Rs. 50180/ha in grapes. Reduction in cost of cultivation was Rs. 1300/ha in banana and Rs. 13400/ha in grapes	B-C analysis was based on direct costs and direct benefits and not based on incremental returns against incremental cost of drips
Narayanamoorthy (1997)	Nashik, Maharashtra	Socio-economic (respondent survey)	B-C Ratio ranged from 2.07 to 2.36 for banana and 1.48 to 1.80 for grapes with varying discounting rates	Do
Shivanappan (1994)	Tamil Nadu	Physical and Socio-economic	B-C Ratio ranged from 1.3 for sugarcane to 11.5 for grapes. The B-C ratio improved when the benefits of water saving was reckoned with	The incremental benefits calculated for the scenario of irrigated area expansion did not include the cost of establishing the crops in case of orchards
Reddy and Thimmegowda (1997)	Bangalore, Agricultural University Research Station	Experimental farm measurements	Average establishment cost was Rs.92522/ha for emitter drip irrigation, and Rs. 57482/ha for turbo tape. Turbo tape drip irrigation was found more profitable than emitter drip irrigation as indicated.	The pay back period was three years for turbo tape drip and five years for emitter drip irrigation for the main crop.

Name of researchers	Location	Nature of study	Results on	
			Economic Viability	Remarks
R. L. Shiyani and others (1999)	Four districts of Saurashtra in Gujarat viz., Junagadh, Rajkot, Amreli and Bhavnagar (Cotton)	Socio-economic survey	Significant differences in cost-B and cost-C between drip adopters and the farmers using surface method of irrigation. The major advantages of drip system over conventional method were: higher yield, higher profit, rise in labour productivity and reduction in unit cost of production	Other advantages of drip system included saving in water, reduction in weeding and labour cost, suitability for un-leveled and stony soils, increase in water use efficiency, decline in diseases and pests incidence and improvement in the quality of product
Palanisamy and others (2002)	Coimbatore, Tamil Nadu (Coconut)	Economic performance of drip irrigation	Aditional cost of drips in coconut cultivation was Rs. 31,165/ha. The cost of cultivation went up by 19% in drip-irrigated coconut. The financial viability of drip irrigation system showed more than 30 per cent modified internal rate of return in the water scarcity condition.	Reasons for improved financial viability were: higher price of coconut, 20 to 30 % increase in yield; increased fertilizer use efficiency; reduction in expenditure on plant protection chemicals; 50% water saving; and labour saving to the tune of Rs. 3000/ha.
Luhach et al. (2003)	Haryana	Socio-economic survey of sprinklers adoption in wheat	Average net returns per ha from sprinkler irrigation was found to be 19.53% higher than that for pump irrigation. On an average, the net present value of sprinkler was found to be Rs. 7970, benefit-cost ratio was 1.97, and the internal rate of return was 17%	

Source: Synthesis of various studies by the authors

The reason for this is that the crops are high valued and even a marginal increase in yield results in significant rise in value of crop output. Dhawan (2000) argues that higher value of crop output is realised also from improved price realization due to quality improvements on one hand and early arrival of the drip-irrigated crop in the market on the other. The same need not be true for other cash crops, and field crops.

3.2.2 Economic impacts of MI Systems

There is enormous amount of research-based literature showing the positive economic impacts of water-saving irrigation devices. Many research studies available from India during the past one decade quantified economic benefits from drips. They are summarized in Table 6 cant see.

For instance, the income benefit due to yield improvement depends on the type of crop. For cereals, it cannot be significant. A 10% rise in yield would result in an incremental gain of 400-500 kg of wheat or Rs. 3000-Rs.3750/ha of irrigated wheat. At the same time, a 10% rise in yield of pomegranate, whose minimum yield is 60000 kg per ha per year, would result in an incremental gain of 6000 kg/ha or Rs.90000/ha. Besides the incremental value of outputs, an important factor which influences the economic performance of drip system is the cost of installation of the system.

From the point of view of deciding investment priorities including the provision of subsidies, it is important to know the social benefits from drip irrigation. As Dhawan (2000) notes, cost-benefit analyses, which do not take into account social costs and benefits, are on weak conceptual footing as the government subsidies in micro irrigation systems are based on the premise that they have positive externality effect in terms of water saving. In areas, where available water in wells is extremely limited, it is logical to take water-saving benefits and convert the same in monetary terms based on market price or in terms of additional area that can be irrigated. Same is the case with energy saving. But the same methodology cannot be applied to areas where access to water is not a limiting factor for enhancing the area under irrigation, or energy is not a scarce resource. But, such analysis are absent in India.

Given the range of variables - physical, socio-economic and financial - that affect the costs and returns from crops irrigated by MI systems, it is important to carry out comprehensive analysis taking into account all these variables, across situations where at least the physical, socio-economic conditions change. Now, we examine how these variables change under different situations.

As regards water saving, in many areas, the well owners are not confronted with the opportunity cost of wasting water. Hence, water saving does not result in any private gains. Where as in some hard rock areas like Kolar district in Karnataka, the amount of water that farmer can pump from the well is limited by the geo-hydrology. The price at which water is sold is also high in such areas (Deepak *et al*., 2005), as is the opportunity cost of using water. Hence, the amount of water saved would mean income saving for the adopters.

As regards benefit due to energy-saving, it is applicable to certain MI devices, especially low pressure systems and gravity systems such as drip tapes, micro tube drips and easy drips. But, farmers of many water-scarce regions are not confronted with marginal cost of using energy. Hence, for them energy saving does not result in any private gain. But, from a macro economic perspective, if one wants to examine the economic viability of the system, it is important to consider the full cost of supplying electricity to the farms while evaluating the economics of irrigation using the system. Also, we consider the price at which water is traded in the market for irrigation (ranging from Rs.1.5/m3 to Rs.2.5/m3 in north Gujarat to Rs.6/m3 in Kolar) as the economic value of water[14] then any saving in water resulting from drip use can be treated as an economic gain. The real economic cost of pumping water ranges from Rs. 1.5/m3 in north Gujarat to Rs. 2/m3 in Kolar district.

The private income benefit due to water saving is applicable to only those who purchase water on hourly basis. Dhawan (2000) cautions that over-assessment of private benefits are possible in certain situations where return flows from conventional irrigation are significant (Dhawan, 2000). But in regions where reduction

[14]Though the actual economic value of the groundwater would be equal to the economic surplus generated by the use of that water for irrigation, which would vary according to the type of crops farmers grow, this would be a reasonable assumption that can lead to more conservative estimates of economic benefits of water saving.

in deep percolation means real water saving, it leads to private benefits. Here, for water buyers, the private income gain from the use of drip or sprinkler system depends on the price at which water is purchased (volumetric) and the reduction in water use achieved. There could be significant social benefits due to water saving in water scarce regions, owing to the reduced stress on water resources (Dhawan, 2000), resulting from reduced pumping. In situations like north Gujarat, such social benefits could not be over-emphasised.

As regards the cost, the capital costs could vary widely depending on the crop. For widely spaced crops (mango, sapota, orange and gooseberry) the cost could be relatively low due to low density of laterals and drippers. For closely spaced crops such as pomegranate, lemon, papaya, grapes, the cost could go up. For crops such as castor, cotton, fennel and vegetables, the cost would go further up as denser laterals and drippers would be required. Even for low cost micro tube drips, the cost per ha would vary from Rs. 12000 for sapota and mango to Rs.28000 for pomegranate to Rs.40000 for castor.

Keeping in view these perspectives and situations, economics of water-saving technologies can be simulated for four typical situations for alfalfa in Banaskantha district of north Gujarat based on real time data collected from four demo plots in farmers' fields. Alfalfa is an annual crop used as forage grown in north Gujarat region, including Banaskantha district.

The first level of analysis is limited to private cost-benefits (level 1). Yield increase and labour saving are the private gains here. The annual yield benefit was estimated by taking calculated daily yield increase (col. 3-col. 5 in Table 11) and multiplying by 240, which is the approximate number of days for which the fodder field yields in a year. The labour saving benefit was calculated by taking the irrigation equivalent (in daily terms) of total water saved (total volume of water saved/discharge of pump in 8 hours) and multiplying it by the daily wage.

In the second level of analysis, the actual economic cost of using every unit of electricity is considered as a benefit from saving every unit of the energy (level 2). In this case, the energy saving and cost saving depend on two factors: the energy required to pump unit volume of groundwater, and the total volume of water saved. Here, it is assumed that no extra energy would be required for using the inline drip system, which is connected to the existing pumping devise[15]. In the third level of analysis, the unit price of water in the market was treated as economic gain from "actual saving" of every unit of water and was added to the cost of electricity to pump unit volume of water (level 3). This was multiplied by the total volume of water saved to obtain the total economic gain in excess of the gain from yield increase and labour saving. The fourth level of analysis for farmers who are irrigating with purchased water. Here in this case, the unit price of water could be considered as a private gain from saving every unit of water (level 4). In this case, the cost of construction of a storage tank and a 0.5 HP pump are added to the cost of installation of the system. The results are presented in Table 10.

Table 10: Economics of Drip Irrigation in Alfalfa for Four Different Situations

Plot No.	Initial Cost of the System (US $)	Total Water Saving/ Year (M3)	Equivalent Energy Saving/ Year (K.W. hr)	Labour Saving / Year (person days)	Yield Increase From the entire plot (Kg)	Private Benefit/ Cost (Level 1)	Economic Benefit/ Cost Ratio (Level 2)	Economic Benefit/ Cost Ratio (Level 3)	Private Benefit/ Cost Ratio (for water buyers) (Level 4)
1	157.0	479.50	149.00	4.00	448.00	1.09	1.83	2.78	1.39
2	136.0	111.30	92.30	6.00	409.00	1.29	1.48	1.74	0.99
3	201.0	63.60	31.60	4.90	586.00	1.10	1.18	1.28	0.88
4	168.0	468.00	232.80	6.00	414.00	1.05	1.73	2.59	1.33

Source: The authors' own estimates based on primary data

An analysis of economics of some water-saving technologies (pressurized drips, sprinklers and micro tubes) was attempted on the basis of data on crop inputs and outputs, and capital investments collected from

[15]The system being designed and installed for small plots of 500 m2 with an operating pressure requirement of 0.4kg/cm2 for the inline drips, all the farmers who used the system ran them under the residual head.

primary survey of adopters and non-adopters for Kachchh, Bhavnagar, Rajkot and Banaskantha districts. While Kachchh has arid climate, Bhavnagar and Rajkot have semi arid climate. The results are presented in Table 11. The analysis is based on the estimates of incremental returns from drip irrigation over the entire life of the system against the additional capital investment for the system. For calculating the present value of an annuity, a discount rate of 6% was used and the life of the system was considered as 10 years. The incremental returns considered are the average of two consecutive years. This was done to take care of the problems of yield reductions due to crop failure and price fluctuations. While estimating incremental returns, the effect of differential input costs, and differential return were considered. The benefit cost analysis was carried out for three important crops in all the four districts irrigated by micro irrigation systems and are presented in Table 11.

Overall, two major findings emerge from the results of benefit-cost analysis. First: for cash crops and orchard crops, the B/C ratio often become very high but with wide variations across crops. For instance, in case of castor in Banaskantha, the B/C ratio is 5.2, whereas it is only 0.56 for the same crop in Kachchh. Second: for conventional field crops, the B/C ratios are generally low, but with low variation.

Table 11: Private costs and returns from micro irrigation in the selected districts

Sl. No.	Crop	Incremental net income (Rs)	Incremental annual cost of the system (Rs)	B/C Ratio
Rajkot				
1.	Chilly	17518.28	16792.63	1.06
2.	Cotton	20064.84	6266.75	3.30
3.	Groundnut	7574.25	9216.00	1.30
Banaskantha				
1.	Alfalfa	49062.77	9998.76	4.90
2.	Bajra	1787.88	1221.13	1.40
3.	Castor	5373.78	1016.48	5.20
4.	Mustard	6021.25	3970.70	2.00
5.	Wheat	2305.95	2602.72	0.98
Kachchh				
1.	Banana	54297.21	10949.73	6.00
2.	Cotton	17303.65	11158.78	1.70
3.	Lemon	34029.61	15677.26	2.70
4.	Mango	8570.48	8386.90	0.94
5.	Brinjal	42816.90	32608.70	1.30
6.	Castor	18953.74	33840.17	0.56
Bhavnagar				
1.	Groundnut	3509.98	685.47	5.10
2.	Bajra	2155.14	2559.86	0.84
3.	Jowar (Fodder)	38150.91	8861.06	4.30
4.	Cotton	3719.35	2138.46	1.70
5.	Mango	29901.90	1953.13	15.30
6.	Lemon	3933.28	2822.49	1.40

Source: Authors' own estimates based on primary survey

It is noteworthy that the incremental net returns were generally markedly higher for cash crops viz., ground nut, cotton, castor; and fruits viz., mango and banana than for food crops viz., bajra and wheat. This is in conformation with the work of earlier researchers (see Narayanamoorthy, 1997; Sivanappan, 1994; Narayanamoorthy, 2003). The incremental returns from cash crops, particularly fruits, could, however, fluctuate significantly depending on the price and yield fluctuations. At the same time, it is also equally striking to note that the benefit-cost ratios are good for cereals also given the fact that the capital cost of the system is high and the market value of the produce is not high. Perhaps, this could be because farmers who did not use the system faced significant yield losses due to water stress.

4. POTENTIAL FUTURE BENEFITS FROM MICRO-IRRIGATION TECHNOLOGIES

This section is based on inference drawn from section 3 concerning the conditions under which micro irrigation system becomes a good bet technology.

Table 12: Crops conducive to water-saving technologies in India and their Potential Spread

Crop Category	Different crops conducive for WSTs	Type of WSTs that can be used	Regions*
Tree crops and orchards	Mango, Guava, Goose-berry, Pomegranate, Sapote, Orange, Coconut, Banana, Date palm, Grapes, Papaya, Citrus and Kinnow, Drumstick	Drips (for all); and also Sprinklers (Banana, Mango) and plastic mulching in case of extreme water stress	Maharashtra, Andhra Pradesh, Kerala, Karnataka, Tamil Nadu, and Punjab
Row field crops	Potato and Groundnut	Drips; and also mulching (for groundnut and potato)	Gujarat, Maharashtra and Punjab
Plantation Crops	Coconut, Coffee, Tea, Teak	Drips (for coconut and teak); and sprinklers (for tea and coffee)	Kerala and Karnataka (coco-nut, tea and coffee), Orissa (tea); Tamil Nadu (coconut)
Field Crops	Wheat, Pearl millet, Sor-ghum, Maize, Alfalfa, Mustard	Overhead sprinklers (wheat, pearl millet, maize and sorghum) and mini and micro sprinklers for alfalfa	Punjab, Haryana, Gujarat, Maharashtra, Rajasthan and Madhya Pradesh, Andhra Pradesh, and Karnataka
Fruit/Vegetables	Tomatoes, Cucumbers, Capsicums, Brinjal, Gourds, Chilly, Cabbage, Cauliflower, Strawberry	Drips, and plastic mulching	Maharashtra, Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu, Karnataka
Cash crops	Cotton, Fennel, Castor, Sugarcane, Vanilla and Cumin, betel vines	Drips for sugarcane; fogger sprinklers for Vanilla; and micro sprinklers for cumin	Maharashtra, Tamil Nadu and Gujarat (for cotton, sugar-cane and ground nut), Gujarat for cumin and fennel, Orissa and central India for betel vines, and Kerala for vanilla

Note: Drips include pressurized drips (integrated drips, emitters, drip tapes); easy drips; micro tube drips; Regional priority only indicates, any of these crop types could be grown there and not all the crops under the category

4.1 Crops Conducive to Micro-irrigation Technologies

A rigorous analysis of published and unpublished literature shows that there are a wide range of crops that are conducive to micro-irrigation technologies from physical feasibility point of view. They could be classified into: 1] tree crops and orchards; 2] row crops; 3] plantation crops; 4] field crops; 5] vegetables; and 6] cash crops. A list of crops which are conducive to different water-saving irrigation technologies are presented in Table 12. However, this does not mean that micro irrigation systems would be economically viable for these crops in the regions mentioned.

4.2 Water-scarce River Basins that can benefit from Micro-irrigation Technologies

Though the economic viability of MI systems for a given crop would depend on a wide range of factors, such as natural environment (soils and climate), production conditions, market conditions, spread of the technology in an area and the type of price considered for economic evaluation (whether, farm gate price or market price) due to paucity of data on the actual conditions for which the evaluation is performed, general conclusions are drawn on the conduciveness of the basins to the technologies based on the available data and the knowledge about the regions' physical and socio-economic conditions and institutional settings.

That said, there are many basins that can benefit from MI devices. But, the extent to which it can contribute to overall improvement in basin water productivity would depend on: 1] the total area under crops that are conducive to micro irrigation devices in the basin; 2] the types of sources of irrigation of those crops, i.e., whether lift irrigated or gravity irrigated; 3] the climatic conditions in the basin; and, 4] the geo-hydrological conditions.

We have seen that crops that are served by gravity irrigation are least likely to be covered under MI systems due to physical, socio-economic and institutional constraints. Hence, large areas of Haryana, Uttar Pradesh, and Punjab offer no potential for scaling up of micro irrigation systems as mostly they are covered under canal systems. Over and above, paddy, one of the major crops grown in these areas, is also not conducive to water-saving irrigation devices. Though sprinklers can be used for wheat, the water-saving and yield impacts are not likely to be significant enough to motivate farmers to go for it. Nearly 55% of the groundwater in Haryana is saline and alkaline, and the problems are more severe for deeper aquifers in the region (Kumar, Dhindwal and Malik, 2003:pp9). The use of groundwater for irrigation itself is marginal, making micro irrigation system adoption difficult. In Bihar, leaving aside the problem of low appropriateness of the prevailing cropping system (comprising wheat and paddy), power crisis would be a stumbling block in adopting sprinklers which are energy-intensive.

As regards climate, most of Ganga-Brahmaputra-Megha basin covering most parts of Uttar Pradesh, Bihar, and north east has sub-humid and cold climate, and the extent of water-saving possible through MI system adoption could be quite insignificant.

If we consider physical availability of water, physical conditions of water supply and land use, cropping systems, groundwater table conditions, the basins where MI system adoption could take off and where it would result in enhancement in basin level water productivity are: west flowing rivers north of Tapi (river basins of Saurashtra, Kachchh and Luni in Rajasthan); Banas, Sabarmati, south-western parts of Punjab and Haryana in Indus; Cauvery basin; Krishna basin; Pennar basin; Vaghai basin; Narmada; downstream areas of Tapi; Mahanadi and Godavari.

The enhancement in water productivity would come from two phenomena - 1. Reduction in the amount of water depleted with no effect on crop consumptive use. 2. Raising the yield of all the crops that are grown in these basins. Nevertheless, within these basins, there are areas where the groundwater table is very shallow, and climate is sub-humid. They include: south and central Gujarat, which fall in the downstream of Tapi and Narmada.

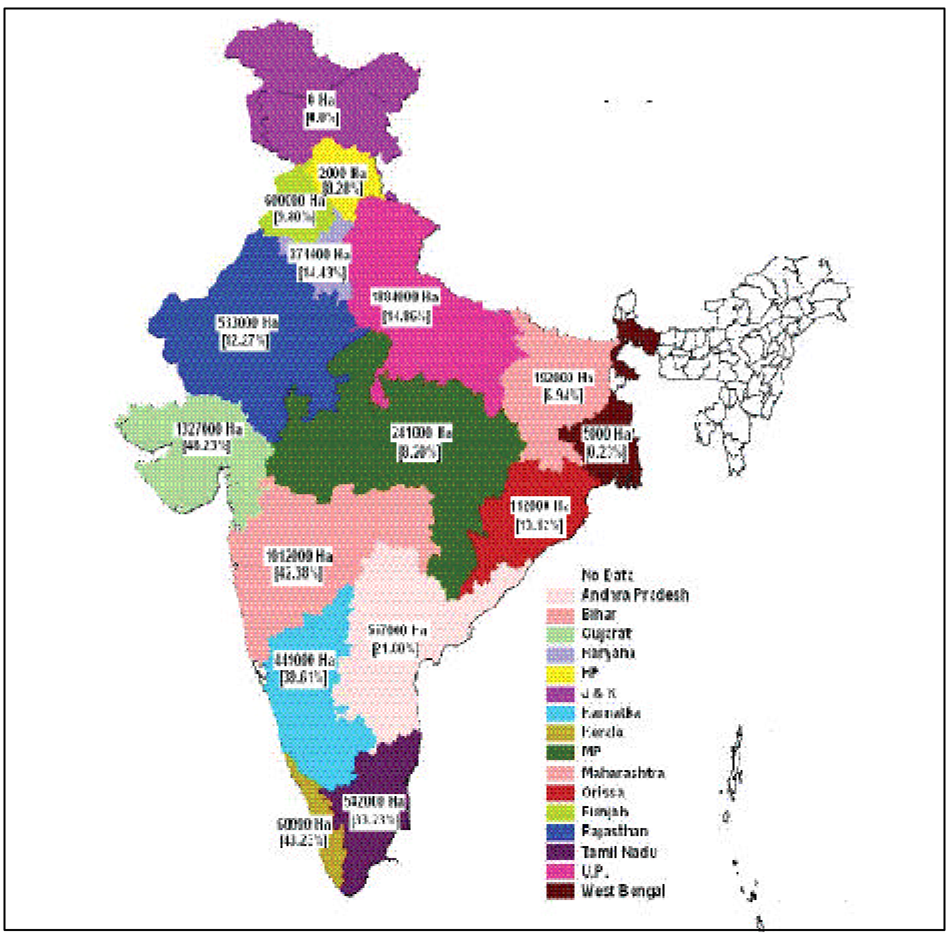
The western Ghat areas in Kerala, Karnataka, Maharashtra and Goa provide favourable environment for adoption of micro-irrigation devices due to the presence of tree and fruit crops and plantation crops such as coconut, arecanut, coffee, tea, mango and banana. The semi arid, hard rock areas of Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra and most parts of Gujarat, provide favourable environment for adoption of MI systems owing to limited groundwater potential; the dominance of well irrigation; and dominance of tree crops, fruit crops, cash crops, row crops and vegetables. At the same time, there would be real saving in water due to declining groundwater table in these regions.

The available data on adoption of micro irrigation systems in different states of India during the past four years is a testimony to what has been discussed in the preceding paragraphs. The highest area under drip irrigation is in Maharashtra (22358 ha). This is followed by Andhra Pradesh (17556 ha), Karnataka (16731 ha) and Gujarat and Rajasthan. But, at the aggregate level, micro irrigation accounts for nearly 1.6% of India's total irrigated area, against 21% in the United States, and 30% (8% under drips and 22% under sprinklers) in Australia.

4.3 Area that can be brought under MI Technologies in Major Indian States

The map shows the area under different crops that are conducive to MI devices in different states of India. The empirical basis for estimating this: 1] the gross irrigated area under such crops; and 2] the percentage of net irrigated area under well irrigation in the respective states. Such approach has the inbuilt assumption that percentage area under well irrigation is uniform across crops. This may not be true. In fact, it has been found that in surface irrigated areas, farmers normally take water-intensive, but less water-sensitive crops. It considered only 16 major states, and had excluded the minor states (13 nos.) and Union Territories. Further, it has excluded area under crops viz., wheat, mustard, rapeseed, pearl millet and sorghum which can be irrigated using sprinklers, but with poor results in terms of water-saving, and had included only those which are amenable to drips and plastic mulching.

It shows that Uttar Pradesh has largest area (1.884 million ha) under crops amenable to WSTs. It is followed by Gujarat with 1.327 million ha, and Maharashtra with 1.012 million ha.



4.4 Basins and Cropped Area Conducive to Adoption of Micro-irrigation Technologies

In order to estimate the figures of "total irrigated cropped area that would benefit from MI systems", we have superimposed the cropped area that are conducive to MI systems, and the basins where MI adoption would lead to real water saving, and water productivity improvements.

The earlier analysis has shown that peninsular and western India had substantial area under crops that are conducive to MI technologies. It has also shown that central and north India have very little area under such crops. Uttar Pradesh is an exception, which accounts for nearly 25% of the area that is conducive to MI systems. The basins in peninsular, western and central India have natural environments (soil, geo-hydrology, climate), wherein MI adoption can actually result in real water saving and basin level water productivity improvement. Western part of Mahanadi is also conducive to MI systems. But, in Ganga-Brahmaputra basin, in which UP falls, adoption is going to be poor due to poor rural electrification; relative water abundance; shallow groundwater in most areas; and very low size of operational holdings of farmers. Even if this region adopts MI systems on a large-scale, it may not result in reduction in depleted water, but a little difference in crop yields, with the resultant meager increase in water productivity at the basin level. Hence, Ganga-Brahmaputra-Meghna) have to be excluded from our analysis.

The cropped areas that will benefit from MI system would hence be from: 1] basins of all east-flowing rivers of peninsular India; 2] basins of west-flowing rivers north of Tapi in Gujarat and Rajasthan; Mahanadi; some parts of Indus basin covering south-western Punjab; and west flowing rivers of South India. The total would be 5.844 m ha (79.30-20.86) of cropped area. This is the absolute potential, and the real adoption would depend on several socio-economic and institutional factors.

Now, let us look at the area estimates provided by Narayanamoorthy (2004b), and the task force on MI in India. Narayanamoorthy (2004b) provided an estimate of 21.27 m. ha as the net area under all irrigated crops that can be brought under drip systems in India, with an upper figure of 51.42 m. ha including area under those crops, which are currently rain-fed. But this analysis did not consider the several physical and socio-economic factors that would ultimate determine the viability of drips for these crops. The task force on MI had estimated a figure of 69 m. ha as the area suitable for MI systems in India. It is quite clear from such a high figure that the task force estimates had included all regions and area irrigated by different types of irrigation systems, therefore not considered the physical (technical, and hydro-meteorological), and socio-economic constraints in the adoption of MI systems.

4.5 Quantification of Potential Future Impact of MI Systems on Water Requirements

In order to analyze the impact of MI devices on aggregate water requirement for crop production in India, we started with the data provided in Table 2 in which data on water use efficiency[16] impact of drip irrigation for various crops are presented. A total of six crops, for which country-level data on irrigated crop area are available, were considered for estimating the future water-saving benefits. Then the data on aggregate output from these crops are obtained. Assuming that the same output for the respective crops is to be maintained in future, the future water requirement for growing the crops could be estimated by dividing the improved water use efficiency figures by the crop output.

The reduction in water requirement for crop $_i$ = Present Output of Crop $_i$ [1/Current Water Productivity -1/Improved Water Productivity]

The procedure can be repeated for all crops.

* States where MI systems are likely to be adopted. This is obtained by multiplying the average crop yield under conventional irrigation (as provided in Table 4) with the sum of the estimated area under that crop in each state. The water productivity figures are estimated from the yield and water consumption figures provided for the respective crops in Table 4 of this report.

[16]We treat them as water productivity values as the modified values of WUE capture the net effect of improved water application and improved agronomic practices.

Table 13: Aggregate Reduction in Water Requirement for Crop Production Possible with Drip Irrigation Systems

Sr. No	Name of Crop	Current Yield (ton/ha)	Expected Yield Coming from the Potential States* (million ton)	Water Productivity (Kg./m^3)	Improved Water Productivity (Kg./m^3)	Reduction in Crop Water Requirement (BCM)
1	Sugarcane	128.0	170.0	5.950	18.09	31.00
2	Cotton	2.600	4.391	0.303	1.080	10.42
3	Groundnut	1.710	2.840	0.340	0.950	1.453
4	Potato	23.57	34.47	11.79	17.21	0.127
5	Castor	1.260	1.350	0.340	0.670	0.497
6	Onion	9.300	12.20	1.544	2.700	0.963
7	Total					44.46

While estimating the crop area that are likely to be brought under drips, the area under the respective crops in water-abundant states viz., UP, Bihar, West Bengal, Haryana and north eastern states were subtracted. The aggregate reduction in crop water requirement due to the adoption of drip systems was estimated to be 44.46 BCM. It can also be seen that highest water-saving could come from the use of drips in sugarcane, followed by cotton. This is the maximum area that can be covered under the crops listed in well-irrigated areas, provided all the constraints facing adoption are overcome through appropriate institutional and policy environments. In the subsequent section, we would discuss what these policies are.

5. INSTITUTIONAL AND POLICY ALTERNATIVES FOR SPREADING MICRO-IRRIGATION TECHNOLOGIES

The most ideal policy environment for promotion of MI technologies in well irrigated areas is pro-rata pricing of electricity. While this creates direct incentive for efficient water use (Kumar, 2005), to what extent the MI technologies would reduce energy use depends on the crop type and the type of technology (pressurized system or gravity drip system) used for the crop. Not all MI technologies are energy efficient. Hence, bringing non-conventional (non-pressurized) drip systems under subsidies is very important, once pro-rata pricing of electricity is introduced. It would also force farmers in areas irrigated by diesel engines to adopt such MI systems as it could save diesel and reduce input costs.

While in the long run, total metering and consumption-based pricing would be the most desired (Kumar, 2007), the governments can start with metering of agricultural consumption. Cash incentives or heavy subsidy for MI devices could be provided to farmers who are willing, provided they minimize electricity consumption. This cash incentive could be inversely proportional to the total energy use and directly proportional to the percentage area under MI system. This would create incentives for farmers to maximize the coverage of MI systems in their irrigated crops, particularly less energy intensive crops; and limit the total irrigated area.

Improving power supply, both quality and duration, is extremely important for boosting adoption of pressurized MI devices in many areas. Such areas include alluvial north Gujarat and south-western Punjab. One can argue that with improved power supply, groundwater use could go up. However, in reality, with improved hours of power supply, the quality of irrigation would go up, enabling farmers to realize the full potential of MI systems. The actual impact of improved power supply regime on sustainability would depend on the type of crops farmers grow with MI systems, and the availability of extra land for area expansion.[17]

[17] In areas where the entire cultivable land is under irrigation, adoption of MI devices would result in reduction in groundwater use at the farm level. Subsidies are required here to promote MI adoption as it would lead to social benefits from reduced stress on groundwater

All these policy measures would help address the issues in well-irrigated areas. Still, a large chunk of the irrigated area (23.606 million ha in 1999-00 in India, source: Ministry of Agriculture and Cooperation, GoI), which is from surface sources, would be left untouched. In addition to amendments in administration of subsidies and improvements in extension activities, the way to bring these areas under MI systems is to either change the delivery practices or to increase the economic incentives.

The water delivery systems need to be designed such that farmers can directly connect the source to their distribution system. The irrigation schedules need to be reworked so that the duration between two turns becomes much shorter than the present duration of 2-3 weeks. In the ideal situation, the supply should be perennial. This can happen in the most advanced stage of irrigation systems design and would take time. Moreover, it can be thought about only in case of new schemes. One of the reasons why the farmers in Israel adopt micro irrigation systems at such a large-scale (with 95% of the irrigated crops are under drip systems) is that the surface water is delivered in their fields under pressure through pipes.

Economic incentives for MI adoption in canal commands can be improved by increasing the price of irrigation water. High prices for irrigation water increase cost and result in applied water saving. Alternatively, the cost of building intermediate storage systems can be reduced through proper design of subsidies. In command area of Indira Gandhi Canal Project, most of the farmers are using intermediary storage tanks locally called "*Diggi*". The farmers are using electric pump for lifting this water and irrigating crops whenever they required. After seeing the benefits of such interventions on reducing the pressure on the resource, government has started providing subsidy for construction of "*Diggi*". Many farmers are using sprinklers to irrigate their crops from the tank water.

Apart from saving the cost of water, the differential economic returns farmers get under lift irrigation over canal irrigation (IRMA/UNICEF, 2001; Kumar and Singh, 2001) and the differential return in drip irrigated crops would be the strongest incentive for farmers to go for intermediate storage systems. The justification for subsidizing the systems is that the private benefit-costs ratio would not be very attractive with very high capital cost of the system and the additional infrastructure, whereas the social benefits accrued from saving the scarce water resources would be high when compared against the social costs. The differential returns could be due to the better control over water delivery possible with lift (IRMA/UNICEF, 2001) or due to the increased ability to grow cash crops such as cotton, banana, and fruits and vegetables in the command areas. With this, the actual area that could be brought under MI systems would be larger than the potential area estimates we have provided.

Improving the administration of subsidies is necessary to increase welfare impacts. The farmers should be made to pay the full cost of the system initially, and subsidies be paid in installments based on periodic review of system performance. As manufacturers have to sell the system at the market price, it would compel them to improve the competitiveness of their products, and also provide good technical input services. Rural credit institutions can advance loans to farmers for purchase of MI systems to maximize coverage to include small and marginal farmers. In Gujarat, a new model for promoting MI devices is being implemented by the state government through a state-owned company called Gujarat Green Revolution Company (GGRC). Under this model, the subsidy is paid by GGRC to the farmer in installments, and the results are very encouraging. Not only is the adoption of MI devices fast, but significant percentage of the adopters belongs to small holder category, having less than 2.0 ha of land. They use it for cash crops viz., cotton, ground nut, potato and vegetables. Within a year after the creation of GGRC, a total of 30,000 ha of crop land had already been brought under drips in the state.

On the other hand, there is a need for creating a separate agency for promoting MI in each state to increase the speed of processing of application from farmers. The agency can work in tandem with the manufacturers and farmers to enable timely technical inputs to the farmers. In areas where agricultural processing units are concentrated, provision of all critical inputs including subsidies would not be a problem, as they could come from these processing units. The example is that of sugarcane and grape grower cooperatives of Maharashtra. However, in areas where demand for drip irrigation is scattered vis-à-vis crops and geographical spread, this would be an issue. A new agency should facilitate survey of farmers' fields by the manufacturer, and get the designs and estimates prepared along with the most desirable cropping system. This would also help farmers procure the system well in advance of the crop season to make full benefit of it.

6. MAJOR FINDINGS

1. The extent of adoption of MI devices in India today is just 1.6% of the total irrigated area, due to the lack of favourable, physical, socio-economic, institutional and policy environments. Adoption is also heavily skewed vis-à-vis geographical spread and crops.
2. The available literature shows that drip irrigation leads to substantial saving in applied water over conventional method of irrigation, yield improvements, and improvements in water use efficiency. The extent of field level water saving is the highest for orchards. The available data are from experimental farms; and social research. Both have limitations. In the first case, issue is of replicability and in the second case, the reliability and adequacy of data.
3. There are methodological issues involved in the estimation of water-saving and water productivity impacts of MI systems. The available estimates are based on the assumption that all the water applied to the crop is depleted. But, in view of the fact that MI devices are mostly adopted in semi arid and arid regions with deep and falling water table conditions, such methodological compromises can also yield reliable results.
4. Analysis of the potential contribution of MI systems in India in reducing the aggregate demand for water in crop production involves three complex considerations: 1] the extent of coverage of MI systems that can be achieved at the national level; 2] the extent of real water saving possible with MI system adoption at the field level; and 3] what farmers do with the water saved through MI systems, and the changes in the cropping systems associated with adoption.
5. Some of the factors that limit the expansion of MI technologies in India are: 1] lack of independent source of water and pressurizing device for many farmers; 2] poor quality of groundwater in many semi arid and arid regions; 3] mismatch between water delivery schedules in surface irrigation systems, and irrigation schedules required in MI systems; 4] cropping systems that dominate field crops in semi arid regions; 5] dominance of small and marginal farmers, and small plot sizes; 6] low opportunity costs of pumping groundwater due to lack of well-defined water rights; 7] negative technical externalities in groundwater use; viii] poor extension services; and 8] poor administration of subsidies.
6. The field level water saving due to MI systems depends on: a] the geo-hydrological environment; b] crop type; c] agro-climate; d] type of MI technology. Water saving impacts would be high for drip systems, particularly under arid to semi arid climate, for widely spaced row crops, when groundwater table is deep. While MI system would result in field-level water saving in various degrees, depending on the situation, its impact on aggregate water use would depend on the groundwater availability vis-à-vis power supply situation, the crops farmers choose with MI, and the extra land available for cultivation. In groundwater scarce areas, MI adoption would result in area expansion, with no likely reduction in aggregate groundwater draft.
7. Available studies on the costs and benefits of MI systems suffer from many inadequacies. First of all, they do not capture the physical settings, the socio-economic conditions and institutional and policy environments that affect the actual private, economic and social benefits from MI adoption. Secondly, some of the analyses are based on direct costs and returns and not incremental costs and benefits associated with system use.
8. A comprehensive analysis of economics of different WSTs for different crops across Gujarat shows that B/C ratios are highly influenced by crop choices and largely limited to high value crops (fruits and some vegetables), which have further capital investment requirements apart from the irrigation system.
9. The river basins that are likely to benefit by and are also conducive to MI systems are: western part of Indus in Punjab and Haryana; west-flowing rivers north of Tapi; east-flowing rivers south of Tapi; west-flowing rivers south of Tapi in the Western Ghats; Sabarmati; and Mahanadi. In these basins, extensive adoption of efficient irrigation technologies would result in overall enhancement in basin-level crop water productivity. The total well-irrigated area that can be potentially brought under MI systems from 16 major states of India is estimated to be 5.6 million ha.

10. The total potential reduction in crop water requirement with the full adoption of drip systems in six selected crops is estimated to be 44.46 BCM. It can also be seen that highest reduction in water requirement could come from the use of drips in sugarcane, followed by cotton. Both the estimates are much lower than the estimates provided by Narayanamoorthy (2004b) and that by the Task Force on Micro Irrigation in India.

7. CONCLUSIONS

Adoption of MI systems is likely to pick up fast in arid and semi arid, well-irrigated areas, where farmers have independent irrigation sources, and where groundwater is scarce. Further, high average land holdings, large size of individual plots, and a cropping system dominated by widely spaced row crops, which are also high-valued, would provide the ideal environment for the same. The extent of real water-saving and water productivity improvements at the field level through adoption of MI systems would be high for widely spaced row crops, in arid and semi arid conditions, when the groundwater table is deep or aquifer is saline. In hard rock areas with poor groundwater potential, MI adoption would result in improved efficiency of water use, but would not reduce the total groundwater draft.

In semi arid and arid areas, which face severe groundwater scarcity, the economics of MI systems would be sound for high-valued cash crops. In areas where electricity charges are not based on power consumption, and opportunity cost of using water is zero, the saving in energy and water achieved through MI system do not get translated into economic benefits. Hence, economics of MI system will not be sound in such areas. But, the evaluation studies are skewed towards drip systems, and do not capture the effect of changing physical, socio-economic and institutional settings on the economic dynamic.

The future potential of MI systems in improving basin level water productivity is primarily constrained by the physical characteristics of basins and the opportunities they provide for real water-saving at the field level, and area under crops that are conducive to MI systems in those basins. Preliminary analysis shows very modest potential of MI systems to the tune of 5.69 m ha, with an aggregate impact on crop water requirement to the tune of 43.35 BCM possible with drip adoption for six selected crops. Creating appropriate institutions for extension, designing water and electricity pricing policies apart from building proper irrigation and power supply infrastructure would play a crucial role in facilitating large-scale adoption of different MI systems. The subsidies for MI promotion should be targeted at regions and technologies, where MI adoption results in real water and energy saving at the aggregate level.

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COST AND BENEFITS OF INTERMEDIATE WATER STORAGE STRUCTURES: CASE STUDY OF DIGGIES IN RAJASTHAN

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Abstract

This paper assesses the cost and benefits of "diggies", the intermediate water storage structures in the Indira Gandhi Nehar Pariyojana project in Rajasthan. A diggi helps provide reliable water deliveries to farms and that in turn expects to increase crop production. Our analysis shows that through better water control, farmers with diggi's have increased cropping intensity, input application and crop productivity. The net value of crop production per ha of irrigated area of farms with diggi's is 68% higher than that of farms without diggi. A cost-benefit analysis shows that diggi is a financially viable intervention for farms with size larger than 4 ha.

1. INTRODUCTION

Unreliable water supply associated with rigid schedules of water delivery is a major constraint for increasing the performance at farm level in the canal irrigation commands. Often, the schedules of water delivery do not match the periods of crop water stress at field level. They result in, at times delayed sowing and often improper input application leading to low productivity. The canal irrigation through the warabandi system in north-western India is one in which farmers often complain of unreliable water supply. The major objective of the warabandi system is to distribute the scarce water resources to as many farmers as possible through a system of rotational water supply. So, untimely water delivery is an inherent feature in the warabandi system.

The Indira Gandhi Nehar Pariyojna (IGNP) project in Rajasthan, which uses warabandi system of delivery of water, envisages irrigating 1.9 m.ha of crop land. It off takes from the Harike barrage, located a few kilometers downstream of the confluence of the Sutlej and the Beas rivers in Punjab, and takes water along 650 km long main canal and terminates near Jaisalmer in Rajasthan. Water scarcity is an in-built feature of irrigation distribution in the IGNP canal system. The warabandi in IGNP has promoted equitable water distribution, but water deliveries at times become unreliable or inefficient. Farmers do not receive water at a time when the irrigation is critical even for the survival of crops or for higher yields.

A diggi, intermediate storage or surface water banking, is a farmers intervention to mitigate the effects of scarce and unreliable canal water supply in the IGNP. Through this intervention, farmers first construct a small pond, called a diggi, in their farm to store the canal water supply. Next they pump the water out from a diggi to irrigate the crops, through field channels or micro-irrigation technologies. With increase in control of the water management, farmers meet the crop-water requirement as best as possible. In fact, a diggi addresses the reliability issue through a self enforcement mechanism and corrects the allocative inefficiency of water use. In the end, the society achieves both equity and efficiency. The cost of achieving efficiency is reflected in the cost of diggi.

This report assesses the impacts of the "diggi" intervention on the irrigation performance at the farm level, and estimates the incremental value of the net income benefits. The study has significant policy relevance. The results suggest how a farmer in canal command system can achieve a Pareto improvement through saving of water. The specific objective of the report is to assess

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- the extent that "diggi" helps increase the irrigation performance, which include increasing the crop area, crop yield, crop diversification and net value added economic benefits at the farm level, and
- to evaluate cost and benefit of "diggi" intervention in the IGNP,

The report is organized into five sections. Section two gives a brief description of how "warabandi" and "diggi" perform. Section three describes the methodology of impact assessment of Diggi. Section 4 shows the cost and benefits of introducing a "diggi". Section 5 discusses the up scaling and possible impacts. And we conclude the paper with a policy discussion and implications to further development of IGNP in the second phase.

2. WARABANDI AND DIGGIES IN IGNP

The main goal of the IGNP canal system was to provide irrigation to a major part of the Thar Desert in Rajasthan. Located in the north-west, Rajasthan is the largest state in India, covering 10 per cent of the total land area in India. Two-thirds of the land area of Rajasthan is covered by the Thar Desert. This includes 85 out of 142 desert blocks in whole of India. Moreover, a major part of the state of Rajasthan is covered by the arid to semi-arid climates. The rainfall patters are highly erratic, and they vary from low rainfall in north-east region to high rainfall in south-west region (Khan, 1998). Most of the rain falls from June to September. On an average Rajasthan, receives 560mm rainfall annually. So, without irrigation, crops cannot survive in many parts of the state. In fact, irrigation covers about one-third of the net sown and gross cropped area, 15.5 and 19.3 million ha, respectively in 1999-2000.

Tubewells and canals are major sources of irrigation in the State of Rajasthan. Of the net and gross irrigated area (5.61 and 6.93 million ha), tubewells and canals provide, 64 and 33 per cent, respectively. Groundwater is virtually the only source of irrigation in the southern plateau and arid region of the west (93 and 92% respectively) and dominates irrigation in southern and eastern plain regions (79 and 65% respectively). However, canals provide almost all the irrigation in the arid north region. The IGNP project, popularly known as the Rajasthan canal, is the largest surface irrigation projects in arid north-west. The warabandi is the system of water deliveries in the IGNP project.

3. WHAT IS WARABANDI?

In warabandi, "wara" means turn, and "bandi" means fixed. According to Malhotra (1982), "warabandi is a rotational method for equitable distribution of the available water in an irrigation system by turns fixed according to a predetermined schedule specifying the day, time and duration of supply to each irrigator in proportion to the size of his landholding in the outlet command".

The warabandi system, mainly practiced in semi-arid and arid north western India for more than 125 years, rotates irrigation supply according to a predetermined schedule, where one cycle generally last for 7 days. It allocates the irrigation quantity proportion to farm area. The higher water-use efficiency and equitable water distribution are prominent goals of a Warabandi system (Malhotra 1982). The water-use efficiency is to be achieved through the imposition of water scarcity on each and every user, and the equity in distribution through enforced equal share of scarce water per unit area among all users. The key features of warabandi system are:

- Individual farms are aggregated into hydrologic units (chaks) of 100-400 ha (50-200 farms),
- Each chak is served by a water course whose capacity is proportional to the size of chak;
- Each farm holding in the chak is entitled to take full supply in watercourse during a specified period proportional to its size. Since the watercourse flow is proportional to the size, each farm in a command area of distributaries is ensured a uniform volumetric allocation per hectare per week,
- Watercourses are un-gated and are served by parent channels (minor canals) that at any given chainage has capacity exactly equal to the sum of the discharges of the watercourses offtaking at downstream points.

- Minor canals in turn are usually gated and are served by a distributary whose capacity at any given chainage is exactly equal to the combined capacity of offtaking minors and watercourses downstream).

For more information of warabandi, see Reidinger (1971), Malhotra (1982), and Berkoff and Huppert (1987), Sakthivadivel et. al. (1999).

Throughout IGNP, the canals operate on the warabandi scheme due to variation in water availability at the Harika barrage in the river Sutlej. The demand for irrigation water throughout the year is met by changing the days on which each branch canal is operated. Water flows in canals for one week, and then the canal is dry for a week. This water distribution system forces all minor and branch canal, distributaries, water courses to share the deficit of water supply in the IGNP system. This means that farmers, in general, get their quota of irrigation at fortnightly intervals.

4. WHAT IS A DIGGI?

"Diggi", a "surface water bank" is an intermediate water storage tank between the watercourse and the farm. It is a farmer's response to water scarcity and unreliable canal water supply in the IGNP. The canal irrigated area in the IGNP command has gradually increased over the last 15 years. Accordingly, the frequency of canal water releases to the farms in the command area has decreased. Initially, the number of turns into the field was 4 turns a month, and 4-5 hours per each turn. Today, with increasing command area, the number of turns has decreased to two times a month and 2-3 hours per each turn. The reduction of duration of water supply had many negative implications, which includes decreased irrigated area; crop failures; and in some cases where the supply was not adequate or available to meet crop requirement at the critical stages of growth. The IGNP farmers responded to the water stress and unreliable water supply by constructing diggi's.

The diggi stores the canal water supply from watercourses in allotted turns to the fields. Water from the "diggi" is then pumped from an electric motor and applied to field by micro-irrigation devices such as sprinklers (typically with 20-25 nozzles). In the IGNP canal commands, the sprinklers are used not to save irrigation water, but to irrigate more area. A diggi combined with the sprinkler irrigation increases the number of irrigation and the irrigated area; provides a reliable water supply to meet the cropwater requirements; increases the crop yields; helps diversify to high value cropping patterns; and reduces land leveling requirements of the uplands, and allows irrigating the undulating lands through sprinklers, where normal canal water courses cannot.

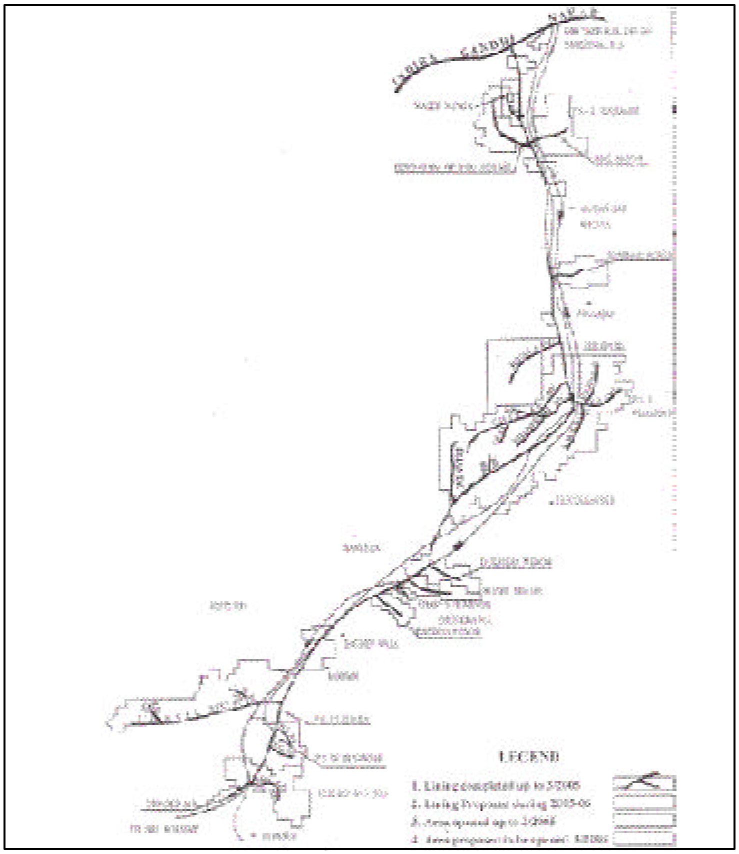
Initially, the IGNP farmers constructed diggis from their money. Now, the Government of Rajasthan provides a 20 percent subsidy of the total cost. The average cost of constructing a diggi is RS 172,710 or US$ 3111 (at 2006 prices). The cost is based on the primary survey.

Although it is not as prevalent as in the canal command areas, the diggis are also being constructed in the groundwater irrigated area. The primary reasons for constructing diggis in groundwater irrigated area are the low yields in tubewells and unreliable electricity supply. Due to these constrains, farmers are unable to apply irrigation when the cropwater requirement is most critical. So, first they pump groundwater into the diggi and then pump out to irrigate the crops. Although this practice is highly energy expensive, farmers claim that without diggis farming is not effective or is not possible in many of groundwater irrigated areas.

5. STUDY LOCATION AND METHODOLOGY FOR IMPACT ASSESSMENT

A distributary of the IGNP canal, the Kanwarsain lift Canal, is the location of this study (Figure 1). The canal offtakes at Birdhwal in the IGNP main canal and stretches about 200 km to Bikaner.

Figure 1: Study Location- Kanwarsain Lift Canal of IGNP project



5.1 Sampling Plan

A stratified random sampling scheme is used for assessing the benefits from diggi. First we identify the watercourses with and without diggi across head, middle and tail sections of the canal and also across the tube-well irrigated areas. From the watercourses with diggis, 31 watercourses were selected, with 10 each from the head, middle and 11 from tail end of the canal command area. From each selected watercourse, two farmers were selected with one having a diggi and the other without a diggi. We also selected 10 farmers from the groundwater irrigated area, with five each having diggi and irrigating their crop directly from tube-wells. Both groups of farmers in groundwater irrigated areas used sprinkler for irrigating their crops. In all, 72 sample farmers were selected for in-depth survey.

5.2 Methodology and Data Requirements

The hypothesis which is being tested in the study is that adoption of diggi helps the farmers to expand the irrigated area; increase the crop yield diversify cropping patterns; improve input application; and increase the gross and net value of crop output.

These hypotheses are tested using simple statistical techniques-- two sample or paired t-tests. We collect the primary data from the selected samples, which include total land holding size, irrigated area and irrigation paterns, seasonal cropping patterns, crop inputs and outputs. The data related to diggi were also collected, which includes the year of construction of a diggi, physical details, fixed and working cost of diggis, tube-well and sprinklers.

We also estimated the cost:benefit ratio (CBR) and the internal rate of return (IRR) from diggis. The benefit is estimated as the net value added after the construction of a diggi. The cost includes the capital investments for a 'diggi, sprinklers, electricity connection and electric or diesel motors, and the operational and maintenance cost. In groundwater irrigated areas, the capital cost includes the cost of installing a tube-well. For estimating the benefit:cost ratio, we assumed the useful life of all structures as 20 years..

6. RESULTS AND DISCUSSIONS

The decreasing and reliability of canal water supply to the farm are the main reasons for constructing a diggi. Over the time, water supply has decreased in the IGNP canal system. We observe a similar pattern from the data. On an average, farmers received 20 hours less canal water supply as compared to that prior to constructing diggi when water supply was initially started in their watercourses. Today, the number of hours of canal water supply is even less. Farms with a diggi receive on average only 65-68 hours canal water supply in kharif (July-October) and rabi (October-March) seasons, as against 148 to 129 hours water supply at the time of construction of a diggi. Farms without a diggi receive only about 32 hours of water supply in each season. The difference of duration of water supply to farms with and without a diggi is due to farm land holding size.

In general, diggi is constructed in farms of larger size. The average size of farms with a diggi is about twice the size of the farms without a diggi (Table 1). The farm size decreases from head to the tail reach of the canal command. This seems to indicate that diggi is not a viable option in smaller farms and also when the distance from the main offtake from distributary increases.

The portion of land holding that is cultivated decreases from head to tail reach of the distributary. This is clearly related to inequitable water supply between the head end and tail end, and similar situation exists in farms with and without diggi. The inequity in water supply is very prominent in farms without diggis, where

Table 1. Average land holding size and the area of cultivation in farms with and without diggis

	Land holding size of farms with and without diggis (ha)		Cultivated area- % of land holding size Cultivated area of farms with and without diggis (%)		Number of hours of canal water supply in farms with and without diggis in 2006 (Hours)	
	With	Without	With	Without	With	Without
Canal command area						
Head	13.7	7.7	83	89	164	108
Middle	12.9	5.6	77	66	128	35
Tail	10.3	4.5	59	59	102	52
All	12.3	5.9	73	70	135	64
Groundwater irrigated area	10.2	11.9	67	46	-	-

Source: Authors' estimates based on the primary survey

head end farms receive water supply for greater duration than that in middle and tail reaches. Of course, land holding size is a determinant of the duration of water allocation in warabandi system. But our sample shows, the duration of water supply per unit area of farms in head end of the distributary is significantly higher than that at the tail end farms. The average durations of water supply per ha in the head end farms with and without diggie were 12 and 14 hr/ha of land holding size respectively. The middle and tail end farms with diggie receive about 9 hr/ha of water supply; and farms without diggie received 6 and 12 hr/ha, respectively.

The average land holding size of farms in groundwater irrigated areas showed insignificant difference between farms with diggis and farm without diggis. But they have substantially lower percentage of cultivated area, and similar to tail end farms with diggie.

6.1 Expansion of Irrigated Area

Irrigated area expansion was a major goal of farmers in constructing a "diggi". We explore here the extent to which diggi helps increase the irrigated area in farms. With diggis farmers were able to irrigate all their cultivated area compared to only two-thirds of the area before diggi construction (Table 2). This increase is significant and is uniform across reaches in canal command and groundwater irrigated areas.

Farms without diggis, except those in the middle reaches, irrigate almost all their cultivated land. Due primarily to significantly lower number of hours of canal water supply (see Table 1), the farms without diggis in the middle reach irrigate only 79 per cent of the cultivated area. Farmers with diggis uses sprinkler irrigation to irrigate their crops, and this allows them to irrigate even the undulated land, which the direct canal irrigation did not allow, and as a result it increases the irrigation coverage substantially. Overall, the crop area has increased by 33 percent with diggi construction. A similar increase is evident in groundwater irrigated areas. In groundwater irrigated areas, farms without diggis irrigate almost all their cultivated area. However, the farms with diggis only now mange to irrigate 93 per cent of the cultivated area, whereas they irrigate only 63 per cent crop area before construing diggis.

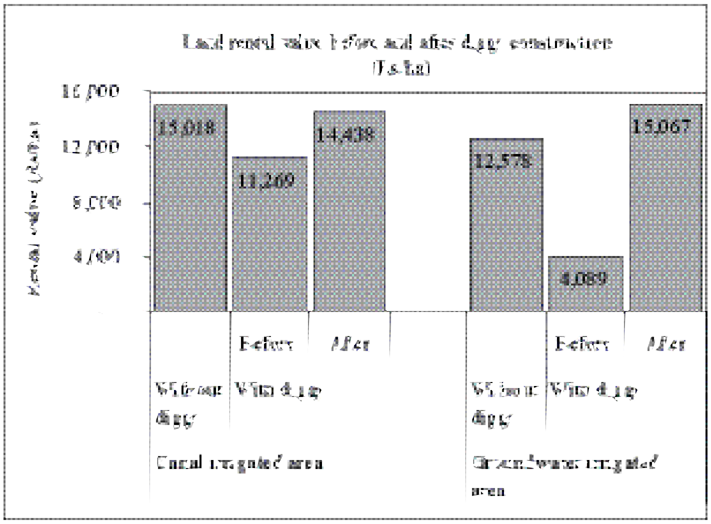
Table 2. Irrigated area (%) of cultivated area in farms with and with-out diggis

	Irrigated area (%) of cultivated area		
Command area	Farms with diggis		Farms without diggis
	Before	After	
Canal irrigated area			
Head	61	100	100
Middle	66	100	79
Tail	67	100	100
All	67	100	93
Groundwater irrigated area	63	93	96

6.2 Increased Land Rental Value

The construction of a diggi has also brought many changes to the irrigated lands. An immediate impact was the increase in land rental value. As per the response survey, the rental value of agricultural land in canal irrigated area before construction of diggi was Rs 11,269/ha/year (US$ 269 in 2006 prices, US$ 1= Rs. 43). But after the construction, the rental value has increased to Rs 14,438/ha/year (US$ 335). The value addition owing to extra infrastructure is more than Rs 3,000. Although not significantly different, the higher rental value of the lands without a diggi was because the land was more suitable for irrigating from canal. In fact, the overwhelming response of the farmers for investing in diggi was the poor irrigable conditions of their land.

Figure 2. Land rental value before and after diggi construction

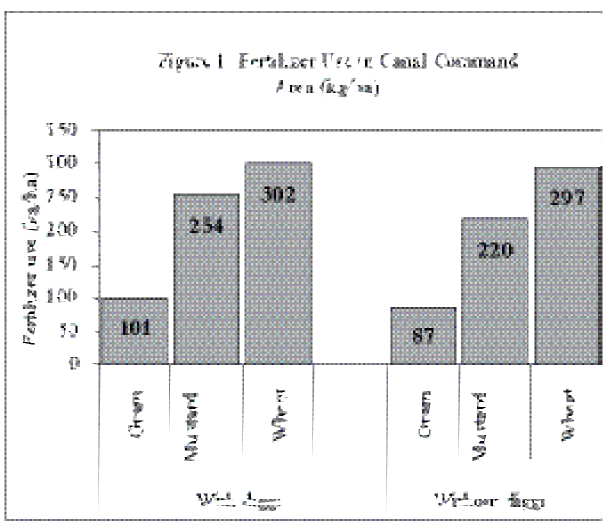


The general trends of increase in land rentals in the groundwater irrigated areas are similar. The rental value of lands after constructing a diggi is vastly different from land before construction and also lands without a diggi.

6.3 Increased Input Application

With diggis, now farmers have the ability to apply irrigation to crops, when the crop demands the most. With a reliable irrigation supply, farmers in general manage their input application better. This is evident in fertilizer application of some crops (Figure 3). Farmers without a diggi in canal command areas did not take an undue risk of applying more fertilizer with an unreliable canal water supply. However, a significant increase in fertilizer application can be seen for gram and mustard crops, which have relatively higher value than cereal crops. The fertilizer application of wheat crop, which is already high before the construction of diggi, shows non significant change.

Figure 3: Fertilizer use in canal command area for selected crops (kg/ha)



6.4 Increased Crop Yields

In the IGNP canal command area, diggi helps farmers to irrigate crops through sprinklers, and when the crop demands the most. Microirrigation technologies, in general, seems to have a positive effect on increasing the yield of many crops (Narayanmoorthy, 2006, Kumar et al., 2008). The data also show a similar trend. In the canal command areas, almost all farmers with diggis irrigates their crops using sprinklers, whereas only one farm out of 30 sampled without a diggi used sprinklers. However, in groundwater irrigated areas, both farms with and without diggis use sprinklers. So, yield increases in groundwater irrigated areas did not show any apparent pattern. However, yield increase in canal command area is very significant. There is difference in crop yields in canal command area with and without diggis.

The crop yields are significantly higher in areas with diggis than those without diggis' (Table 3). The increase in yield is significant in all canal reaches, from head to tail end. Kharif crop yields of farms with diggis are 18 and 39 per cent higher for guar and groundnut, respectively. In Rabi season, crop yield of gram, mustard and wheat in farms with diggis are 30, 29 and 7 per cent higher than those in farms without diggis, respectively. The difference between the main crop yield and their byproducts between farms with and without diggis are statistically significant.

The diggis with sprinklers have helped farmers not only meet the crop water requirements better, but also increase the input application. So diggis have directly and indirectly increased the crop yields.

6.5 Increased Gross Value of Crop Production

The average gross value of output of farms with diggi is significantly higher than that without diggis (Table 4). It is 39 per cent higher in kharif season, and 21 per cent higher in rabi season. There are significant differences of increments in different canal reaches. In the kharif season, the farms in head reach had a significantly higher increment than farms in middle and tail reaches. In rabi season, farms in head and middle reaches had significantly higher increments in gross value of outputs.

The difference in gross value of output per ha of land between head reach and tail reach could be due to the differential access to water supply. Although,warabandi is supposed to ensure equitable distribution, our results show otherwise. We have earlier shown that water supply to farms in head reach is significantly better than that in middle and tail reach. So, these farmers have more gains by storing them in diggi's and distributing them among different crops. In fact, many farmers with high gross value had high yields and also high value crops.

Table 4: Gross value of output per ha of irrigated area

Location	Gross value of output[1] per ha of irrigated land (Rs/ha, Rs 43 = US$ 1 in 2006)			
	Kharif season		Rabi season	
	Without *diggi*	With *diggi*	Without *diggi*	With *diggi*
Head	23,915	42,416[2]	19,843	25,857
		(77%)		(30%)
Middle	23,414	31,355	18,855	24,474
		(34%)		(30%)
Tail	20,188	29,672	21,755	24,586
		(47%)		(13%)
All	22535	34207	20109	24956
		(52%)		(24%)

[1] Values within the parenthesis are the percentage differences of the average gross value of output with and without a *diggi*.
[2] This average for the head end farmers is based on 9 observations, and has highly skewed distribution. Only two farms in this group have higher than average gross value of outputs, Rs 87,000/ha and Rs.54,000/ha. This is mainly because significantly higher yields of these farms.

Table 3: Yields of selected crops in canal command areas with and without *diggis*

	Yields in canal command area (kg/ha)											
	Without *diggi*		With *diggi*		Without *diggi*		With *diggi*		Without *diggi*		With *diggi*	
	Main	By-product	Main	By-product	Main	By-product	Main	By-product	Main	By-product	Main	By-product
***Kharif* season**	Guar				Groundnut							
Head	562	924	684	902	2,435	2,950	3,156	4,067				
Middle	711	1,089	975	1,550	1,765	2,080	2,422	3,511				
Tail	556	889	540	900	1,667	2,367	2,267	3,311				
All	610	967	717	1,093	1,982	2,475	2,615	3,630				
***Rabi* Season**	Gram				Mustard				Wheat			
Head	740	1,060	1,120	1,560	1,200	2,000	1,300	1,600	2,711	7,600	2,700	3,820
Middle	600	800	900	1,250	1,020	1,560	1,345	1,836	2,340	2,860	2,850	4,700
Tail	800	1,200	624	920	800	1,120	993	1,444	2,356	3,111	2,400	6,667
All	723	1,031	943	1326	976	1,482	1,206	1,650	2,464	4,464	2,644	5,030

Source: Author’s estimates using the sample survey

6.6 CROP DIVERSIFICATION

To what extent does a diggi help crop diversification? Our sample suggests no major differences of cropping patterns between the farms with and farms without diggis (Table 5). The only exception is bajra and narma (cotton) area in the Kharif season and gram and mustard in the Rabi season. While the area under narma (cotton) and bajra is higher in farms with diggis, the area under gram and mustard is lower.

Table 5: Cropping pattern in farms with and without *diggi*s

Crop	Cropping paattern - % of total irrigated area	
	Without *diggi*	With *diggi*s
Kharif season		
Bajra	13	7
Cotton	3	3
Narma (cotton)	13	5
Gawar	13	16
Groundnut	9	9
Green gram (moong)	3	0
Rabi season		
Gram	15	22
Joi	4	4
Mustard	11	14
Taramira	7	4
Wheat	8	9
Total	100	100

6.7 Benefit Cost Ratio of Diggi Intervention

The annual net value added through diggi construction is the increase in net value of agricultural output in farms with diggis over those without diggis. The net value of agricultural outputs is the value of production of crop and livestock minus the cost of inputs, interest of the capital expenditure, and variable cost (operation and maintenance cost) of diggi, sprinklers and electric or diesel motors.

6.7.1 Cost of Construction, Operation and Maintenance of a Diggi

The operationalization of a diggi in canal command area includes: constructing a diggi, installing diesel/electric motor for pumping water from a diggi, and then installing sprinklers for irrigation. Installing tube-well for pumping groundwater to diggi is an additional investment in groundwater irrigated areas. These are the capital investment involved in diggi operations. The variable cost include the cost of electric/diesel for pumping water from diggi and pumping groundwater to diggi; and the operation and maintenance cost for diggi, sprinkler and electric/diesel pump. The capital cost and variable cost of a diggi operation in the canal and groundwater irrigated areas are given in Table 6.

The average size of a diggi in canal command areas is generally larger than those of groundwater irrigated area. In fact average storage of a diggi in a canal command area, 2,877 m^3 (29 m * 29m * 3.4m), is three times more than that of a diggi in groundwater irrigated area, 944 m3 (16.9m * 16.3m * 3.4 m). The

Table 6. Capital and operation cost of *diggi* and sprinklers

Items	Cost[1] (Rs/year)		
	Canal irrigated areas	Groundwater irrigated areas	
		With *diggi*	Without *diggi*
Capital cost of construction of *diggi*[1]	1,49,912	96,526	-
Subsidy	35,041	-	-
Net cost of construction of a *diggi*	1,14,871	96,526	-
Cost of maintenance (Rs/year)	11,113	9,200	-
No. of sprinklers	21	37	39
Capital cost of sprinklers	35,602	74,800	58,955
Cost of maintenance of Sprinklers (Rs/year)	6,071	3,600	2,100
Capital cost of electricity connection and			
electric/diesel engines	25,902	79,602	77,302
Cost of electricity/diesel cost (Rs/year)	19,513	43,000	36,800
Capital cost of installation of tube-well	-	2,03,488	3,44,567
Cost of maintenance of tube wells (Rs/year)	-	4,800	4,800
Electricity charges (Rs/year)		40,560	33,600
Fixed cost	1,76,375	4,54,416	4,80,824
Variable cost			
Operational cost (Rs/year)	19,513	83,560	70,400
Maintenance cost (Rs/year)	17,184	17,600	6,900

Government of Rajasthan has provided a subsidy, o InRs 35,000, for construction of a diggi in canal command area, while farmers have borne the full cost of diggi construction in groundwater irrigated area.

In groundwater irrigated areas, a sprinkler irrigates only half the area than in the groundwater irrigated area. As a result, number of sprinklers required to irrigate the farm land and the capital cost for installing them are significant in the canal command areas than in the groundwater irrigated areas. Additionally, the groundwater irrigated areas require tube wells for pumping water into the diggi. Therefore the capital and the operational cost are significantly higher in the groundwater irrigated areas.

6.8 Net Value of Crop Production

The net value of crop production is the difference between the gross values of crop production and the cost of production. The cost of production includes the cost of labour, seeds, fertilizer, insecticide, and ploughing, threshing, machinery and water charges. In canal command area, the net value of crop production of farms with a diggi is significantly higher than in the area without diggi's (Table 7).

The incremental benefits from kharif crops are much higher than the incremental benefits from Rabi crops. This is because of the reason that farmers in IGNP command tend to allocate more area under wheat in Rabi season, and difference in wheat yield is not significantly high between the areas with and with diggis.

[1] Cost estimated on the basis of 2006 constnat prices

Table 7: Net value of crop production and the net value of output per ha of irrigated area per year (Rs/ha)

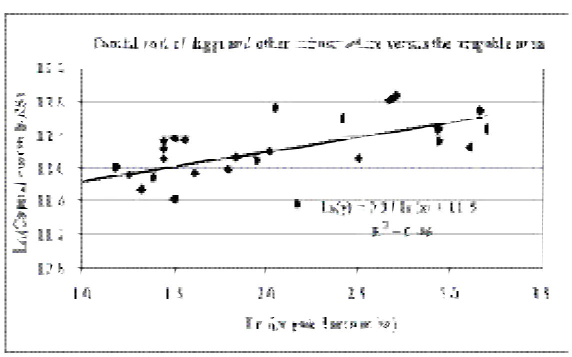
Canal reach	Average net value of crop production per ha in farms *with* and *without diggi*s					
	Kharif		Rabi		Annual	
	Without *diggi*	With *diggi*	Without *diggi*	With *diggi*	Without *diggi*	With *diggi*
Head	14,776	34,860	11,755	20,114	16,778	34,847
		(136%)		(71%)		(108%)
Middle	12,573	23,077	9,553	16,891	16,678	27,814
		(84%)		(77%)		(67%)
Tail	12,141	19,508	12,407	15,288	21,139	29,137
		(61%)		(23%)		(38%)
All	13,144	25,503	11,191	17,413	18,152	30,509
		(94%)		(56%)		(68%)

However, value of incremental output varies substantially across the canal reaches. The head reach farmers have more than doubled their net value of crop production, and have more than three times the incremental benefits that the tail reach farmers secure. While the head reach has increased the annual benefit, by 108 per cent by introducing a diggi, the tail reach farmers have increased only by 38%. This has to do with the available water supply for diggis. As we have shown earlier, the diggis in tail reach receives on an average 60% less water supply than diggis in head reach. So, opportunity for tail end farmers to increase cropping intensity and yield through diggis is much lower.

6.9 Benefit:Cost Ratio for Diggi Investment in Canal Irrigated Area

The cost of diggi operation in a farm in canal irrigated area includes cost of constructing a diggi, installing sprinklers and required electric and diesel motors, and investment for electricity connection. An average sized diggi in IGNP costs about Rs 176,000. But capital cost is related to irrigable area. Our sample shows that 1 per cent increase in irrigated area results in 0.31 per cent additional capital cost of diggi and other infrastructure (Figure 4). We estimated the required capital investment for different irrigable areas using the equation in Figure 4 (Table 6).

Figure 4: Capital cost of diggi, sprinklers and electricity connection and electric/diesel motors vs irrigable area



[1] Net value of crop production is gross value of crop production minus cost of inputs (US$1=Rs 43 in 2006).
[2] Values within parenthesis are incremental average net value of output of the farms with *diggi*s.

In estimating the cost and benefits, we assume useful life time of diggi and other infrastructure as 20 years. The cost of diggi and related infrastructure (in 2006 prices) for different irrigable area is given in Table 8. The operation and maintenance cost of an average size diggi and other infrastructure, with a capital cost of Rs 1,76,000, is about Rs 36,000. There is variation in operation and management cost for diggis with different size. On the benefit side, new infrastructure brings an additional benefit of Rs 12,257/ha/year independent of size of irrigable land. The annualized cost, benefits: cost ratio for diggis for different farm sizes are given in Table 8.

Table 8: Annualized cost, benefits, and benefit:cost ratio of a *diggi* and other infrastructure

Irrigable area (ha)	Capital cost (Rs)	Annualized cost and benefits (Rs)					Benefit-cost ratio
		Interest on capital @ 6%	Depreciation @ 5% discount rate	Operation and managem-ent cost	Total cost	Total benefits	
1	98,716	4,936	5,923	20,619	31,477	2,357	0.4
2	122,379	6,119	7,343	25,561	39,023	24,714	0.6
3	138,770	6,938	8,326	28,985	44,249	37,071	0.8
4	151,714	7,586	9,103	31,688	48,377	49,428	1.0
5	162,580	8,129	9,755	33,958	51,842	61,785	1.2
6	172,034	8,602	10,322	35,933	54,856	74,142	1.4
7	180,454	9,023	10,827	37,691	57,541	86,499	1.5
8	188,081	9,404	11,285	39,284	59,973	98,856	1.6
9	195,075	9,754	11,705	40,745	62,203	111,213	1.8
10	201,552	10,078	12,093	42,098	64,269	123,570	1.9

The analysis shows that diggis are economically viable for farms with large holdings. The benefit:cost ratio is more than one for farms with size more than or equal to 4 ha. In fact, the average land holding size of the farms with diggis in the command area is 8.7 ha. A farmer with an irrigable land of more than 7ha can recover the full investments for the new infrastructure in 6 years.

Due to variation in the net crop production benefit across the canal reach, the benefit:cost ratio of new infrastructure is much higher in the head reach. For example, the incremental value of the crop production benefit from irrigated lands in head reach from diggis is about Rs 18,100/ ha. Thus, the incremental value of the output from an irrigated land holding of 4 ha in head reach is about Rs. 72,000, and is 1.5 times the total cost. In fact, a diggi and other infrastructure in the head reach area can be cost effective even for an irrigable land holding size equal to 2 ha.

6.10 Benefit: Cost Ratio in the Groundwater Irrigated Area

The average size of land holding of diggi owners in groundwater irrigated areas does not vary much. It varies from 10.2ha for diggi owners to 11.9ha for those without diggi. We have estimated the benefit cost ratio of a farm of average size 10 ha, and the results are provided in Table 7.

In groundwater irrigated areas, farmers have already installed tubewells and sprinklers for irrigating their fields. We assumed that in groundwater irrigated areas, only additional cost that farmers have to incur with new infrastructure is that of diggi. The capital cost of the diggi is Rs.96000. The annual operation and maintenance cost is Rs.17400. The change in net value of crop production through a diggi in groundwater area is about Rs

Table 9: Benefit and cost of adopting a *diggi* in groundwater irrigated area

Cost and benefit items	Without *diggi*	With *diggi*
Cost of a *diggi* construction (Rs)		96526
Interest on capital at 6% (Rs)		5792
Depreciation cost @ 5% discount rate (Rs)		4826
Operational and management cost (Rs)	41,700	59,180
Change in total annualized cost (Rs)		28,098
Net value of crop production (Rs/ha)	22,867	26,893
Change in net value of crop production for a 10 ha land		40,257
Benefit-cost ratio		1.4

4,000, generating a net benefit of Rs. 40257 for a land holding of 10 ha. Thus, even in groundwater irrigated areas benefits of introducing a diggi is far out weigh the cost. A farmer can recover the full cost of constructing a diggi of a farm with land holding size 10 ha after 3 years.

7. OTHER BENEFITS OF DIGGIS IN THE CANAL COMMAND AREA

7.1 Addressing Water Logging and Salinity

The problems of water logging are increasing in the IGNP command area. The rise of water table leads to water logging and development of salinity in many parts. The soils of the IGNP command are calcareous, and the soils in the desert plains are underline by nodular lime horizon, consolidated gypsum and sand stone. Sandy soils have poor water holding capacity, are susceptible to wind erosion. The infiltration capacity of fine texture sandy soils is very poor. They are highly saline and sodic. With rising groundwater tables, these soils pose problems of drainage, salinity and alkalinity. In fact, a few villages in the IGNP area were abandoned due to unfavorable living conditions due to water logging and salinity.

Although characterized as water scarce, farmers in some regions of IGNP apply excess water to irrigate their crops. This is especially true in the head reaches of the canal command. Long periods of flood irrigation recharge the shallow aquifer, and due to poor vertical drainage conditions, the water table comes, which results in water logging and salinity. Thus, this can be decreased by lowering canal irrigation, increasing conjunctive water use, or increasing consumptive part of the total irrigated water applied in the command area. The diggi and sprinklers help overcome these problems. The diggi, which stores the water supply from the watercourse, address the increasing unreliability with decreasing canal water supply the warabandi system. Sprinklers help spread the irrigation into a large area, increasing consumptive water use. Thus diggi and micro-irrigation help avert water logging and salinity in long-run.

7. 2 Spreading Microirrigation Technologies

In general, canal irrigation does not support microirrigation technologies such as sprinklers and drips. However, water stored in a diggi facilitates microirrigation. Microirrigation not only improves the water-use efficiency, but also increases the crop yield. So spreading micro irrigation in canal command area will increase the crop productivity and ultimately benefits the farmers.

7.3 Increasing Crop Diversification

Crop diversification has a large potential for increasing the net value of crop production. With proper crop choice, crop diversification to high-value crops can especially, help the small to medium land holders in water scarce regions (Birthal et al., 2007). They need to increase the value of crop production from the same amount of consumptive water use. A reliable water supply is the critical requirement for high-value crops that require proper application of inputs, where some of them are expensive. The diggi is an ideal solution for unreliable water supply to farms. Farmers have full control of managing water stored in a diggi. But, why then it is not an economically-viable option for small farmers in the IGNP canal command area. It is precisely because of this reason that diggis have not brought about significant changes in the cropping pattern. However, by shifting to high value crops, it could be possible for small holders to significantly increase the value of crop production. In such cases, diggis can be an economically-viable intervention even for small land holders.

7.4 Increasing Multiple Use of Water

Diggis in the IGNP are so far being used only for enhancing the crop production. Can it also be used for raising fish? Since water is supplied round the year, certain level of water supply can be maintained in a diggi for raising fisheries also. According to farmers, this has not been practised in the IGNP due to: low local demand, poor facilities for marketing the produce outside; and limited knowledge for raising fish in conjunction with crop production. Raising fish means that farmers cannot empty there diggi for an extended period of time of the year. However, we do not know whether net benefit loss of crop production after retaining water in diggis for fisheries is less than the net value of production gain through fisheries. However, data show that fisheries in conjunction with crop production can increase the income of farmers from every drop of water used manifold So with proper extension, diggis can eventually become an even better economically viable enterprise for farmers in the IGNP command area.

7.5 Bridging gap between Potential and Actual Irrigated Areas

A major problem in IGNP command area is irrigating the undulating land. This is exacerbated by the differences of water supply between the farms in head, middle and tail reaches of the canal command. Our research show, that water distribution between head, middle and tail reaches are highly inequitable. Farmers in head reach may still be using large quantity of water for irrigating their crops with a diggi. Indeed, a proper water accounting study could assess the quantity of water needs to be diverted to a diggi for meeting the full requirement of crops and other multiple uses. The excess water can then be diverted to meet the requirements of tail end of the command area, which often suffers due to water scarcity. This additional water supply can make a diggi an economically-viable option even in tail end areas. And it can increase irrigated area and bridge the gap between potential created and actual irrigated area.

8. CONCLUSIONS

In this paper, we had evaluated the physical and economic performance of diggis with sprinkler irrigation for farmers of different land holding sizes in IGNP command area. The diggi combined with microirrigation has substantially increased the irrigated area, yield, with improved input management and finally the net income benefits from crop production.

The capital cost of diggi and other infrastructure can be recovered within 6 years in a farm of size 6 ha. At larger land holding sizes, the returns to investments are much higher, and the investment can be recovered quickly from increase in crop production itself. The diggi can also become a viable option for small land holders, if they grow high-valued crop or diversify their farming to include fisheries. Due to the vegetarian diet being followed in this region, whether this type of intervention would be successful or not is not clear. However, given the present trends in states such as in Andhra Pradesh, where most of the inland fish production is exported for consumption outside the state, it is likely that with proper marketing facilities this can be a viable option in the IGNP project in Rajasthan.

It is clear that a diggi can: 1) mitigate the waterlogging and salinity in canal command area, 2) spread microirrigation; 3) help promote crop diversification; and 4) mitigate water scarcity in tail reach. All these require further research and extension in the IGNP canal command areas.

The intermediate storage structures with micro irrigation technologies, such as diggi and sprinklers in the IGNP, can be a viable solution to water scarce areas in other parts of the country. While they increase the private benefits, they could mitigate the environmental impacts such as waterlogging and salinity in high water table areas and reducing groundwater overdraft in semi arid and arid areas.

We need to further explore whether the use of diggis in the head reach farms could mean making more water available to tail end areas. This is important for successful completion of Phase II and III of the IGNP. The reason is that completion of these phases of the project would depend largely on water availability in the main canal for delivery to downstream locations.

Although, size of the sample from g roundwater irrigated areas for this study is not large, the general patterns show that an intermediate water storage structures are economically viable there also, even though they are highly energy-intensive. However, more research is required to assess the impacts of these intermediate structures on energy requirements, or to know at what level of energy prices can these structures be viable.

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IMPACT OF QUALITY AND RELIABILITY OF IRRIGATION ON FIELD AND FARM LEVEL WATER PRODUCTIVITY OF CROPS

Kairav Trivedi[1] and O. P. Singh[2]

Abstract

This paper examines the impact of quality and reliability of irrigation on water productivity of individual crops and cropping system in the farm through comparison of crops watered by different types of irrigation systems such as canal irrigation; well irrigation and conjunctive use. Then it analyzes the actual factors that drive differential productivity, and which change due to change in quality and reliability regime of irrigation. The study area is Bist Doab area in Punjab and the analysis was carried out for two agro-climatic regions, both semi-arid, one having medium to high rainfall and the other having low to medium rainfall. The first location (Changarwan) is predominantly canal and well irrigated, whereas the second location (Skohpur) has well irrigation and conjunctive use.

The analysis involved working out an index called "irrigation quality index" for different types of irrigation systems, and then compares water productivity of individual crops vis-à-vis estimated values of this index, for each location. The crop water productivity parameters analyzed are: physical productivity of water in kg/m^3; and water productivity in economic terms.

Overall, the irrigation quality index was higher for: well irrigated fields as compared to canal irrigated fields and fields irrigated by both wells and canals in Skohpur; and canal irrigated fields for most crops in Changarwan. Comparison of irrigation water quality index estimated for major crops under different sources of irrigation vis-à-vis the water productivity of the respective crops show that differential reliability has an impact on economic productivity of water (Rs/m^3). The fields, which received irrigation water of higher quality and reliability got higher water productivity in rupee terms. However, the impact of differential quality and reliability was not visible on physical productivity of water for fodder crops.

Contrary to the belief that higher quality and reliability of irrigation would result in better yields, the fields, which were receiving poor quality irrigation gave higher yields. This was primarily due to the high nutrient load which canal water contained that increased the yield of those crops. Fodder crops also gave higher yields under less reliable irrigation water supply. Hence, one can conclude that improved quality and reliability of irrigation would help enhance the water productivity in crop production.

1. INTRODUCTION

The criteria for evaluating irrigation systems have undergone major modifications in the last 30 years from the classical irrigation efficiencies to measuring performance using a variety of indicators (see Bastiaanssen and Bos, 2001), taking into account productivity of irrigation water with accent on yield (Perry and Narayanamurthy, 1998; Sarwar and Perry, 2002; Seckler *et al*., 2003), and revenue enhancement per unit of depleted water (Barker *et al*., 2003); and equity in water distribution (Svendson and Small, 1990). As scarcity of irrigation water is becoming evident in many regions and demand for water increasing from other competing sectors of use (Perry and Narayanamurthy, 2001), there is a need to assess the quality of irrigation services in relation to productivity of water rather than land (Sarwar and Perry, 2002). This means, the criteria for assessing system-wide irrigation management strategies adopted by irrigation agencies also needs to be revisited. In other words, the factors that need to be taken into account for assessing the quality of irrigation also needs to change, the reason being the factors that influence yield are not exactly same as those, which influence water productivity.

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Crop water productivity can be defined either as the yield per unit of water depleted in crop production or applied for crop production; or the net return from crop production per unit of depleted water or water applied (Kijne *et al*., 2003). Hence, the key drivers of change in water productivity are: amount of water depleted in crop production as it changes both the numerator and denominator of productivity parameters; and all crop inputs including crop variety, fertilizer and pesticide dosage and labour as they determine the crop yields and net returns, which change the numerator of water productivity. Now let us see how the reliability and quality of irrigation affects these drivers; and therefore water productivity. It is an established fact that while crop yield or biomass production increases in proportion to increase in transpiration, at higher doses, irrigation does not result in beneficial transpiration, but non-beneficial evaporation. This way, increased evapo-transpiration does not result in proportional increase in yield of crops (Vaux and Pruitt, 1983). Non-recoverable deep percolation is another non-beneficial component of the total water depleted from crops during irrigation (Allen *et al*., 1998). This also increases at higher dosage of irrigation.

It is very likely that with greater quality and reliability of irrigation, the farmers are able to provide optimum dosage of irrigation to the crop, controlling the non-beneficial evaporation, and non-recoverable deep percolation. The result will be that the consumed fraction will remain low, and the fraction of beneficial evapo-transpiration within the consumed fraction (CF) (depleted water) will remain high[2]. It is also possible that with high reliability of available supplies, even under scarcity of irrigation water, the farmers can adjust their sowing time such that they are able to provide critical watering, thereby obtaining high yield responses. Both result in higher water productivity. Further, if more reliable irrigation water is available, farmers would be encouraged to use high yielding varieties, and apply adequate amount of fertilizers and pesticides to their crops, resulting in better crop yields. Hence, the overall outcome of improved quality and reliability of irrigation would be higher water productivity.

The purpose of the paper is to: i] develop quantitative criteria for measuring the quality and reliability of irrigation water that capture the complex physical variables relating to irrigation and affecting crop water productivity; ii] assess the impact of quality and reliability of irrigation on water productivity in agriculture, through analysis of individual crops; and then, iii] analyze the factors that cause differential water productivity, and which change due to change in quality and reliability regime.

2. REVIEW OF LITERATURE ON ANALYZING THE IMPACT OF IRRIGATION MANAGEMENT STRATEGIES

The recent past has seen an increase in enthusiasm among irrigation researchers worldwide, in trying to develop indicators for measuring performance of irrigation systems and also to assess the impact of different irrigation management strategies on crop yields and productivity of land and water quantitatively, in view of the growing shortage of irrigation water, and the competing demands for water from other sectors. Four main strategies, which were examined are: providing deficit irrigation; improving the timeliness of irrigation; precision irrigation; and improving the quality and reliability of irrigation. One of the motivating factors behind this is to identify the best strategy for improving the performance of irrigation systems, given its potential as a powerful tool to manage the demand for water in agriculture.

Svendson and Small (1990) analyzed farmers' perspective of irrigation system performance. They found that the way farmers evaluate performance of irrigation systems mainly concern the outcomes and impacts of irrigation systems rather than the processes involved in managing irrigation such as staffing policies of the agency, pattern of communication and nature of farmers' participation in water users associations. According to them, the ten important measures that farmers use to assess irrigation system performance are: depth related measures viz., adequacy, equity and timeliness; farm management related measures such as tractability, convenience and predictability; and water quality related measures viz., temperature, sediment content, nutrient content, toxics and pathogens. How these criteria can be converted into normative indicators for analyzing irrigation system performance, or even strategies for improving the same were not addressed.

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[2]See Allen et al., (1998) for detailed discussion on various components of the applied water, such as consumed water, consumed fraction, beneficial transpiration, non-beneficial evaporation from the soil and non-recoverable deep percolation.

Bastiaanssen and Bos (1999) argued that a new generation of irrigation performance indicators such as adequacy, equity and productivity could be quantified using remote sensing data, based on previous work by several scholars such as Azzali and Menenti (1987), Bastiaanssen (1994), Menenti *et al*. (1989), Moran (1994), Roerink *et al*. (1997). For instance, Menenti *et al*. (1989) measured equity in irrigation water distribution by evaluating the actual flow per unit irrigated area, at different spatial scales, in which the irrigated area was measured using satellite data. Moran (1994) used vegetation index and surface temperature to assess the adequacy. Bastiaanssen (1994) expressed adequacy in irrigation as a ratio of the total energy consumed by the crop in the form of ET and the total energy available for ET, and computed it from surface energy balance. He argued that equity in irrigation performance could be evaluated by taking a digital overlay of the SEB, with administrative boundaries and calculating the coefficient of variation across space. Roerink *et al*. (1997) extended the ET fraction approach used by Bastiaanssen (1994) and calculated coefficient of variation of actual ET over total water supplied to quantify productivity.

There were lots of anecdotal and research based evidences from around the world showing differential productivity gains in well irrigation over canal irrigation vis-à-vis yield and water productivity, and this gain has been attributed to virtues of well irrigation over canal irrigation such as timeliness, and greater quality in terms of adequateness and control over water delivery (Llamas, 2000; Chakravorthy and Umetsu, 2004). Some empirical studies showed positive impact of timeliness of irrigation on paddy yields in canal command areas (Meinzen-Dick, 1995). Whereas some studies showed positive differential yield and net returns from crop production in diesel engine irrigated crops over electric-pump irrigated crops (Kumar and Patel, 1995), with the difference being attributed to access to and control over irrigation possible with diesel engine operated wells, i.e., the ability of the farmers to irrigate the crop as and when required or better "timeliness".

Studies in Pakistan Punjab showed greater yields obtained by farmers who use conjunctive irrigation in canal command areas as compared to those who use only canal water for their wheat and rice crop (Hussain *et al*., 2003). A study by Sarwar and Perry (2002) in Indus plains of Pakistan, which simulated crop growth and ET under different irrigation schedules, using SWAP (Soil-Water-Atmosphere-Plant) model showed that it is possible to enhance crop water productivity through deficit irrigation. The study showed 47% higher crop water productivity under deficit irrigation conditions as compared to unrestricted irrigation supply condition, which led to the conclusion that while applying water to meet the exact crop water requirement would be the right strategy under situations of plentiful water, in situations of scarcity, restricted water supply would be the strategy to maximize productivity of water. But, whether irrigation is in deficit regime, or in water surplus regime, is highly crop specific, and their actual impacts on crop production cannot be assessed realistically, unless the farmers' response in terms of crop choices are also modeled.

According to another analysis by Perry and Narayanamurthy (1998), rationing irrigation to make it available during critical stages, which correspond to points where the yield sensitivity to ET is high, is a useful strategy in enhancing crop yields. However, there are practical problems in assessing quality of irrigation in terms of water availability during critical stages, and then applying it to devise appropriate water delivery policy for an irrigation scheme. First: the sowing time for crops varies significantly across farmers within the same irrigation command thereby the timing for critical watering changes across farmers. Second: farmers in many irrigation systems in Asia grow multiple crops with critical stage with respect to "growth response to ET" differing widely. More over, the quality of irrigation available from an irrigation system cannot be assessed in relation to water availability during critical stage alone.

In a nutshell, review of available irrigation literature shows that the studies cover either analysis of different indicators for analyzing irrigation system performance from different perspectives - farmers and irrigation agencies; use of different scientific methodologies to assess the performance of irrigation schemes in terms of crop yields or crop growth; or different approaches to improve the performance of irrigation systems in terms of their outcomes, under a set of conditions existing in the field vis-à-vis crops and climate; or merely qualitatively analyze the impact of quality of irrigation on crop yields. But, it is important to note here that the real field outcomes of introducing irrigation management strategies suggested by such crop growth-based econometric models (see for instance, Perry and Narayanamurthy, 2001) would deviate from the model predictions. This is because such models fail to take into account the farmers' decision making variables with regard to crop choices under different irrigation water supply regimes. Most of the studies assess productivity in relation to land.

Such studies, therefore, leave major information gaps about the governing parameters in irrigation management that need to be manipulated for improving the performance and that are critical for working out operational policies for irrigation management, and their expected outcomes. There is hardly any empirical research that attempts to develop quantitative criteria, which uses measurable physical indicators, for assessing the quality and reliability of irrigation and which captures the complex variables such as timeliness of irrigation, physical access to irrigation water source, water delivery rates and control over water delivery[3] . Such quantitative measures are important for working out operational policies for irrigation management.

Further, very little is known about how improved quality and reliability of irrigation cause differential productivity, and the extent to which they contribute. What is best known is the physical processes involved in plant growth, and how that changes with irrigation. But, what is needed is the real life impacts of different irrigation management interventions like improving "quality and reliability" of irrigation on productivity of water.

3. THE STUDY OBJECTIVES AND METHODOLOGY

3.1 Study Location

In Bist Doab area of Punjab, the climate varies from semi arid to hot, sub-humid from south west to north east (Hira and Khera, 2000). The Bist Doab area provides a unique opportunity to analyze the impact of reliability of irrigation on crop yields and water productivity. The reason is the presence of farmers using canal water, groundwater and both in the same location with similar agro-climate. Also, incidentally, there are pockets where reliability of canal irrigation is quite high, against locations which are traditionally known for poor quality canal irrigation. This can help overcome the problem of wrongly attributing differential productivity to a particular source of irrigation.

One of the locations (Changarwan village) chosen for the study in Hoshiarpur district, which receives adequate amount of canal water from Shah Neher canal. Very few farmers have wells, which are located outside the command. But, farmers who receive canal water do not practice well irrigation. The area, which is part of the sub-mountainous region of Punjab, receives nearly 900mm of rainfall, and is hot and sub-humid. The second location (Skohpur village) located in Nawanshehr district is well known for intensive well irrigation, and the canal water supply is generally poor, except in very good rainfall years. The area receives a mean annual rainfall of approximately 450 mm (source: based on Hira and Khera, 2000). Most of the farmers who receive canal water also practice well irrigation, at least for some crops.

3.2 Objectives

The objective of this paper is to analyze the impact of quality and reliability of irrigation on field level water productivity of crops. This is done by comparing the physical productivity of water for individual crops; and water productivity in economic terms under different types of irrigation systems with differential quality and reliability vis-à-vis the irrigation quality and reliability index for these systems.

3.3 Methodology[4] , Sampling, Analytical Procedures

The quality and reliability of irrigation influences water productivity in many different ways. First, good quality and reliable irrigation services provide farmers with the opportunity of optimizing the dosage of irrigation, which can help prevent non-beneficial evaporation of soil moisture from the field during the crop development stages and residual moisture in the soil after the crop harvest thereby bringing the depleted water close to beneficial ET. Reliable and quality irrigation would motivate farmers to use fertilizers adequately, use high yield-

[3] This does not ignore the fact that several scholars had highlighted the need for improving the timeliness or irrigation on crop yields (Meinzen-Dick, 1995); providing watering at critical stages of crop growth (Perry and Narayanamurthy, 1998); and deficit irrigation under situations of water scarcity as crucial factors in enhancing productivity (Sarwar and Perry, 2002)

[4] This part draws heavily on the proposal titled "Analyzing the Trade offs in Maximizing Farming System and Regional Level Water Productivity" prepared by M. Dinesh Kumar for submission to the Department of Environmental Sciences, Wageningen University and Research Centre, Wageningen, the Netherlands.

ing seed varieties, invest in agronomic practices and also go for high-valued crops that involve more risk. This would positively affect yield. Since, differential input costs need to be factored in the productivity analysis, combined physical and economic productivity of water also need to be compared. Further, since cropping pattern might change from one source to another, overall net water productivity (Rs/m^3), including all the crops needs to be compared for understanding the real impact (Kumar, 2005).

Since there are perceptible differences in the quality and reliability of irrigation between canal irrigation and well irrigation and also between well irrigation and conjunctive use, the impact of reliability and quality on water productivity can be compared by comparing field level water productivity of depleted water for the same crop for these different sources (both in Kg/m^3 of applied water and Rs/m^3 of applied water). It is also important to quantify the quality and reliability of irrigation using certain realistic criteria based on physically measurable indicators. Then the productivity values for different sources will be compared against the estimated values of quality and reliability of the source.

The sample size for Changarwan village is 36, with 18 farmers using canal irrigation and 18 using well irrigation. In case of Skohpur village the sample size is 35, of which the farmers using well irrigation are 21 and those adopting conjunctive use are 14. Among these, there are 3 farmers who use only canal water supply for irrigating certain crops.

Primary data were collected from the sample farmers, in both the locations using real time monitoring. The data collected included: area under different irrigated crops; date of sowing and harvesting; the actual irrigation schedules including the timing and duration of each watering; crop outputs; the price of produce (price at which it is being procured by Food Corporation of India); the discharge of pumps; canal discharge rate.

4. ESTIMATING RELIABILITY AND QUALITY OF IRRIGATION

The differential quality and reliability of irrigation vis-à-vis a crop can be quantitatively estimated by using certain irrigation related physical parameters. They are: water control index; no. of irrigations; average duration per watering per unit cropped area; and maximum time duration between two waterings during the entire crop season. It is argued here that higher frequency improves the quality and reliability of irrigation. Also, the greater the duration of watering, the better would be the quality. On the contrary, greater the time gap between two watering for the same crop, poorer would be the quality of irrigation and greater would be the chances for crop damage due to water stress. Correct dosage of water could prevent leaching of fertilizers and other nutrients in the soil, thereby maintaining good growth.

Quality and reliability of irrigation for wells, canals and conjunctive use for a farmer, with respect to a given crop is assessed in terms of an irrigation quality index (δ_l) defined by

$$\delta_l = \frac{In_l Id_l \psi_l}{t_l} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 7$$

$= [aq - bq_l^2]$ where, a=0.13 and b=0.0026

Whereis ψ_l the water control index for farmer l, In_i and Id_i are the number of irrigations and duration of irrigation (hr/acre), respectively, given by the sample farmer l for a crop; t_l is the maximum time duration between any two consecutive watering given by sample farmerfor l the crop in days. q_l is the rate of water delivery (l/s) for that farmer. It is assumed that a water delivery rate of 15 litres per second is best for the crop for which the index would be one and accordingly the values of coefficients a and were estimated. Further, the relationship between q and is assumed to be according to a convex curve. From the index obtained for each farmer in the sample, the mean values would be estimated and compared against the field level water productivity.

The way quality and reliability of irrigation is measured for a particular farm will have to be different from that for a particular field. This is because unlike in case of a field, in a farm, there would be many crops, each having different irrigation requirements, in terms of dosage and frequency. Therefore, assessing the quality and reliability of irrigation in relation to number of irrigations given, duration of irrigation and the maximum time duration between two waterings would be futile. For a farm, the parameters that matter when it comes to comparing reliability and quality between two sources of irrigation are: 1] the total time duration for which water is available at the farm gate for a given cropped area; 2] the time interval between two consecutive water deliveries at the farm gate; and, 3] the degree of control with which water can be applied in the field, which is determined by water control index.

Quality and reliability of irrigation with respects to all the crops in a farm can be assessed quantitatively as a function of the water control index (ψ); the average duration of water delivery per unit cropped area in the farm t_{farm} (hours per ha); and an inverse function of the cumulative time interval between water deliveries in the farm $t_{off-farm}$ (hours). The underlying premise in developing these criteria is that greater the duration of water delivery in the farm, greater would be the ability of the farmer to manage his irrigation. Larger the time interval between two water deliveries, lesser would be the reliability of the water supplies. Again, higher the water control index, greater would be the ability to provide optimum dosage of irrigation.

The detailed analytical procedure employed for estimating water productivity parameters is available in Kumar et al. (2008).

5. RESULTS AND DISCUSSION

5.1 Quality and Reliability of Irrigation Water Supplies for Different Irrigation Systems

Based on real time data on irrigation schedules, duration of irrigation and the water delivery of the source, the irrigation quality index was estimated for all the sources, viz., well irrigation, conjunctive irrigation and canal irrigation. The estimates for Changarwan are provided in Table 1 and that for Skohpur are provided in Table 2. As Table 1 shows, the IQ value is higher for well for all crops except paddy. This is understandable. In the case of wells, for a given crop, the number of irrigations was much higher. Also, the time gap between two consecutive watering was higher. In the case of paddy, the index is slightly higher for canal.

Table 1: Estimates of quality and reliability for canal irrigation and well irrigation at Changarwan (Zone I) for selected crops

Season	Crop	Source of Irrigation	Irrigation Quality Index
Kharif	Paddy	Well	2.66
		Canal	3.33
	Maize	Well	10.28
		Canal	0.65
	Bajra	Well	1.37
		Canal	0.25
Winter	Wheat	Well	2.26
		Canal	0.5
	Barseem	Well	0.44
		Canal	0.17

Source: author’s own analysis based on primary data

In the case of Skohpur, there are three sources of irrigation, i.e., well, canal and conjunctive use. The IQ values are higher for well irrigation except for kharif bajra and maize. For maize, the IQ value is highest for conjunctive irrigation, and in the case of bajra the value is highest for canal.

Table 2: Estimates of Quality and Reliability for Well irrigation, Canal Irrigation and Conjunctive Use at Skohpur (Zone III) for selected crops

Season	Crop	Source of Irrigation	Irrigation Quality Index
Kharif	Paddy	Well	26.77
		Canal	13.51
		Conjunctive	28.16
	Maize	Well	2.63
		Canal	2.2
		Conjunctive	5.01
	Bajra	Well	1.44
		Canal	2.29
		Conjunctive	1.16
Winte	Wheat	Well	1.05
		Canal	0.87
		Conjunctive	1.25
	Barseem	Well	1.43
		Canal	1.17
		Conjunctive	0.32

Source: author's own estimates based on primary data

5.2 Water Productivity of Different Crops

The mean values of crop yields, and estimated mean values of irrigation dosage, and water productivity in physical and economic terms for the major crops viz., paddy, maize, bajra, wheat and barseem for well irrigated crops and canal irrigated crops are presented separately in Table 3 and Table 4. Comparing crop yields between irrigation sources show higher yield values for canal irrigated fields. The comparison shows the following: 1] the irrigation dosages are much higher for canal-irrigated fields for all the five crops; 2] physical productivity of water is higher for well-irrigated fields, for paddy, maize and wheat; and 3] the values of water productivity in economic terms are higher for well- irrigated fields for maize, bajra and wheat.

The irrigation dosages are excessive for fields, which are receiving canal water. But, still the yields are much higher for these fields when compared to well-irrigated fields in spite of the fact that the well irrigated fields are getting adequate quantities of water. One important reason for this differential yield is the chemical quality of irrigation water available through canals. As reported by the farmers in Changarwan village, the canal water, which comes from Bhakra irrigation scheme in Punjab-Himachal border is very rich in many minerals from the hilly catchments in the Shivalik hills. The continuous availability of this water for the past four decades had made the land receiving this water also very fertile. Hence, the nutrient regime in the soil is much higher in the canal irrigated fields.

The mean values of crop yields, mean values of estimated irrigation dosage, and mean values of estimated water productivity in physical and economic terms for the major crops irrigated by wells, canals and conjunctive method in Skohpur village are presented separately in Table 5, Table 6 and Table 7, respectively. Comparison across sources shows the following: 1] the depth of irrigation is highest for fields irrigated by canals, followed by conjunctive use, and lowest for wells for paddy and wheat; 2] the yield is higher for well irrigated fields for paddy, and barseem, whereas it is higher for canal irrigated fields in the case of maize; 3] the physical productivity of water is higher for well irrigated fields in the case of paddy, bajra, and wheat and highest for canal irrigated field in the case of maize. As regards water productivity in economic terms, values were higher for well-irrigated fields for all crops except bajra.

Table 3: Water Productivity Estimates of Different Crops under Well irrigation at Changarwan (Zone 1)

Well Irrigation					
Crop	Total Irrigation Water Use [m³/acre]	Crop Yield [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	3518.5	1169.5	548.8	0.57	0.32
Maize	598.7	941.7	1629.3	1.53	6.44
Bajra	1497.9	6025.0	3425.5	7.82	0.43
Wheat	915.4	1003.6	754.1	1.97	4.45
Barseem	1184.5	4864.6	9474.0	1.72	12.99

Source: authors' own estimates based on primary data

Table 4: Water Productivity Estimates of Different Crops under Canal Irrigation at Changarwan (Zone 1)

Canal Irrigation					
Crop	Total Irrigation Water Use [m³/acre]	Crop Yield [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	5849.8	1661.2	6183.8	0.41	1.50
Maize	2600.0	880.0	4336.2	0.53	2.00
Bajra	1935.8	8122.2	7358.2	10.41	0.09
Wheat	1109.0	1100.6	2465.4	1.57	3.46
Barseem	2488.5	7216.7	16454.0	3.60	24.01

Source: authors' own estimates based on primary data

Table 5: Water Productivity of Different Crops under Well Irrigation at Skohpur (Zone 3)

Well Irrigation					
Crop	Total Irrigation Water Use [m³/acre]	Crop production [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	4548.0	2270.0	12520.7	0.79	4.46
Maize	1381.0	1060.0	310.3	3.30	6.34
Bajra	1040.9	5607.8	-244.40	17.21	0.37
Wheat	697.5	1494.1	8584.8	3.41	19.80
Barseem	3050.6	6214.3	12676.8	3.52	30.28

Source: authors' own estimates based on primary data

Table 6: Water Productivity Estimates of Different Crops under Canal Irrigation at Village Skohpur (Zone 3)

Canal Irrigation					
Crop	Total Irrigation Water Use [m³/acre]	Crop production [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	11722.6	1766.7	3966.2	0.20	0.06
Maize	2836.1	1260.0	6656.4	9.15	1.99
Bajra	6433.6	4500.0	1752.2	1.45	1.03
Wheat	1787.0	1592.9	9820.0	2.37	14.32
Barseem	2382.3	5400.0	11263.7	2.41	10.56

Table 7: Water Productivity Estimates of Different Crops under Conjunctive use of Irrigation at village Skohpur (Zone 3)

Conjunctive Use					
Crop	Total Irrigation Water Use [m³/acre]	Crop production [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	7740.0	2188.9	11628.3	0.79	4.19
Maize	1247.4	783.3	1635.8	0.73	1.50
Bajra	475.20	8600.0	4400.0	9.05	4.38
Wheat	1745.0	1518.3	9528.8	2.51	16.99
Barseem	3909.6	5675.0	8869.40	3.76	9.73

Source: authors' own estimates based on primary data

5.3. Impact of Quality and Reliability of Irrigation on Water Productivity of Crops

Table 8 shows the estimates of irrigation quality index for five major crops under two major sources of irrigation, viz., wells and canals, and the corresponding estimates of physical and economic productivity of water for these crops for Changarwan village. It can be seen that in situations where the irrigation quality index is higher, the water productivity in economic terms is higher. The only exception is barseem. Another interesting observation is that water productivity in economic terms does not follow the same trend as that of physical productivity of water. The physical productivity of water was found to be higher for fields, which have lower irrigation quality index, in the case of paddy, bajra and barseem.

One reason for this could be the difference in duration of the crop between fields under different sources of irrigation. In crops such as bajra and barseem where only leafy biomass is harvested, if water is available in plenty through excessive water delivery, farmers might take more harvests of these fodder crops with more number of irrigations. This would reduce the value of IQ, but may not reduce physical productivity of water as the biomass output would increase in proportion of the amount of water.

Table 8: Productivity of Water for Crops at Changarwan (Zone 1)

Crop	Source of Irrigation	Irrigation Quality Index	Water Productivity (kg/m^3)	Water Productivity (Rs/m^3)
Paddy	Well	2.66	0.57	0.32
	Canal	3.33	0.41	1.50
Maize	Well	10.28	1.53	6.44
	Canal	0.65	0.53	2.00
Bajra	Well	1.37	7.82	0.43
	Canal	0.25	10.41	0.09
Wheat	Well	2.26	1.97	4.45
	Canal	0.5	1.57	3.46
Barseem	Well	0.44	6.53	12.99
	Canal	0.17	10.23	24.01

Source: authors' own estimates based on primary data

Table 9 shows the estimates of irrigation quality index for five major crops under well irrigation, canal irrigation and conjunctive use, and the corresponding estimates of physical productivity and economic productivity of water for these crops for Skohpur village. Similar to what was seen in the case of Changarwan, comparing well irrigated crops and canal irrigated crops in Skohpur shows that water productivity (Rs/m^3) was found to be higher for fields which have higher estimated values of irrigation quality and reliability except paddy.

Table 9: Productivity of Water for Crops at Skohpur (Zone 3)

Crop	Source of Irrigation	Irrigation Quality Index	Water Productivity (kg/m^3)	Water Productivity (Rs/m^3)
Paddy	Well	26.77	0.79	4.46
	Canal	13.51	0.20	0.06
	Conjunctive	28.16	0.79	4.19
Maize	Well	2.63	3.30	6.34
	Canal	2.2	9.15	1.99
	Conjunctive	5.01	0.73	1.50
Bajra	Well	1.44	17.21	0.37
	Canal	2.29	1.45	1.03
	Conjunctive	1.16	9.05	4.38
Wheat	Well	1.05	3.41	19.80
	Canal	0.87	2.37	14.32
	Conjunctive	1.25	2.51	16.99
Barseem	Well	1.43	3.33	30.28
	Canal	1.17	2.41	10.56
	Conjunctive	0.32	2.02	9.73

Source: authors' own estimates based on primary data

5.4 How Water Productivity in Crop production Changes with Quality and Reliability of Irrigation Water?

We have begun our analysis with the premise that improved quality and reliability of irrigation, expressed in terms of irrigation quality index (IQ), would be able to manipulate the water productivity parameters through controlling the major drivers of change in water productivity such as irrigation dosage, fertilizer and pesticide inputs.

Increase in irrigation dosage, largely, increases the beneficial evapo-transpiration from the crop, and therefore the crop yield. But, excessive irrigation will not have any positive effect on crop yields. On the other hand, it increases the value of denominator of water productivity. We have seen that the IQ values are much higher for well-irrigated fields for both the locations. Simultaneously, the irrigation dosages are much higher in canal irrigated fields as against well-irrigated fields for most crops in Changarwan. Also, it was much higher in canal irrigated fields and field irrigated by both canals and wells, than that of well irrigated fields for most crops in the case of Skohpur. This means that the highest influence of IQ index is in controlling the water delivery in the field.

Excessive dosages of irrigation are likely to reduce both the physical and economic productivity of water. But, fertilizer and pesticide dosage and labour input are also other drivers of change in water productivity as they can increase the yield, without changing the denominator of water productivity in kg/m^3. Generally, their effect on physical productivity of water would be positive. At the same time, these inputs can increase the cost of production significantly, and therefore its marginal impact on the net returns may not always be positive. We have begun our analysis with the assumption that better quality and reliability in irrigation services would lead to optimal use of other inputs such as fertilizers, pesticides and labour.

Comparative analysis of crop inputs such as fertilizer, pesticide and labour use between crops, which receive irrigation of differential quality and reliability does not fully support this hypothesis. In Changarwan, for instance, the change in levels of fertilizer and pesticide dosage with change in source of irrigation was found to be significant only for paddy, wheat and maize. What emerges from the comparison is that the dosage of these inputs does not increase with increase in reliability of irrigation water (Table 12). This is evident from the fact that canal-irrigated fields, which have lower reliability, do not necessarily receive lower dosage of fertilizer and other inputs. One reason could be that as the irrigation dosage is very high in the case of canals resulting in heavy percolation, farmers provide for leaching of fertilizers, which occur due to it. Another reason could be that the quality and reliability does not matter so much for fodder crops such as bajra and barseem, farmers try to obtain higher yield through higher dosage of inputs. Significant difference in labour use was found between sources, for three crops viz., paddy, maize, and barseem. Here, contrary to what was generally perceived, labour input was higher for fields, which received irrigation water of lower reliability.

Analysis for Skohpur (Table 13) shows that there is no general pattern in the input use vis-à-vis source of irrigation or quality and reliability of irrigation. Similarly in the case of labour input also, no general pattern is seen to be emerging. As a result, lower quality and reliability of irrigation does not necessarily result in lower water productivity in physical terms, but in economic terms, as shown by majority of the cases from both the field locations.

Table 12: Comparison of Input Use and Water Productivity in Economic Terms at village Changarwan (Zone 1)

Crop	Source of Irrigation	Irrigation Quality Index	Input Use (Rs./acre)		Labour (Rs./acre)	Water Productivity (Rs./m^3)
			Fertilizer	Pesticide		
Paddy	Well	2.66	607.8	179.0	1393.81	0.32
	Canal	3.33	701.5	157.0	1207.37	1.50
Maize	Well	10.28	566.3	135.5	333.3	6.44
	Canal	0.65	272.3	196.2	666.6	2.00
Bajra	Well	1.37	215.0	-	1200	0.43
	Canal	0.25	242.9	-	-	0.09
Wheat	Well	2.26	629.1	176.0	918.6	4.45
	Canal	0.5	775.5	169.8	944.6	3.46
Barseem	Well	0.44	438.5	120.0	560	12.99
	Canal	0.17	426.5	350.0	300	24.01

Source: authors' own estimates based on primary data

Table 13: Comparison of Input use and Water Productivity in Economic Terms at village Skohpur (Zone 3)

Crop	Irrigation Quality Index	Source of Irrigation	Fertilizer (Rs./acre)	Pesticide (Rs./acre)	Labour (Rs./acre)	Water Productivity (Rs./m^3)
Paddy	26.77	Well	1004.9	151.9	1032.0	4.46
	13.51	Canal	857.70	245.7	1195.2	0.06
	28.16	Conjunctive	1019.4	196.0	1047.6	4.19
Maize	2.63	Well	954.0	228.4	1201.2	6.34
	2.2	Canal	1058.7	148.9	966.6	1.99
	5.01	Conjunctive	1007.3	178.3	281.5	1.50
Bajra	1.44	Well	345.0	-	845.0	0.37
	2.29	Canal	500.0	55.0	500.0	1.03
	1.16	Conjunctive	-	-	-	4.38
Wheat	1.05	Well	835.2	199.2	824.8	19.80
	0.87	Canal	1080.7	206.7	727.7	14.32
	1.25	Conjunctive	875.9	165.6	1300.0	16.99
Barseem	1.43	Well	535.9	-	-	30.28
	1.17	Canal	591.0	495.0	466.6	10.56
	0.32	Conjunctive	675.0	175.0	-	9.73

Source: authors' own estimates based on primary data

The quality and reliability of irrigation had some impact on the cropping pattern chosen by the farmers. The well irrigators in Changarwan were allocating more area under maize during kharif season as compared to canal irrigators (see Table 14 and 15). Obviously, maize is a low water consuming crop when compared to paddy. But, it is not a highly water-efficient crop either. There are two reasons for greater preference for maize. One is the water shortage during summer months induced by restricted power supply in the farms. The other is the high cost of diesel required for pumping groundwater. In Punjab, monsoon arrives in the first week of July, while the transplanting of paddy starts in June itself. During the month of June, the potential evapo-transpiration of the crop rapidly goes up due to very high temperatures and high aridity, and the crop needs frequent waterings. This makes paddy production with diesel pump irrigation an un-attractive proposition for the farmers. But, the canal irrigators in the same village get plenty of canal water for paddy, with good reliability as seen from the estimates of quality and reliability of canal water supply for paddy in that village. Hence, they are able to allocate more land for paddy.

Contrary to this, in Skohpur village, the reliability of canal water supply is very poor. This is evident from the discussions with the farmers, and the irrigation quality and reliability index estimated for canal water supplies for paddy. The lower reliability of canal water supplies is forcing farmers to allocate much less area for water-intensive paddy. The main reason for this is that the returns from paddy are dependent on the adequacy of irrigation water applied, as seen from the comparison of net returns from paddy. While the well irrigators get net returns of Rs. 12000 from an acre of paddy, the canal irrigators get Rs.3900 per acre in that village. Hence, we could infer that quality and reliability of water influences the cropping pattern wherein the farmers choose crops, which give higher return from every unit of land they cultivate.

Table 14: Comparison of cropping pattern at village Changarwan (Zone 1)

Crop	% of area under different water source	
	Well	Canal
Paddy	31.41	43.41
Maize	11.42	2.37
Bajra(GF)	5.21	7.14
Wheat	44.85	42.15
Barseem	5.93	4.90

Source: authors' own estimates based on primary data

Table 15: Comparison of cropping pattern at village Skohpur (Zone 3)

Crop	% of area under different water source		
	Well	Canal	Well + Canal
Paddy	24.1	9.99	48.90
Maize	18.5	25.8	7.52
Bajra (GF)	4.56	8.43	1.25
Wheat	42.3	44.5	28.5
Barseem	6.72	10.2	4.7

Source: authors' own estimates based on primary data

6. FINDINGS AND CONCLUSIONS

In this paper, we have developed quantitative criteria for assessing the quality and reliability of irrigation water, and using these criteria, a composite index called the irrigation quality index was developed. The index uses the water control index, a function of water delivery rate; the frequency of irrigations; the duration of irrigation; and the maximum time gap between two consecutive waterings as the determinants. The index was worked for different crops under three different sources of irrigation in Bist Doab area.

Overall, the irrigation quality index was found to be higher for well irrigated fields as compared to canal irrigated fields and fields irrigated by both wells and canals in Skohpur village. But, the estimates of irrigation quality index were found to be higher for canal irrigated fields than well-irrigated fields in the case of Changarwan village for a few crops. This is in confirmation with what the farmers in these villages perceive about the quality and reliability of irrigation water deliveries from canals from the respective villages. Hence, we could conclude that the quantitative criteria evolved for estimation of this composite index are realistic.

Comparison of irrigation quality index estimated for major crops under different sources of irrigation vis-à-vis the water productivity of the respective crops show that differential reliability has an impact on economic productivity of water (Rs/m^3). The fields, which received irrigation water of higher quality and reliability got higher water productivity in rupee terms. But, the impact of differential quality and reliability was not visible on physical productivity of water for fodder crops.

Contrary to the belief that higher quality and reliability of irrigation would result in better yields, the fields, which were receiving high quality irrigation gave lesser yields as compared to those which received poor quality irrigation. This was primarily due to the high nutrient load which canal water contained that increased the yield of those crops substantially. Also, fodder crops also gave higher yields under less reliable irrigation water supply. Hence, one can conclude that improved quality and reliability of irrigation would help enhance the water productivity in crop production. Nevertheless, the index developed here is not adequate to assess the IQ of crops, which can be harvested many times. Also, it needs refinement to take into account the difference in chemical quality of irrigation water.

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WATER PRODUCTIVITY OF IRRIGATED AGRICULTURE IN INDIA: POTENTIAL AREAS FOR IMPROVEMENT

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Abstract

The objective of the study is to explore the scope for water productivity enhancement in irrigated agriculture in India through: i] water control; ii] optimizing nutrient input to crop; iii] improving the quality and reliability of irrigation water; and, iv] growing crops in regions where climate is favourable. The study is based on data from three important river basins in India, viz., Indus, Narmada and Sabarmati. The study involved: 1] estimating the incremental water productivity of selected crops viz., wheat and cotton in response to applied water, and fertilizer dosage; 2] estimating water productivity of the same crop across agro-ecological zones within the basin, and 3] comparing determinants of crop water productivity with different sources of irrigation with differential reliability and quality.

Most farmers are applying water within a regime where the yield response to both irrigation and fertilizer dosage is positive. Also, their water application corresponds to a regime where water productivity (Rs./m^3) response to irrigation is negative and fertilizer is positive. But, in certain situations, farmers' water application regime corresponds to a regime where both yield and water productivity responses to irrigation are either positive or negative. Within basins, for the same crop, water productivity in both physical and economic terms is much higher in high rainfall, sub-humid area as compared to that in low rainfall, arid areas. The quality and reliability of irrigation can significantly impact the type of crops chosen by farmers and the crop yield, thereby raising water productivity.

There is ample scope for improving water productivity in irrigated agriculture through water control. But, in most cases, it may lead to reduced net return per unit of land. Hence, they would have incentive to go for water control measures only if there is sufficient land, which can be put to use for irrigated production using the saved water.

1. INTRODUCTION

Economic value of water in agriculture is much lower than that in other sectors (Barker et al., 2003), including manufacturing (Xie et al., 1993). Growing physical shortage of water on the one hand, and scarcity of economically accessible water owing to increasing cost of production and supply of the resource on the other, had preoccupied researchers with increasing productivity of water use in agriculture in order to get maximum production or value from every unit of water used (Kijne et al., 2003).

Raising water productivity is the cornerstone of any demand management strategy. Definition of water productivity is scale dependent. Water productivity can be analyzed at the plant level, field level, farm level, system level and basin level, and its value would change with the changing scale of analysis (Molden et al., 2003). The classical concept of irrigation efficiency used by water engineers omitted economic values and looked at the actual evapo-transpiration (ET) against the total water diverted for crop production (Kijne et al., 2003). Moreover, it does not factor in the "scale effect" (Keller et al., 1996).

At the field level, there is no single parameter to determine the efficiency of water use in crop production. Measures to enhance yield to raise water productivity in biomass per unit of water depleted, might increase the cost of production thereby reducing net return per unit of water depleted. Therefore, crop water productivity needs to be assessed in terms of both kilogram of crop per cubic metre of water diverted or depleted (Kg./m^3); and net or gross present value of the crop produced per cubic metre of water (Kijne et al., 2003).

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While the yield would increase with an increase in actual ET, the water productivity (Rs./m^{3}) would start leveling off and then start declining much before the yield reaches maximum (see for instance Molden et al., 2003). The reason is that the amount of depleted water might increase with increase in irrigation dosage, and beyond a point, it does not result in yield increase (Vaux and Pruitt, 1983). Similarly, while the yield would keep increasing until a point with increase in nutrient inputs, the net return might start decreasing even at level of nutrient dosage lower than that corresponding to maximum yield. Hence, the challenge is to identify optimum level of water and nutrient inputs to ensure maximum return per unit of land and water. The measure can be referred to as "water control"; and optimizing nutrient dosage, respectively.

"Water control" refers to supplying water dosages close to the difference between crop water requirement and available soil moisture in the root zone. It ensures greater utilization of applied water for ET, and minimal non-recoverable percolation from the applied water, which is non-beneficial. It also reduces the fraction of non-beneficial evaporation from applied water. Hence, with controlled water delivery, the yield would be more for the same depletion or consumed fraction, resulting in higher water productivity.[1] The measures for this include on-farm water management practices and improving the conveyance of water. Micro irrigation systems take care of water control for many crops, and in certain other crops by farm leveling.

Crop water productivity also depends on the reliability and quality of irrigation water applied in addition to control over water delivery. Improved reliability can ensure better timing of irrigation to ensure crop growth needs (Meinzen-Dick, 1995). With the same amount of water applied, the crop consumptive use (ET) would change depending on the timing of water application. On the other hand, non-availability of moisture at critical stages of crop growth can significantly reduce the crop growth and yield and the reduction would not be proportional to the reduction in water applied or water consumed. Therefore, the quality and reliability of irrigation should affect water productivity, with the same amount of irrigation water applied.[2]

Now, opportunities for enhancing water productivity would change when one moves from the field to the basin. Enhancing water productivity at the field through water control may adversely affect the availability of water for downstream uses in a closed basin. The reason is the probable reduction in non-consumptive part of the water applied (Allen et al., 1998; Molle and Turral, 2004). If those downstream uses have higher return per unit water use, water control measures would result in productivity losses at the basin level. On the other hand, at the basin level, as Abdulleev and Molden (2004) note, opportunities might exist for growing the same crop in areas where their ET values are lower, which result in improved water productivity in both physical and economic terms. Hence, crop water productivity needs to be mapped across different agro climates in the basin.

In this paper, the potential for enhancing water productivity in agriculture and water saving are explored in selected river basins of India through the following measures: 1] water control and optimizing nutrient input to crops; 2] improving the quality and reliability of irrigation; and 3] growing certain crops in regions where the ET requirements are lower and genetic potential of the crop can be realized.

2. REVIEW OF LITERATURE ON WATER PRODUCTIVITY IN IRRIGATED AGRICULTURE

Over the past few years, the concept of productivity of water in agriculture has gained ground owing to increasing scarcity of irrigation water from physical and economic perspectives, mostly locally and often also regionally. Several studies are available from the past which deal with water productivity of crops with respect to evapo-transpiration (ET) of crops (see for instance, Table 1, Kijne *et al*., 2002: pp8 and Zwart and Bastiaanssen, 2004). But, we would discuss only those which are relevant for the present study.

Choudhury and Kumar (1980) and Singh and Malik (1983) showed large differences in water productivity of wheat between wet and dry years. Tuong and Bouman (2002), estimated water productivity of rice in India; found it in the range of 0.50-1.10 Kg./m^3 against 1.4-1.6 Kg./m^3 for wet-seeded rice in the Philippines;

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[1]See Allen *et al.,* (1998) for definitions of consumed fraction (CF), non-recoverable deep percolation, non-beneficial evaporation, consumptive use and ET, and differences thereof.

[2]However, plants have highly developed adaptive mechanisms to compensate for water stress in different growth stages, and the only way to factor these in properly is to use a well calibrated crop growth model, or through the development of crop production functions.

Oweis and Hachum (2002) analyzed water productivity impact of supplementary irrigation on pulses. Study by Saeed and El-Nadi (1998) in Shambat, Sudan, Utao and Idaho on forage crops showed improvement in physical productivity of water with supplementary irrigation. Rockström *et al*., (2002) provided evidence from Kenya and Burkina Faso to the effect that supplementary irrigation enhances water productivity (Kg./m^3) of rain-fed maize and sorghum, respectively, remarkably with greater effect coming with fertilizer management; and from Tanzania to show that conservation tillage increases water productivity of maize.

Ahmad *et al*. (2002) used Soil Water-Atmosphere-Plant (SWAP) model to estimate water flux in the unsaturated soil profile of groundwater irrigated areas of Pakistan Punjab under rice-wheat system and cotton-wheat system. Singh *et al*. (2003) used the same model to estimate the same for Sirsa district of Haryana. Both the studies quantified the moisture changes in unsaturated soil profile during crop seasons. The studies found that the vertical water flux in the unsaturated zone is continuous under rice-wheat system with frequent and intensive irrigation. Though both the studies showed that a significant amount of the water applied is recycled, they also showed significant build up of moisture in the unsaturated zone, which can be lost in soil evaporation.

It is recognized that the ET values themselves could reduce with better irrigation and soil management (Burt *et al*., 2001), and thereby improving the chances of cutting down groundwater depletion. However, the significance of achieving better groundwater balance through irrigation management increases with decreasing efficiency of conveyance of percolating water from the crop root zone to the groundwater system.[3]

Ahmad *et al*., (2004) estimated the spatial and temporal variations in water productivity (physical and economic) separately for process evaporation, soil evaporation and actual ET which were estimated using SWAP model for rice-wheat area in Punjab. They found that the applied water (sum of precipitation and irrigation) far exceeded the evapo-transpired demand (ET) in case of rice causing deep percolation. Whereas, it fell short of the ET requirements in case of wheat since some of the requirements were met by soil moisture depletion. They also found that the process depletion (transpiration) to produce a unit weight of cereal was slightly lower for rice when compared with wheat.

Abdulleev and Molden (2004) examined the issue of spatial and temporal variations in water productivity in Syr Darya Basin in Uzbekistan and analyzed its economic and equity implications for basin water economy. From the spatial analysis of water productivity, it was found that the water productivity for supplied water (WP_{supply}) and potential evapo-transpiration (WP_{pet}) are higher for private farms. Water productivity of supplied water is much lower than that of PET, indicating the scope for limiting water application. There is significant difference in lowest and highest water productivities indicating the scope for increasing average water productivity within the basin.

The temporal analysis of water productivity for paddy and cotton for three years (1999, 2000 and 2001) showed the following: highest water productivity in case of cotton for both applied water and PET was obtained in low rainfall years. It also showed that the difference between WP_{supply} and WP_{pet} was smaller in low rainfall years, owing to the fact that irrigation water dosage was close to crop water requirement. In the case of paddy, the highest water productivity (WP_{supply} and WP_{pet}) was obtained in 2001, which was a normal year and lowest in 1999. Water productivity for paddy was not high during dry years.

Singh (2004) analyzed composite farming system in north Gujarat consisting of crops and dairying and estimated productivity of applied well water in dairy farming. Kumar (2007) analyzed the composite farming system in north Gujarat, to analyze the applied water productivity in dairy production. It also analyzed the extent to which groundwater use in the region can be reduced without compromising on the farm economy and milk production through efficient irrigation water use technologies using a simulation model based on linear programming.

To summarize, past research on water productivity were on analyzing average physical productivity of water for select crops, including variation according to climate. There is limited analysis of marginal water productivity (Kg./ET) in response to supplementary irrigation and change in depleted water. However, the economic dimensions of water productivity were not analyzed. Analyses of incremental changes in water

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[3]The conveyance efficiencies would be low when the unsaturated zone is very deep due to loss of soil moisture through evaporation, and non-recoverable deep percolation.

productivity of crops in economic terms in response to changes in irrigation water dosage, or ET, were not attempted. It is crucial to assess the potential for improving water productivity of a particular crop and deciding on allocation priorities between crops.

3. OBJECTIVES OF THE STUDY

The objective of the study is to explore the scope for water productivity enhancement in irrigated agriculture in India through: i] water control; ii] optimizing nutrient input to crop; iii] improving the quality and reliability of irrigation water; and, iv] growing crops in regions where climate is favourable.

3.1 Hypothesis

1) Better reliability and adequacy of irrigation can improve yield and water productivity of irrigated crops through better agronomic practices and better water management
2) Better control over water and fertilizers can ensure water productivity improvements in irrigated crops, as water application regime might correspond to either ascending or descending water productivity response curve to irrigation and nutrient inputs.

3.2 Approach and Methodology

The potential for improving water productivity through water control and optimum nutrient use is assessed by estimating: 1] the incremental changes in water productivity (for select crops) with increase in irrigation water allocation and fertilizer inputs. The potential for improving water productivity using climate advantage is assessed by mapping the spatial variation in average productivity of crops vis-à-vis agro-climatic regions. The potential for raising water productivity through improvement in quality and reliability of irrigation is analyzed by comparing average water productivity with different sources of irrigation, which represent different degrees of control over water delivery.

The regions of the study basins are shown in Map 1. The approach is that of primary surveys in the study area. Three river basins in India were selected for the study. They are Indus; Narmada; and Sabarmati.

The study analyzed water productivity variations across: 1] farms growing the same type of crops with same pattern of irrigation; and 2] irrigation sources (wells, canals and conjunctive use); and 3] agro-climates within the same basin. It involved collection of data on parameters governing water productivity in crop production such as cropping system, cropped area, crop inputs (bio and chemical fertilizers, farm labour, irrigation water use, irrigation schedules, and crop technology), crop outputs (main product, by product, market price of crops), and method of irrigation. For each irrigated crops, the sample size is 30-35 for each agro-climate within a river basin. In addition, there were samples for each type of irrigation source. Hence, the maximum sample size was 90 in one location; but limited to only situations where sufficient samples for different modes of irrigation were available. The detailed sampling design is given in Table 1.

Table 1: Sampling Design for Water Productivity Study

Name of the Basin	No. of Locations	No. of Agro climates	No. of Different sources of Irrigation	Total Sample Size
Indus basin	3	3	3 (wells; conjunctive use; canals)	200
Narmada	9	7	1 (wells only)	450
Sabarmati	6	3	1 (wells only)	180

3.2.1 Data and Sources

Data used for water productivity analysis are primary data from farmers. Data collection was done using a structured questionnaire from locations in all the four basins, viz., Indus, Narmada and Sabarmati. From the Indus, only one location was covered; from Narmada, nine locations, each representing one agro-climatic condition, was covered. From Sabarmati, four locations, each representing one agro-climate, were selected. The data collected from farmers included: data on crop inputs comprising cost of seeds, labour, fertilizer and pesticides, quantum of irrigation water, and quantity (weight in Kg.) and market price (Rs./Kg.) of main and byproduct of the crop output. In addition, discharge of irrigation wells (litre/sec) was measured using a bucket and stop watch to quantify the volume of water pumped, for which data on number and hours of irrigation for each crop and for each season were obtained from the farmers.

3.2.2 Analytical Procedure

The physical water productivity $\sigma_{irri,i}$ (Kg./m^3) and water productivity in economic terms, $\theta_{irri,i}$ (Rs./m^3) in a purely irrigated crop i are estimated as:

$$\sigma_{irri,i} = \frac{\nabla_{irri,i}}{1000\Delta_{irri,i}} \; ; \; \theta_{irri,i} = \frac{NR_{irri,i}}{1000\Delta_{irri,i}} \text{ .... 1, 2}$$

$\Delta_{irri,i}$, and $\nabla_{irri,i}$ are the irrigation water dosage (mm) and yield (Kg./ha.) for purely irrigated crop, respectively in mm. $NR_{irri,i}$ is the net return per unit area of the crop (Rs./ha.). All winter crops selected for the study are treated as purely irrigated crops, and the green water use for these crops was ignored. The reason is that their yields under un-irrigated condition as well as residual soil moisture before sowing are negligible. All crops covering two seasons, viz., kharif and winter, having no rain-fed yields were also treated as irrigated crops. Winter wheat in Narmada basin, cotton in west Nimar in Narmada basin, winter wheat in UP, Punjab, and all crops selected from Sabarmati basin (namely, wheat, castor, bajra and cotton) were treated as irrigated crops, and therefore the water productivity values estimated for them are irrigation water productivity.[4]

Marginal physical productivity of water, $\sigma_{comb-irri,j}$ (Kg./m3), and marginal water productivity in economic terms $\theta_{comb-irri,j}$ (Rs./m^3) for crops, which receive supplementary irrigation, and have rain-fed yields, with respect to irrigation, are estimated as:

$$\sigma_{comb-irri,j} = \frac{\nabla_{comb-irri,j}}{1000\Delta_{comb,j}} \; ; \; \theta_{comb-irri,j} = \frac{NR_{comb-irri,j}}{1000\Delta_{comb,j}} \text{ .... 3, 4}$$

Where, $\nabla_{comb-irri,j}$ is the yield corresponding to irrigation water applied (Kg.) and $\Delta_{comb,j}$ is the irrigation water applied for the crop j (mm). $NR_{comb-irri,j}$ is the net return per unit area corresponding to the irrigation water applied for the same crop (Rs./ha). $\sigma_{comb-irri,j}$ and $\theta_{comb-irri,j}$ were obtained by running a regression of yield and net returns from the crop against irrigation water applied for each crop, respectively. The regression coefficients give the marginal physical productivity of water and water productivity in economic terms, respectively, of irrigation for these crops. This gives the mean value of marginal water productivity for all

[4]In areas with moderate rainfall like eastern UP, this must have resulted in over-estimation of irrigation water productivity.

the farmers growing that crop. One major assumption involved in this analysis is that the water application is still in the scarcity regime, meaning the total consumptive use may fall short of or just meet the evapo-transpirative demands. Therefore, the response curve of yield and net return to irrigation water use were treated as linear. This no way means that the volumetric water applied (effective rainfall and irrigation) is below ET demand, as farmers can provide excessive irrigation in certain periods of the crop season, resulting in losses.

The marginal water productivity of irrigation water for individual farmers were estimated by subtracting the "a" coefficient , i.e., Y intercept, of the regression equation for yield and net return, respectively, from their corresponding crop yield and net returns, and dividing by the volume of irrigation water applied. Paddy from Jabalpur and Mandla in Narmada river basin were considered for this methodology, as it had rain-fed yield in many locations.

4. SCOPE FOR ENHANCING IRRIGATION WATER PRODUCTIVITY IN AGRICULTURE

4.1 Using water control for improving irrigation water productivity

In order to assess the potential of "water control" in improving crop water productivity, the incremental changes in crop yield and crop water productivity with respect to irrigation were analyzed. For this, the data collected from four agro-climatic regions in Narmada river basin were analyzed. The analysis included the following: 1] the crop yield response to irrigation water applied; 2] the water productivity (Rs./m^3 of water applied) response to irrigation; and, 3] the yield response to fertilizer use.

In the case of Hoshangabad district, data of applied water, fertilizer dosage, crop yield, and water productivity in economic terms (estimated) were available for two consecutive years, viz., 2002 and 2003. The regression analysis showed that the relationship between dosage of irrigation water and yield for winter wheat of 2002 is linear. The R square value here is only 0.14, and hence the relationship is not strong. As shown in Figure 1, wheat yield responded to increase in dosage of irrigation water. However, for the same level of irrigation, the yield differences across farmers are quite substantial. This can perhaps be explained by the difference in fertilizer use by these farmers, differences in soil quality, changes in date of sowing, and differences in crop variety.

Figure 1: Yield vs. Irrigation Dosage in Wheat (Hoshangabad 2002)

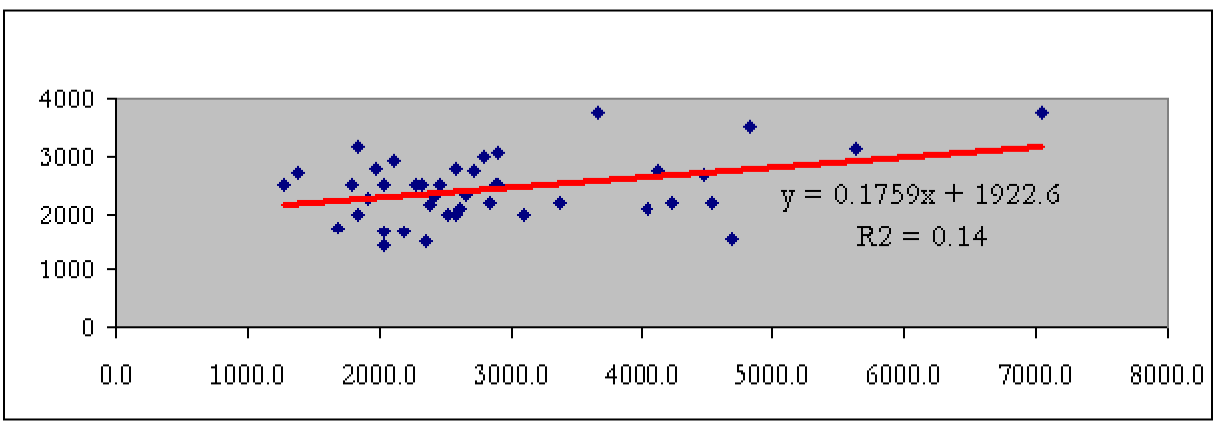
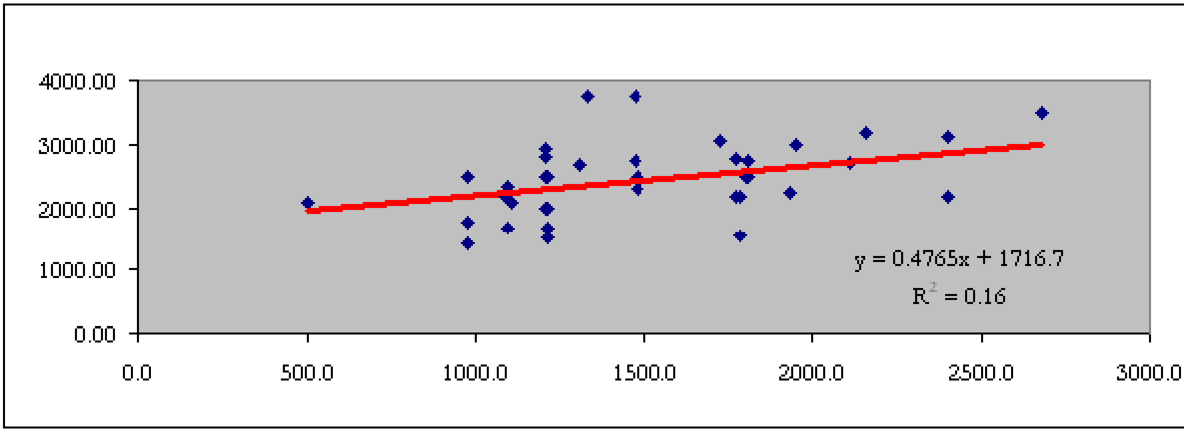


Figure 2 shows the graphical representation of the variation in yield with differential levels of fertilizer input. It shows a slightly stronger relationship between fertilizer use and crop yield (R^2=0.16). Higher dosage of fertilizer meant higher wheat yield. This does not mean that it is the higher fertilizer dosage, which caused higher yield. Generally, it is the farmers who have good irrigation facilities and who use higher quantum of irrigation water use proportionally higher dose of fertilizers. Due to this co-linearity between irrigation and fertilizer dosage, the increase in yield cannot be attributed to higher dosage of fertilizers. Hence, in order to segregate the effect of fertilizer dose on crop yield, a more thorough examination of data was carried out.

Figure 2: Yield vs. Fertilizer Dosage (Hoshangabad 2002)



It was found that two farmers applying the same dosage of irrigation (1834 mm) applied different quantities of fertilizers (worth Rs.1213/ha and Rs. 2160/ha, respectively) and got different levels of yield (19.8 quintal/ha and 31.7 quintal/ha, respectively). In another case, two farmers applied same dosage of irrigation (2035mm), but applied fertilizers in varying doses (worth Rs. 975/ha and Rs. 1205/ha respectively), and got different yields (1480 Kg./ha and 2500 Kg./ha respectively).

Figure 3: Water Productivity vs. Irrigation Dosage in Wheat (Hoshangabad 2002)

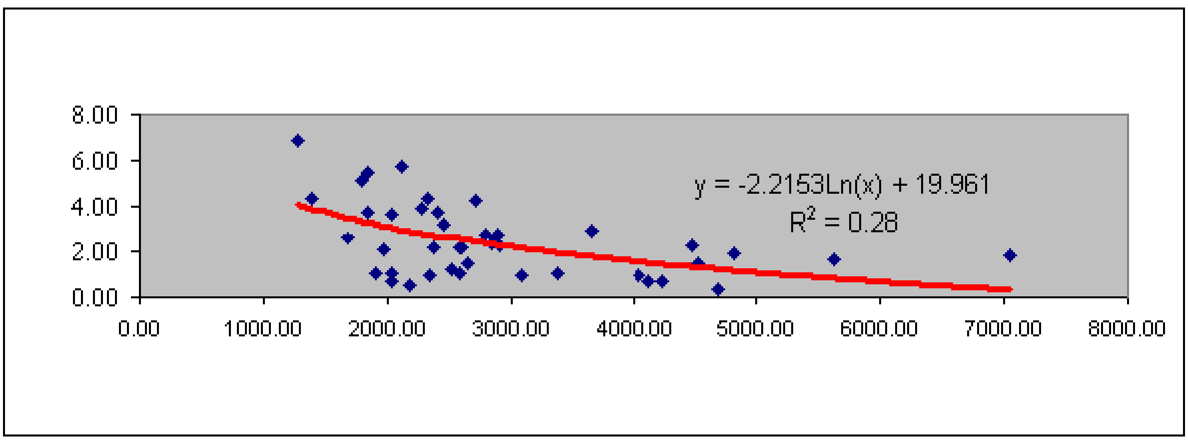
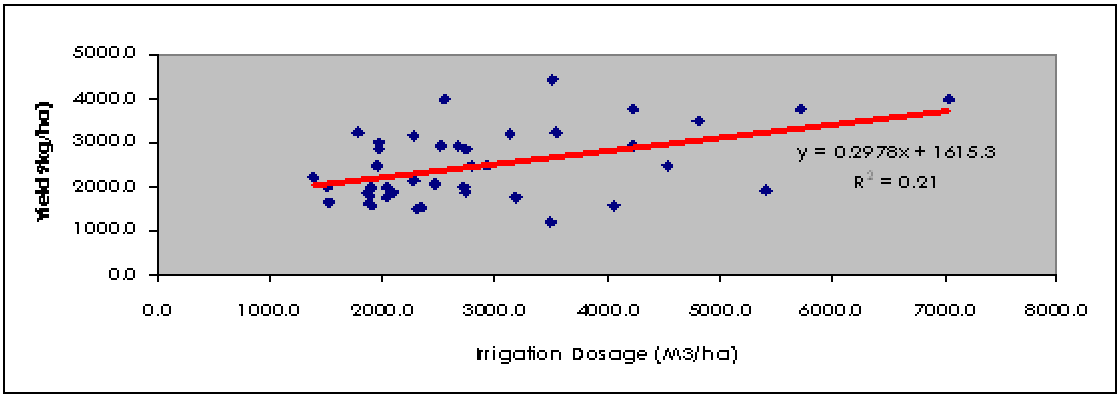


Figure 1 also meant that many of the farmers are applying scarcity irrigation and could have actually got higher yield had they applied higher dozes of irrigation with proportional increase in fertilizer inputs. However, the amount of water applied to the soil also influences the nutrient absorption capacity of the plants, and therefore, irrigation water shortage might be limiting farmers' ability to apply adequate quantities of fertilizers. Mostly, the maximum yield corresponded to maximum irrigation.

The graphical representation of water productivity response to irrigation is given in Figure 3. The relationship is inverse and exponential. Higher dosage of water applied meant lower water productivity (R^2= 0.28). Generally, those who applied higher dosage of water had lower levels of water productivity, while many farmers who applied lower dosage of irrigation (200 to 225 mm of irrigation) got high water productivity. At the same time, many farmers who maintained similar dosage of irrigation got much lower water productivity (Rs./m^3). This could be due to the lower levels of fertilizer inputs, which reduced the crop yields. The lower water productivity at high dosage of irrigation could be due to lack of proportional increase in yield, increase in cost of fertilizers which reduces the net returns, and increase in volume of water applied, which increases the value of denominator.

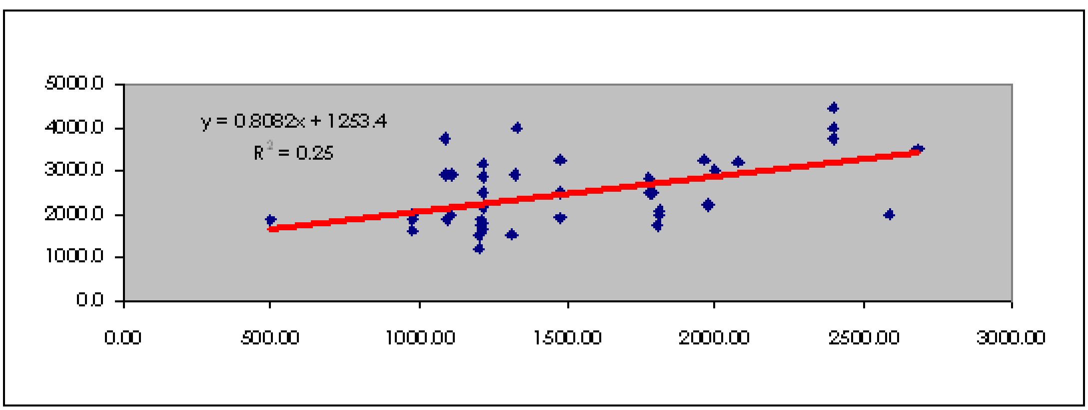
The analysis was repeated for the 2003. It showed a stronger positive linear relationship between applied water and crop yield in wheat (R^2=0.21). Higher levels of water dosage generally ensured higher yield (Figure 4). The incremental yield due to increase in dosage of irrigation by 100 mm was around 230 Kg./ha. Again, there were significant yield differences between farmers who applied more or less same amount of water. This could be explained by the factors mentioned above. Nevertheless, slightly improved relationship better fertilizer and irrigation dosage (with an R^2 value of 0.25) confirms to this (Figure 5).

Figure 4: Yield vs. Irrigation in Wheat (Hoshangabad-2003)



Now, the regression values for the response of yield to irrigation dosage being very small (Figure 1 and Figure 4). So, one could argue that many factors other than irrigation explain yield variations. But, given that the data presented here are for different farmers, who represent different soil conditions, different planting dates and different seed varieties, all of which have a potential to influence the crop yield, the relationship and regression coefficient is significant5 . Also, the slope of yield curve is very mild in the case of Figure 3, which is quite contrary to what can normally be found given the wide range in irrigation water dosage among the sample farmers.

Figure 5: Yield vs. Fertilizer Dosage in Wheat (Hoshangabad-2003)

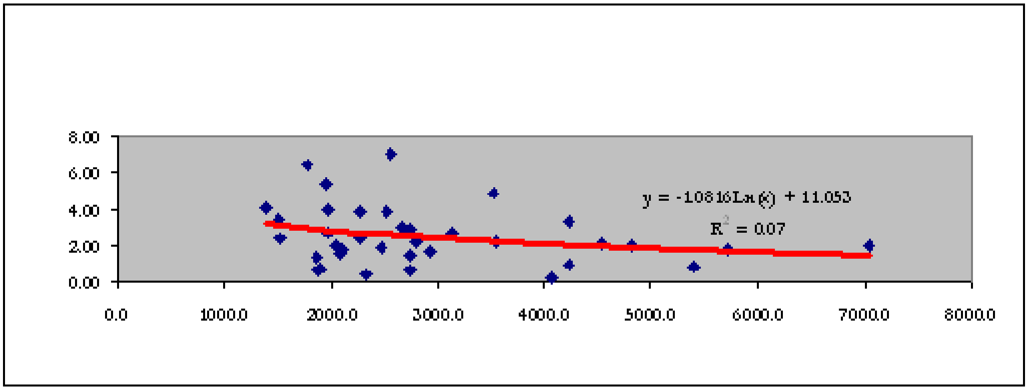


The regression between water dosage and water productivity (Rs./m^3) showed a poor inverse relationship between the two unlike what was found for 2002 (Figure 6). This could be due to the reasons explained above for the same crop grown during 2002. Some of the farmers who were in the lower range of irrigation dosage (between 200 mm and 300 mm) got very low water productivity values (between Rs. 0.41/m^3 and Rs. 1.38/m^3), while some other farmers got values of approximately Rs. 7/m^3 of water. This could be due to the wide differences in fertilizer dosage, which resulted in differential yields. The strong linear relationship between fertilizer dosage and crop yield (R^2=0.25) are shown by Figure 5.

[5]With changing soils, the nutrient levels could change. With changing planting dates, the soil moisture availability could change; so the crop water requirement and yield potential. Yield potential could also change with seed variety.

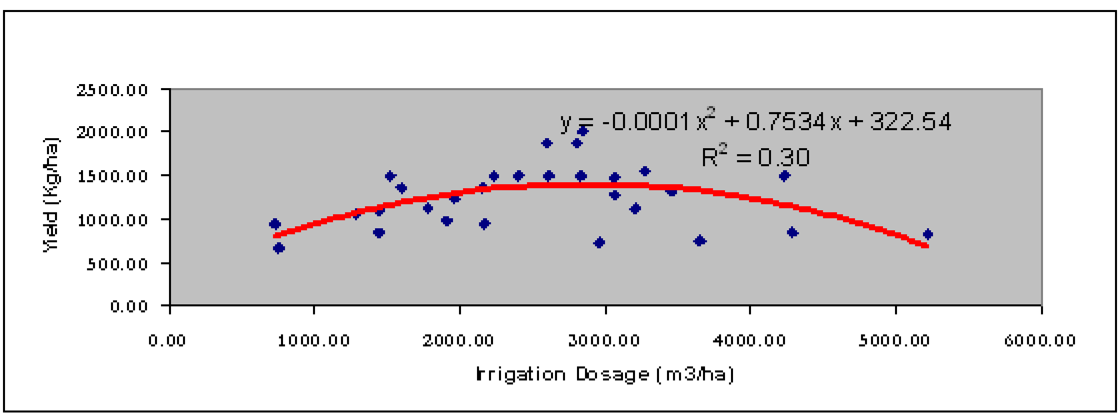
A closer look at the chart showing relationship between irrigation dosage and crop yield also provide better clues to this effect. There are many examples of farmers applying similar dosage of irrigation, but different dosage of fertilizers and getting different levels of yield. For instance, two farmers who applied irrigation dosages of 2518 and 2557 m^3 of water to their wheat, applied different levels of fertilizers (worth Rs.1112/ha and Rs. 2400/ha) and in turn got yields of 2910 Kg/ha and 4000 Kg/ha, respectively.

Figure 6: Water Productivity vs. Irrigation Dosage in Wheat (Hoshanganad-2003)



The analysis was repeated for west Nimar in Narmada basin, for cotton for 2003. After the rainy season, the crop is normally irrigated. The yield response to irrigation was polynomial (Figure 7), with yield increasing up to a point (from 100mm to 300mm), and then declining. Many farmers who applied close to 300 mm got highest yields. Beyond 300mm, the yield started declining. The curve showing the water productivity (Rs./m^3) response of irrigation dosage (Figure 8) is again "polynomial". With increase in dosage of irrigation, while the yield increased, the water productivity did not get affected much. But, beyond the point of optimum yield, increase in irrigation dosage led to declining water productivity. This is the third set of response curves (Figure 7).

Figure 7: Yield vs. Irrigation Water Dosage in Cotton (West Nimar 2003)

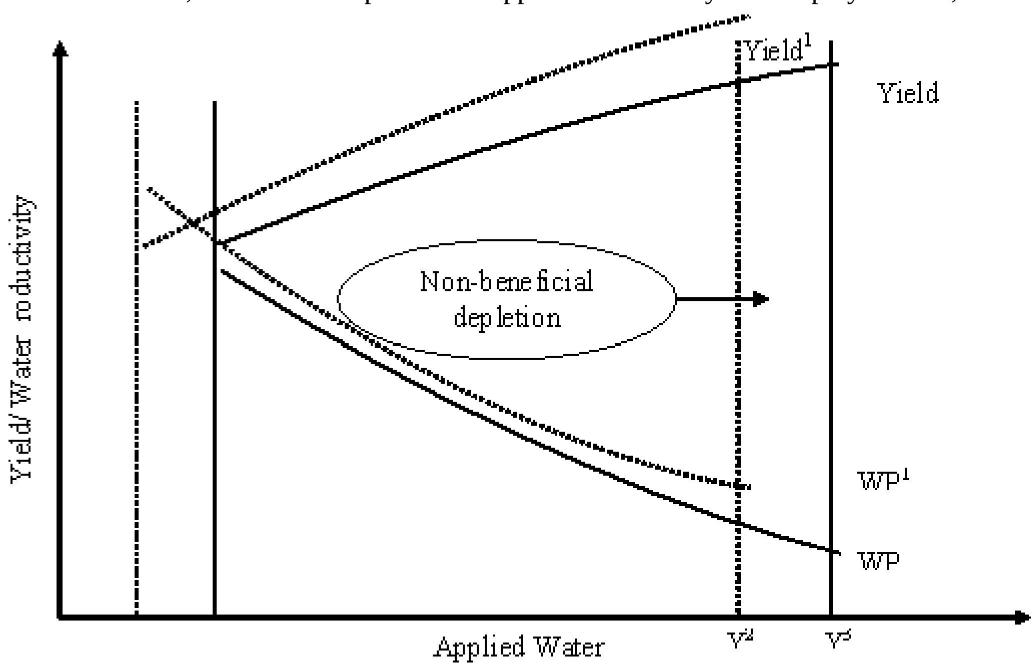


The foregoing analyses show that water productivity can be manipulated through water control. It is based on the premise that in many situations farmers do not have control over water delivery and fertilizer dosage, or are tempted to apply more water to maximize yields and returns per unit of land. In the process, they are not able to get the optimum yield that gives highest water productivity.[6] To what extent "water control" would help enhance water productivity depends on that point of yield and water productivity response curve to which, the irrigation dosage corresponds. It would also depend on what fraction of the applied water from the crop is used for non-beneficial evaporation. We do not have any information about non-beneficial depletion from applied water. Some of the sources are: a] the deep percolation, which is lost in the vadose zone;[7] b] the evaporation of soil moisture after crop harvest during the fallow period; c) direct evaporation from the soil surface, especially during crop establishment and d) possibly un-necessary watering at the end of the season when it does not contribute to yield.

There are three different types of responses of yield and water productivity to irrigation dosage. In the first situation: a] the relationship between applied water and yield is positive, but weak; and b] the response of WP to applied water is inverse and exponential. In such situations, the reduction in dosage of irrigation water would not affect the yield significantly; and often the effect may not even be adverse. The same would significantly enhance WP. However, this strategy would work only if there is sufficient arable land, which remains uncultivated due to shortage of water. The reason is that farmers would like to expand area under irrigation and use the water saved from field to irrigate additional land to maintain income returns.

The second situation is one in which the relationship between applied water and yield is strong and positive, where in most farmers are applying water under scarcity regime and very few under water abundance regime (Figure 4, 5 and 6). It is likely that with increase in dosage of irrigation, the physical productivity of water also might increase slightly. However, the response of water productivity in economic terms (Rs./m^3) to applied water is “inverse-logarithmic”. Here, the best strategy for most of the farmers would be to minimize the irrigation dosage, which would help obtain highest water productivity in economic terms. Here, it may be necessary for the farmers to expand the area under irrigation slightly to maintain the net returns.

Figure 9: Potential Changes in Crop Yield and Water Productivity under Micro Irrigation



In the third situation, the relationship between applied water and yield is “polynomial”, where yield increases with irrigation dosage up to a certain point, and then declines (Figure 7). In such a case, with increasing dosage of water, water productivity declines abruptly beyond the point, which corresponds to the maximum yield. Hence, the relationship between applied water and water productivity in economic terms is “polynomial” (Figure 8). This is the ideal situation where farmers who are losing on the yield and income returns have an incentive to reduce irrigation dosage. By doing this, they enhance both yield and water productivity. The reason

[6]Water productivity is not an objective for farmers to realize when water is in plenty. On the contrary, they would try and maximize the income returns per unit of land, for which crop yield (Kg./ha) enhancement is the best route.

[7] Water “lost in the vadose zone” normally becomes non beneficial E or ET as bare soil evaporation or transpiration through other (non-productive) vegetation.

for over irrigation of crop beyond the point of maximum return is zero marginal cost of electricity used for groundwater pumping owing to flat rate system of electricity pricing in the regions under study. In such situations, it is not even necessary that farmers expand the area under irrigation to maximize their aggregate returns from farming. There are many farmers, who are not getting optimum yield and water productivity due to inadequate irrigation dosage. It is important for them to reduce the area under irrigation while increasing irrigation dosage to save water8 .

Now, let us look at the option of micro-irrigation. For a given amount of nutrient inputs, the only determinant of crop yield is ET and how far the transpirative requirements of the crop area met during critical stages of crop growth. Under micro irrigation, non-recoverable deep percolation is negligible. Further, the non-beneficial evaporation of applied water can be reduced to nil, particularly for row crops. Such non-beneficial depletion, which is the difference between CF and crop ET (Allen *et al*., 1998), would be much less as compared to traditional method of irrigation, more so for row crops. It is possible to achieve the twin-objectives of higher water productivity and higher yield through micro-irrigation. The theoretical response curve of yield (Kg./ha) and water productivity in economic terms (Rs./m^3) to irrigation dosage under traditional irrigation and micro irrigation is given in Figure 9. It shows that the yield corresponding to the same amount of "applied water" would be higher under micro irrigation. Research in many parts of India had already shown that for cash crops, particularly those grown in rows such as cotton, the net incremental returns for drip irrigation plots over flood irrigated plots are higher than the sum of capital and operational costs of drip systems (Narayanamoorthy, 2004).[9] This means that even in situations where the entire land is irrigated, farmers might have incentive to go for micro irrigation for such crops. The water productivity gain automatically comes under such situations.

4.2 Improving irrigation water productivity through optimizing input use

In order to assess the potential of "optimum nutrient dosage" in improving crop water productivity, the incremental changes in crop yield and crop water productivity with respect to fertilizer dosage were analyzed. For this, the data collected from four agro-climatic regions in Narmada river basin were analyzed. The analysis included the following: 1] the yield response to fertilizer application; and 2] the water productivity response to fertilizer application.

As regards yield response to fertilizer inputs, in the case of wheat in Hoshangabad, it was found that response is extremely weak for the drought year (2002) as shown in Figure 2 (R^2=0.16). At the same time, the response was reasonably good for the normal year 2003 (R^2 =0.25) as shown in Figure 5. Water productivity was also higher for farmers who applied higher dosage of fertilizers (R^2=0.27) in 2003, though such trends were not seen for 2002 which was a drought year. Figure 10 shows the response curve of water productivity to fertilizer input across the farmers. Such a response does indicates that farmers are optimally using fertilizers and irrigation water to enhance the returns.

In case of cotton crops in West Nimar, water productivity response curve for fertilizer dosage was "polynomial" for 2002 (drought year) with productivity (Rs./m^3) increasing from the lowest values at low levels of fertilizer use towards the middle range, and then declining (R^2= 0.11). Such a response curve can be explained this way. Very high doses of fertilizers is generally accompanied by increased dose of irrigation water. Higher dosage of irrigation water could also increase the chances of fertilizer leaching, reducing the nutrient intake by the plants and flattening the response curve of yield. At the same time, the yield gains obtained due to the same were not significant to offset the effect of increased cost of inputs, and increase in the volume of water applied. This is quite natural as the farmers are interested in maximizing the returns pet unit of land, and not water.

Figure 8: Water Productivity vs. Irrigation Water Dosage in Cotton in West Nimar- 2003

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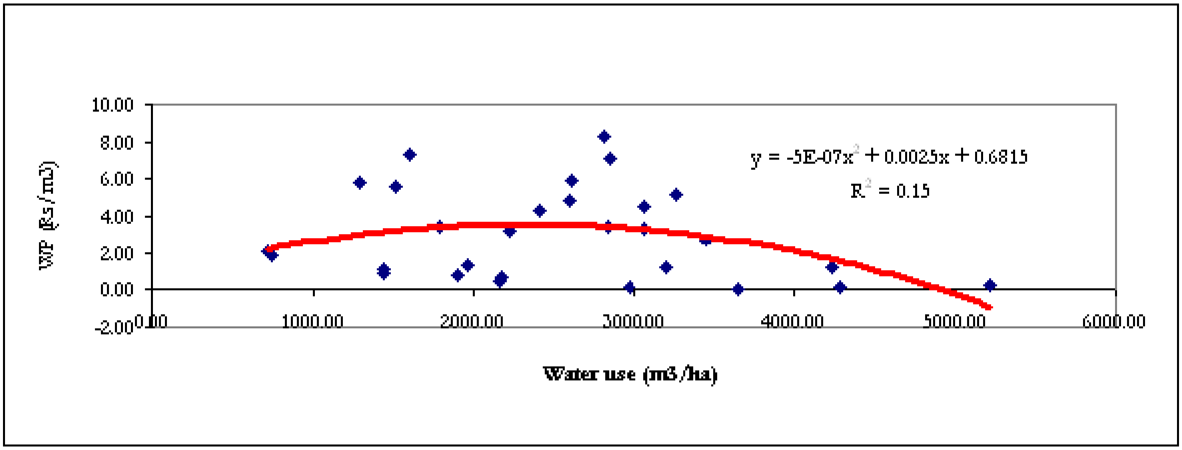
[9]Such crops include banana, sugarcane, orange, grapes and cotton.

[9]But, cases where farmers are not able to secure optimum levels of water productivity due to water shortages are rare. Well owners have reasonably high degree of control over water delivery. Power supply is the only factor that reduces their water control. In states such as Punjab, Gujarat and Madhya Pradesh, quality of farm power is poor. The supply is provided in rotations, including during night. This might affect the dosage of water farmers could give to crops in hard rock areas with limited groundwater.

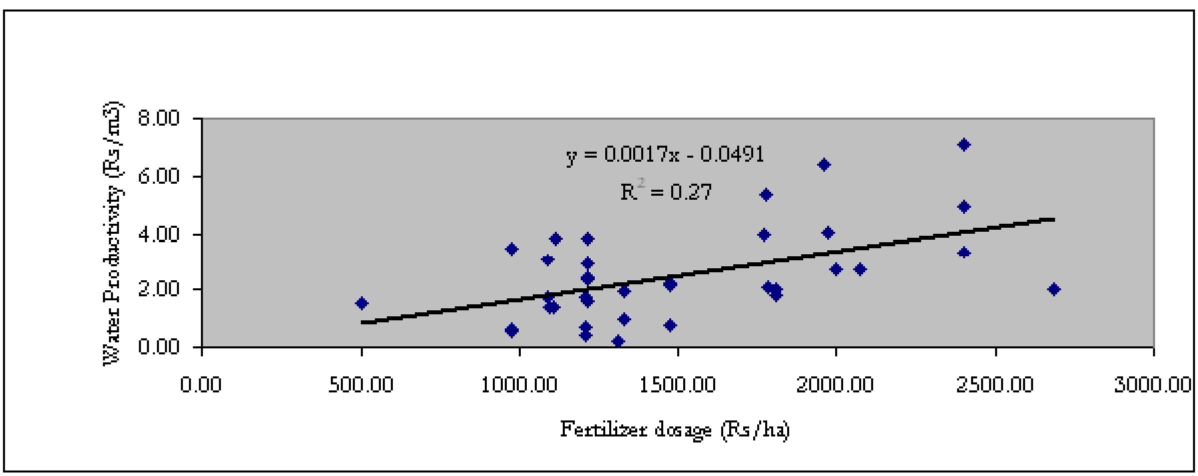
For a "linear response curve" of yield to fertilizer dosage, the response curve for water productivity



(Rs./m^3) may not be inverse exponential or inverse logarithmic; but "direct and linear" as shown in the case of wheat in Hoshangabad for 2003 (Figure 10). Inverse relationships can occur only if the fertilizer dosage is accompanied by increased dosage of irrigation. With increase in fertilizer dosage, the water productivity could actually rise, and then decline. This is because it would be possible to increase yields with increase in fertilizer dosage, without much change in irrigation dosage up to certain point. Beyond this point, increased use of fertilizer dosage would require greater dosage of irrigation for increasing the nutrient absorption capacity of the plants. This may not result in increase in ET, thereby showing no effect on crop yield. However, this would reduce water productivity as the total depletion or CF would increase. Here adjusting the fertilizer dosage to optimal levels is crucial.

Figure 10: Water Productivity vs. Fertilizer Dosage in Wheat (Hoshangabad 2003)

For the same dosage of irrigation water, crop yield can be enhanced to an extent with optimal dosage of



fertilizers. This means that the physical productivity (Kg/m^3) of water, apart from returns from land, can be enhanced through manipulation of fertilizer use.[10] This might increase water productivity in economic terms as well (as seen in the earlier section). Such situation may be encountered in central India (covering most parts of Narmada, Tapi, Mahi and Krishna basins), where fertilizer use in agriculture is one of the lowest. If fertilizer dosage does not increase the yield, then simple reduction in dosage would result in saving of input costs, thereby

[10]Primary data collected from farmers in Narmada basin show that with increase in irrigation dosage, there is proportional increase in the dosage of fertilizers in most situations. Hence, the effect of fertilizer on crop yield and water productivity cannot be assessed through multiple regression model estimation procedures.

increasing water productivity in rupee terms. Such situations are possible in Punjab and Haryana where application of nitrogenous fertilizer is excessively high.

4.3 Improving water productivity through improving quality & reliability of irrigation water

There is not much empirical evidence to suggest that greater reliability and quality of irrigation leads to greater water productivity.

Analysis from groundwater irrigated areas of north Gujarat showed that the gross returns per cubic metre of applied water was higher for shareholders of tube well companies, when compared to farmers who were buying water from well owners. The gross water productivity was Rs. 5.61/m^3 for tube well owners against Rs. 4.61/m^3 for water buyers. The gross returns only indicate the physical efficiency of water use. It does not take into account the input costs, and only converts the main product and byproduct into cash equivalents. In the case of shareholders, the entitlement of water is fixed in volumetric terms, and water supply is highly reliable. In case of water buyers, the well owner supplies enough water to make sure that the cultivator gets sufficient yield as his irrigation charge is paid in proportion to the total crop yield.

The difference between the two cases is in terms of water allocation norms and reliability of water supply. In the case of shareholders, supply is rationed and known to the farmers much in advance of the season. Hence, they are able to do proper water budgeting and apply optimum dosage of fertilizers. Whereas the farmers who purchase water on hourly basis are at the mercy of the well owners. They do not try to optimize fertilizer dosage or go for the best quality seeds, as they are not sure of getting adequate water supplies. This reinforces the fact that net return from crop production is less elastic to the cost of irrigation than the reliability of irrigation.

Yields in two major crops, viz., wheat and paddy in three different types of irrigation systems, which represent three different degrees of water control, in two different regions of Bist Doab area in Punjab, were compared to understand the impact of differential quality of irrigation water. The three systems selected are canal irrigation, well irrigation and conjunctive use. The underlying premise was that canal irrigators will not be able to apply water at critical stages in right quantities, whereas well irrigators would be able to apply water to their crops as and when they require, subject to the availability of electricity. As farmers using both canal water and well water should have a higher degree of control over water application compared to canal irrigators, the “overall quality of irrigation” would depend on what proportion of the total demand is met from canals, and what proportion from groundwater.

Analysis involved comparing water productivity in wheat under different sources of irrigation in two distinct agro-ecological regions. Adequate numbers of irrigators for each of the three sources of irrigation were not available from the same agro-ecological region. The first is lower Bist Doab area, with low rainfall and semi arid climate; and the second the sub-mountainous region with medium to high rainfall with sub-humid climate. Comparison of yield with different sources of irrigation was made between conjunctive use and canal water (in sub-mountainous region). The analysis showed that yield figures are lowest for farmers using only canal water for both paddy and wheat; second lowest for farmers using both canal water and groundwater (Table 2). The farmers using well water (in Jalandhar and Kapurthala) got the highest yield. The yield differences between categories within the region and across regions are substantial. While agro-ecology would be an important factor affecting the crop yields, such large differences in yield could only be explained by the quality and reliability of irrigation water.

The foregoing analyses clearly show that improvement in quality and reliability of irrigation would impact yield significantly. Here, quality of irrigation includes adequacy and reliability. With greater reliability and adequacy of irrigation, farmers would be able to adopt good agronomic practices and adjust nutrient use. Enhanced quality and reliability of irrigation would also help farmers optimize the irrigation dosages in each watering and give adequate number of watering including watering at critical stages of plant growth. This would not only increase the yield, but also reduce non-beneficial depletion.

Table 2: Differential Land Productivity with varying quality of irrigation in Punjab

Name of Region	Name of District of Irrigation	Predominant Source Crop Yield (ton/ha)	Paddy	Wheat
Lower Bist Doab	Jalandhar	Well Water	6.26	4.68
			5.20	4.40
	Kapurthala	Well Water	5.98	4.73
			5.52	5.30
Sub Mountainous	Hoshiarpur	Conjunctive Use	4.46	3.82
			4.65	3.79
		Canal Water	2.77	3.52
			3.47	2.80

Source: Authors' own analysis using primary data

Whereas with uncertainty in irrigation schedules and water delivery, as found in the case of canal irrigation, farmers hesitate to apply adequate quantities of fertilizers, thereby losing yield. In many cases, the depth of each application is much higher than the optimum dosage determined by the capacity of the field with uncertainty of water supply as compared to assured water supply (well water). This leads to heavy percolation losses and excessive residual moisture after harvest. These cause increase in non-beneficial depletion over crop ET. Greater irrigation dosages may also increase fertilizer leaching, reducing nutrient use efficiency.

4.4 Enhancing irrigation water productivity using climatic advantages

The spatial analysis of water productivity is an important aspect of the strategy to enhance water productivity at the agro-climatic level (Kijne *et al*., 2002: page 13), as productivity of applied water is a function of agro-climate (Abdulleev and Molden, 2004). Spatial analysis of water productivity of selected crops was carried out for nine districts falling in seven agro-climatic regions in Narmada basin, and three agro climatic regions in Sabarmati river basin (Table 3 and Table 4). Theoretically, climate can influence both physical productivity of water and water productivity in economic terms. The climate determines the actual consumptive water requirements and potential crop yields, and the availability of soil moisture from precipitation. In regions, with favourable climatic conditions, the biomass output per unit of water evapo-transpired would be higher. Here, we have compared water productivity of wheat and paddy, which are two significant crops.

The physical productivity of applied water for grain production during the normal year was estimated to be highest for Northern hill region of Chhattisgarh in Mandla district (1.80 Kg./m^3) although Raisen falls in the traditional wheat-growing belt; it was lowest for Jabalpur in Central Narmada Valley (0.47 Kg./m^3). This is mainly due to the major difference in irrigation water applied, 127 mm in Mandla against 640 mm in Jabalpur. This is a significant difference, with the highest being 250% more than the lowest. The difference in irrigation can be attributed to the difference in climate between Jabalpur (dry semi-humid) and Mandla (moist sub-humid), which changes the crop water demand. It can also be noted that the physical productivity in normal year is second highest in Raisen (1.01 Kg./m^3). Higher biomass output per unit volume of water (physical productivity) should also result in higher economic output especially when the difference is mainly due to climatic factors, which changes the ET requirements, unless the factors which determine the cost of inputs significantly differ. In our case, it was found that the net economic return per cubic metre of water was highest for the same region for which physical productivity was higher (Rs. 4.09/m^3). The same was lowest for Narsingpur (Rs. 0.86/m^3), which had the second lowest physical productivity.

The difference between gross and net water productivity (furnished in Table 3) is that in the first one, the total economic value of outputs from unit area of outputs is only considered in the numerator, whereas in the second case, the net income from crop production after deducting the cost of inputs per unit area is considered.

Table 3: Region-wise Irrigation Water Productivity (Wheat) and Marginal Productivity of Irrigation Water (Paddy) in Narmada River Basin for Selected Crops

	Name of the Region	Name of the District	2002-03 (Drought Year)				2003-04 (Normal Year)			
			Physical Productivity (Kg./m^3)		Water Productivity in Economic Terms (Rs./m^3)		Physical Productivity (Kg./m^3)		Water Productivity inEconomic Terms(Rs./m^3)	
			Main Product	By-Product	Gross	Net	Main Product	By-Product	Gross	Net
			Wheat							
1.	Central Narmada Valley	Hoshangabad	0.81	0.81	5.74	2.09	0.91	0.90	6.25	2.31
		Jabalpur	0.44	0.43	3.08	0.89	0.47	0.46	3.42	1.06
		Narsingpur	0.53	0.49	3.84	1.11	0.49	0.47	3.47	0.86
2.	Jhabua Hills	Jhabua	0.73	0.65	5.32	1.38	0.60	0.55	4.69	1.20
3.	Satpura Plateau	Betul	0.72	073	5.34	2.14	0.84	0.82	6.05	2.61
4.	Malwal Plateau	Dhar	1.07	1.02	8.05	2.46	1.05	1.05	7.67	2.04
5.	Nimar Plain	West Nimar	0.85	0.83	6.65	2.38	0.83	0.83	6.20	1.99
6.	NHRC	Mandla	0.92	0.88	6.62	1.44	1.80	1.78	12.75	4.09
7.	Vindhya Plateau	Raisen	0.77	0.77	5.33	2.00	1.01	1.01	6.82	2.77
			Paddy							
1.	Central Narmada Valley	Jabalpur	1.08	0.79	5.86	1.99	1.62	1.15	9.36	3.95
2.	NHRC	Mandla	1.74	1.26	11.69	2.12	2.13	1.59	12.50	1.43

NHRC: Northern Hill Region of Chhattisgarh
Source: authors' own analysis based on primary data

There are only two regions in Narmada basin, which irrigate paddy. The physical productivity for grain during the normal year was higher for Northern hill region of Chhattisgarh in Mandla district (2.13 Kg./m^3) while it was only 1.62 Kg./m^3 in Jabalpur district of Central Narmada Valley. Likewise, water productivity in economic terms was higher for Northern hill region of Chhattisgarh (Rs.3.95/m^3) against Rs. 1.43/m^3 for Jabalpur, in Central Narmada Valley. Similar figures were found for the drought year (2002) in which the physical productivity of applied water was 1.74 Kg./m^3 in Mandla against 1.08 Kg./m3 in Jabalpur.

Similar patterns of variation in water productivity across agro-climates were found in Sabarmati rive basin also. The physical productivity of water for wheat ranged from 0.71 Kg./m^3 in Daskroi to 2.75 Kg./m^3 in Bayad. The water productivity in economic terms (gross) ranged from Rs. 4.66/m^3 in Daskroi to Rs. 18.39/m^3 in Bayad, and the net water productivity from Rs. 1.38/m^3 to Rs.4.66/m^3. Similar variations in physical productivity of water were found for castor oil between Himmatnagar and Kapadwanj. The physical productivity of water ranged from 0.66 Kg./m^3 to 1.62 Kg./m^3. The gross economic water productivity ranged from Rs. 9.69/m^3 in Himmatnagar to Rs. 25.57/m^3 for Bayad. The net economic water productivity ranged from Rs. 3.56/m^3 in Himmatnagar to Rs. 16.4/m^3 for Bayad. Interestingly, unlike in the case of wheat, the locations which gave highest economic water productivity did not coincide with that of highest physical productivity of water in case of castor oil.

Synthesis of results on crop water productivity in Narmada basin and Sabarmati basin show that the variation in water productivity of irrigated crops across regions is mainly due to variation in agro-climate, which reduces the crop water requirement. The northern hill region of Chhattisgarh has moist sub-humid to dry-sub-humid climate. The four regions, viz., Kymore plateau and Satpura hills, Vindhya plateau, Satpura plateau and Central Narmada Valley (CNV) have "dry sub-humid" climate. The regions, viz., Malwal plateau, and Nimar plain have semi arid climatic conditions. The district of Jhabua, which falls in the region, named "Jhabua hills", is "semi arid".[11] The question therefore is: whether the natural advantage, which certain crops enjoy in certain regions in terms of higher water productivity by virtue of the agro-climate can be made use of, without compromising on farmers' need and priorities. This means, earmarking certain crops only in those regions where they have relative advantage of high water productivity-both physical and combined (physical and economic).

5. POTENTIAL FOR IMPROVING IRRIGATION WATER PRODUCTIVITY IN INDIA

5.1 Crops and areas for increasing Irrigated water productivity

Regions which receive intensive canal irrigation are regions that should get priority in water productivity improvements because: 1] the water-intensive crops are grown in these regions; 2] there is poor control over water delivery, and 3] quality and reliability of irrigation is poor. Semi arid and arid regions with deep water table conditions are ideal for water productivity enhancement (reduction in non-beneficial evaporation and non-recoverable deep percolation). Semi arid Punjab and Haryana are known for intensive cropping of wheat and paddy, which have ample scope for improving yield.

After canal irrigated areas, areas that depend on well irrigation and where substantial area is still left uncultivated due to water scarcity should receive attention. The reason is that under such situations, the farmers can expand the area under irrigation and increase aggregate returns. The priority areas would be hard rock areas of peninsular, central and western India. The water-intensive crops grown in large areas in this region are paddy, cotton, sugarcane, banana, cotton, castor, groundnut, and potato (Kumar and Singh, 2006).

Row crops such as cotton, groundnut, potato, castor, banana and sugarcane can also be prioritized for water productivity improvement. Here, it can come from the use of micro irrigation devices, especially in sandy soils, as it is very difficult to maintain high distribution uniformity in water application with traditional method of irrigation such as level borders and furrows. Large-scale adoption of drip irrigation for banana and sugarcane in Maharashtra and for potato, groundnut, cotton and castor in north Gujarat serve as successful examples.

5.2 Potential improvements in water productivity and water saving at the basin level

The gain in applied water productivity through "water control" results in same extent of gain in productivity of depleted water only in semi-arid and arid regions where the depth to groundwater table is large,[12] and where non-beneficial evaporation from fallow land is high. In such regions, a significant portion of the applied water depletes. Hence, there can be basin level productivity gains through control over water delivery.[13] However, for farmers to adopt water control measures, they must have extra land to bring under irrigation. This is because the net return per unit area might decline due to water control measures. At the aggregate level, there would be no reduction in the demand for water.

Though micro irrigation would raise crop water productivity both in physical and economic terms without reducing yield (as illustrated by Figure 11). The impact of micro irrigation would be significant in arid and semi arid areas, and for row crops. This is because in case of row crops evaporation component of consumptive use of water by crop (ET) is quite large, especially under aridity conditions (Kumar *et al*., forthcoming). The area under row crops is very small in the sub-humid and humid areas and water abundant areas.

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[11] See Kumar and Singh (2006) for detailed description of average annual rainfall and reference evapo-transpiration in all the nine agro-climatic regions falling in Narmada basin.

[12] Deep groundwater table and aridity means that the return flows from applied water are not significant; and evaporation of residual soil moisture from fallow is very high.

[13] In other regions—sub-humid and humid regions with shallow groundwater, the basin level water productivity gain would be very much lower.

Peninsular India and Western India have substantial area under crops that are conducive to micro irrigation technologies; north and central India has very little area under such crops with the exception of Uttar Pradesh. Western part of Mahanadi is another area that would be conducive to water saving technologies (WST). Use of micro irrigation system can significantly reduce crop water demand per unit area of cultivated land in semi-arid and arid area, with deep groundwater table conditions or with saline aquifers. However, in these areas, farmers use the saved water to expand the area under irrigation to maximize their aggregate returns (if un-cultivated land is available). As a result, the aggregate demand for water may not change. However, areas where intensity of irrigation is already highest like in central Punjab and Haryana might be exceptions.

The basins that are conducive to measures for improvement in water productivity through water control are: 1] all east-flowing rivers of peninsular India; 2] rivers north of Tapi in Gujarat and Rajasthan; Mahanadi; some parts of Indus basin covering south-western Punjab; and 3] west- flowing rivers of South India. This is because these basins fall under semi arid and arid climatic conditions, and have moderately deep, to deep groundwater levels. These basins have very large areas, which are un-irrigated due to limited availability of groundwater and canal water. Hence, farmers would have incentive to improve water productivity. In the process, they would be able to maximize the aggregate returns.

There are some regions in India where water productivity is not a consideration for individual farmers. The economy here would benefit a lot by reducing the amount of water depleted and the energy used up in growing crops. Such areas include parts of Indus in central Punjab, Haryana and UP, which are groundwater irrigated. In such areas, water productivity improvement measures can help raise income returns from every unit of land irrigated. The only option to enhance water productivity is water delivery control. It can be used effectively in such situations where excessive irrigation leads to yield losses.

In Punjab and Haryana, improving adequacy and reliability of canal water supplies would lead to greater yield for wheat and paddy, apart from reducing non-beneficial depletion and improving water productivity. Hence, irrigation departments should have incentive to go for improving both quality and reliability of irrigation water, and “water control”. Since there is no scope for exploding groundwater-irrigated area, it would lead to reduction in groundwater draft as well.

6. POLICY ALTERNATIVES FOR IMPROVING WATER PRODUCTIVITY

It is widely recognized that flat rate mode of pricing of electricity resulted in inefficient, and unsustainable use of groundwater (Kumar and Singh, 2001; Kumar, 2005). Pro-rata pricing of electricity would create direct incentive for efficient water use as it induces positive marginal cost of water application. There will be two different outcomes of this policy change: 1] as the marginal cost of using electricity is positive, farmers would adopt water abstraction systems that are more energy efficient, which means the electricity used for pumping and applying a unit of water would be less, so the marginal cost of increasing the dosage of water; and 2] farmers could increase water use efficiency in crop production, enhancing physical efficiency (Kumar, 2005).

By enhancing water use efficiency, the farmer can reduce the water application to their crops, as the net marginal returns would become negative at original level of water dosage. Such reductions in applied water will be affected without any change in the consumptive use through better farm water management and better conveyance methods. Farmers can also adopt drip irrigation systems that require low energy to run,[14] which also save energy. There would be no adverse effect of reduced irrigation dosage on yield. Instead, the irrigation-net water productivity curve itself would shift diagonally upwards due to slight improvement in net water productivity.

In the long run, total metering and pro-rata pricing would be the most desired scenario, The government can start with metering of agricultural consumption. Heavy subsidy for WSTs can be provided to farmers who are willing to use meters, provided they minimize electricity consumption. It could reduce with increase in total energy consumed, and increase with increase in percentage cropped area under water-saving irrigation technol-

[14] Like micro tubes and sub-surface drip irrigation systems (porous pipes). For details please see Kumar, Singh, Sharma and Amarasinghe (2007).

ogy. This can help realize the twin objective of more efficient and sustainable groundwater use, and efficient energy use.

In groundwater irrigated areas, improving power supply conditions – both quality and hours of supply – is extremely important for achieving greater control over water delivery. Unreliable power supplies and power supply during night time force farmers to apply excess water whenever power supply is available (Kumar and Singh, 2001), instead of application at the critical stages of crop growth that gives higher productivity. This leads to inefficient use from both physical and economic points of view as shown by a study in Mehsana. In canal command areas, farmers should be provided with subsidies for storage systems and small pump sets. This would result in greater control over "water delivery" and better quality of irrigation to achieve higher water productivity in physical and economic terms.

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SOCIAL COSTS AND BENEFIT OF MICRO IRRIGATION SYSTEM ADOPTION IN CANAL COMMANDS: A STUDY FROM IGNP COMMAND AREA OF BIKANER IN RAJASTHAN

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Abstract

It is generally perceived that adoption of micro irrigation (MI) system leads to increase in yield; real water saving; and expansion in area under irrigation, all resulting in social benefits. But, most of these perceptions are based on research on drip irrigated farms of orchards and cash crops. Again, they looked at saving in applied water rather than actual water consumption by the crop. Thus, the social benefits tend to get over-emphasized. Since the studies were done in agriculturally prosperous regions where labour is in short supply, the social costs associated with removal of labour from farms get ignored. Thus, governments and donors are motivated to subsidize MI systems. But, many research studies in the past on drip irrigation seem to suggest that these systems are viable even when the full costs of the system are compared against the private benefit. Hence, subsidies may not be desirable from an equity perspective as it is mostly large farmers having capital who go for micro irrigation systems.

The broad research question being addressed in the present study is whether subsidies are desirable for promoting micro irrigation systems in canal commands. The study was undertaken in IGNP (Indira Gandhi Nehar Project) command area where farmers have adopted sprinklers with the help of an intermediate storage system locally known as diggie. The objectives of the study are to: 1] analyze the farming systems changes associated with MI adoption; and, 2] evaluate the economic and social costs and benefits of sprinkler and diggie adoption in the region. The study shows that sprinkler with diggie is economically viable for the farmers even without subsidies. It further shows that the social benefits exceed the social costs.

The study had shown that under situations of induced water scarcity, incremental income return over pre-adoption scenario will not be the decisive criterion for farmers to go for MI systems. Instead, the criterion would be water productivity enhancement, which also ensures that the income returns are higher than what they would probably secure with flood-irrigated crops under conditions of reduced water availability. Since the social costs are less than the social benefits, the subsidies are justifiable as it makes the private benefits exceed the private costs. The study also validates the unique methodology used for economic cost benefit analysis of micro irrigation systems. On the social cost benefit front, we have only considered the positive externality associated with water saving. The other positive externality of sprinkler adoption is reduced risk in livestock keeping. However, we have not quantified this.

1. INTRODUCTION

Water scarcity problems are growing in many arid and semi-arid regions in India. Given the fact that agriculture consumes lion's share of total water diverted in these regions (GoI, 1999; Kumar, 2003), micro irrigation is advocated by the government of India (GoI) as a panacea for all water problems. The task force on micro irrigation constituted by government of India estimates the area that can be brought under micro irrigation systems at 97 mha. But, little attention has been paid to the constraints facing the farmers in adopting this system such as erratic power supply conditions; and lack of clear economic incentives for saving water and energy due to inefficient pricing of electricity and water. The existing cereal dominated cropping systems, and the small sizes of land holding of farmers are other physical constraints (Kumar et al., 2008). Particularly, in canal commands the delivery of water under gravity makes it difficult for farmers to adopt MI systems as they have to go for

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intermediate storage systems and pressurizing devices, which mean capital investments in addition to that required for the MI system making the economics poor. With the least recognition of these constraints, government has been using subsidy as an instrument for promoting adoption of MI.

That said, another important question which remains unanswered is whether subsidies are really justifiable. Subsidies are desirable when the social benefits exceed the social costs, whereas private benefits do not exceed the investment farmers have to make. Water saving and yield enhancement are generally perceived as positive externalities of MI adoption on society. Exchange of farm labour is perceived as a negative externality (Dhawan, 2000). But, the extent of real water saving depends on climate, soils, crop type, type of MI technology and geo-hydrological environment. Similarly, the negative impact on farm labour depends on the socio-economic conditions of the region and the farming system change associated with MI adoption. However, there is hardly any research available from India to throw light on these issues.

On the other hand, many research studies in the past seem to suggest that the micro irrigation systems, particularly drip systems are viable for the farmers when the full private costs of the system are compared against the private returns. Hence, subsidies may not be desirable from an equity perspective. The reason is that it is mostly large farmers having capital who go for MI systems.

The general perception is that MI adoption leads to increase in yield (kg/ha), water saving; increase in area under irrigation due to reduction in water requirement per unit area, and advancement in produce harvest, all resulting in social benefits. But, most of these perceptions are based on research on drip irrigated farms of orchards and cash crops. Again, they looked at applied water rather than actual water consumption by the crop (Kumar et al., 2008). Also, studies concentrated in agriculturally prosperous regions where labour is in short supply. In the absence of rigorous analysis, the social benefits tend to get over-emphasized, and costs ignored.

A very recent research on drip irrigated cotton showed a 114% increase in yield and 45% reduction in applied water (Narayanamoorthy, 2008). The effect of climate, geo-hydrological environment, crop type and type of technology used were never considered in assessing the physical impacts of MI adoption on water and energy use, which determine the real economic and social benefits. The potential negative impacts MI system adoption can have on society (social cost) such as reduced labour absorption in agriculture were generally ignored, and instead the labour saving impact was highlighted as a private benefit. Part of the reason might be the fact that large-scale MI adoption takes place in regions where agriculture is progressive, and labour is in short supply. The research on the actual physical and economic benefits from sprinkler irrigation is very scanty in India (Kumar et al., 2008).

2. CONTEXT

On notable example for large-scale and intensive adoption of MI systems, is the Indira Gandhi Nahar project–Phase - I located in Bikaner district of Rajasthan. In lieu of the growing problems of water logging and salinity in the command area, and inter state conflict over sharing of water, government motivated farmers to use a local system called *diggie* to store canal water in order to make water use more efficient. The construction of the diggie enables farmers to use the water for irrigation as and when required. It also enables the use of pressurized irrigation techniques like sprinkler irrigation.

While the large scale adoption can be attributed to high returns against the investments, the subsidies being made available to the farmers play an important role in raising the net returns, there by boosting adoption. In Rajasthan, the government gives a maximum subsidy of Rs. 40,000 for constructing a *diggie*. This is in addition to the subsidy for MI systems which GoI provides. In Lunkaransar taluka of Bikaner district, farmers had adopted sprinkler irrigation for their existing crops on a large-scale. A properly designed lay-out of a sprinkler system ensures relatively uniform application of water over the field. Sprinkler systems are usually designed to apply water at a lower rate than the soil infiltration rate, so that the amount of water infiltrated at any point depends upon the application rate and time of application. But, it is important to note that the distribution efficiencies would be low in sprinkler irrigated fields, if the fields are small. This is due to high edge effects.

3. PHYSICAL AND SOCIO-ECONOMIC CHARACTERISTICS OF THE STUDY AREA

As discussed in the earlier part of the paper, the physical impacts of use of micro-irrigation technology in a particular region depends on soil, climate, geo-hydrology and crops. The economic dynamic of micro irrigation depends on the socio-economic factors, including the land-holding pattern, crops, nature of access to irrigation sources etc. (Kumar et al., 2008). Hence, it is important to discuss the physical and socio-economic profile of the region to analyze the physical impacts, and economic and social benefits of sprinkler adoption.

3.1 The Location and its Physical Environment

Bikaner is one of the desert districts situated in the north-west of Rajasthan. It is bound in the north by districts of Sri Gangbanger, on the west by Jaisalmer and Pakistan, Churu in the east and Nagaur and Jodhpur in the south-east. Jaipur, Ganganagar, Amritsar are some of the important cities near to this district. The district is situated between the latitude 27^0 11'03'' to 29^0 03' north and longitude 71^0 54' to 74^0 12' east comprising a total geographical area of 27244 sq. km.

The district's climate varies from arid in the east to extremely arid in the west. The mean rainfall of the district is 247 mm varying from 300 mm in the east to 180 mm in the west bordering Pakistan with coefficient of variability ranges from 50 to 65%. The annual potential evapo-transpiration is 1770 mm (Gheesa Lal, 1999). The mean maximum temperature ranges from 24.4^0 to 47.9^0 C and mean minimum from 7.3^0 to (-) 1.2^0 C. Frequent drought once in 2.5 years is a common phenomenon.

Soils of this district are predominately light textured, weak structured and well drained. Moderately deep to very deep, loamy sands, sandy loams and loam soils occur on the flat aggraded older alluvial plaints and flat interdunal plains. Deep to very deep, fine sandy to fine loamy sand soils occur on the undulating sandy aggraded older alluvial plains and undulating interdunal plains and very deep fine sands on the dunes.

3.2 Socio-economic Conditions

The total population of the district is 16, 73,562 (10, 79,060 rural and 5, 94,502 urban) with a density of 61 persons / sq. km. and literacy rate of 46.55% as per 2001 census. The district has 580 inhabited villages and 67 uninhabited villages. Cultivators account for nearly 45% of the workforce in the district, and agricultural labourers are only 4.6%. The other workers account for 49% of the workforce.

As per 2000-01 land use statistics, the net sown area is 45.43% of the geographical area; forest constitute 2.68%; area not available for cultivation, 8.36%, barren and uncultivable land 1.27%, permanent pasture and other grazing land 1.27%, cultivable waste 26.77%, other fallow lands 8.93%, current fallow 4.84%, respectively. The area, which is cropped twice, is only 2.84%.

Out of the 2.33 lac ha of irrigated area, 84.91% is served by IGNP canal system and rest is served by wells and tube well. Groundnuts, american cotton, guar, kidney beans (moth), bajra, green fodder are the main crops grown in Kharif season. Except bajra all other crops are cash crops. Wheat, mustard, cow-pea, are the main crops in Rabi season. Wheat is grown only for home consumption. Horticulture crops or vegetables are not grown in slightest in the region.

3.3 Indira Gandhi Nahar Project

The Indira Gandhi Nahar Project (IGNP) is one of the largest water resources projects in the world, aiming to transform the desert into an agriculturally productive region. The IGNP was conceived and executed to utilize 9,393 MCM of the 10,608 MCM of water allocated to Rajasthan from Ravi-Beas in order to convert 1.96 mha of land in the arid desert to agriculturally productive land. The project aims at drought proofing, providing drinking water, improving environmental conditions, afforestation, employment generation, rehabilitation of project affected people, livestock development and increasing agricultural production in the region. Though the project, started in 1958 and only partially complete, it has shown remarkable success. The construction of the project has been divided into two stages.

Stage I comprises a 204 km long feeder canal, having a discharge capacity of 460m^3/sec. The stage I also consists of a 189 km long main canal and 3454 km long distribution system. It is concrete lined, and serves 5.53 lac ha of cultivable command area. Of this, 4.6 lac ha area is served by pumping with a 60m lift.

Stage II comprises a 256km long main canal and 5,606 km long lined distribution system, and serves 14.10 lac ha of CCA (873577 ha area in flow and 537018 ha under lift), utilizing 4,930 MCM of water annually. The stage II area has been divided into 7 regions. As of now 2, 33,850 ha of cultivable land in Bikaner are coming under this canal system. According to Central Water Commission: "Indira Gandhi Canal was built at a cost of Rs.70 crore. But now the income generated is about Rs. 700 crore every year from the project. An outlay of Rs. 70 crore has brought about a return of Rs. 700 crore, 10 times more. The life pattern of the people in this area has also dramatically improved."

The problems of vertical drainage of water in IGNP command area are quite well known. This is created by the occurrence of impervious layer between the water table aquifer and deep aquifers. Gypsum-Ferrous layer is present just below the surface layer of soil. It is an impervious layer and it is very thick. As the soil of the area are coarse textures with a significant amount of sand resulting in low water holding capacity. The percolated water is deposited over the gypsum-ferrous layer and as a result stagnation of water has been increased considerably. The evaporation of this water is possible because of the capillarity action of sand dunes; this is the prime reason of the salinity of the land.

3.4 Reason for Sprinkler Adoption

Three factors have contributed to sprinkler and diggie adoption. They are presence of upland, which cannot be watered by flow irrigation from canals; sharp reduction in water availability; and availability of subsidy for purchase of sprinklers and construction of *diggie*. Since there has been a remarkable reduction in the supply of canal water, the timeliness of water availability reduced, affecting the quality and reliability of irrigation. Here, the *diggies* act as an intermediate storage system for the water. The *diggie* and the pumping devise together increase their ability to improve the quality and reliability of irrigation. Although the farmers are not able to irrigate the land adequately, they can now irrigate more land both by virtue of the pressurizing device. Subsidies also act as a motivation for the farmers to adopt the MI system.

4. OBJECTIVES AND METHODOLOGY FOR THE STUDY

4.1 Objectives

The objectives of the study are: to analyze the farming systems changes associated with MI adoption in Indira Gandhi Canal command area; and to evaluate the economic and social cost benefits of micro irrigation adoption in the region.

4.2 Methodology

Generally, the variable affecting the economic dynamic of micro irrigation adoption in Bikaner region are: i] change in crop yield; ii] change in area under irrigation; iii] change in cost of crop cultivation; and, iv] change in value of the produce (Dhawan, 2000). But, how these variables get altered depends on the socio-economic conditions of the farmers and the region under consideration, the climate and the geo-hydrological environment (Kumar, 2007). In the following section, we would discuss how each one of these variables had been altered due to sprinkler irrigation.

Often in the context of MI, the reduction in water applied due to prevention of deep percolation is counted as a private benefit. But, as Dhawan (2000) cautions, such private benefits can be over-emphasized in situations where the deep percolation appears as return flows to the shallow aquifer and recharge to the well. Nevertheless, such private benefits are applicable in situations where farmers are confronted with marginal cost of using water. Since, the farmers here are not paying for canal water on volumetric basis, changes in volumetric consumption of water due to adoption of micro irrigation system does not lead to cost saving for the farmers.

But, in regions of water shortage, the social benefits due to water saving could be enormous. But, the actual social benefit depends on the extent of real water saving, rather than saving in applied water (Dhawan, 2000). Real water saving comes from reduction in non-beneficial evaporation from soil, and non-recoverable deep percolation (see Allen et al., 1998 for details). Real water saving due to MI depends on several physical factors (Kumar et al., 2008). In regions, with semi-arid and arid climatic conditions and light textured soils and deep water table conditions, the real water saving comes from reduction in non-beneficial evaporation and non recoverable deep percolation (Kumar et al., 2008). Again, since return flows create water logging and soil salinity problems, it can be treated as non-beneficial depletion of water. Hence, in the present condition, the applied water saving can be treated as real water saving.

4.2.1 Sampling frame, and method of data collection

The universes of sampling were the villages of Lunkaransar taluka of Bikaner district. Four villages Rozha, Phuldesar, Bada Delana and Chota Delana were selected. The farmers were selected randomly. A group of 30 farmers who had adopted *diggies* and use sprinkler irrigation and 30 other farmers who have not adopted *diggies* and use sprinkler irrigation were chosen for the analysis.

Structured interview using questionnaire were conducted. Based on the questionnaire the data on the cost and benefit components of crop cultivation were collected. The main constituents of cost components are, inputs viz., fertilizers, manure, seeds; labour cost; transportation; cost of maintenance of MI system; and water charges. The crop returns are, the main product; and the by-product (for wheat, cluster bean and groundnut); and fodder.

4.2.2 Analytical procedure

The social cost-benefit of micro irrigation adoption was evaluated by taking the ratio of the sum of private benefit and positive externalities associated with MI adoption and the sum of private cost of MI adoption and the negative externalities associated with adoption. On major assumption involved in the evaluation of both positive and negative externalities associated with MI adoption is that the externalities are a linear function of the area irrigated.

The variables to be considered for evaluation of social costs and benefits were decided after preliminary field investigations. These investigations provided insights into the nature of positive and negative externalities associated with sprinkler adoption. Reduction in the amount of water consumed for crop production was identified as a major positive externality. Expansion in the irrigated area and the proportional increase in crop yield were identified as major private benefits of sprinkler adoption. This is contrary to what has been found in most cases due to adoption of MI systems.

The private benefit-cost ratio for sprinkler irrigated crops was evaluated by taking the ratio of the difference between the aggregate net private return from all the sprinkler irrigated crops and the aggregate net private returns from all the flood irrigated crops prior to adoption for the same water supply conditions (as post adoption); and the sum of annualized capital cost and annual operation and maintenance of the systems (C_{SPRINK}). Both numerator and denominator were estimated per unit area of the sprinkler system. This can be expressed mathematically as:

$$B-CRatio=\frac{[\sum_{i=1}^{m} NR_{SPRINK_i} * ASUM_{SPRINK_i} - RF * \sum_{j=1}^{n} NR_{FMI_j} * ASUM_{FMI_j}}{C_{SPRINK}} \quad .... (1)$$

Here, $RF = \frac{[\sum_{j=1}^{n} V_j]}{[\sum_{i=1}^{m} V_i]}$ .... (2)

Here, $NR_{SPRINK,i}$ and $NR_{FMI,j}$ are the weighted averages of the net private return for all the farmers growing sprinkler irrigated crop i, and flood-irrigated crop , respectively. $ASUM_{SPRINK,i}$ is the sum of the area under crop i from all the sprinkler adopter farmers in the sample. $ASUM_{FM,j}$ is the sum of the area under crop j, which is flood-irrigated, from all farmers. Here , and V_j are the volume of water allocated to crop i by all farmers in the sample using sprinkler irrigation, and allocated to crop j by all farmers using flood irrigation, respectively.

Water saving benefit through sprinkler adoption (Δ_{SPRINK}) is the difference between the amount of water that is actually needed to produce the current economic outputs from the farms under traditional method and the actual amount of water used for production currently.

$$\Delta_{SPRINK} = \frac{[\sum_{i=1}^{m} NER_{SPRINK,i} ASUM_i]}{[\sum_{j=1}^{n} \theta_{FMI,j} * V_j / \sum_{j=1}^{n} V_j]} - \frac{[\sum_{i=1}^{m} NER_{SPRINK,i} ASUM_i]}{[\sum_{i=1}^{m} \theta_{SPRINK,i} * V_i / \sum_{i=1}^{m} V_i]} \quad \text{......... (3)}$$

Here, $NER_{SPRINK,i}$ is the net economic return from the sprinkler irrigated crop i. $\theta_{FMI,j}$ is the water productivity for crop j in economic terms under flood method of irrigation. $\theta_{SPRINK,i}$ is the water productivity for crop i in economic terms using sprinklers. Water productivity is estimated using the functional formula, by dividing the net returns from crop production and the volume of water applied. V_i

The positive externality induced by sprinkler use for irrigation through water saving is estimated by multiplying the average volume of water that can be saved from unit area under sprinkler irrigation, and the average net return under flood-irrigated crop from unit volume of water (it is same as the overall net water productivity for flood-irrigated crop). Mathematically, it can be expressed as:

$$\left[\frac{\sum_{j=1}^{n} NR_{FMI,j} ASUM_j}{\sum_{j=1}^{n} V_i}\right] * \frac{\Delta_{SPRINK}}{\sum_{i=1}^{m} ASUM} \quad \text{........................ (4)}$$

The social benefit-cost ratio is estimated by taking the ratio of the sum of private benefit +positive externality and the sum of private cost and negative externality. This is basically adding up of Equation (1) and Equation (4).

The net water productivity in relation to applied water for different crops under flood method of irrigation were estimated by taking the ratio of net return from crop production and the total volume of irrigation water applied. Similarly for sprinkler irrigated crop, the net water productivity was estimated by taking the net return and the volume of water applied through sprinklers[1] . Here, it is assumed that the rainfall contribution of yield is negligible, and that the entire yield comes from irrigation only.

[1] The volume of water applied through sprinklers for each plot was estimated by multiplying the average number of sprinklers for a unit area of plot, with the discharge of the sprinkler, number of irrigations, the hours of irrigation per watering and the area of the plot.

5. ANALYSIS AND RESULTS

5.1 Changes in Crop Inputs

Comparison of data on crop inputs for flood irrigated crops and their sprinkler irrigation counterparts was done for the four main inputs, viz., seed quantity, irrigation dosage, fertilizer and pesticide. The results are presented in Table 1. It did not show any significant change in the level of inputs except for irrigation. Under sprinkler method, farmers increased the frequency of irrigation for all crops. Though the duration of watering also increased with sprinklers for all the crops, this was due to low rate of water delivery through the sprinklers. But, closer analysis using data on discharge rates showed major reduction in water application depth under sprinkler irrigation.

Table 1: Comparison of Crop Inputs during Pre and Post Adoption of Sprinklers

Crop	Crop inputs before adoption of sprinkler					Crop inputs after adoption of sprinkler				
	Seed (kg)	Irrigation		Fertilizer (kg)	Insecticide (Rs.)	Seed (kg)	Irrigation		Fertilizer (kg)	Insecticide (Rs)
		No.	hr.				No.	hr.		
Kharif										
Cluster Bean	14.3	1.0	1.5	0.0	283	13.1	2	5.8	0.0	292.0
Groundnut	87.3	4.5	4.3	DAP-54 U-94.2	0.0	83.2	6.8	7.2	D-53.2 U-92.1	0.0
Cotton	13.5	5.4	4.9	DAP-90 U-180	90	12.4	5.6	7.0	D-82.8 U-165.6	144.0
Green Fodder	7.8	1.0	1.2	0.0	0.0	7.8	2.1	4.4	0.0	0.0
Black Gram	15	1.0	1.2	0.0	0.0	15.8	2.6	5.4	0.0	0.0
Rabi										
Wheat	74.3	5.8	4.8	DAP-84 U-176	0.0	72	8.4	8.2	D-86 U-172	0.0
Mustard	4.3	3.4	4.4	DAP-54 U-92	0.0	4	5.8	7.2	D-53 U-92	0.0
Cow Pea	23	1.3	2.8	34	0.0	23	2.9	6.2	D-31	0.0
Green Fodder	8	1.2	1.6	0.0	0.0	7.8	2.3	3.9	0.0	0.0

Source: Authors' own analysis using primary data

5.2 Changes in Crop Yield Due to Sprinkler Adoption

Generally, it is believed that use of micro irrigation systems result in increase in yield due to uniform application of water across the field resulting in more uniform distribution of soil moisture, and uniform growth; frequent application of smaller dosage of water to the crop resulting in lower chances of moisture deficit and water stress, particularly prevention of moisture stress at critical stages of crop growth; optimum dosage of irrigation in each watering, preventing chances of nutrient leaching. But, in the IGNP command area, no trend was found vis-à-vis the crop yield change due to sprinkler adoption.

The major kharif crops that are grown in Lunkaransar taluka are groundnut, cluster bean, bajra and green fodder. The yield figures for these crops before and after adoption of sprinklers are compared and presented in Table 2. It shows that there has not been a substantial change in the yield after adoption. In case of groundnut and cluster bean, yield has decreased marginally where as for bajra it had increased marginally. Over all there is no general trend in yield. While the effect of sprinkler irrigation on yield could be both positive and negative, the availability of rains during kharif season can nullify this effect.

Table 2: Impact of Sprinkler Use on Yield of Kharif Crops

Name of Crop	Crop Yield Under		Percentage change in yield (+/-)
	FMI (qtl/ha)	Sprinkler irrigation (qtl/ha)	
Groundnut	21.74	21.38	-1.65
Cluster bean	12.76	12.60	-1.25
Cotton	22.20	22.20	0
Bajra	15.30	22.20	45

Source: Authors' own analysis using primary data

Note: + indicates increase after adoption; "-" indicates decrease in yield after adoption

The major winter crops that are grown in Lunkaransar taluka are wheat, mustard, pea and green fodder. The crop yields are compared and presented in Table 3. It shows that the yield of green fodder has increased substantially where as that of wheat had decreased. There was marginal improvement in the yield of mustard. The yield reduction for wheat can be attributed to the poor distribution uniformity in watering which affect the crop growth adversely. It is to be kept in mind that the input factors that can potentially affect the yield, other than irrigation, had not changed after adoption. What is to be inferred is that the effect of poor distribution uniformity is much higher than that of improved quality and reliability of irrigation.

Table 3: Impact of Sprinkler Use on Yield of Winter Crops

Name of Crop	Crop Yield Under		Percentage change in yield (+/-)
	FMI (qtl/ha)	Sprinkler irrigation (qtl/ha)	
Wheat	24.43	23.10	-5.44
Mustard	14.53	14.82	1.99
Cow Pea	9.39	9.39	0
Green Fodder	55.44	64.80	16.88

Source: Authors' own analysis using primary data

5.3 Changes in Area under Crops and Irrigation

In well irrigation, there are no limits on the amount of water farmers can access, except those imposed by the aquifer characteristics and energy supply. But here, in this case, canal water supply is restricted, and the amount of land which farmers can irrigate is constrained by the amount of canal water. In the case of IGNP, the water availability from canals was adequate to bring all the operational holdings under flood method of irrigation. But due to undulating terrain and higher elevation, a significant portion of the land, which cannot be irrigated through gravity flow, had to be left fallow.

But, as farmers in the area experienced drastic reduction in water supply from canals, they had to resort to more efficient method of water application even to maintain the previous levels of irrigation. The availability of subsidies for construction of *diggie* enabled use of sprinkler irrigation. With the adoption of sprinklers, the farmers could also bring a lot of the undulating land lying in higher elevation, under irrigation. We would examine the changes in area under irrigation for Kharif and Rabi crops.

Table 4 shows that the total area under Kharif crops experienced a very marginal increase of 1.7 ha. Groundnut and cluster bean area increased slightly, and more importantly, the area under irrigation increased for both the crops. The significant change due to adoption is that more area is put under irrigation. There are three major reasons for this increase. First: framers receive remunerative prices for this crop. Second: the agro-climate is very favorable for the cultivation of groundnut. Third: sprinkler is very suitable for irrigating groundnut. The area under irrigated cluster bean saw an increase of 12%; and the absolute increase in area (7.5 ha) is also quite substantial. This is because cluster bean does not require much water and is mostly rain-fed. Even prior to adoption of sprinkler, the area under cluster bean was quite high.

In the case of cotton, the area under cultivation was also not very large prior to adoption. No change in area under this crop was seen after adoption. It is also to be noted that cotton is not amenable to sprinkler irrigation.

Table 4: Impact of Sprinkler Adoption on Area under Kharif Crop

Name of crop	Area under cultivation before adoption (ha)	Area under cultivation after adoption (ha)	Irrigated area before adoption (ha)	Irrigated area after adoption (ha)
Groundnut	41.39	43.33	41.39	43.33
Cluster bean	136.94	136.12	53.06	60.56
Cotton	6.39	6.39	6.39	6.39
Black Gram	2.78	2.78	0.00	0.00
Bajra	3.05	3.62	2.50	3.06
Green fodder	1.68	1.68	0.00	0.52
Total	192.23	193.92	103.34	113.86

Source: Authors' own analysis based on primary data

As regards winter crops, as Table 5 indicates, there has been some increase in the area under cultivation of there crops, namely wheat, mustard and cow pea. Area under wheat had increased by 0.80ha. The main reason for this increase is that before adoption of MI system the staple food crop of the area was bajra, but with time wheat has become the staple crop, indicating a general improvement in the welfare of the people. This is in spite of the yield reduction after adoption of sprinklers. Farmers grow it only for domestic consumption. Perhaps the reason is that wheat is a water intensive crop.

Table 5: Impact of Sprinkler adoption on Area under Winter Crop

Name of Crop	Area under cultivation before adoption (ha)	Area under cultivation after adoption (ha)	Irrigated area before sprinkler adoption (ha)	Irrigated area after sprinkler adoption (ha)
Wheat	28.61	29.44	28.61	29.44
Mustard	35.00	37.78	33.891	36.68
Cow Pea	48.33	49.72	32.78	32.78
Green fodder	3.62	3.62	3.33	2.78
Fennel	1.39	1.39	1.39	1.39
Total	116.95	121.95	100.00	103.07

Source: Authors' own analysis based on primary data

The area under mustard has also increased by 2.78 ha (8%). The main reason for increase in the area for mustard is the high returns. Also, the yield was found to be improving with sprinkler use for this crop. The farmers are able to sell the mustard for attractive price. There was increase in the area under cultivation of cow pea also, but the irrigated area did not increase. The total increase in area under cultivation is 4.3% and that under irrigation is 3.1%. In the case of green fodder, the irrigated area decreased by 0.55 ha.

One could argue that change in area under crops in such plots cannot be attributed to sprinkler adoption. But, given the fact that the rainfall is quite low, during droughts these crops also will have to be irrigated. The absence of proper water lifting and irrigation device prevents farmers from taking crops in these plots as the investment for crop inputs would be lost in situations of droughts. But, the access to storage system and the sprinkler technology enables the farmers to take crops in plots which otherwise cannot be irrigated under gravity. Hence, this is a positive externality of sprinkler and *diggie* adoption.

5.4 Impact on Livestock Rearing

Livestock forms the organizing feature of the region's farming system. The farmers of the area keep cow, buffalo, goat and camel. The number of livestock per family ranges from 2 - 20. The livestock holding per family had remained more or less constant over the past many years. When the animals give birth to new ones, the farmers either sell either the calf or the older animals according to the need.

The farmers keep cows and buffalos mainly for dairying. The average production of milk per animal in the area varies from 2 - 5 lt/day. The farmers own only the local breed of animals. The amount of feed supplied to the animals varies from 10 -15 kg/animal each time, with a two-time feeding generally practiced. The fodder is available from within the farm. It includes both green and dry fodder. The residents of the area do not buy milk from the others. They meet their household milk demand from their cows and buffaloes. The excess milk is sold to either the local trader, who makes mawa out of it, or to Urmul diary. The price of milk varies from Rs.10 - Rs.12/lt. The farmers also keep camels for ploughing and transport.

The area used to face severe seasonal fodder shortages in the past. To overcome this, a practice that was prevalent in the area till a few years ago is that during scarcity, one or two persons from the village would collect the cattle from the entire village. These animals would be taken to the neighbouring state of Punjab where plenty of green fodder is available. These animals are taken back to the villages only with the onset of monsoon season when sufficient amount of fodder is available locally. Now-a-days, with the introduction of IGNP waters, farmers produce fodder in their own farms and the shortfall is met through purchase from the local market. Under conditions of water shortage, it is the use of sprinklers which enables the farmers to sustain the area under fodder crops and also those crops which have byproducts that can be used as fodder. This can be treated as a positive externality of sprinkler adoption.

5.5 Impact of Sprinkler Adoption on Crop Water productivity

Water productivity in crop production can be defined in terms of biomass production for every unit of water used or the net income return per unit of water used. The crop water productivity could be estimated either in relation to the amount of water applied (applied water productivity); or the amount of water consumed by the crop (productivity of consumed water ET) or the total amount of water applied, i.e., irrigation plus the effective rainfall (Kijne et al., 2003). Water productivity in crop production could be manipulated by improving the crop (biomass) output through crop management involving agronomic practices, nutrient management or crop technology management, or by reducing water use through on-farm water management[2].

Table 6 shows that the water productivity for ground nut, cluster bean, mustard and pea are high and for wheat and green fodder is lower under both flood-irrigation and sprinkler irrigation. The reason for high

[2] On farm water management can be through any of the following measures: i] reducing conveyance losses in irrigation water delivery; ii] applying optimum dosage of water; iii] ensuring water application at critical stages of crop growth; and iv] efficient use of rainwater. First and second measure reduces non-beneficial depletion. The third measure increases the yield response to ET; and the fourth measure reduces the irrigation water requirement and total water depletion.

productivity of mustard is that the income per unit of land is high (Rs.22000/ha), and is low water-consuming. The reason for low water productivity of wheat is that it is a water intensive crop and takes nearly 2-3 times more water than mustard, while the net returns is more or less same as that of mustard.

Table 6: Applied Water Productivity of Kharif and Rabi Crops under Sprinkler and Flood Irrigation

Sr. No.	Name of crop	Applied water productivity (Rs/m^3) under sprinkler	Applied water productivity (Rs/m^3) under flood irrigation
Kharif Season			
1	Ground Nut	24.24	10.24
2	Cluster Bean	34.00	18.27
3	Cotton	13.86	8.31
4	Bajra	10.47	5.55
Rabi Season			
1	Wheat	8.38	4.19
2	Mustard	20.23	6.69
3	Green Fodder	7.74	4.68
4	Cow Pea	25.49	8.72

Source: Authors' own estimates based on primary data

Water productivity for cluster bean is also very high. The reason being it requires only 1-2 irrigations. Despite being a water-intensive crop, water productivity for groundnut is high. The reason is that the net return from this crop under both flood and sprinkler irrigation (Rs.43700/ha and Rs.35500/ha, respectively) is highest among all the crops grown. The slight increase in area under cultivation for mustard from 35 ha to 93.33 ha (see Table 5) is a clear indication that the farmers use there land efficiently so that they can get the maximum returns out of that.

Comparison between sprinkler-irrigated crops and flood-irrigated crops shows that the water productivity values are higher under sprinkler irrigation for all the 8 crops. For the remaining crops, since farmers have not irrigated, the estimates of irrigation water productivity are not available. The difference is quite substantial for cluster bean, ground nut and cow pea. The enhancement in water productivity has mainly come from the reduction in applied water in the case of sprinkler irrigated crop rather than enhancement in net returns. We would see in the subsequent section that the net returns are much higher under flood irrigation for most crops. In the case of cluster bean, cow pea, green fodder and bajra, some farmers were found to be growing the crop under rain-fed conditions. For these crops, those farmers who are irrigating these crops are only considered for water productivity estimates.

5.6 Incremental Economic Benefits from Sprinkler Adoption

Past research on economics of micro irrigation were for well irrigators. Two important considerations were involved in the analysis. They are: i] increase in net crop return from unit area of micro irrigated plot over that irrigated using conventional method; and, ii] potential return from the additional area that could be brought under irrigation using the water saved through use of micro irrigation. While the first is realistic, the second consideration assumes that physical scarcity of water does not permit the farmers from expanding the area under irrigation prior to adoption. Such analyses were not based on any field evidence of area expansion due to MI adoption. Such considerations are valid for situations where wells are the source of water.

But, here, canal is the only source of irrigation water for the farmers, in which case the amount of water which farmers can access is limited. Under such situations, the criteria for assessing the economic performance should be: increment in aggregate return from all the crops that are irrigated with sprinklers, including the expanded area. Here, the validity of the assumption about area expansion can be tested. Unfortunately, the farmers experienced a major cut in the volumetric water availability, which prompted them to go for diggie construction and sprinkler irrigation for their crops. Hence, comparing the net return from sprinkler irrigated crop area against the flood-irrigated crop areas does not make sense. The volume reduction should be factored into the area under conventional method of irrigation to make the comparison realistic.

Using equation (2), we have estimated the total amount of water used by the farmers in our sample both prior to and after adoption of sprinkler system. The difference was quite substantial and it corroborated with what farmers reported. While the total water use was 0.638 MCM before adoption of sprinkler, it was reduced to 0.237 MCM, which forced farmers to go for micro irrigation. The reduction factor was estimated to be 0.371.

To begin the economic analysis, the net income return per unit area of land was worked out for all the irrigated crops for both flood method of irrigation and sprinkler method of irrigation. The results are presented in Table 7. It graphical representation is given in Figure 1.

As Table 7 indicates, the mean values of net return per ha of the crop is much higher under flood irrigation for four crops, and lower for three crops. Further, the average reduction in net return per unit area for the first set of crops is higher than the average rise in return for the second set of crops. This does not mean that the aggregate returns would be lower under sprinkler irrigation. The reasons are many: 1] every farmer grows more than one crop in each season; 2] the net outcome of sprinkler adoption in terms of change in net return would depend on how much area the farmer allocate to each crop. Nevertheless, it is important to note that comparative income return won't be an important consideration for farmers to go for sprinkler irrigation. The reason is the water supply situation had changed. With heavy rationing of water, the productivity of water would become the most important consideration for farmers rather than returns from unit area of land.

Table 7: Net Return from Different Kharif and Rabi Crops under Flood and Sprinkler Method of Irrigation

Sr. No.	Name of crop	Net return (Rs/ha) of land under	
		Flood irrigation	Sprinkler irrigation
Kharif Crops			
1	Groundnut	43693.0	35538.0
2	Cluster Bean	23960.0	16110.0
3	Cotton	36586.0	21959.0
4	Bajra	6644.6	6633.0
Rabi Crops			
1	Wheat	23637.0	17497.0
2	Mustard	22012.0	24054.0
3	Green Fodder	6165.0	6790.0
4	Cow Pea	11618.0	12330.0

Note: the net return is exclusive of the cost of sprinkler system

The economic returns from sprinkler irrigation were estimated using the figures of aggregate incremental returns from sprinkler irrigated plots over plots irrigated under conventional method of irrigation (0.371*203.37ha). The incremental return per unit area was deduced from this figure based on the figure of the total area under sprinkler irrigation (215.57ha). This was compared against the incremental cost of the sprinkler per unit area covered by the system (Rs.7519.8/ha). The incremental return was estimated to be Rs. 15937/ha. Hence, the private cost-benefit ratio for the system is Rs. 2.11. The reason for the high benefit-cost ratio is the unique characteristic of the system itself. The system is movable, and with just with an extra HDPE pipes to be used as main pipe, the same set could be used to irrigate large area, provided sufficient labour is available.

Figure 1: Impact of Sprinkler on Land Productivity (Rs./ha)

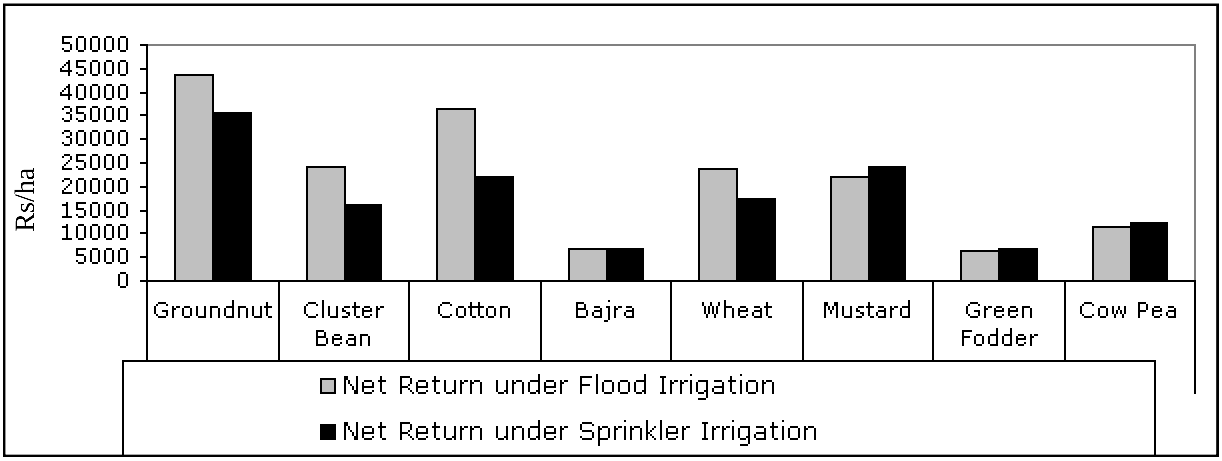

Table 8 shows that the net return from sprinkler irrigated crops (Rs. 53.74 lac-row 3, column 3) is slightly higher than that of flood-irrigated crop (Rs. 52.25 lac). The net incremental return per ha is negligible, and is far less than the additional cost which farmers have to incur for sprinklers, which is Rs.7519.8/ha. But, if we consider the fact that the volume of water available for crop production has been much lower for the post adoption scenario, the effective incremental return from sprinkler-irrigated crops becomes Rs.15937/ha. The positive incremental return is mainly due to the effective increase in area (see numerator of Equation 1 in methodology section) from 75.44ha - 215.57ha. Table 8 shows that both the private cost benefit ratio and economic benefit cost ratio are more than 1.0. Hence, it can be concluded that farmers would have incentive to adopt the systems even if subsidies are not available.

Table 8: Private Costs and Benefits from Sprinkler Irrigation

Sr. No.	Attributes of costs and benefits of sprinkler irrigation	Amount in Rs.	
		Aggregate	Per ha
1.	Net Return from Crops Irrigated by FMI (Rs)	5225368.80	
2.	Net Private Return from Sprinkler Irrigated Crop (Rs)	5374196.00	
3.	Incremental Return after Sprinkler Adoption	148827.00	
4.	Annual Incremental Private/Economic Returns due to Sprinklers (Rs) (2)-(1)*0.371	3435584.50	15937.2
5.	Annual Incremental Private Cost (Capital and O & M)	1621033	7519.8
6.	Annual Incremental Economic Cost (Capital and O & M)	1801605	8357.4
7.	Private B-C Ratio		2.11
8.	Economic B-C Ratio		1.90

Source: Authors' own analysis based on primary data

Note: the sprinkler irrigated area is 215.57ha out of the 314.48ha under crops; the total cost of sprinklers and diggies is Rs. 43.5 lac without subsidy and Rs.31.5 lac with subsidy for the entire sprinkler irrigated area. The annualized capital cost (both private and economic) was worked out using a discount rate of 10% and a life of 10 years for the system. The total annual operation and maintenance cost of the motor, sprinklers and the diggie was estimated to be Rs. 11.32 lac rupees for the entire sprinkler irrigated area.

5.7 Social Benefits due to Sprinkler Adoption

The most significant social benefit in the region due to adoption of sprinkler irrigation is real saving in irrigation water. This is in view of the scarcity value of the resource being acutely felt in this arid region with growing competition from other sectors such as industry and urban drinking, in addition to that from farmers in other parts of IGNP command. The non-adoption of sprinkler irrigation would have forced the farmers to either tap groundwater to sustain the income from crop production or led to conflicts.

As regards the potential social costs, no major negative externalities were seen to have been induced by sprinkler adoption in the area. The potential negative externalities, as evident from a recent study in Nalgonda district of Andhra Pradesh, are: 1] reduced labour absorption in agriculture, mainly coming from replacement of labour-intensive crops by cash crops which depend on mechanized farming, and decline in wage rates due to the reduction in labour demand; and 2] increase in food prices due to decline in cereal production in the area mainly due to replacement of traditional food crops by high valued cash crops. But, in the case of IGNP, no major change in cropping pattern that could affect cereal production was found. Also, there was no positive or negative impact on either labour demand or wage rate after technology adoption.

Ideally, the aggregate water saving due to adoption depends on the real water saving at the field level per unit area through MI adoption; and what economic value could be generated from the saved water. We have already estimated the reduction in water use at the aggregate level for the sample farmers through MI adoption to be 0.401MCM (i.e., 0.638-0.237=0.401). But, for the purpose of social cost benefit analysis this figure will not make sense. The reason is that the yield and income figures corresponding to pre and post adoption scenarios were different. Hence, it is imperative to know how much water could have been used up by the farmers to generate the return that occurs from the sprinkler-irrigated plots, had they used the conventional method of irrigation.

We had employed equation (3) to estimate this. This uses net private return from sprinkler irrigated crop, and water productivity (Rs/m^3) estimates for all the crops under the two different methods of irrigation to estimate the hypothetical water consumption for generating returns using FMI, and the current water consumption. The net income return from sprinkler irrigated area is estimated by taking the gross returns from all the sprinkler irrigated crops and the total cost of all inputs, including the full cost of sprinkler systems. This was estimated to be Rs. 35.72 lac. The overall net water productivity of all the crops irrigated under flood method of irrigation was estimated to be Rs. 8.63/m^3. The amount of water needed to generate the said income returns from flood irrigated crops is estimated to be 0.413MCM. Hence, the water saving is 0.163MCM (i.e., 0.413-0.237=0.176MCM).

This means, every hectare of sprinkler irrigated area saves water to the tune of 816m^3. Had the farmers not used sprinkler irrigation, they would have been forced to depend on tube wells for maintaining the current level of farm returns. Hence, the water saving can be treated as real. If we assume that the farmers allocate the saved water to put additional area under irrigation using flood method, the additional income that can be generated from one cubic metre of water would be Rs.8.63. Hence, the surplus value product associated with the positive externality induced by sprinkler adoption per ha is Rs.7045. As Table 9 indicates, the social benefit cost ratio is 2.75. This means, subsidies in sprinkler irrigation could be justified.

Table 9: Private Costs and Benefits from Sprinkler Irrigation

Sr. No.	Attributes of costs and benefits of sprinkler irrigation	Amount in Rs/ha
1.	Annual Incremental Economic Cost of Sprinkler & Diggie	8357.00
2.	Annual Incremental Benefit (Rs.) (from Table 6)	15937.20
3.	Total Water Saving per ha of Sprinkler-irrigated Area due to Technology (m^3)	816.00
4.	Positive Externality due to Water Saving	7045.00
5.	Social Cost-benefit Ratio (2)+(4)/(1)	2.75

Source: Authors' own analysis based on primary data

6. FINDINGS

1. One major consequence of sprinkler adoption in Bikaner is slight expansion in area under irrigation from 203.33ha to 215.57ha. This is in spite of reduction in volume of irrigation water available to the farmers to an extent of 62.9%. Hence, the real area expansion benefit due to sprinkler adoption has to be seen from a hypothetical pre-adoption area of 75.44ha.

2. In many regions, MI system adoption is associated with introduction of new high valued fruit and cash crops that replace traditional food crops or change in cropping pattern towards high valued crops, with impacts on food security, use of animal power for cultivation and labour absorption. But, in Bikaner, no major change in crops or cropping pattern is observed. Hence, there are no major negative externalities.

3. With sprinkler adoption, the yield of mustard, bajra and winter green fodder had increased marginally, while that of wheat, groundnut and cluster bean had decreased marginally. Sprinkler and diggie use could impact on yield both positively and adversely, the first due to improved quality and reliability of irrigation, and the second due to reduced distribution uniformity. But, the farmers seem to take advantage of reduced water requirement by allocating more area to those crops which gain in terms of yield through sprinkler use.

4. The mean values of net return per ha of land was lower under sprinkler irrigation for four crops, while it was slightly higher for three other crops. But, farmers could manipulate the aggregate returns by allocating more land to such crops which give relatively higher net income per unit of land. Nevertheless, aggregate net return won't be the consideration for farmers to decide in favour of sprinkler irrigation. The reason is the changed water supply situation under which they would try and maximize the return per unit of water.

5. The net water productivity for all the crops is higher under sprinkler irrigation than under flood irrigation. The improvement has mainly come from reduction in applied water use achieved through reduction in conveyance loss and deep percolation loss, rather than improvement in net income.

6. The private returns from sprinkler-irrigated crops under the scenario of reduced water availability are far higher than the returns that could have secured if the farmers continued with the traditional method of irrigation under the same scenario of water availability. The net incremental benefit was estimated to be Rs. 15937/ha. This means, the opportunity benefits of adoption are very high. Hence, adoption of sprinkler with *diggie* is economically viable for the farmers. The private benefit-cost ratio is 2.11.

7. But if we consider the actual cost of construction of the *diggie* and the actual price of sprinklers, the system gives net returns slightly lower than that under flood method of irrigation. The economic benefit-cost ratio is 1.90. This means that farmers can adopt the system even without subsidies.

8. As regards the positive externality induced by large-scale sprinkler use on society, the main benefit is from water saving. The aggregate income benefit due to sprinkler use for an area of 215.2 ha is equivalent to using an additional 0.176 MCM of water for generating the same economic output from flood-irrigated crops. Hence, the water saving is 0.176MCM. Another positive externality is on the impact on livestock.

9. The positive externality of water saving per ha of sprinkler adoption is 816m3. This is equivalent to an economic surplus of Rs. 7045/ha if we assume that the farmers use the saved water to grow the same crops with flood irrigation. Hence, the social benefit due to sprinkler adoption is Rs.22982/ha. The incremental cost to the society is Rs.9734.8/ha. Hence, the social benefit-cost ratio is 2.75. Hence, the subsidies for diggie and sprinkler system could be justified.

7. CONCLUSION

The study shows that sprinkler with diggie is economically viable for the farmers even without subsidies. It further shows that the social benefits exceed the social costs. The present study had shown that incremental income return over pre-adoption scenario will not be the consideration for farmers to go for micro irrigation systems under situations of induced water scarcity. Instead, they would be concerned with enhancement in productivity of water, which also ensures that the income returns are higher than what they would probably secure under conditions of reduced water availability, with flood-irrigated crops. Since the social costs are less than the social benefits, the subsidies are justifiable as it makes the private benefits exceed the private costs. The study also validates the unique methodology used for economic cost benefit analysis of micro irrigation systems. On the social cost benefit front, we have only considered the positive externality associated with water saving. The other positive externality of sprinkler adoption is reduced risk in livestock keeping. However, we had not quantified this.

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IMPROVING WATER PRODUCTIVITY IN AGRICULTURE IN DEVELOPING ECONOMIES: IN SEARCH OF NEW AVENUES

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Abstract

This article shows how the various considerations for analyzing water productivity (WP) differ due to the differences in stakeholder interests, and objectives and units of analysis. Also it identifies some major gaps in WP research and the key drivers of change in WP. The main arguments are: 1] in developing economies like India the objective of WP research should also be to maximize net return per unit of water and aggregate returns for the farmer, rather than merely enhancing "crop per drop"; 2] the determinant for analyzing the impact of efficient irrigation technologies on basin level WP and water saving should be consumed fraction (CF) rather than evapo-transpiration; 3] in closed basins, determinants for analyzing basin level WP improvement through water harvesting and conservation should be incremental economic returns & opportunity costs; 4] at the field level, the reliability of irrigation water and changing water allocation could be the key drivers of change in WP that need to be analyzed, whereas at the farm level, changes in the crop mix and farming system could be key drivers of change. In composite farming systems, measures to enhance WP should be based on farm-level analysis involving considerations such as risk taking ability and investment capabilities of the farmer. Finally, the options to enhance WP in agriculture seem to be quite limited, given the larger objective of addressing food security, poverty alleviation, and employment generation concerns in rural areas.

1. INTRODUCTION

Water productivity in agriculture would be the single most important factor driving the water use globally in the future (Molden et al., 2000; Rijsberman, 2004). Hence, research to evaluate crop water productivity and analyze the drivers of change in the same, has fascinated many researchers and scholars worldwide (Ahmad et al., 2004; Ambast et al., 2006; Grismer, 2001; Howell, 2001; Kijne et al., 2003; Zwart and Bastiaanssen, 2004; Singh, 2005; van Dam et al., 2006). As a result, most of the research studies on crop water productivity were undertaken in naturally water-scarce regions of the world. Such regions include western United States, drought-prone areas of arid Australia, semi arid areas of Indian and Pakistan Punjab, Turkey, and Mexico.

Water productivity in crop production can be expressed in terms of biomass production per cubic metre of water diverted or depleted (kg/m^3), known as physical productivity of water; and net or gross present value of the crop produced per cubic metre of water diverted or depleted (Rs/m^3) known as economic productivity of water (Kijne et al., 2003). A recent synthesis by Zwart and Bastiaanssen (2004) of an extensive body of literature available research world over showed that water productivity in terms of biomass output per unit of depleted water (kg/ET) or physical productivity of water in crop production has been mostly analyzed across the world at least for some of the major crops; and enough is already known about the factors that explain its variations across locations. But, it also showed that no attention is paid to know how the crops compare in terms of economic returns from every unit of water depleted. But, this is crucial, because the measures to enhance water productivity of a crop such as higher dosage of nitrogenous fertilizers; improved soil management; better agronomic practices, including the use of high yielding varieties, and pest control; water harvesting and supplementary irrigation; and investment in water delivery control measures, have economic imperatives.

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This heavy focus on physical productivity of water is perhaps because most of these analyses were done by agricultural scientists, who are concerned with raising the dry matter yield of crop per unit of evapo-transpiration. The other factors, which might have been responsible for this bias are: 1] water is a limiting factor at the societal level for enhancing crop production in these regions (Howell, 2001: pp), which still have large cropped areas under un-irrigated conditions (Loomis and Connor, 1996: pp10), and water productivity improvement enable farmers to divert part of the saved water to expand irrigated area; and, 2] with volumetric rationing and prices farmers have to pay for water, they are likely to get higher net returns along with higher yields through efficient irrigation technologies that reduce consumptive use[2]. Another factor could be the fluctuating price of agricultural commodities in the market, which changes the net return per unit volume of water.

But, the avenues to improve agricultural WP through farming system changes are not explored. This is a major shortcoming, when we consider the fact that most of the farms in developing economies like India and most of Africa are complex with several crops; and also composite with crops and dairying instead of one or two crops. After Rothenberg (1980), as farms are organized to maximize the net economic return they are the best fundamental units for economic analysis. Hence, how productively farmers use their water cannot be assessed in relation to particular crop alone, but in relation to the entire farm. In sum, this dominant paradigm of "more crop per drop" influence WP research in Asia and Africa.

On the other hand, there has also been greater recognition of the distinction between securing field level "water-saving" and field-level WP improvement, and water-saving and WP improvement at the basin-scale (Allan et al., 1998; Howell, 2001; Molle and Turral, 2004; Seckler et al., 2003). The concept of "open basins" and "closed basins" is often used to explain how the determinants of WP could be manipulated and water saving achieved, or otherwise, in different situations. The received wisdom is that in "closed basins", field-level water saving does not result in water-saving and WP improvement at the basin level, except when the return flows meet with saline aquifers or are non-returnable; and otherwise basin level water saving and WP improvements comes only from reduction in consumptive use (Molle and Turral, 2004).

This new paradigms in water resource management also seems to have influenced research in many countries in Asia and Africa: 1] in deciding what one should look for as key "determinants" in WP analysis; and; 2] in identifying the drivers of change in WP. They have hardly captured the complex technical, social, economic, institutional and policy settings that govern water allocation policies by government and water use decisions by farmers. This concerns the poor technical efficiency and reliability of public canal systems; heavily subsidies in pricing of water and electricity in farm sector; huge public investments in water harvesting; and, lack of institutional regimes governing the use of water from canal schemes and groundwater.

This article first takes a critical look at these two paradigms in agricultural water management to see how far they are useful in exploring new avenues for WP improvements and water saving, particularly in situations like India. It also explores new opportunities for WP improvements and water saving for fields, farms and regions, by analyzing the complex variables which drive these WP parameters, and identifies new areas for research.

The questions being addressed are as follows. 1. Given the heavy subsidies in electricity and water used for agriculture and lack of well-defined rights in surface water and groundwater in developing countries like India, does research on raising "crop per drop" make sense, or what should be the new determinants of WP for both farmer and basin water managers? 2. What considerations should be involved in analyzing basin level WP and water saving impacts of efficient irrigation? 3. What are the likely impacts of improved reliability of irrigation, and changing water allocation on crop water productivity and water saving? 4. In composite farming systems, what should be key objectives and priority areas of WP research? 5. What should be the priority areas for research on enhancing regional WP in agriculture, in countries like India where food security, rural employment and poverty alleviation are still major issues?

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[2] As water saving leads to cost saving in irrigation sufficient to offset the additional cost of fertilizer and technology inputs.

2. WHY A NEW PARADIGM OF RESEARCH ON AGRICULTURAL WATER PRODUCTIVITY IN INDIA?

2.1 More Income Returns Vs. More Crop Per Drop

The main considerations involved in analyzing WP in the West is in reducing the amount of water required to produce a unit weight of crop, as this would automatically ensure higher net return per unit of land. But this is not the concern in many developing economies in Asia, where land use intensity is already very high in many regions. Surface water is heavily subsidized, and pricing is also inefficient (Kumar, 2003). There is zero marginal cost of electricity used for pumping groundwater for irrigation (Kumar, 2005). Hence, the measures to enhance water productivity through ET reduction and yield enhancement may not result in significant improvement in net income for the farmer for a unit area of irrigated land, though net water productivity in rupee terms may increase. While major investments are required to achieve irrigation efficiency improvements and yield enhancement, the increased benefit farmers get is only in terms of market price for higher yield. The reason is that the real water-saving and energy saving[3], which are major impacts of the technological interventions, do not get converted into saving in private costs of water.

A study by Sander Zwart (2006), which involved analysis of system level WP in irrigated wheat in six different regions around the world using SEBAL (Surface Energy Balance) methodology, shows that the variation in WP is not so much due to variations in ET, but due to variations in yield (see Table 1). The average ET was highest in Pakistan (443mm) and lowest in Sirsa (361mm), which is approximately 10% higher/lower than the average (source: analysis by Sander J. Zwart, 2006). Though the potential evapo-transpiration (PET) depends on the climate, especially the relative humidity (air temperature and solar radiations remaining in a narrow range across these six regions), actual ET could have been manipulated by changing water available to crops through irrigation. But, this does not seem to have happened. As a consequence, WP is strongly related to wheat yields. The reason that ET remains the same is that there is a shift from evaporation (E) to transpiration (T). As soon as the environment for crop production are improved (fertilizers, weeding, better seeds, water management, etc., etc.) there will be a shift from non-beneficial to beneficial water depletion. This shows enhancement in WP (kg/ET) can mainly come from crop technologies, which needs farmer investments.

Table 1: Average System-level Water Productivity in Wheat in six Different Wheat Growing Regions around the World

Location	Average ET/ Standard Deviation (mm)	Average yield (ton ha^{-1})	Average WP_{ET} (kg m^{-3})
Nile Delta, Egypt	408 (59)	6.1 (0.9)	1.50 (0.12)
Yaqui Valley, Mexico	402 (36)	5.5 (0.9)	1.37 (0.16)
Sirsa, India	361 (16)	4.4 (0.3)	1.22 (0.06)
Linxian County, China	436 (35)	3.8 (1.4)	0.86 (0.28)
Hebei Province, China	380 (50)	2.5 (0.9)	0.64 (0.21)
Sindh Province, Pakistan	443 (82)	2.2 (0.7)	0.50 (0.11)

Source: analysis by Sander J. Zwart dated May, 2006

Now, the only way to create incentive among farmers to adopt efficient irrigation technologies for WP improvement is to subsidize it. The idea is to make private benefits offset the private costs (Kumar, 2007).

[3] Whether use of efficient irrigation technologies can reduce energy use for irrigation or increase depends on the type of irrigation technology and how pressurized is the traditional water supply (Loomis and Connors, 1996).

While yield enhancement is also a benefit of efficient irrigation technologies (Loomis and Connor, 1996: pp398), it can also come from improved agronomic practices mentioned above. The extent of subsidy for a system which can save "X" amount of water could be kept higher than the difference between the private costs and benefits. It should be guided by the positive externality that "X" creates on the society. Since, government subsidies for efficient irrigation technologies are extremely limited in developing countries[4] such measures to enhance WP do not result in increased land productivity.

This means that they have to divert part of the water saved to another plot to sustain their income as net return is WP multiplied by the volume of water. But, in situations where the entire holding is used, farmers will not have much incentive to go for measures that do not increase their returns from the land, but only returns per unit of water. This is the situation in India, where the average holding of farmers is quite low (less than 1 ha) when compared to that in Western US or Australia. The size of median landholding in Australia is 300 ha (ABS, 2002). This clearly means that what is socially optimal is that farmers look for alternatives that enhance productivity of their land remarkably, simultaneously reducing water requirement, or divert part of the water to other water-based farming systems that have minimal dependence on land. In nutshell, there is a clear trade off between enhancing physical productivity of water, and maximizing income returns. This argument also holds true when it comes to analyzing the WP impacts of water harvesting for supplementary irrigation, which happens with public investment. This is dealt with the subsequent section.

2.2 Poor Focus on Economics of Water Harvesting and Supplementary Irrigation

In the west, the focus in WP research has been on efficient irrigation technologies, including those for supplementary irrigation, in some African countries (Oweis et al., 1999; Rockström et al., 2002), Mexico (Scott and Silva-Ochoa, 2001) and in India, the focus has shifted to potential impact of water harvesting.

This is applicable to some of the recent work in eastern African countries. Rockström et al., (2002) have shown remarkable effect of supplementary irrigation through water harvesting on physical productivity of water expressed in kg/ET, for crops as sorghum and maize. However, the research did not evaluate the incremental economic returns due to supplementary irrigation against the incremental costs of water harvesting. It also does not quantify the real hydrological opportunities available for water harvesting at the farm level and its reliability. The work by Scott and Silva-Ochoa (2001) in the Lerma-Chapala basin in Mexico showed higher gross value product from crop production in areas with better allocation of water from water harvesting irrigation systems. But, their figures of surplus value product which takes into account the cost of irrigation are not available from their analysis. In arid and semi arid regions, the hydrological and economic opportunities of water harvesting are often over-played. A recent work in India has shown that the cost of water harvesting systems would be enormous, and reliability of supplies from it very poor in arid and semi arid regions of India, which are characterized by low mean annual rainfalls, very few rainy days, high inter-annual variability in rainfall and rainy days, and high potential evaporation leading to a much higher variability in runoff between good rainfall years and poor rainfall years (Kumar et al., 2006).

With high capital cost of WH systems needed for supplemental irrigation, the small and marginal f armers would have less incentive to go for it. The reason is incremental returns due to yield benefits may not exceed the cost of the system. This is particularly so for crops having low economic value such as wheat and paddy, which dominate arid and semi arid regions in India. But, even if the benefits due to supplementary irrigation from water harvesting exceed the costs, it will not result in higher WP in economic terms in closed basins. The exception is when the incremental returns are disproportionately higher than the increase in ET. This is because, in a closed basin, increase in beneficial ET at the place of water harvesting will eventually reduce the beneficial use d/s. Lack of this economic perspective in decisions, however, results in too much

[4] For instance, the government of India had provided Rs. 5 billion towards subsidy for drip and sprinkler systems in the five year plan. But, this amount is just sufficient to cover an area of 100,000 ha against a total net irrigated area of nearly 55 m ha, accounting for just 0.20%, if one considers an investment of Rs. 100000 per ha of area under MI system, and a subsidy to the tune of 50%.

public investment in India towards subsidies to farmers to harvest water locally. To sum up, gain in crop per drop (kg/ET) cannot drive water harvesting for supplementary irrigation in semi arid and arid regions. Also, incremental net benefit considerations can drive water harvesting at the basin scale only if there is no opportunity cost of harvesting.

2.3 Distinction between Consumed Fraction and Evapo-transpiration

The effect of scale factor on the overall impact of water saving measures at field level on real water saving had been thoroughly discussed by several scholars (Allen et al., 1998; Molle and Turral, 2004; Molle et al., 2004; Seckler 1996). The main argument is that in "closed basins", real water saving is not possible through improvements in irrigation efficiencies as it does not reduce depleted water, but only return flows (Molle and Turral, 2004). While there are sufficient evidences from across the world on the relationship between ET and yield (Connor et al., 1985; Grismer, 2001; Rockström et al., 2002), it has made at least a few scholars argue that reduction in consumed fraction and therefore "real water saving" are not possible through such technologies without reducing yield unless we use better crop varieties or agronomic practices.

But, these technologies might be able to reduce the consumptive use as well as consumed fraction[5] (CF), without reducing the beneficial evapo-transpiration (ET) and the yield (see page 76 of Allen et al. (1998) for details on ET and consumed fraction) thereby leading to "real water savings" at the field level. It could be through reduction in evaporation from the excessively wet soil or reduction in non-reusable deep percolation resulting from water application in excess of the soil moisture deficit in the root zone. However, the distinction between ET and CF is often not made in analyzing the impact of depleted water on yields. Hence, an automatic conclusion is that real water saving at the basin level is not possible without changing ET (Zhu et al., 2004), or affecting other uses in water-scarce basins (Molle et al., 2004). Whereas in reality, improvements in crop water productivity in physical terms and water saving might be possible at the basin level through efficient irrigation technologies. Hence, research on basin level WP impacts of efficient irrigation technologies should consider CF as a determinant.

3. ARE THERE NEW OPPORTUNITIES FOR ENHANCING WATER PRODUCTIVITY IN COUNTRIES LIKE INDIA?

3.1 Opportunities for Improving Field-level Water Productivity

It is widely acknowledged that reliability and degree of control over field-level water allocation are by and large very poor in surface irrigation systems in India (Brewer et al., 1999; Meinzen-Dick, 1995), leading to poor technical efficiencies (GOI, 1999; Ray, 2002). Whereas the irrigation systems in the US and Australia are far more reliable and are designed for high degree of water delivery control. Two major dimensions of irrigation service, which have significant impacts on crop yields, are timeliness of water delivery (Perry and Narayanamurthy, 1998) and excess water deliveries, with the impact of first being positive and that of the second being negative, as illustrated by a study on irrigated rice production in Sone irrigation command in Bihar (Meinzen-Dick, 1995). But, the opportunities available with improved reliability of irrigation and "changing water allocation" in enhancing WP have not been examined.

3.1.1 Impact of reliability of supply on WP

This research is particularly more important when there are theoretical (Malla and Gopalakrishnan, 1995; Perry, 2001) as well as practical issues involved in using pricing as a tool for demand regulation (de Fraiture and Perry, 2004; Perry, 2001a). But, the task also lies in developing quantitative criteria for assessing reliability. There are evidences from several different parts of the world that well irrigation results in higher yields than canal irrigation. Though there are sufficient evidences to the effect that well irrigators get higher

[5] See Allen et al., (1998) for detailed discussion on various components of the applied water, such as consumed water, consumed fraction, beneficial transpiration, non-beneficial evaporation from the soil and non-recoverable deep percolation.

yield, and in spite of higher cost of irrigation higher net returns as compared to canal irrigators (Kumar and Singh, 2001; IRMA/UNICEF, 2001) there is limited research data on the differential productivity of groundwater irrigation over surface irrigation. A recently published study for the Andalusian region (Southern Spain) shows that each cubic meter of groundwater used for irrigation provides five times more money and almost four times more jobs than a cubic meter of surface water used also for irrigation (Hernández-Mora et al., (1999).

But, how this positive differential reliability in case of well irrigation does get translated into WP gains is a major point of enquiry. There are two possibilities. First, it is an established fact that while crop yield increases in proportion to increase in transpiration, at higher doses irrigation does not result in beneficial transpiration, but non-beneficial evaporation. Irrigation water dosages are normally higher in canal irrigation. This way, increased CF does not result in proportional increase in yield of crops (Vaux and Pruitt, 1983). Non-recoverable deep percolation is another non-beneficial component of the total water depleted (CF) from the crop land during irrigation (Allen et al., 1998). This also increases at higher dosage of irrigation, which occurs in case of canal irrigation. Moreover, with controlled water delivery, the efficiency of utilization of fertilizers would be more in the first case. Hence, with improved reliability and water delivery control, both denominator (CF) and numerator (yield) of water productivity parameter (kg/m^3) could be higher. This can be better understood by the negative correlation between surplus irrigation and crop yields in Sone command that surplus irrigation led to reduced yields (Meinzen-Dick, 1995). Since, there are no extra capital investments it would also lead to higher productivity in economic terms.

The second possibility is that with greater quality and reliability of irrigation, the farmers are able to provide optimum dosage of irrigation to the crop, controlling the non-beneficial evaporation, and non-recoverable deep percolation, with the result that the CF remains low, and the fraction of beneficial evapo-transpiration within the CF or the depleted water remains high. Also, it is possible that with high reliability regime of the available supplies, even under scarcity of irrigation water, the farmers can adjust their sowing time such that they are able to provide critical watering. This can bring out high yield responses. Both result in higher WP in kg/ET.

But, does the differential WP in economic terms (Rs/m^3) come from well owners growing more water-efficient and sensitive crop with assured water supplies? Evidence in support of this argument is a recent study comparing water productivity of shareholders of tube well companies and water buyers in north Gujarat. The study showed that the shareholders of tube well companies got much higher returns from every unit of pumped water, i.e., overall net water productivity in economic terms (Rs.4.18/m^3), as compared to water-buyers (Rs.1.3/m^3). The reason was that water allocation for shareholders was quite assured in volumetric terms, and irrigation water delivery was highly reliable, owing to which they could do their water budgeting properly, select water-sensitive and high-valued crops, and make investments for inputs judiciously, whereas water buyers were at the mercy of the well owners (Kumar, 2005).

Now, with expanding well irrigation in many arid and semi arid countries like India, including canal command area, new opportunities for improvement in reliability of water supplies is available. If well irrigation gives positive differential WP over surface irrigation, we can build in such features that contribute to higher water productivity in well irrigation, in gravity irrigation systems. They include creating intermediate storage system for storing canal water; and lifting and delivery devices for the stored water. That said, in real economics terms, what does the productivity gain means given the fact that the economic costs of irrigation is much higher than the private costs for both canal irrigation and well irrigation? Understanding these linkages will help design better policies for water allocation (whether to supply water by gravity or promote conjunctive use) and pricing in surface irrigation. If reliability results in higher WP (Rs/m^3) in well irrigation, which cannot be explained by price variations, then that makes tariff increase in canal water contingent upon improving the quality of irrigation.

3.1.2 Impact of changing water allocation on water productivity and water saving

Water management decisions are often taken on the basis of average water productivity estimates. For the same type of system, water productivity for the same crop can change at field scale (Singh et al., 2006:pp272) according to water application and fertilizer use regimes. Hence, it is important to know the marginal productivity with respect to water and nutrient use. It helps to analyze the role of changing water allocation strategies at the field level on enhancing WP. But, there are no data available internationally.

For a given crop, the irrigation dosage and the crop water requirement (beneficial use plus beneficial non-consumptive use) corresponding to the maximum yield may not correspond to the maximum water productivity (Rs/m^3) (Molden et al., 2003). The WP (k/m^3) would start leveling off and decline much before the yield starts leveling off (see Figure 1.2 in Molden et al., 2003). Ideally, WP in terms of net return from crop per cubic metre of water (Rs/m^3) should start leveling off or decline even before physical productivity of water (kg/m^3) starts showing that trend. When water is scarce, there is a need to optimize water allocation to maximize water productivity (Rs/m^3) through changing the dosage of irrigation. But, this may be at the cost of reduced yield and net return per unit of land, depending on which segment of the yield and WP response curves the current level of irrigation corresponds to.

Recent analysis with data on applied water, yield and irrigation WP for select crops in the Narmada river basin in India showed interesting trends. In many cases, trends in the productivity of irrigation water in response to irrigation did not coincide with the trends in crop yields in response to irrigation (Figure 1 and Figure 2); whereas in certain other cases the trends in irrigation WP in response to irrigation and the trends in yield in response to irrigation did actually coincide at least for some range in irrigation (Figure 3 and Figure 4). Knowing at what segment of the WP response curve irrigation dosage to a given crop lies helps understand how changing water allocation would change the crop yield and WP.

Figure 1: Yield vs Irrigation Dosage in Wheat (Hoshangabad 2002)

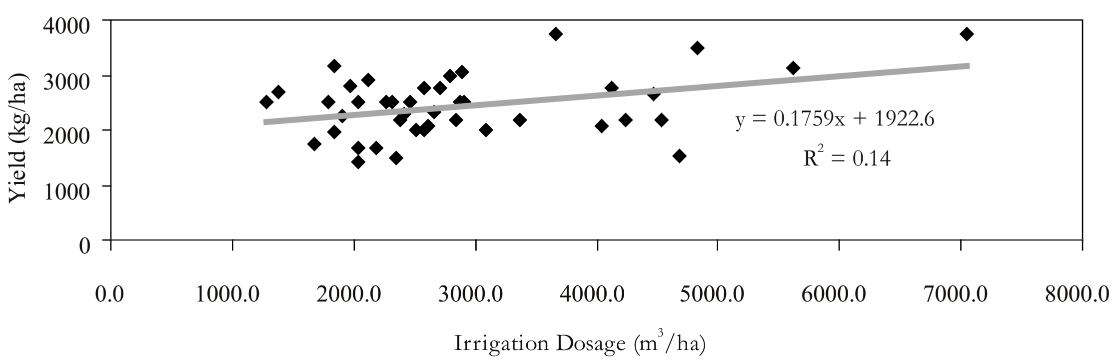
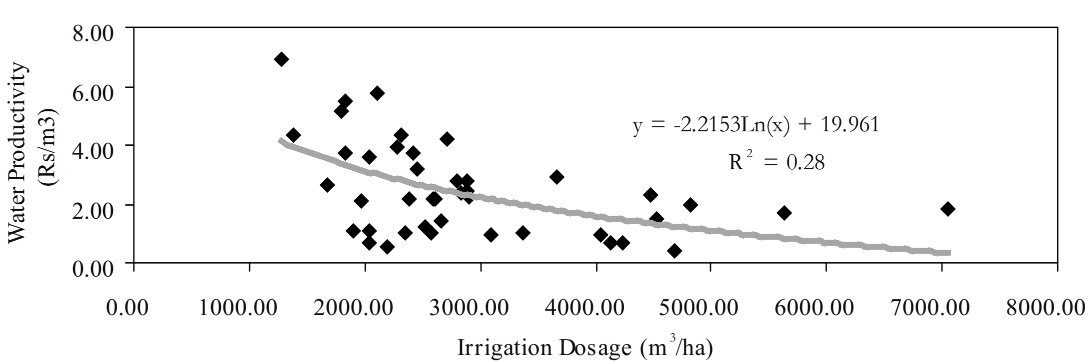


Figure 2: Water Productivity vs Irrigation Dosage in Wheat (Hoshangabad 2002)



The regression values for the response of yield to irrigation dosage being very small (Figure 1 and Figure 3), one could argue that many factors other than irrigation explain yield variations. But, the data that are presented here are for different farmers, who represent different soil conditions, different planting dates and different seed varieties, all of which having a potential to influence the crop yield. If one takes into account this, one could say that the actual yield response to irrigation would be much stronger if planting date, soils and seed varieties and same. Also, the slope of yield curve is very mild in the case of Figure 1. This is quite contrary to what can normally be found given the wide range in irrigation water dosage among the sample farmers. This can be explained by the variation in PET, and the moisture availability across farmers in the sample, which changes the irrigation water requirements.

Figure 3: Yield vs Irrigation Water Dosage in Cotton (West Nimar 2003)

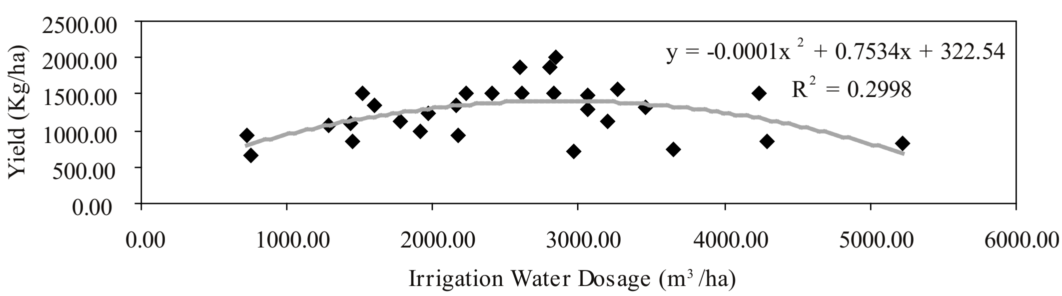
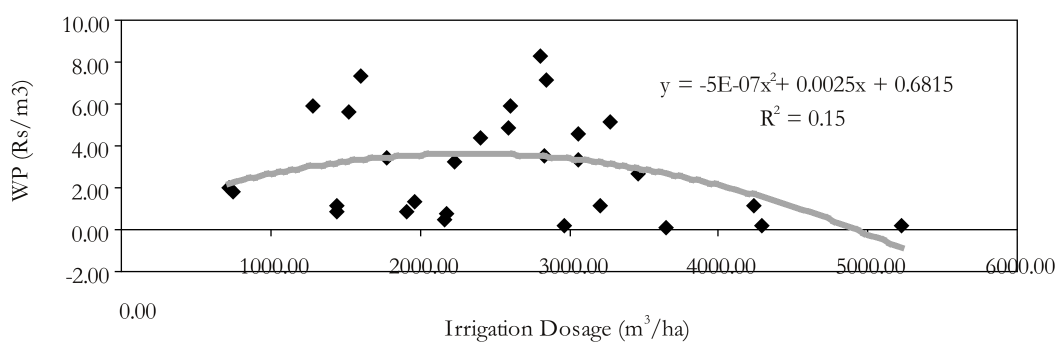


Figure 4: Water Productivity vs Irrigation Dosage in Cotton (West Nimar 2003)



In the first case, where the level of irrigation corresponds to the ascending part of the yield curve, but the descending part of WP curve (Figures 1 and 3), then limiting irrigation dosage might give higher net return per unit of water. But, farmers may not be interested in that unless it gives higher return from the land. Hence, if the return from the land does not improve, the strategy can work only under three situations: 1] the amount of water farmers can access is really limited either by the natural environment—like limited groundwater reserves—; 2] there is a high marginal cost of using water due to high prices for water or electricity used for pumping water that it is much closer to the WP values at the highest levels of irrigation; and, 3] water supply is rationed. In all these situations, the farmers should have extra land for using the water saved. Under condition of supply rationing, farmers would anyway be using water for growing economically efficient crops. But, the issue being addressed here is for a given crop, how far the water productivity can be enhanced to a level which the best managed farm achieves.

In all these three situations described above, the WP improvements would lead to farmers diverting the saved water for irrigating more crops to sustain or enhance their farm income. The reason is that the amount of water being handled by farmers is too small that they need to use the same quantum of water as previously since the WP differences are just marginal. This behaviour of the farmer can better be understood from the following equation, which defines net improvement in farm income:

Net change in farm income = $\{V - ÄV\}*\{\Phi + Ä\Phi\} - V*\Phi = V*Ä\Phi - ÄV*\{\Phi + Ä\Phi\}$

Where, "V" is the volume of water diverted for irrigation prior to adoption of productivity improvement measures; ÄV is the reduction in volume of water diverted for irrigation after adoption (+ve); Φ is the productivity of water when volume V was used for irrigation; Ä Φ is the rise in water productivity after adoption (+).

Analyzing the equation, the only way a small farmer can maximize his net farm return in the improved WP scenario is by making ÄΦ zero. In the case of a large farmer in US or Australia, who might use 100 to 500 times more water than an average farmer in India, there is still option available for enhanced returns, even if he decides to reduce the volume of water used for irrigation (i.e., ΦV> 0) because V is very large making V* ÄΦ. Hence, the impact would be greater economic outputs for the same quantum of water. Nevertheless, the impact can be different if the farmers get higher returns along with higher WP through changing water allocation as illustrated earlier. Hugh Turral[6] (per. com) argues that to achieve real demand regulation, water for agriculture needs to be formally allocated or re-allocated. If that means less water for agriculture, improving WP will be one of the responses. Howell (2001) cites the example of the Texas high plains. The increased use of irrigation technologies for wheat had resulted in enhancement of water use efficiency (Kg/ET), which followed significant yield increase, in wheat (Table 8, Howell, 2001). He argues that in such situations, farmers would achieve real water saving. This could result in water saving at the system level, if the farmers do not expand the area under irrigation. But, in this case, the farmers can afford to reduce the area under irrigation as the net return per unit of land also might have improved.

In the second case, where both the yield and WP curve are descending (Figures 3 and 4), the impact of change in water allocation on both WP and yield would be similar, i.e., reduced water allocation would result in both yield and WP gain. This is the most ideal situation where farmers have strong incentive to get adapted to water allocation strategies enforced by official agency in case of canal irrigation, and do voluntary cuts in irrigation dosage in well irrigation. But, this is a situation which is not very common in semi arid and arid conditions. Over-irrigation is more common in rich alluvial areas like central Punjab and Haryana, where farmers get free electricity and canal water is heavily subsidized.

For instance, analysis of soil water balance in rice-wheat fields in Sirsa district of Haryana by Singh (2005) using SWAP (Soil Water Atmosphere Plant) model shows that the total water applied to was in excess of the estimated ET (in the order of 290mm to 561 mm). Interestingly, the ET value was higher for the field which had lower dosage of irrigation (see Table 2). It shows that there is amble opportunity for real water saving through reduction in non-beneficial E of ET and the part of soil moisture storage change, which would eventually get evaporated from field. By reducing irrigation dosage in such conditions as cited above, the farmers gain both higher land productivity (return per unit of land) and higher return per unit of water.

Table 2: Water Balance in two Rice-Wheat Fields in Sirsa, Haryana during Kharif

Field No.	Irrigation Dosage (mm)	Rainfall (mm)	ET (mm)	Groundwater recharge (mm)	Soil moisture change (mm)
1.	1062	177	949	98	175
2.	1250	177	858	121	440

Source: Singh, Ranvir (2005): Table 4.6, pp: 46

[6] Principal researcher, International Water Management Institute, Colombo, Sri Lanka.

In the ultimate analysis, it may appear that to affect demand reductions, it is important to ration water allocation in canals along with behaviour change through better education of the farmers about crop management. Proper regional and sectoral water allocation can drive WP improvement. Experiences from the Murray-Darling basin (Haisman, 2003) and Chile (Thobani, 1997) show significant improvements in water use efficiency and value of water realized, respectively, in irrigated production after introduction of volumetric rationing enforced through properly instituted water rights. Nevertheless, marginal WP analysis of the kind presented above can help decide on allocation and delivery strategies for canal water, provided farmers are quite aware of water allocation and irrigation scheduling policies.

Hence, there is much more one can achieve in WP enhancement and water demand management in gravity irrigation without resorting to water pricing options technically. As Perry (2001a) notes, assigning volumes to specific uses, and effectively rationing water where demand exceeds supplies, would be an effective approach to cope with water shortages. But, its actual potential might depend on the situation in terms of access to land and water, and the institutional and policy environment such as water and energy prices and water rights regimes.

The recent past has shown significant debates over the usefulness of irrigation water pricing as a way to regulate water demand. While, some argue for it (Malla and Gopalakrishnan, 1995; Tsur and Dinar, 1995; Johansson 2000), some others argue against it pointing out shortcoming at both theoretical and practical levels (Bosworth et al., 2002; Perry, 2001a). There are three major, and important contentions of those who argue against pricing: 1] questioning the logic in the proposition that “if the marginal costs are nil, farmers would be encouraged to use large quantities of water before its marginal productivity becomes zero, consuming much more than the accepted standards and needs” (source: Molle and Turral, 2004); 2] the demand for irrigation water is inelastic to low prices, and the tariff levels at which the demand becomes elastic to price changes would be so high that it becomes socially and politically unviable to introduce (de Fraiture and Perry, 2002; Perry, 2001a); 3] there are no reasons for farmers to use too much water, which can cause over-irrigation (Molle and Turral, 2004). But, these arguments have weak scientific basis. We would discuss them in the subsequent paragraphs.

As regards the first point, the impact of zero marginal cost is not in “creating incentive to waste water”, but in “creating disincentive to prevent wastage”. These two concepts are distinctly different for public irrigation systems as control of water delivery devices is not in the hands of the farmers. One exception is the situations where Water Users’ Associations function. That takes use to the point about “disincentive”. The reason for disincentive is that the direct cost or the opportunity cost of taking measures to prevent wastage would be more than the benefits that can be derived from it in the form of reduction in yield losses. In certain other situations, in the absence of proper control structures in the tertiary systems, water delivery is not regulated. As farmers are not sure of getting the next release in time, apply water excessive irrespective of the field capacity of soils. This is common in paddy, which is widely grown in canal commands. So, the impact of price increase would be the creation of a strong economic incentive to reduce wastage, equal to the irrigation charges they have to pay for the wasted water.

The second point is about linking irrigation charges and demand for water. Merely raising water tariff without improving the quality and reliability of irrigation will not only make little economic sense but also would find few takers. As returns from irrigated crops are more elastic to quality of irrigation than its price (Kumar and Singh, 2001), poor quality of irrigation increases farmers’ resistance to pay for irrigation services they receive. Therefore, the “water diverted” by farmers in their fields does not reflect the actual demand for water in a true economic sense, so long as they do not pay for it. In other words, the impact of tariff changes on irrigation water demand can be analyzed only when the water use is monitored and farmers are made to pay for the water on volumetric basis.

It also means that if positive marginal prices are followed by improved quality, the actual demand for irrigation water might actually go up, though efficiency would improve. To what extent it goes up depends on the availability of land and alternative crops that give higher return per unit of land. This increase in demand is due to the tendency of the farmers to increase the volume of water used to maintain or raise the net income

(Kumar and Singh, 2001). Hence, water rationing is important to affect demand regulations in most situations (Perry, 2001a). The challenge lies in understanding the science of WP, particularly WP response to irrigation and actual consumptive use of water, and managing irrigation water deliveries accordingly. In the case of well irrigation, it is important for the farmers to understand this linkage, whereas the official agencies have to ensure that power supply is available for critical waterings.

As regards the third point, often the farmers do not make correct judgments about the level of irrigation dosage that corresponds to zero marginal returns. This has been found in the case of well owners, who are not confronted with positive marginal cost of pumping, resulting in lowering yield with incremental irrigation (Kumar, 2005). Price reforms only make farmers more conscious about the negative economic consequences of giving over-dose of irrigation water.

3.2 Opportunities for Improving Farm-level and Regional Level Water Productivity

We have seen that there are clear trade offs between options to enhance physical productivity of water and WP in economic terms at the field level itself. We would see that there is trade off between maximizing WP at the field level and that at the farm level, though farm level water productivity is dependent on the processes that govern WP at the individual fields. We would also see that the options available to maximize WP in a region, which often is the concern of water policy makers, are much less than those for an individual farms. The water policy maker looks for approaches that would not only enhance the economic returns, but also increase the social welfare. Many of the decisions relating to public investment in irrigation systems in countries like India are driven by larger societal concerns such as producing more food, employment generation and poverty alleviation. Often policy makers are more driven by social and political considerations than purely economic considerations (Perry, 2001a). We would elaborate on these issues in the subsequent paragraphs.

From the analysis presented in the previous section, it is evident that the scope for improving field level WP is extremely limited given the social, economic, institutional and policy environment in India. Limitations are more when we want to use it as a driver for changing water demand. Therefore, WP enhancement should

Table 3: Applied Water Productivity in Selected Crops in North Gujarat, Western Punjab and eastern Uttar Pradesh

Sr. No.	Name of the Crop	Net Water Productivity of Crop (Rs/m^3) of Applied Water in		
		Western Punjab	Eastern UP	North Gujarat
1.	Kharif Paddy	7.75	4.78	-
2.	Fodder Bajra	2.93	4.78	-
3.	Kharif Cotton	40.40	-	-
4.	Kharif Castor	-	-	8.09
5.	Brinjal	-	-	-
6.	Wheat	8.05	9.11	4.46
7.	Fodder Jowar	6.32		-
8.	Mustard	-	-	4.73
9.	Winter Gram	24.48	-	-
10.	Jowar	-	-	4.01
11.	Cumin	-	-	19.84
12.	Summer Bajra	-	-	2.85

Source: based on Kumar et al. (forthcoming) for western Punjab and eastern UP; and Kumar (2005) for north Gujarat. In the case of north Gujarat crops, the mean values of water productivity figures for different categories of farmers were taken.

focus on crops that are inherently more water efficient in economic terms, but also have high return per unit of land. As Molden (per. com) notes, "increasing WP is not often relevant to farmers. If it is important to the society, then society should figure out ways to align everyone's incentives".

It is established that many fruit crops have higher WP (Rs/m^3) than the conventional cereals such as wheat and paddy in arid areas. For instance, pomegranate grown in north Gujarat gives a net return of nearly 40,000 rupees per acre (i.e., USD 1000/acre) of land against Rs. 8,000 per acre (i.e., USD 200/acre) in case of wheat. The WP is approximately Rs.100/m^3 for pomegranate (Kumar, 2007) against Rs. 4.46/m^3 for wheat in the same region. Also, there are crops such as potato, cumin, cotton and castor which are more water efficient than rice and wheat, which can be grown in Punjab (see Table 3). With greater reliability, and control over water delivery, farmers using well irrigation would allocate more water for growing water-efficient crops. Perhaps, farmers have already started shifting to high valued cash crops.

But, there are limits to the number of farmers who can take up such crops due to the volatile nature of the market for most of these crops, its perishable nature, and the high risk involved in producing the crop. For instance, cumin grown in north Gujarat is a very low water consuming crop, with a high return per ha. But, crop failure due to disease is very common in cumin. In case of vegetables, that are fast perishable, markets are often very volatile, and price varies across and within seasons. The problem of price fluctuation is also applicable to cotton grown in western Punjab, which has high WP. Also, the investments for crops are also very high, demanding risk-taking ability.

But, farmers organize their entire farm, rather than field to maximize the net economic returns (Ruthenberg, 1980). The extent to which farmers can allocate water to economically efficient crops would perhaps be limited by the need to manage fodder for animals. It may also get limited by the poor market support for orchard crops. Many farmers in Punjab and other semi arid parts of India, manage crops and dairy farming together. But, even globally, research analyzing WP in composite farming systems that really take into account water depleted in biomass production is almost absent. Literature on water use efficiency and WP in dairy farming is also extremely limited. In regions for which they are available, the conditions are extremely different, from that in countries like India. Studies from northern Victoria and Southern New South Wales analyzed water use efficiency in dairy farms that are irrigated (Armstrong et al., 2000) and dairy farming is not integrated with crop production in this region. Green fodder produced in irrigated grass lands is used to feed the cattle by dairy farmers in Australia and United States, unlike Sub-Saharan Africa and developing countries in south Asia.

Recent analyses from western Punjab seem to suggest that the overall net WP in rupee terms gets enhanced when the byproducts of cereal crops are used for dairy production (see Table 4).

Table 4: Water Productivity in Crops and Dairy Production

Sr. No	Name of Crop/Farming	Water Productivity (Rs/m^3)
1.	Paddy	7.75
2.	Wheat	8.05
3.	Milk Production	13.06

Source: Kumar et al., forthcoming (derived from Table 11)

Reduced area under cereal crops such as paddy and wheat would mean reduction in availability of fodder. Farmers may have to grow special crops that give green fodder, and in that case, they might in turn be increasing the water use intensity[7]. Otherwise, farmers may have to procure dry fodder from outside, which would involve more labour. Hence, there could be a "trade off" between maximizing crop WP and farm level WP. But, there is not much of literature about economic productivity in dairy farming, especially with cereals and dairying, to understand this trade off.

[7] In a similar semi-arid situation in north Gujarat, it was found that dairy production, which used irrigated alfalfa, was highly water-inefficient, both physically and economically (Singh, 2004).

At the regional level, enhancing WP through either shift to water efficient crops (like orchards and vegetables) or with crop-dairy based farming system might face several constraints from socio-economic point of view. Food security is an important consideration when one thinks about options to enhance WP. Labour absorption capacity of irrigated agriculture and market price of fruits are other considerations. Paddy is labour intensive and in fact a large chunk of the migrant labourers from Bihar work in the paddy fields of Punjab. Replacing paddy by cash crops would mean reduction in farm employment opportunities. On the other hand, the lack of availability of labour and fodder would be constraints for intensive dairy farming to maximize WP at the regional level, though some farmers might be ale to adopt the system. Large-scale production of fruits might lead to price crash in the market, and farming loosing revenue unless sufficient processing mechanisms are established. Hence, the number of farmers who can adopt such crops is extremely limited.

In a developing country context, poverty reduction potential or the food security impact of irrigation are more important than return per unit of water. Food security and poverty reduction are in-built goals in large-scale subsidies in irrigation (Gulati, 2002), which enable poor farmers to intensify cropping. Therefore, WP in irrigation needs to be looked at from that perspective also, and not merely "crop per drop". One can argue that with more reliable irrigation, farmers could as well produce more food or generate more employment, and with that achieve higher physical and economic productivity along with meeting social objectives. But, the heavy subsidies in irrigation reduce the ability of the agencies to improve its quality through regular investments.

Perhaps this welfare oriented policy of keeping irrigation charges low now needs a re-look. With extensive well irrigation in India and with the poor paying heavy charges for pump renting or well water to irrigate their crops, the policies to subsidize canal irrigation may not bring about the desired equity and welfare outcomes. In fact, a large chunk of the subsidies in canal irrigation goes to large farmers, due to the crop-area based pricing followed (Kumar and Singh, 2001). These farmers also have access to well irrigation in the command area.

Another fact that supports the above argument is that often the unreliable canal water supplies force farmers to adopt only paddy, and not domestic food security concerns. The stable and high procurement prices offered by the Food Corporation of India for cereals such as rice and wheat allow farmers to stick to this cropping system. But there are major macro economic imperatives of trying to meet these social objectives (Gulati, 2002). The intensive paddy cultivation in Punjab is associated with intensive use of electricity for pumping groundwater even in canal commands during summer. Irrigating one ha of winter wheat requires 74 Kwhr to 295 Kwhr of electricity, which costs Rs.300 to Rs.1175 to the economy (source: field data). The region is already facing power crisis, with resultant impact on the quality of power supply to farm sector. Enhancing productivity of pumped groundwater also means enhancing energy productivity and reducing the revenue losses to the government in terms of power subsidies.

If farmers are able to secure higher net return from every unit of water applied or depleted in well irrigation, this could be a major starting point for irrigation bureaucracies to start charging higher for irrigation along with improving the quality—adequacy, reliability— and control. Following norms of rationing in water allocation would be crucial in achieving higher WP. Perhaps, what would be required would be higher prices for food crops or special incentives for farmers who grow it so as to reflect its social benefit, while reducing the irrigation subsidies heavily. So, the net result would be a compromise between socio-economic productivity and productivity enhancement in monetary terms, with positive impact on the water resource system.

4. SUMMARY AND CONCLUSIONS

Research to explore potential improvements in physical productivity of water (kg/ET) in crops without due consideration to income returns per unit of water will not be relevant for Indian farmers under the current electricity and water pricing policies in agriculture, and institutional regimes governing water use. The reason is it does not link WP improvement to raising aggregate farm income. In countries like India, major determinants for analyzing improvements in basin level WP due to WH & supplementary irrigation should use: i] incremental economic returns from enhanced crop yield; and ii] opportunity costs of water harvesting at basin scale.

Analysis of basin level impacts of efficient irrigation technologies on basin WP and water saving should involve consider CF as a determinant of WP rather than evapo-transpiration.

Research on potential impact of improved reliability of irrigation water and changing water allocation on WP is relevant for developing countries like India as it gives due consideration to maximizing farmers' income, while reducing the total water depleted. Nevertheless, their overall potential in improving WP in agriculture and more so in reducing water demand is open to question, unless policies and institutions are aligned to make society's interests and farmers' interests match. For the composite farming systems that are characteristic of countries like India, WP research should focus on optimizing water allocation over the entire farm to maximize the returns, through changes in crop mix and crop-livestock compositions. But, due consideration should be given to risk taking ability of the farmer, investment capabilities etc.

In countries like India, research on measures to enhance regional level WP should integrate socio-economic considerations such as food production, employment generation along with wealth generated per unit of water used up in irrigation. But, often farmers' choice of food crops like rice is not by design, but by default. Meeting food production needs or other social objectives cannot be an excuse for poor productivity. Given these constraints, regional WP scenarios can examine the scope for improving WP through increment in productivity of crops such as wheat and paddy with reliability and control regimes in irrigation, along with other measures.

To conclude, the options to enhance WP in crops in countries like India seem to be quite limited, and different from those being tried in the West, given the larger objective of addressing food security, poverty alleviation, and employment generation concerns in rural areas. Research should aim at strategies to enhance WP that are based on improving reliability, adequacy, and water allocation for reducing non-beneficial consumptive use, and non-beneficial non-reusable portions of water supplies. The inherent advantages of well irrigation systems need to be built in while designing surface irrigation systems and designing water allocation norms. But, in most cases, they could regulate water demand only if water allocation is rationed volumetrically.

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GROUNDWATER STRESS DUE TO IRRIGATION IN SEMI ARID AND ARID REGIONS: IS DAIRYING A BOON OR A BANE?

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Abstract

One of the most remarkable impacts of India's growing economy is the demand for dairy products. However, the impact of this trend on the country's land and water resources has not been analyzed. India is the largest producer of milk in the world. A recent research in north Gujarat, which is known for intensive dairy farming, has shown that dairying is the most water-inefficient production systems, taking lion's share of the groundwater resources in the region. This has made many scholars argue that dairying in semi arid regions could lead to increased use of water in agriculture with direct impact on groundwater resources in such regions. However, distinction between commercial dairy farming, and dairying which complements crop production, and their implications for water intensity, is hardly every made.

The paper makes two major arguments. The first argument is that the water-intensity of dairying in semi arid and arid regions is largely determined by the nature of dairy farming, i.e., whether crops supplement milk production or dairying is intensive (high number of cattle supported per unit area of land). In the first situation, dairying would he highly water-efficient. In the second situation, it would be water-intensive. The second argument is that the trade offs in maximizing agriculture water productivity for a region as a whole would he different in the two situations. In intensive dairy farming areas, route to reduce groundwater stress would be through reducing milk production, and increasing the contribution of high-valued crops to overall farm income. Thus, there is a trade off between increased farming risk, and reduced cash flows and regional food security. This can be minimized by making dairy production more water efficient.

In areas where cereal production complements dairying, limited opportunities exist in enhancing agricultural water productivity if food security and employment generation are not concerns. Opportunities to raise milk production in such regions from the current levels, without making it water-intensive, are extremely limited. Water-intensive dairying would result in further depletion of groundwater in such areas. Further analysis shows that dairy production in humid and sub-humid areas would be highly water-efficient, as demonstrated in the case of Kerala. Nevertheless, intensive dairy farming would require more arable land or land which can be used for grazing.

1. INTRODUCTION

India is the largest producer of milk in the world. The country's milk production had gone up from 22.51 million ton in 1970-71 to 80.81 million ton during 2000-01 with per capita milk availability increasing from 115.3 gm/day to 238.06 gm/day during the period. Both semi arid and arid regions and sub-humid and humid regions have contributed to this growth (Singh and Pundir, 2003). This achievement was possible with the gradual replacement of traditional breeds of livestock by high yielding ones (Pandey, 1995). One of the most remarkable impacts of India's economic growth is on the demand for dairy products. This is different from other countries where demand for meat products increase with growing income levels. The milk consumption in India increased by 20% during 1990-2005 in per capita terms (von Braun, 2007). According to a recent projections, the consumption of milk products in India, which currently stands at nearly 185 gm/person/day, is likely to grow at a rate of 0.7% per annum to reach 236 gm/person/day during 2000-2025 (Amarasinghe et al., 2007), further increasing the demand for increased production

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But, the likely impact of this trend on the country's land and water resources has not been analyzed. A recent research in north Gujarat, which is known for intensive dairy farming, has shown that dairying is the most water-inefficient production systems, consuming a large share of the groundwater resources in the region (Singh, 2004; Kumar, 2007). This has made many scholars argue that dairying in semi arid regions could lead to increased use of water in agriculture with direct impact on groundwater resources in such regions. But, the distinction between commercial dairy farming which is intensive, and the one which complements crop production, and their implications for water intensity in dairy production, is hardly every made.

The actual impact of dairy farming on water resources would depend on where all the milk is produced, and the nature of dairy farming. In this article, we provide comparative analysis of water productivity in crops and dairying in the two semi arid regions, viz., north Gujarat and Punjab, and demonstrate how the opportunity for reducing groundwater depletion through enhancing water productivity of crops differs between two regions, if socio-economic concerns have to be integrated in regional water allocation decisions. The first region selected for the purpose is semi-arid north Gujarat, where farmers had taken up intensive dairy farming on commercial basis, where intensively irrigated fodder crops like water-intensive alfalfa is fed to animals along with byproducts of cereal crops like wheat, bajra and sorghum. The other region is south western Punjab where cereals form a major chunk of the irrigated field crops, and dairying is taken up as a supplementary activity in which byproducts of crops are fed to animals.

2. THE CONTEXT

In water scarce regions, particularly arid and semi arid regions, heavy withdrawal of groundwater for irrigation has several undesirable consequences. Demand management in agriculture is a standard approach to water management suggested for such regions (Kumar, 2007). One important element of this approach works on water productivity of individual crops (as cited in Kumar, 2007). Water productivity in agriculture refers to the biomass output or net income returns per unit volume of water applied or consumed for crop production[1]. It suggests replacement of cereal crops which are economically less efficient in water use with cash crops which are economically more efficient in water use.

Semi arid north Gujarat is one region in India where heavy withdrawal of groundwater for agriculture is causing secular decline in groundwater levels and scarcity of water for irrigation and drinking. Enormous increase in cost of groundwater abstraction and increasing inequity in access to water are some of the socio-economic consequences. Throughout most of semi arid Punjab, heavy withdrawal of groundwater is causing depletion, with negative economic and environmental consequences. With the demand for milk and dairy products growing in India, milk production is also increasing in many areas. More importantly, dairying is emerging as a major livelihood option in rural areas of semi-arid and arid regions facing water stress like north Gujarat, Kolar district in Karnataka and Alwar district in Rajasthan. One reason for farmers' preference for dairying as a livelihood option is the ability to manage the inputs such as feed and fodder through imports during scarcity.
Recent research in north Gujarat had shown that dairying is highly water intensive, with estimated values of net water productivity in economic terms remaining far less than that of several conventional field crops[2]. Against this in Punjab, the rice-wheat system of production is supposed to deplete Punjab's groundwater resources.
The natural course for agronomists and water resource managers to reduce water stress in regions such as north Gujarat is to replace dairy crops by some of the highly water-efficient fruit crops and vegetables. Whereas in Punjab, the suggestion often made by water resource scientists and groundwater managers is to reduce the area under cultivation of paddy and wheat that take a lot of water in the form of evapo-transpiration. Another suggestion is to delay the transplanting of paddy saplings during kharif to make use of the rains.

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[1] While the first one is called physical productivity, the second one is called water productivity in economic terms.

[2] In case of cash crops, castor offered highest net water productivity (Rs.7.21/m^3) and cotton the lowest (Rs.0.68/m^3). In case of food grains, highest net water productivity was found for kharif bajra and lowest for wheat crop with Rs.4.82 and 1.08 per m^3, respectively. In case of milk production, net water productivity for buffalo milk was Rs.0.19 per m^3 of water whereas the net water productivity for crossbred cow was Rs.0.17 per m^3 (see Kumar, 2007).

But this approach has serious limitations in most situations. Firstly, it ignores the linkages between different components within the farming system, which are often integrated. For instance, reduced cultivation of low water-efficient cereals and fodder could affect dry fodder availability, which could directly have an impact on dairying, a major source of income for millions of farmers. There is a need to recognize that farmers allocate their water over the entire farm and not to individual crops. Unless we know about the comparative water productivity in dairying, decisions on changing crop compositions that help reduce water stress cannot be made. As a result, the unit of analysis of water productivity should be farming system rather than field. Secondly, it ignores the effect of such changes on local food security and livelihoods. For example, large scale replacement of low water efficient cereal crop by a highly water efficient cash crops by farmers in a region might result in reduction in water use. But, it can cause local food insecurity, and affect domestic nutritional security of farm households.

3. WHAT DETERMINES WATER INTENSITY OF MILK PRODUCTION?

The water intensity of milk production is inversely related to its water productivity. High water intensity means low water productivity. Water productivity in milk production is analyzed using the concept of "embedded water", i.e., the amount of water depleted by the crops through evapo-transpiration that are used as animal feed and fodder. The reason for this is that direct water consumption by cattle is low, whereas growing fodder and feed cereals need large quantities of water. The functional relationship between water productivity in milk production, and cattle inputs and outputs can be expressed as:

$$\sigma_{dairy,} = \frac{Q_{MP}}{\Delta_{milk}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

Where Q_{MP} is the average daily milk yield of a livestock over the entire life cycle. Δ_{milk} is the total volume of water, including the water embedded in feed and fodder inputs, used by an animal in a day. Both are worked out for the entire animal life cycle. Δ_{milk} is estimated as:

$$\Delta_{milk} = \frac{Q_{cf}}{\sigma_{cf}} + \frac{Q_{df}}{\sigma_{df}} + \frac{Q_{gf}}{\sigma_{gf}} + \Delta_{drink} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Where, Q_{cf} , Q_{df} and Q_{gf} are the average weights of cattle feed, dry fodder and green fodder used for feeding livestock; σ_{cf} , σ_{df} , and σ_{gf} are water productivity values (kg/m^3) of cattle feed, dry fodder and green fodder, respectively; Δ_{drink} is the daily drinking water consumption by livestock.

If water productivity of green fodder like fodder jowar, fodder bajra, and maize is high, then quantum of water used for dairying (Δ_{milk}) would be low. This can raise milk water productivity. If, on the other hand, the milk yield of the animal is high ($Q_{MP\ j}$), then again, water productivity of milk production would be high.

Similarly, if the amount of feed and fodder which an animal requires to be productive is low, then again milk water productivity will be high. Again, the feeding pattern would determine the amount of water needed. Wheat hay and paddy straw have high water productivity in kg/m^3. So, when farmers just depend on these crop residues for feeding animals, water productivity will be high. But, intensive dairying would force farmers to grow fodder crops for the purpose, as crop residues won't be enough. Alfalfa, used as green fodder, is highly water-intensive.

The water productivity in crop production can be estimated in relation to the total water consumed by crop during its growth (evapo-transpiration), or the total irrigation water applied for crop production or the total effective water applied, which includes the irrigation dosage and effective rainfall. Since we are concerned with the depletion of water resources available from groundwater system or surface flows for crop and milk production, it would be appropriate to consider the productivity of applied (irrigation) water. But, as precipitation also contributes to yield of many crops grown during monsoon, it is important to estimate the marginal yield due to irrigation, by segregating the rainfall contribution of the yield from total yield. This has to be used in the denominator for estimating irrigation water productivity. However, for semi arid and arid areas, the yield contribution of soil moisture from precipitation can be treated as negligible for most crops grown during monsoon[3]. This would make marginal productivity of irrigation water equal to total productivity of irrigation water (Equation 3).

Irrigation water productivity in crop production σ_{crop} (kg/m^3) $= \dfrac{Y_{crop}}{\Delta_{crop}}$ ………. (3)

Y_{crop} and Δ_{crop} are the crop yield (kg/ha) and volume of water applied per hactare of irrigated area (m^3/ha) respectively.

Nevertheless, such assumptions would induce significant errors in estimation of water productivity for kharif crops that are grown in humid and sub-humid conditions. Hence, for such areas, the marginal productivity of irrigation water is estimated by running regression between yield and irrigation water dosage. The beta coefficient of regression equation gives the marginal productivity of irrigation water.

The estimated values of physical water productivity for crops and byproducts are inputed in Equation (2) mentioned above to arrive at the value of Δ_{milk} . For byproducts of crops that are used for dairy production as inputs, the total irrigation water applied and cost of production of the crop are allocated between main product and by products in proportion to the revenue generated from them, as suggested by Dhondyal (1987).

Water productivity in milk production in economic terms (θ_{dairy}) is estimated by taking the ratio of net return from milk production (NR_{dairy}) and the total volume of embedded water, and direct water use in milk production (Δ_{dairy}). Here again, the net returns are average values, estimated for the entire animal life cycle, taking into consideration the average milk yield worked out for the entire animal life cycle, the market price of milk and the cost of production of milk worked out for animal life cycle.

$$\theta_{dairy} = \frac{NR_{dairy}}{\Delta_{dairy}} \quad \text{………………..} \ (4)$$

4. AVERAGE PHYSICAL PRODUCTIVITY OF WATER IN MILK PRODUCTION IN TWO SEMI ARID REGIONS

The physical productivity of water in milk production was estimated using the standard formula (for details see Kumar (2007) or Singh (2004)) for 2 types of livestock in north Gujarat and three types of livestock in western Punjab. The input data used for this were average daily milk yield; the average daily quantities of dry and green fodder, and cattle feed for the livestock (kg); the daily drinking water use by the livestock (m^3), all estimated for the animal's entire life cycle; and the physical productivity of water for different types of green and dry fodder (kg/m^3). Subsequently, the water productivity in milk production in economic terms was estimated using the average net return from milk production using the gross return and average cost of production of milk.

The results are presented in Table 1. It shows that the physical productivity of water for both buffalo and cross bred cow is much higher in western Punjab, when compared to north Gujarat. Further, the difference in economic productivity is much higher than that in physical productivity. The high physical productivity of

[3] Needless to say, for winter and summer crops, such assumption would be quite reasonable and would not result in errors in estimation as residual soil moisture for growing crops would be negligible.

water in milk production in case of western Punjab is attributed to the lower volume of embedded water in the inputs used for cattle owing to higher physical productivity of both green and dry fodder. In the case of western Punjab, it was found that only, green fodder such as winter jowar (fodder) and kharif bajra (fodder), and dry fodder available from residues of paddy (hay) and wheat (straw) were used. Since paddy and wheat have very high yields in the region, the physical productivity of dry fodder is very high. The cumulative effect of both these factors reduces the amount of embedded water. Whereas in the case of north Gujarat, alfalfa, a highly water intensive irrigated green fodder, was used commonly as feed for cattle.

Table 1: Milk Yield, and Physical and Economic Productivity of Water in Milk Production in two Semi Arid Regions

Variables	Punjab			North Gujarat		
	Buffalo	Cross bred Cow	Indigenous Cow	Buffalo	Cross bred Cow	Indigenous Cow
Average Milk Yield (lt/day)	3.25	4.46	2.98	3.12	5.33	N. A
Water Productivity (WP) (lt/m^3)	1.79	2.53	3.68	0.31	0.49	N.A
WP in Milk Production (Rs/m^3)	7.06	17.44	16.41	0.190	0.17	N. A

Source: based on Singh (2004) and Kumar, et al., (forthcoming)

The difference in feeding pattern can be seen from Table 2. Though the amount of green and dry fodder quantities are less in the case of north Gujarat, alfalfa (figures in brackets) accounts for nearly 70% of the green fodder for both buffalo and cross-bred cow. Further, the quantum of cattle feed used for dairy animals in north Gujarat is much higher that that for western Punjab. The much higher water productivity in economic terms was due to: i] lower cost of production of milk, owing to the lower cost of production of cattle inputs such as dry and green fodder, resulting in much higher net returns; and, ii] the lower volume of embedded water in cattle feed and fodder. The difference in cost of inputs mainly comes from water. In north Gujarat, pumping depths are much higher than in Punjab. This results in very high capital and variable cost of irrigation owing to expensive deep tube wells, high capacity pump sets, and very high electricity charges.

Table 2: Comparison of Daily Average Feed & Fodder Consumption per Milch Animal in Western Punjab and North Gujarat

Feed/Fodder	Animal Type	Bathinda (Western Punjab)	Mehsana (North Gujarat)
Green Fodder(Kg/day)	Buffalo	19.46	12.98 (9.25)
	Indigenous Cow	12.92	Nil
	Crossbred Cow	14.41	12.96 (9.07)
Dry Fodder(Kg/day)	Buffalo	7.94	5.48
	Indigenous Cow	5.07	Nil
	Crossbred Cow	4.33	6.44
Concentrate(Kg/day)	Buffalo	2.28	5.21
	Indigenous Cow	1.2	Nil
	Crossbred Cow	1.4	5.36
Drinking Water(lt/day)	Buffalo	55.8	59.10
	Indigenous Cow	52.6	Nil
	Crossbred Cow	60.2	49.10

Kumar, et al., (forthcoming) and Singh, (2004)

5. TRADE OFFS BETWEEN ENHANCING FIELD-LEVEL WATER PRODUCTIVITY AND REGIONAL WATER PRODUCTIVITY

5.1 The North Gujarat Case

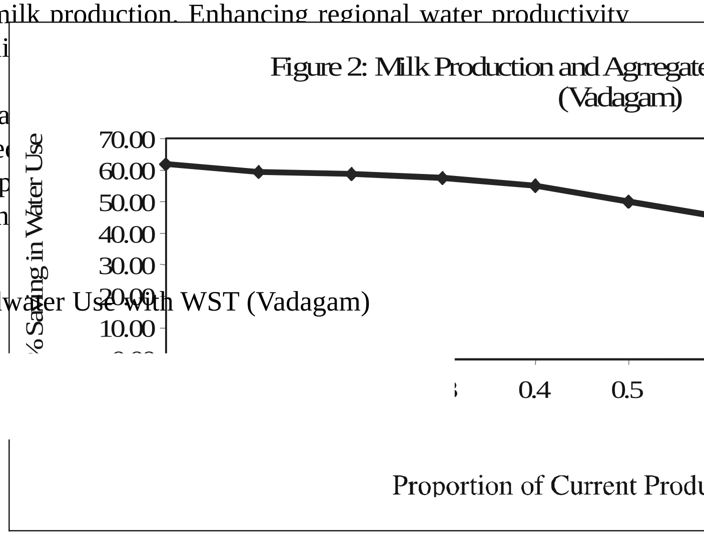
While a standard approach to improve water productivity in agriculture to reduce the stress on groundwater would be replacement of low water-efficient crops by those which are highly water-efficient. For north Gujarat, this would mean replacement of dairying by highly water-efficient crops such as orchards and cash crops like cumin. But, this would result in lower production of milk, which gives stable income and regular cash flow to the farmers. It would have significant impact on the region's milk production, which not only sustain its rural economy, but also produces surplus for export to other deficit regions.

In order to analyze the opportunities and constraints for improving regional water productivity in agriculture and reducing stress on groundwater, farm economy in four talukas of Banaskantha district in north Gujarat were simulated using linear programming. The results from 2 different optimization models, minimization and maximization, for all the four talukas were more or less similar. Results from Vadgam taluka of Banaskantha district of north Gujarat showed that the volume of groundwater used for agriculture can be reduced to an extent of 49.5% through introducing cumin or lemon. This would not affect the initial level of net farm income nor compromise on the food security of the region's population. However, while doing this, the milk production would fall sharply. This is because milk production was supported by irrigation of high water intensive crops, and any effort to cut down groundwater use meant reducing milk production.

With the introduction of water saving technologies (WSTs) for field crops including alfalfa, the extent of reduction possible in groundwater use was high (60.1%), with lower extent of reduction in milk production. The net farm output would not be adversely affected by this. Further analysis showed that using WSTs, the groundwater use could be brought down by 17.5% even if milk production in the region is maintained at the previous level. As Figure 1 (source: Kumar, 2007) shows, the extent of reduction possible in groundwater use reduces with reduced willingness to compromise on milk production. Enhancing regional water productivity and cutting down groundwater use for farming have li percentage of the total farm income is high.

Now, adoption of orchard crops and drip irriga of the capital intensive nature of the system and the nee marginal farmers would show great resistance to adop enhancing water productivity of farming system th farming risks.

Figure 1: Milk Production and Agrregate Groundwater Use with WST (Vadagam)

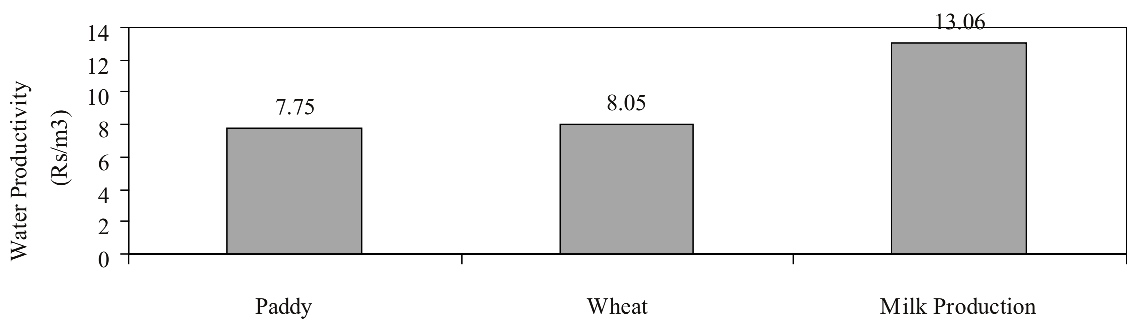


5.2 The Punjab Case

Now, let us examine farming system interactions in western Punjab. Punjab's rice-wheat system of farming has been under criticism for the low resource use efficiency, low water use productivity and groundwater over-draft. It is established that many fruit crops have higher water productivity (Rs/m^3) than conventional cereals such as wheat and paddy in arid areas. For instance, pomegranate grown in north Gujarat gives a net return of nearly 40,000 Rs/acre (i.e., USD 900/acre) of land against Rs.8000/acre (i.e., USD 180/acre) in case of wheat. WP is approximately Rs.100/m^3 for pomegranate (with an estimated annual water application of 90 mm) against Rs.4.46/m^3 for wheat. Also, there are crops such as potato, tomatoes, cumin, cotton and groundnut which are more water efficient than rice and wheat, which can be grown in Punjab. Some farmers in this region have already started shifting to high valued cash crops.

However, there is a limit to the number of farmers who can take up such crops due to the volatile nature of the market for most of these crops, the perishable nature of these crops, the high risk involved in their production[4] and the need to manage fodder for animals. In addition, investments for these crops are very high, demanding the ability to take risk. It may also be limited by the poor market support for orchard crops. Many farmers in Punjab and other semi arid parts of India, manage crops and dairy farming together. Recent analyses from western Punjab suggests that the net water productivity in rupee terms is enhanced when byproducts of cereal crops are used for dairy production (see Figure 2). Water productivity in dairying was found to be higher than that of wheat and paddy (Kumar et al., forthcoming).

Figure 2: Water Productivity in Crops and Milk Production inWestern Punjab



The equation presented in the earlier section explains this phenomenon. Unlike in the case of north Gujarat where dairying is intensive, farmers in Punjab practice it as a complementary activity to crop production, and depend mostly on crop residues such as wheat hay and paddy straw. They also do not grow highly water-intensive fodder crops like alfalfa. Water productivity (in kg/m^3 of water) for these byproducts is very high.

There are potential trade off exists between maximizing field level water productivity through crop shifts and maximizing water productivity at the farming system level. It is possible to enhance both field and farm level water productivity simultaneously by introducing high valued crops such as vegetables and fruits, if those crops have higher water productivity values than dairy production[5]. However, in both the cases, the risk involved in farming might increase. The reason is highly volatile nature of vegetable prices; and the high chances of drastic increase in fodder prices or fodder scarcity, in the event of a drought. It is found that while the normal price of dry fodder such as wheat hay and paddy straw is Rs. 1/kilo, it goes up to Rs. 4/kilo during drought years.

[4] The markets for fast perishing vegetables are often very volatile, and price varies across and within seasons. The problem of price fluctuation is also applicable to cotton grown in western Punjab, which has high water productivity.

[5] Otherwise, if the water productivity values of newly introduced crops is not higher than that of dairying, but, higher than that of cereals, then fodder will have to be imported to practice dairying.

At the regional level, attempts to adopt water efficient crops or crop-dairy based farming to enhance agricultural water productivity might face several socio-economic constraints. National food security is an important consideration when one thinks about crop choices. Punjab produces surplus wheat and rice and supplies them to many other parts of India, which are food deficit, including eastern India (Amarasinghe et al., 2004; Kumar, Gulati and Cummings, 2007). 20% of country's wheat production, and 10% of its rice production comes from Punjab; it contributes 57% and 34% respectively to the central pool of grains for public distribution (Kumar, Gulati and Cummings, 2007).

Labour absorption capacity of irrigated agriculture and market prices of fruits are other considerations. Paddy is labour intensive, and a large chunk of the migrant labourers from Bihar work in the paddy fields of Punjab. As per our estimates, 2.614 million ha of irrigated paddy in Punjab (as per 2005 estimates) creates 159 million labour days[6] during the peak kharif season. The total percentage of farm labour contributed by migrant labourers during peak season was reported to be 35% as per the Economic Survey of Punjab 1999-00 (GoI, 2001). Based on these figures, we estimate that the total number of labour days contributed to paddy fields by migrant labourers in Punjab was 55.75 million.

Replacing paddy by cash crops would mean reduction in farm employment opportunities. On the other hand, the lack of availability of labour and fodder would be constraints for intensive dairy farming to maximize farming system water productivity at the regional level, though some farmers might be able to adopt the system. Large-scale production of fruits might lead to price crashes on the market, and farmers loosing revenue unless sufficient processing mechanisms are established. Hence, the number of farmers who can adopt such crops is extremely limited.

5.3 The Contrasts between North Gujarat and Punjab

Comparison of north Gujarat and western Punjab shows that even under similar climates, the routes to enhance water productivity and impacts of such initiatives on the farmers at the household level and on the socioeconomic system would be different, because of the difference in their farming systems. In north Gujarat, water productivity improvement calls for replacing dairy farming with cash crops, and use of micro irrigation systems for conventional crops. In Punjab, paddy-wheat system needs to be replaced by crops with higher water productivity than that in livestock farming, and dairying needs to be continued with imported fodder. Import of fodder from neighbouring regions of is not an option. Situation in eastern India appears bleak, as these regions are net importers of food grains, and have very little arable land. While Haryana is an agriculturally prosperous region, dairying is also quite intensive in this region.

Introduction of cash crops in the farming system of north Gujarat would have adverse impact on the stability of farm income and cash flow to farm households. However, there would be no impact on self sufficiency in cereals. On the contrary, in western Punjab, there will be adverse impacts on regional food security, employment and risks in farming. In spite of the differences between the two regions, integrating socio-economic concerns such as food security, reducing risk in farming, improving livelihood opportunities through agriculture and improving water productivity in agriculture to save water for environment are extremely limited.

Now there are many semi arid and arid regions in India, where dairying is emerging as a major source of livelihood in rural areas. They include western Rajasthan and Peninsular and Central India. These regions are also facing problems of groundwater over-draft. It is difficult to conclude that in semi arid and arid regions, dairying would lead to further depletion of groundwater on the basis of the north Gujarat experience. In composite farming systems like the one in western Punjab, where dairying compliments cereal production, reasonably high levels of water productivity can be achieved in dairying. Such complementarity comes due to large area under crop production in per capita terms, with the result that the available crop residues are sufficient to feed the livestock. Hence, it does not exert any additional pressure on local water resources.

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6 This is based on the primary data which show that a hectare of paddy creates Rs. 5000 worth of farm labour in Punjab. This is exclusive of the machinery employed in ploughing and harvesting. With a labour charge at the rate of Rs.80/day, the number of labour days/ha of irrigated paddy is estimated to be 61 (source: primary data from Punjab).

Other opportunities for reducing pressure on groundwater through water productivity improvement in agriculture are extremely limited if the region contributes significantly to national food security and rural employment. In addition, there are limits to intensifying dairy production in such regions. The reason is that if dairying were intensive, with fodder crops grown specially instead of using crop residues, it would become water intensive. In that way, it can induce additional pressure on local groundwater resources. But, there are some ways to reduce the pressure on groundwater. They could include: enhancing water productivity of individual crops, including those used for dairying through micro irrigation, which will also make milk production less water-intensive.

6. CAN DAIRYING THRIVE IN WATER RICH REGIONS OF INDIA?

There are regions in India, which are under humid and sub-humid climatic conditions, including Kerala, north east, the western and eastern Ghat regions, and the Sub-Himalayan region. These regions have high rainfall and humidity, and low evaporation and evapo-transpiration. Such regions also indulge in dairy farming. These regions have a lot of naturally grown grasses which provide nutritious fodder for livestock. They also get dry fodder from residues of crops, particularly paddy. The advantage of such regions is that not only the consumptive use of water by fodder crops would be very less, but most of the water needs would be directly met from precipitation. This is evident from a study conducted in Palakkad district of Kerala. It shows that green grass accounts for 84 to 95% of the total green fodder fed to livestock.

Table 3: Average Feed and Fodder Fed to Livestock in Palakkad, Kerala (kg/day/animal)

Name of Feed and Fodder	Average Daily Input (kg) for		
	Buffalo	Crossbred Cow	Indigenous Cow
Green Fodder	16.00	15.59	12.17
Local green grass	13.37	14.05	11.59
Maize	2.64	1.54	0.58
Dry Fodder	11.75	11.39	10.63
Paddy Straw	11.75	11.39	10.63
Concentrate	3.37	3.34	2.59
Balanced cattle feed	1.57	1.73	1.12
Cotton seed cake	0.38	0.44	0.25
Wheat Bran	0.43	0.66	0.28
Rice Bran	0.99	0.51	0.94
Drinking Water (m^3.)	0.034	0.029	0.023

Source: Rajesh and Tirkey (2005)

This has a big impact on the irrigation water used for green fodder fed to cattle. It was found to be in the range of 40 - 160 lt/day/animal (Table 4). As a result, the effective water productivity in milk production (physical) was higher as compared to the semi arid north Gujarat. The study estimated effective irrigation water productivity in milk production to be 0.50lt/m^3, 0.74lt/m^3 and 0.51 lt/m^3, respectively, for buffalo, cross-bred cow and indigenous cow (Table 4). As Table 4 shows, though the actual irrigation water productivity in milk production is much lower than these figures, a significant chunk of the water used up in milk production is the embedded water in cattle feed. It was 48.7%, 46.2% and 47.1% of the total water used for milk production, for buffalo, cross bred cow and indigenous cow, respectively (see Table 3). Since local water resources are not used for their production, and are available from imports, they are not considered while estimating water productivity.

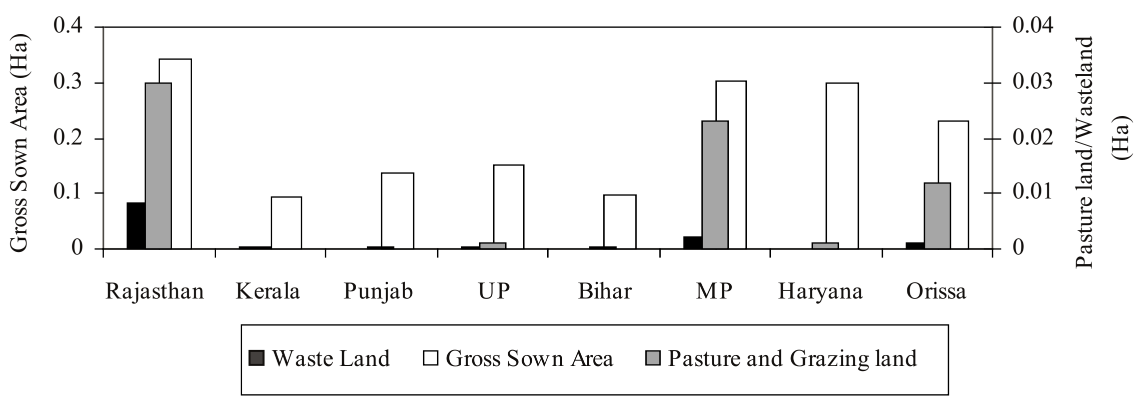
Further, the cost of producing fodder was found to be negligible, when compared to that of cattle feed. It worked out to be 10.6%, 8.9% and 13% of the total input cost, for buffalo, cross-bred cow and indigenous cow, respectively. The water productivity in economic terms was also relatively higher when compared to north Gujarat. The estimated effective irrigation water productivity was Rs. 1.0/m^3, Rs. 1.88/m^3 and Rs. 1.55/m^3 or buffalo, cross-bred cow, and indigenous cow, respectively in Kerala (see Table 4) (Rajesh and Tirkey, 2005). Groundwater depletion due to agricultural withdrawal is not a problem in these regions. But, the amount of land available for dairy farming is a major constraint for increasing dairy production. While per capita land availability is high in semi arid regions, it is extremely low in humid and sub-humid regions. The data on per capita gross sown area, per capita pasture land, and per capita wasteland in eight major Indian states are given in Figure 3. It is clear that the per capita land available in common lands (wasteland and pasture land) and cultivated area in semi-arid to arid Rajasthan is 0.454 ha. It is 0.30 ha in Haryana against only 0.094 ha in Kerala (Figure 3).

Table 4: Total Water Use and Water Productivity in Milk Production, Palakkad, Kerala

Particulars	Kerala		
	Buffalo	Crossbred Cow	Indigenous Cow
Green fodder (m^3)	0.16	0.10	0.04
Dry Fodder (m^3)	4.73	4.59	4.28
Concentrate (m^3)	4.67	4.06	3.87
Drinking Water (m^3)	0.034	0.029	0.023
Total Water used (m^3)	9.60	8.77	8.21
Milk Production (Litre/day)	2.46	3.49	2.36
Irrigation Water Productivity (IWP) (litre/m^3)	0.26	0.40	0.29
Effective IWP in Milk Production (litre/m^3)	0.50	0.74	0.51
IWP in Milk Production (Rs/m^3)	0.51	0.90	0.74
Effective IWP in Milk Production (Rs/m^3)	1.00	1.88	1.55

Source: Rakesh and Tirkey (2005)

Figure 3: Per Capita Land Availability under Different Classes in Selected States of India



7. SUMMARY OF FINDINGS

Within the same agro climate, the nature of dairy farming determines the water intensity of milk production. It is low water intensive in regions where cereal production compliments low levels of dairy production, which minimizes the amount of irrigated green fodder used. The case of Punjab demonstrates this. When dairying is practiced intensively, production of irrigated green fodder becomes compulsory to sustain such high levels of inputs required to maintain high level of production. This makes dairy production highly water-intensive as demonstrated by north Gujarat. In sub-humid regions like Kerala, milk production is highly water-efficient, and it induces no pressure on local water resources, as it is sustained largely by green grass (which is naturally available), and residues from crop production.

In semi arid and arid areas with intensive dairy farming, replacement of dairy farming by highly water-efficient orchards and cash crops would be the way to enhance water productivity in agriculture, and reducing the stress on groundwater without adverse consequences for economic prospects of farming. But, concerns of ensuring stable farm income and cereal security would limit our ability to shift from dairy farming to highly water-efficient crops. The best way to improve agricultural water productivity without adverse effects on farm income, food security and resilience of farming would be to make dairy production more water efficient through efficient irrigation technologies for all fodder crops and crops whose byproducts are used as dairy inputs.

There are other semi arid and arid regions like Punjab, which produce surplus cereals for food deficit regions. Rice-wheat system of production is mainly responsible for groundwater over-draft in this region. Since this region is not a major contributor to India's milk bank, decline in milk production in this region won't pose any major challenge to the country's nutritional security. But, any attempt to replace wheat and paddy should consider crops which have water productivity higher than that in dairying. The reason is dairying, which cereal production sustains, yields much higher water productivity than cereals alone. Again, the scope for introducing crops, which are more water-efficient than dairying (like orchards) have constraints of regional food security and labour absorption in agriculture.

8. CONCLUSIONS

Dairying is emerging as a major economic activity in rural areas of India, given the growing demand for milk and other dairy products, and the ability of farmers to manage the inputs for dairying through feed and fodder imports in the face of water scarcity. In semi arid and arid areas, the pressure dairying puts on local groundwater would depend on the levels of water productivity achieved in dairying, the intensity of dairying, and what portion of the animal feed and fodder are locality produced. Analysis presented in this paper suggests that the water intensity of dairy farming could be remarkably different between regions of same agro climate, depending on the intensity of dairying vis-à-vis the number of dairy animals supported by the available cultivated land.

The most desirable situation is one in which crops compliment dairy farming. Such situation is possible when number of cattle per unit of cultivated land is relatively low. This ensures greater quantities of dry fodder available from crop residues. In such situations, overall water productivity of the farming system would be reasonably higher. There are no easy ways to increase milk production in such regions without making it water-intensive. But, that would cause further depletion of groundwater reserves in those regions. Again, such options are applicable to areas that have extra arable land that can be brought under cultivation. This is not applicable to Punjab, which already has high cropping intensity. Large scale import of dry and green fodder would be difficult. But, sub-humid and humid regions in India are not able to produce surplus fodder that can be exported to these regions.

Intensification of dairy farming is undesirable for semi arid regions, which depend on locally grown irrigated fodder crops, other than those obtained as by products of crop as this implies water-intensive milk production. Dairy intensification is an option where the per capita arable land is very low. In such cases, the opportunities for improving regional water productivity, which do not adversely affect milk production, need to be explored. The idea is to conserve groundwater without affecting the socio-economic conditions of the communities which depend on it. This is in view of the fact that demand for dairy products is increasing exponentially in India, and the country cannot afford to allow decline in milk production. The options include: improving water productivity of crops, included those used in milk production, through the use of micro-irrigation; and replacement of existing low valued crops by high-valued orchard crops. For achieving these, promoting drips through subsidies could be one step, particularly for those fodder crops which fetch lower market value.

While sub-humid and humid regions offer great potential to produce milk without depleting local water resources, they have limited land availability. Unfortunately, such regions in India have much less cropped area (gross sown area), pasture land and wasteland, which can supply biomass for dairy production. In a nutshell, intensive dairy farming is likely to pick up in semi arid and arid areas, which have sufficient arable land. But, this will not be ecologically sustainable, and would eventually result in depletion of local water resources. In such regions, efforts should be made to make it more water-efficient through use of micro irrigation systems for the crops, including water-intensive forage crops. While ecologically sustainable dairy farming is possible in sub-humid and humid areas, there are major constraints to boosting milk production from such regions.

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ECONOMIC VALUATION OF A WETLAND IN WEST BENGAL, INDIA

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Abstract

In the Gangetic flood plain of West Bengal, wetlands are used for multiple purposes, and have significant role in the livelihoods of the local people. Over the years, these Multiple Use Systems (MUSs) are getting converted to single use systems due to economic and social pressure from dominant stakeholders, which are higher than that in single use systems. Economic and ecological functions of MUS changes over time and space. These dynamic aspects of MUS are often not fully appreciated. Attempts to classify wetlands according to their uses across ecological zones and to do their economic valuation are very limited.

Based on available secondary information, a wetland was selected in Bardhaman district of West Bengal to evaluate the economic benefits from multiple uses namely, wetland cultivation, irrigation, fisheries, jute retting, and fodder collection. The study shows that the major economic benefits that people living in the surrounding area of wetland derive are from wetland cultivation; direct irrigation; jute retting; and fisheries. The most important benefit was from fisheries, followed by wetland cultivation and jute retting. The irrigation benefits were found to be low due to larger distance of the land from the wetland, and the easy access to shallow groundwater in the region. However, the many ecological functions of the wetlands are not evaluated in the study.

1. INTRODUCTION

Water systems are used for various purposes. However, except for one or two uses, most uses might be non-consumptive in nature. Supplementary uses, which are consumptive in nature, may compete with the dominant uses. Hence, decision making with regard to allocating wetlands for various uses might involve trade offs. Hence, understanding the nature of trade offs is important for better decision making in water management (Dugan et al., 2006).

In India, wetlands are classified according to their location (coastal or inland), water quality (saline or freshwater), physiognomy (herbaceous or woody), duration of flooding (permanent or seasonal) etc. However, the uses and their economic aspects are missing from the present classification system (Gopal and Sah, 1995). The classification of wetlands according to their major and minor uses (both consumptive and non-consumptive), and quantifying the benefits from them in economic terms is crucial for identifying conservation interventions and improving their performance. As Renwick (2001) argues, accounting for economic value of all uses of water within a multiple use system is essential for informed decision making for productive, equitable and sustainable water uses.

But, uses of wetlands are dynamic. The type of use varies with space, i.e., across different ecological zones. For example, wetlands in the Gangetic floodplain of West Bengal mostly use for irrigation (e.g., Bardhaman and Nadia district), whereas costal wetlands are mostly use for shrimp culture because of sea water interface (e.g., South 24-Parganas and Medinipur district of West Bengal). The wetland uses also change across years depending on the interest of the dominant stakeholders, and the social pressures. For example, a tank, which is predominantly used for irrigation in a normal rainfall year, might be used for fisheries purpose as well in a very wet year when the tank inflows become large. Similarly, in a bad year, the same tank might get used for tank bed cultivation when the inflows are insignificant. Therefore, in order to have a comprehensive understanding, evaluation of wetlands should cover different ecological setting and typical years, i.e., wet, dry and normal.

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Further, the existing property right regimes are important for proper management of MUS. As Datta and Roy Choudhary (1999) argue, ownership pattern of the wetland (e.g., common property resource, private property - single owner or multiple owner, and public property) greatly influence economic and ecological performance of the wetland. Therefore, it is also very important to evaluate the performance of the **MUS** under different property rights regime

There are some studies available on multiple purposes. For example, **Q.** Li et al. (2005) carried out a study for the Lower Bhavani Project canal in Tamil Nadu, Boelee et al. (2007) carried out case studies for irrigation systems in Africa and South Asia. Gowing et al. (2004) argued that auxiliary storage reservoirs could improve the efficiency of Mahaweli System in Sri Lanka through improving service delivery and recovering return flows, it could also provide an opportunity to use the reservoirs as **MUS.** Meinzen-Dick and Bakker (1999) argued that accommodation of stakeholders in participatory management of water system is important to enhance the productivity of the system. Instead of single use system, multiple use systems generate large benefits to the society and it is accrued to different groups of people. Studies analyzing economic and ecological value of wetlands exist in India and elsewhere. However, valuation of wetland, which performs as multiple use systems, is rare.

1.1 Economic Valuation of Wetland as Multiple Use System in India

Economic valuation of wetland has been carried out in different parts of India. Researchers have attempted to capture both use and non-use values of wetlands. Verma (2001) estimated economic value of Bhoj wetland (having water spread area of 32.29 square kilometer) for mainly direct uses. Das et al. (2002) estimated the economic value of ten wetlands in the Gangetic flood plain in Bardhaman district of West Bengal. The area of the wetlands varies from 10 ha to 275 ha with an average area of 66 ha. The estimated economic benefit from fisheries operation varies from Rs. 500 to Rs. 16,000 per ha per year; average irrigation benefit is Rs. 3.543 with a maximum of Rs. 16,000; average benefit of using wetland for jute retting is Rs. 200 per ha per year with a maximum of Rs. 625 per ha per year. Average benefit from fisheries operation varies from Rs. 2,484 per household, irrigation benefit – Rs. 1,105 per acre and jute retting Rs. 483 per household per year.

Chattopadhyay et al. (2002) estimated the potential losses due to conversion of 1500 ha of East Calcutta Wetlands in the year of 1999-2000 as Rs. 338.90 million. The willingness to pay of the stakeholders to conserve the East Calcutta Wetland, the amount varies from Rs. 60/per household/year to Rs. 1200/per household/year, with an average of Rs. 380/per household/year.

2. OBJECTIVES

The maim objective of this study is to assess the economic value of various functions of a multiple use wet land in West Bengal, excluding those which are ecological in nature.

3. DESCRIPTION OF THE STUDY LOCATION

The present study focused on economic valuation of wetland as **MUS** in a perennial fresh water wetland in West Bengal. Though, Bhattacharya et al. (2000) and ISRO, IWMED and NATMO (2003) identified wetlands in West Bengal, it is difficult to identify the wetlands according to their uses. Based on the ecological condition and pressure from economic activities, wetlands in different areas are used for different purposes. Therefore it is difficult to identify wetlands which are used as MUS. The selection of a multiple use water system is based on the study conducted by Das et al. (2002) among ten wetlands in Bardhaman district of West Bengal. Based on available information on different functions and uses of wetlands among ten wetlands, we have selected a single wetland for our case study. Their corresponding returns for a private wetland in West Bengal State of India.

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[2] Beel (or Bheel) **is a** natural lake, generally an oxbow in Assam and West Bengal (Gopal and Sah, 1995). It is a U-shaped lake water body formed when a wide meander from the mainstream of **a** river **is** cut off to create a lake. Source: http://en.wikipedia.org/wiki/Oxbow–lake).

Kalobaur beel is an oxbow lake located in Dainhat municipality of Bardhaman district of West **Bengal.**[2] Mean depth of water of the beel varies from 3.36 meter in pre-monsoon to 8.39 in post-monsoon and the water spread area of the beel is 32 ha in pre-monsoon and 38 ha in post-monsoon. According to 2001 Population Census, Dainhat municipality has 4,526 households with a total population of 22,593. However, the beel is located in Ward No. 2 and 10 of Dainhat municipality. Four habitations viz., Natunpara, Gopalganj, Vhaosingh para and Char Dainhat surround the beel. It is in the East side of the Dainhat railway station and almost 3 Kilometer away from the station. The beel is in the right side of the Hoogly River and within one kilometer of the river. Hydrology of the beel gets influenced by the Hoogly River, and gets water from the river through lateral seepage.

The area of Kalobaur beel is approximately 40 ha which is currently under the ownership of 45 households. Our filed visit revealed that the local municipality wanted to procure the Kalobaur beel and the adjacent land from the owners and farmers to conserve the beel for livelihoods development. However, owners of the wetland are not willing to hand over the beel to the municipality.

After the construction of Farakka Barrage, the wetland got a fresh life. Now, most parts of the year beel gets water. Since the whole area is under the Gangetic flood plain, it gets flooded during rainy season and remains waterlogged for three to four months (June - July to September – October). After construction of Farkka barrage, siltation rate in the Hoogly River has gone up which results in recurrent flood in the Gangetic Flood plain of West Bengal. Deposition of silt during rainy season make the land in the flood plain highly fertile and farmers could cultivate only two crops instead of tree crops in other parts of West Bengal. Jute is the main crop cultivated during water logged periods, as it can with withstand standing water and requires standing water for retting. The Kalobaur beel is a multiple use system, where apart from fisheries (both indigenous and cultured), the wetland bed itself is used for cultivation of boro paddy and jute. The wetland water is also used for irrigation and jute retting and farmers collect fodder from wetland. The farmers told that they find cultivation of paddy in the wetland is remunerative as they could save money in terms of labour, irrigation and fertilizers costs.

Das et al. (2002) estimated number of beneficiaries and benefits derived from different uses of the Kalobaur Beel. Culture fishery is the major activity and 200 households derive total benefit of **Rs.144000/year.** Next is the irrigation benefit where 100 farm-households derive total benefit of Rs. 70,000/year. Another 60 households derive benefits from jute retting where total benefit is Rs. 20,000/Year.

4. METHODOLOGY AND DATA SOURCES

4.1 Methodology of Economic Valuation

There are six major direct economic functions of the wetland, viz., use for cultivation; use of wetland as a source of irrigation; wetland fisheries; use of wetland water for domestic uses; and jute retting and as a source of fodder. The economic value of wetland cultivation was evaluated by taking the incremental benefit from wetland cultivation over upland cultivation and the rental value of land used for wetland cultivation. The economic value of irrigation benefit from wetland was assessed by taking the differential cost/opportunity cost of irrigation from alternative sources and the total area irrigate from the wetland and the opportunity benefit of using wetland water.

Economic value of fisheries in the wetland was evaluated by considering the two management patterns: a) owners operated, i.e., when wetlands owners carry out the fisheries operation; and, b) lease holders operated, i.e., when fisheries operation is leased out to private operators. Both costs and benefits aspects were considered for the estimation of economic value of fisheries operation in the wetland. The economic benefit of using wetland for various domestic uses was evaluated by considering the costs of substitution and benefits of convenience approach. Fodder collection benefit from wetland was evaluated by considering the cost of buying equivalent amount of fodder from the village. However, this is applicable to only those who do not have land, or do not cultivate crops such as wheat and paddy whose byproducts can be used as fodder.

4.2 Sampling Procedure

A random sampling procedure was followed to select sample households on the basis of the discussion of local people and discussion with the local field assistants. Voluntary participations of the respondents were sought based on their availability of time and interest on the subject of our research. A pre structured questionnaire survey has been administered among 55 farm-households spread across eight habitations surrounding the wetland. The survey has been conducted during January 2008 with the help of five qualified field assistants and three local guides. A brief description of the scope and coverage of the study and possible outcomes of the study was provided before starting face-to-face interviews with the head of the household. Apart from household questionnaire survey various secondary information were collected from the local people, fertilizer shop and local political leaders.

4.2.1 Sampling Criteria

Since stratification of the sample households on the basis of their land holding size and dependence on the Kalobaur beel was difficult due to paucity of secondary level information. We have followed selected sample households having land in the beel or use the wetland bed to cultivate crops or use wetland water to irrigate croplands.

4.2.2 Profile of the Respondents

Age of the respondents varies from 15 years to 69 years with an average age of 45 years. Out of 55 respondents, thirteen of the respondents (i.e., 23.6%) were young (£ 35 years), another 30 respondents (54.5%) were middle aged (36 – 55 years) and 12 respondents (21.8%) were old having age greater than 55 years. Education level of the respondents varies from zero to 17 years, with an average year of education of 8 years (Table 1). Family size of the respondents varies from 2 to 15, with an average of 6. Our sample covers a total of 332 population of which 55% male and 45% female, children (below 15 years of age) constitutes 21% of our sample population. Mean family workforce participation rate for our sample households is 45.5% as compared to 75% for male. In our sample population 65.5% of adult male population is economically active as compared to 39.2% of their female counterpart (in Table 2). Forty seven% of respondents were Schedule Caste, 35% Other Backward Caste (OBC) and another 18% were open category.

Table 1 shows that the sample households hold 44.7 ha of land, of which 18.7 ha is under wetland and 26.0 ha is under upland cultivation. Average size of wetland holding is 0.41 ha which varies from 0.04 to 2.31 ha, and for upland average size of land mean holding is 0.65 ha with a minimum of 0.12 ha and maximum of 3.35 ha. For all together mean land holding is 1.01 ha which varies from 0.23 to 4.86 ha. Majority of the farmers are marginal and small farmers having land up to 1 ha. Both number of holdings and area under operation show similar pattern.

5. RESULTS AND DISCUSSION

5.1 Benefits from Wetland Cultivation

0During monsoon the area surrounding the Kalobaur beel gets water logged and except jute it is difficult for farmers to cultivate other crops during the monsoon. Jute is the only crop which could withstand the standing water as a result jute is cultivated both in upland surrounding the wetland and the wetland bed. **As** water recedes from the land surrounding the beel, farmers start cultivation by spreading the deposited silt uniformly through ploughing and taking out extra water from the land. Upland farmers surrounding the beel generally get two crops per year and farmers having land in the water spread area of the beel gets single crop. Boro paddy is the major crop cultivated in the water spread area of the beel, where the process of cultivation starts at the end of November in every year. Farmers found wetland cultivation is remunerative as they could save money in terms of fertilizer costs and labour costs in terms of less time spent on irrigation. Apart from the nutrient enriched silt of the wetland, wetland water has high nutrient value as a result farmers are expected fetch higher yield for wetland paddy as compared to upland paddy. Farmlands surrounding the beel are irrigated mostly from the beel and it helps the farmers to cut down their costs on fertilizers as nutrient of wetland water is higher than the fresh water from ground and/or river.

During summer season when wetland bed dries up, wetland cultivation is a common practice carried out by the farmers having land in wetland bed and/or in the low lying area. According to our sample survey total area under wetland cultivation is 30 acre. Paddy and jute are the major crops cultivated in the wetland bed. 55% of our sample households cultivate wetland paddy with an average size of land holding is 0.6 acre and another 18% of our sample households cultivate jute in the wetland bed with an average size of land holding is 0.9 acre. Total area under wetland paddy cultivation is 18 acre and jute is 9 acre. According to discussion with the stakeholders, 70 households practice wetland cultivation. If the wetland cultivators cultivate the wetland for paddy and jute only, then total area under wetland paddy cultivation is estimated to be 25 acre and jute cultivation is 13 acre. The benefits from an acre of cultivation of paddy and jute are provided in the Table 3. The estimated benefit from wetland cultivation is Rs. 3.59 lac per year.

Table 1: Land Holding Pattern of the Sample Households

Land	Holding category	Wetland Holding		Upland Holding		Wetland and Upland Holding	
		Number	Area (in ha)	Number	Area (in ha)	Number	Area (in ha)
Sub-marginal	(< 0.5 ha)	42 (76)	6.1 (33)	36 (65)	6.3 ***(24)***	23 (42)	7 (16)
Marginal	(0.5 - 1.0 ha)	8 (15)	5.2 ***(28)***	11 (20)	7.7 (30)	14 (25)	9.5 (21)
Small	(1.0 - 2.0 ha)	4 *(7)*	5.1 (27)	7 (13)	8.7 (33)	16 (29)	21 (47)
Semi-medium	(2.0 - 4.0 ha)	1 (2)	2.3 (12)	1 (2)	3.4 (13)	1 (2)	2.3 (5)
Medium	(4.0 - 10.0 ha)	--	--	--	--	1 (2)	4.9 (11)
Total		55 (100)	18.7 (100)	55 (100)	26.0 (100)	55 (100)	44.7 (100)

Note: Figure in the parenthesis shows the percentage of total number of observation and total land holding of the sample households.
Source: Primary Survey

5.2 Benefits from Using Wetland as a Source of Irrigation

Cost of irrigation from wetland is cheaper for upland paddy cultivation as compared to irrigation from wetland. The cost of irrigation from wetland mostly depends on the distance between wetland and farmland, which varies across farmlands from minimum 200 feet to maximum 6,562 feet with an average distance of 2,436 feet. However, costs of irrigation for farmers using both groundwater and wetland water is comparatively lower. Since the pricing of canal and river water is not volumetric basis, the cost of irrigation is cheaper.[3] In the Gangetic flood plain groundwater depth is low and it varies from 50 to 200 feet across our sample farmlands with an average of 137 feet. A different picture emerges for upland jute cultivation. The cost of irrigation from wetland is higher as compared to groundwater. Average depth of groundwater is lower for farmlands where jute is cultivated i.e., 75 feet. For jute nutrient benefit of using wetland water for irrigation is distinct as compared to paddy cultivation.

[3] Cost of using canal and river water for irrigation is **Rs.** 800/bigha/year. Farmlands in this area mostly cultivated twice, therefore **cost** of irrigation from canal **or** river water is **Rs.** 400/bigha/ season.

Table 2: Number of Beneficiaries according to Use of Wetland

Different Uses of Wetland	Beneficiaries (No of Households.)
a) Wetland cultivation (No. of Hhs.):	70
b) Wetland fisheries (No. of Hhs.):	66
c) Imgation from Wetland (No. of Hhs.):	50
d) Jute retting (No. of Hhs.):	250
e) Duck keeping (No. of Hhs.):	25
f) Fodder collection (No. of Hhs.):	150
g) Cattle grazing cattle (No. of Hhs.):	150
i) Collection of small fishes, snails (***Samuk, Googli*** etc.) and amaranthus (***Kalmi, Hincha, Saluk*** etc.) (No. of Hhs.):	30
j) Domestic uses for bathing washing (No. of Hhs.):	250

Apart from wetland cultivation, according to our sample survey 36.6 acre (Kharif 19 acre; Rabi: 16.5 acre and Boro: 1.1 acre) of upland is irrigated from the Kalobaur beel. The farmers irrigating farmlands from wetland do not have to pay any fees or royalty to the owners of the wetland. Pumping groundwater from shallow bore wells fitted with pump set having capacity of 5 Horsepower is also common during dry season. The cost of pumping water from the wetland depends on the distance between wetland and the farmland. Mostly diesel pump set having capacity of 5 horsepower is used to pump water from wetland to irrigate upland surrounding the beel. Farms adjacent to the beel also use manual lifting devices. Average cost of pumping water from the wetland is estimated based on the number of times a farmland is irrigated and average hour of irrigation. Average cost of taking a pump set in rent is Rs. 50/hour and average diesel consumption is 1 litre per hour. There at Rs. 35/litre of diesel price, the cost of pumping water per hour is Rs. 85. Apart from paddy and jute, cucumber, mustard seeds, wheat, and other vegetables are cultivated in the wetland bed and also in peripheral areas of the wetland. Farmers told that they find irrigation from wetland is remunerative as they could save money in terms of fertilizers costs.

To estimate the nutrient benefit of using wetland water for irrigation, we estimated fertilizer cost associated source(s) of irrigation. The difference in the costs is taken as benefit of using wetland water for irrigation. Average benefit of using wetland water over groundwater for upland paddy cultivation is Rs.555/acre/season

Table 3: Economic Benefit of Wetland Cultivation

Sources of Benefits and Costs	Paddy	Jute
Average Net Benefit from Wetland Cultivation (in Rs./acre/season)	12,834	40,812
Average Net Benefit from Upland Cultivation (in Rs./acre/season)	7,143	37,068
Incremental Benefit from Wetland Cultivation (in Rs./acre/season)	5,691	3,744
Cost of Hiring Upland (in Rs./acre/season)*	4,375	4,375
Total Benefit of Wetland Cultivation (in Rs./acre/season)	10,066	8,119
Area under Wetland Cultivation (in acre)	25	13
Net benefit from Wetland Cultivation (in Rs./acre/season)	2,51,650	1,05,547

Note: *-prevailing land rent payable to lease in upland is Rs. 2500/bigha/year and wetland is Rs. 1000/bigha/year. In case of upland it is used for two crops and wetland it is for single crop (3.5 bigha = 1 acre)

Table **4:** Benefit of Wetland Paddy Cultivation

	Wetland Paddy Cultivation			Upland Paddy Cultivation		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Seed Cost (in Rs./acre)	839 (10)	350 (9)	1960 (13	614 (4)	368 (8)	980 (3)
Labour Charges (in Rs./acre)	4950 (59)	2800 (71)	7700 (51)	4,325 (30)	1,750 (39)	10,500 (29)
Cost of Irrigation (in Rs./acre)*				6,157 (43)	1,400 (31)	17,850 (49)
Cost of Hiring / Using Farm						
Machineries Cost (in Rs./acre)	1519 (18)	560 (14)	2450 (16)	1,594 (11)	735 (16)	3,500 (10)
Fertilizer & Pesticide Cost						
(in Rs./acre)	1075 (13)	224 (6)	3136 (21)	1,545 (11)	263 (6)	3,500 (10)
Total Cost (Rs./acre)	***8,383***	***3,934***	***15,246***	***14,235***	***4,515***	***36,330***
Yield (in Quintal/acre)	29.3	22.4	35.0	28.5	19.6	42.0
Market Price (Rs./quintal)	724	500	1000	751	583	1,250
Gross Revenue (Rs./acre)	***21,216***	***11,200***	***35,000***	***21,377***	***11,433***	***52,500***
Net Revenue (Rs./acre)	12,834 7,266	19,754	7,143	6,918	16,170	

Note: Figure in the parenthesis shows the percentage of total cost
*-implies that for wetland paddy cultivation cot of irrigation is included in labour charges and machinery hiring/using costs.
Source: Primary Survey

Table **5:** Benefit from Wetland Jute Cultivation

	Wetland Jute Cultivation			Upland Jute Cultivation		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Seed Cost (in Rs./acre)	247 (3)	105 (2)	350 (3)	198 (2)	105 (3)	300 (2)
Labour Charges (in Rs./acre)	3.981 (44)	2,800 (50)	5,950 (45)	4,788 (47)	1,703 (48)	8,225 (42)
Cost of irrigation (in Rs./acre)	2,532 (28)	1,260 (23)	3,360 (25)	2,863 (28)	893 (25)	4,970 (25)
Fertilizer & Pesticide Cost (in Rs./bigha)	1,042 (11)	723 (13)	1,750 (13)	1,113 (11)	525 (15)	3.342 (17)
Machine Hiring / Using Cost (in Rs./acre)	1,305 (14)	700 (13)	1,890 (14)	1,322 (13)	350 (10)	2,800 (14)
Yield (in Quintal/acre)	14	14	14	13	7	19
Market Price (Rs./Quintal)	3,566	3,150	4,375	3,721	2,800	5,250
Total Cost (Rs./acre)	9,107	5,588	13,300	10,283	3,575	19,637
Total Revenue (Rs./acre)	49.919	44.100	161.250	47.351	119.600	.01.063
Profit (Rs./acre)	40,812	38,512	47,950	37,068	16,025	81,425

Note: Figure in the parenthesis shows the percentage of total cost
Source: Primary Survey

and for jute it is Rs. 184/acre/season. If the entire wetland irrigated area is cultivated with paddy, the annual benefit of wetland irrigation is estimated to be Rs. 20,313/year. And if the entire is cultivated with jute the benefit of using wetland water for irrigation is estimated to be Rs. 6,734/year.

5.3 Benefits from Fisheries Operation

Previously owners used to lease out the wetland for fisheries operation for the period - June-July to October-November. Mostly local people individually or collectively used to bid for the wetland. The last time it was leased out for three years at an amount of Rs. 5 lac. The owners used to make benefit by leasing out the wetland, however during those years they used to deprive of getting fish for their own consumption. After the commercial fisheries, the owners used to cultivate boro paddy in the same wetland bed (November-December to May-June) and farmers from surrounding farmlands used to lift water from wetland for irrigation. The preparation of nursery bed and land used to start during November and transplantation work used to start during December. However, due to construction of Farakka Barrage, the beel gets water for more months and as a result the process gets delayed. Over the years the siltation in the Hoogly River bed has also reduced its water holding and carrying capacity. As a result frequent flood and land subsidence is occurred in the Gangetic flood plain of West Bengal (Prof. Kalyan Rudra, Personal Communication). However, currently the owners themselves are operating the fisheries through the formation of a committee. The committee consisting of 15 members from owners households, of which 5 members are directly involved with the fishing and various operational aspects of the wetland, and another 10 member is involved with security of the beel, as there is continuous threat of fish lifting from wetland by non owners community. The people involved in the protection, fisheries operation and management are paid from the committee depending on their time of involvement.

Economic value of fisheries operation in the wetland is evaluated by considering the two management patterns - a) owners operated - when wetland owners carry out fisheries operation by themselves, and b) lease holders operated - when wetland owners lease out the wetland to private operators for an amount decided by open bidding process. Under owners operated system, the wetland fisheries is managed by the formation of a committee where the costs of the fisheries operation is borne by the committee from previous year's income after paying the land revenue of Rs. 16,000/annum payable to the Dainhat Municipality. The owners get the monetary benefit according to their land holding in the wetland. On an average from each acre of wetland holding, owners get Rs. 4200/year from fishing alone. The total area under wetland fisheries is 80 acre. Therefore, total distribution of income from wetland is estimated to be Rs. 3,36,000/annum. The owner households involved with the protection, fisheries operation and management are also paid according to their contribution in terms of time spent. 22% of our sample farmers are involved with the various aspects of management of wetland, and average payment for their service is Rs. 2250/year. Therefore total payment is estimated to be Rs. 32,400/year. Apart from the monetary benefits, owners also get fishes for their own consumption. On an

	Upland Paddy Cultivation		Upland Jute Cultivation	
	Cost of Irrigation (in Rs./acre/season)	Cost of Fertilization (in Rs./acre/season)	Cost of Irrigation (in Rs./acre/season)	Cost of Fertilization (in Rs./acre/season)
Source(s) of Irrigation	Mean	Mean	Mean	Mean
Wetland (Kalobaur Beel)	8,553 (2,975-13,388)	466 (1,358-2,100)	3,151 (1,190-4,970)	916 (630-2,333)
Beel (in feet)	*2,436 (200-6,562)*		*1,376 (50-9,842)*	
Groundwater	9,202 (5,950-17,850)	372 (263-3,101)	2,985 (893-4,760)	1,266 (525-2,800)
Depth of Groundwater (in feet)	*137 (50-200)*		*75 (14-200)*	
Wetland & Groundwater	4,958 (4,958-4,958)	100 (350-350)	2,797 (2,083-3,570)	1,326 (560-3,342)
Canal and River Water	1,400 (1,400-1,400)	522 (525-3,500)	1,400 (1,400-1,400)	799 (630-1,050)

Note: Figures in the parenthesis show the range for the corresponding mean value average **53%** of our sample get fish for their own consumption. It would have been cost of Rs. 375/household/ month to purchase the same amount of fish from the market. On an average 47% of our sample households collect small fishes and shellfishes from the wetland and the market price of their collection would have fetched Rs. 153/household/month.

5.3.1 Non- owners' Benefits from Collection of Small Fishes and Shellfishes

Collection of small fishes and shellfishes are not restricted to the owners only. A large number of people surrounding the wetland collect small fishes and shellfishes from the wetland. On an average **44%** of sample households collect small fishes and shellfishes from Kalobaur beel during rainy season. Yearly on an average 6 months (on an average) households collect those items which save on an average a cost of Rs. 317 per month per household and it varies from Rs. 120 to Rs. 900. In some instances, respondents revealed that people from lower strata of the society collects various shellfish and sell in local market at a remunerative price. Households were asked to reveal the amount that they have to pay to purchase those items that they collect from the wetland. The well defined market price made it easier for them to reveal the amount they save in each month through collection of various small fishes and shellfishes from wetland.

The total benefit from wetland fisheries is estimated to be Rs. 5,51,856 per annum. However, this is a conservative estimate as we do not take into account the costs of seeds, feeds etc. which is spent from previous year's savings. The estimation of beneficiaries of wetland is not exact. Therefore the estimate is in the lower side.

In 2002, the wetland was last leased out for an amount of Rs. **5** lac for 3 years. The lease holders fetched a profit of Rs. 3 lac. So, total income generation from wetland fisheries was Rs. 8 lac. Under lease holders operation, each of the **45** owner households could earn amount of Rs. 3703/year. However, the owners did not used to get any fish for their own consumption and even collection of small fishes was restricted. Due to costs involved to restrict the non-owners to access the wetland during night time is very high, stealing of fish by local people is a major cause of getting less benefit during owners operated regime. However, under owners operated system the owners meet their own consumption demand and the number of beneficiaries are large.

5.4 Benefits from Jute Retting

Jute (White Jute - Corchours capsularis and Tossa Jute - Corchorus olitorius) is the major commercial crop in the Gangetic flood plain of West Bengal. Availability of water bodies is an added advantage, which helps farmers in jute retting. During monsoon, the Kalobaur beel is used for jute[4] retting by large number of farmers from surrounding habitations. Jute is a commercial crop, and jute sticks (pat kathi) mostly used for house walling, as bio-fuel, and for various religious purposes.

There are several methods of jute retting, e.g., chemical, biological, etc. however biological jute retting in water bodies mostly practiced due to cost efficiency. The study estimates the benefit of using wetland for jute retting. Traditionally farmers from the surrounding habitations are using the Kalobaur beel for jute retting and they do not have to make payment to the wetland owners for the wetland service. However, owners complained that jute retting is one of the main reasons for reducing Dissolved Oxygen in the water body which cause fish death. In the Gangetic flood plain of West Bengal due to availability of large number of water-bodies helps jute cultivation and jute is cultivated in a substantial part of area. There are several reasons for that - a) during rainy season the whole area get flooded with water from the Hoogly River and other than jute other crops cannot withstand the high water logged area. During flood the huge amount of silt is also deposited in agricultural land which acts as natural fertilizer for subsequent crops. Availability of large number of water-bodies is the major advantage for the farmers to go for jute cultivation. However, some farmers prefer to use their own pond (Doba) for jute retting. The diesel cost associated with the filling up of the private pond (Doba) is considered as the shadow cost of jute retting. It has been found that 25 litre of diesel is required to pump the water from wetland to fill the pond which could accommodate jute from 1 bigha of land. The cost associated with 25 litre of diesel

Table 7: Benefits from Fisheries Operation in the Wetland

Sources of Benefit and Cost of Wetland Fisheries	Amount (Rs./Year)
Water Tax payable to Dainhat Municipality	16,000
Payment for protection, fisheries operation and management	32,400
Benefit distributed among wetland holders	3,36,000
Cost saved in terms of expenditure on fish consumption	1,46,534
Non-owners benefit from collection of small fishes and shellfishes etc.	20,922
Total benefits from wetland fisheries	5,51,856

Source: Primary Survey

in West Bengal comes out to be Rs. 875 (@Rs. 35/litre of diesel). Farmers' were also asked to reveal their willingness to pay for jute retting (in Rs. Per bigha of jute produce), which varies from Rs. 50 to Rs. 500 with an average of Rs. 267.

Approximately 150 households from habitations surrounding the Kalobaur beel use the wetland water for jute retting. According to our sample survey among 55 farm households, 64% cultivate jute during Kharif season in the upland area and another 18%of the households practice wetland jute cultivation. Average size of upland under jute cultivation is 1.1 acre and 0.9 acre under wetland cultivation. Therefore total area under jute cultivation is estimated to be 133 acre. Average benefit of using the beel for jute retting is Rs. 935 per acre of jute cultivation. Therefore total benefit of jute retting is Rs. 1.24lac per year.

5.5 Benefits from Domestic Uses

To estimate the benefits of using wetland for various domestic uses (e.g., bathing and washing), we have taken into consideraticn the cost of installing tube well either individually or collectively. The cost of installation varies with respect to the desired depth of the tube well. However, having a tube well or house connection of water supply considerably reduces the time required to commute to the wetland. The convenience of having house connection or tubewell has been captured through the opportunity cost of time spent on commuting wetland. Average yearly benefit from wetland has been estimated. The opportunity cost of time spent could be justified only of the cost saving of having tube well individually or collectively or having house connection is much higher.These costs could be shared by individually or collectively. In case of collective utilization, the costs could be shared among the beneficiaries.

Table 7 shows that the cost saving through the use of wetland for domestic uses is much lower than the opportunity cost of the time spent in accessing the wetlands. Perhaps, this is the reason why the local communities do not depend on these wetlands alone for domestic water needs, and instead try to have their own private hand pumps, or common hand pump provided by the local municipality.

5.6 Benefits derived for Animal Husbandry

5.6.1 Fodder Collection

On an average 29.1% of our sample households collect fodder from the wetland. Farmers collect water hyacinth (Eichornia crassipes) and various water borne vegetations and supplement fodder to reduce cost of feeding the cattle population. On an average four months in a year sample households collect fodder from the wetland. Farmers without having agricultural land and/or do not cultivate paddy/wheat mostly collect fodder from the beel throughout the year. We estimate the benefits of collection fodder from wetland by using the cost

[4] Jute retting is the process which softens the tissues and breaks the hard pectin bond between the bast & Jute hurd (inner woody fiber stick) and the process permits the fibres to be separated (source: http://en.wikipedia.org/wiki/Jute_cultivation)

saved in terms less requirement of straw (paddy/wheat) and mustard cake.[5] In our household questionnaire survey it has been revealed that on an average each household could save Rs. 372/month, which varies from Rs. 20 to 600/month depending on the size of the herd size and family's dependence on wetland fodder. Since, the collection also involves labour time, households having own source of fodder mostly avoids collection from wetland. The total number of households benefit from fodder collection is 150, and the rate of benefit is Rs. 1488/year, therefore total benefit from fodder collection is Rs. 2.23 lac.

5.6.2 Benefits from Grazing

Grazing on wetland and surrounding areas of the beel is limited to one to two months in a year. Having steep slope in the edge of the wetland and depth of water is quite high, it becomes difficult for cattle population to access vegetation in the wetland. The depth of water level in the beel remain high for a large part of the year and having little space surrounding the beel the grazing on wetland is limited. During summer as water recedes, households allow their cattle to graze on wetland bed. Cost saving in terms of grazing in wetland has been estimated to to be Rs. 313 per household per month. The benefits vary across households, from minimum Rs. 120/month to Rs. 700/month depending on their herd size. 150 households surrounding the beel benefit from wetland grazing and their monthly benefit is estimated to be Rs. 313. Therefore, total benefit from wetland grazing is estimated to be Rs. 46,950/year.

Table 8: Average Costs and Benefits of Using Wetland for Domestic Purposes

Descriptions	Mean
Cost of installing a hand pump fitted with tube well (in Rs.)	5.487
Annualized cost of capital (Rs./Year)*	582
Annual O&M cost of hand pump (Rs./Year)	50
Annualised capital and O&M cost of hand pump (in Rs./Year)	632
Time spent to access wetland (in hour/day)	0.74
Opportunity Cost of Time (in Rs./day) **	4.6
Yearly Opportunity Cost of Time (in Rs./Year)	1,692
Number of families could share a single hand pump comfortably for domestic purposes (in No.)	3.3

Note: *- implies annualized cost capital has been estimated using 10% real rate of interest and 30 years in the amortization process
**-implies daily wage rate for agricultural labour (i.e., Rs. 50/head/8 hour) is used to calculate the opportunity cost of time.

5.7 Benefits from Collection of Amaranthus

Apart from small fishes and various shellfishes, 42% of the sample households collect various amaranthus (Kalmi - Ipomoea aquatica; Hincha, Sushni, etc.) from wetlands. The economic benefit varies from Rs. 10 to Rs. 100/household/month, with an average of Rs. 39. Our discussions with the local people revealed that 30 households surrounding the beel collect various leaf vegetables (amaranthus) through out the year and the estimated benefit is Rs. 5,897.

5.8 Benefits from Duck Keeping

Duck keeping is not a regular practice for habitations surrounding the beel and only 11% of our sample households have ducks with an average number of 4.5 birds (minimum 1 to maximum 7). Since ducks are not fed on commercial feed, it becomes difficult for households reveal their costs saving of using wetland to feed their ducks.

[5] Straw and mustard cake are the main commercial items fed to cattle population in rural areas.

6. CONCLUSIONS AND AREAS FOR FUTURE RESEARCH

In the Gangetic flood plain of West Bengal wetlands are used as multiple system and have significant impacts on livelihoods of the local people. Over the years Multiple Use Systems (MUSs) are getting converted to single use systems due to economic and social pressure from dominant stakeholders, which are larger than that of single use systems. Economic and ecological functions of MUS changes over time and space. These dynamic aspects of MUS are often not fully appreciated. Attempts to classify wetlands according to their uses across ecological zones and to do their economic valuation are very limited.

We have undertaken study of one such wetland in the lower Gangetic basin in West Bengal. The study shows that the major economic benefits that people living in the surrounding area of wetland are from wetland cultivation; direct irrigation; jute retting; and fisheries. The most important benefit is from fisheries, followed by wetland cultivation and jute retting. The irrigation benefits were found to low due to larger distance of the land from the wetland, and the easy access to shallow groundwater in the region.

Besides the direct economic functions, there are many ecological functions that a wetland performs. They are: nutrient trapping and recycling; spawning and breeding ground for indigenous fish species; groundwater recharge and impacts on hydrology; runoff and soil erosion control, and flood mitigation; regulating micro-climate on the area surrounding the wetland. They also have economic values. However, they are not evaluated in the present study. This could be taken up for future research. Further, such an evaluation needs to be undertaken at the level of river

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HOW SERIOUS ARE GROUNDWATER OVER-EXPLOITATION PROBLEMS IN INDIA? A FRESH INVESTIGATION INTO AN OLD ISSUE

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Abstract

In this paper, first we deal with the definition of aquifer over exploitation. Then a review of the various definitions and criteria for assessing over exploitation is provided. Subsequently, the existing methodologies in India for assessment of groundwater resources are reviewed to examine: the robustness of the criteria used; and the scientific accuracy of the methodologies and procedures suggested. Finally, the current estimates of groundwater over development for India are reviewed from the perspective of detailed water balance, geology, hydrodynamics, and negative social, economic, ecological and ethical consequences.

The paper argues that there are several conceptual issues involved in the assessment of aquifer over exploitation. Over-exploitation is linked to various "undesirable consequences" of groundwater use that are physical, social, economic, ecological, environmental, and ethical in nature. Further, there are differences in the way undesirable consequences are perceived by different stakeholders. The principle of inter-generational equity used in the concept of sustainability, is built in the standard definitions of aquifer over exploitation. But, defining and assessing over exploitation is both difficult and complex, and not amenable to simple formulations.

The criteria used for assessing groundwater development by groundwater estimation committee (GEC) 1984 are only physical, involving variables such as gross groundwater recharge and net abstraction. The criterion adopted by GEC-97 is more rigorous. It involves net groundwater recharge and gross draft. It takes into account some of the complex variables determining net recharge, such as base flow and lateral flows. But, both fail to integrate complex hydrological, geological, hydro-dynamic, social, economic and ethical factors that capture the physical, social, and economic impacts of groundwater overuse. This apart, there are issues of reliability in estimation of net groundwater recharge and draft, due to lack of robustness in the methodologies, owing to the absence of reliable data required for estimation. The official statistics therefore provide a not-so-bad scenario of groundwater in the country. The paper demonstrates through selected illustrative cases how integrating data on complex hydrology, geology, hydro-dynamics, and socio-economic, ecological and ethical aspects of groundwater use, with the official statistics could change India's groundwater scenario altogether. Some of them are: break up of groundwater balance into natural recharge, recharge from imported water, and consumptive water use; specific yield of aquifer; long term and seasonal trends in groundwater levels; economic cost of groundwater abstraction; incidence of well failures and change in well yields; and drinking water scarcity.

1. INTRODUCTION

In India, groundwater resources play a major role in India's irrigation economy, and are crucial for meeting water supply needs of both rural and urban areas (Kumar, 2007). India's ability to manage its future water needs would depend so much on proper understanding of the availability of groundwater, and the nature and magnitude of groundwater problems. There are ever-increasing evidences of aquifer over exploitation in many localities, which cause negative consequences such as drinking water shortage, enormous increase in cost of water abstraction from wells, frequent well failures, reducing command area of wells, increasing inequity in access to well water for irrigation, and ecological degradation such as reduced groundwater table and soil salinity (Kumar, 2007). While concerns over the future of groundwater use in India are growing (GoI, 2007), official statistics continue to paint a rosier picture of groundwater status in the country (GoI, 2005). At the root of the public concern is the need to arrive at a working definition and comprehensive criteria for assessing

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aquifer over exploitation that integrates various concerns such as shortage of water for basic survival needs, poor economics of groundwater use for irrigation, growing inequity in access to water, eco-system and environmental degradation, and unethical water use practices.

Aquifer over exploitation mainly deals with negative aspects of groundwater development (ITGE, 1991; Custodio, 1992 & 2000; Delgado, 1992; Margat, 1992[2]). Scholars have argued that the concept of groundwater over development or aquifer over exploitation is not simple, merely linked to recharge and extraction balance, but is rather complex linked to various undesirable consequences, which are physical, social, economic, ecological, environmental, and ethical in nature. Again, these undesirable consequences also change with perceptions (Custodio, 2000). Hence, defining and assessing groundwater over development is both difficult and complex and not amenable to simple formulations.

Still, the perceptions of official agencies concerned with groundwater development and management, are characterized by aggregate views based on simple hydrological considerations of recharge and abstraction (Kumar and Singh, 2001). Nevertheless, there have been some recent changes in the official perceptions about groundwater over development, as a result of the recognition of the need to integrate economic and social considerations in assessing degree of exploitation. This is also reflected in the methodology proposed by Ground Water Estimation Committee of 1997 (NABARD, 2006). But, how far such concerns are integrated in actual assessment is however, open to question.

2. PURPOSE OF THE PAPER

The paper first discusses some of the conceptual issues in defining groundwater over exploitation; and presents some of the accepted definitions of aquifer over exploitations. It then critiques some of the methodologies used in India for assessing groundwater resources and stages of groundwater development. Finally, the paper demonstrates through illustrative cases in India how integrating some of the complex considerations such as detailed water balance, geology, hydro-dynamics, and negative socio-economic, ecological and ethical consequences of over exploitation, with the official methodologies can yield an altogether different scenario of groundwater, than what the official statistics provide.

3. ASSESSMENT OF GROUNDWATER OVER-EXPLOITATION

In this section, we shall deal with the conceptual issues involved in defining groundwater over development. The discussion will not touch upon the methodological issues involved in assessing groundwater recharge and extraction, but will identify the complex considerations involved in assessing the degree of groundwater over development or aquifer over exploitation. It will then present some of the most common definitions of groundwater over development that use some of these considerations, so as to provide a comprehensive framework for assessing the same.

3.1 Conceptual Issues in Defining Over-exploitation

Terms such as groundwater over exploitation, over draft, over development, overuse and unsustainable use are commonly used in discussions on hydro-geology and groundwater resources since 1970's (Custodio, 2000). Such phenomena are predominantly applied in arid and semi-arid regions where large volumes of groundwater are abstracted to irrigate extensive areas, under situations where the natural recharge to aquifers is limited due to several reasons such as low rainfalls, unfavourable topographic and geo-hydrological environments. They are applied to aquifer conditions in other regions when exploitation leads to undesirable consequences.

The concept of groundwater over exploitation predominantly deals with negative aspects of groundwater development (ITGE, 1991; Custodio, 1992 & 2000; Delgado, 1992; Margat, 1992). Such consequences may include: [i] large and continuous drops in groundwater levels over long time periods; [ii] large

[2] Such consequence may include: large and continuous drops in groundwater levels over long time periods; large seasonal drops in water levels in wells and the drying up of wells in summer season; and increase in salinity of seawater; land subsidence; enormous increase in cost of groundwater extraction; and reduction of groundwater dependent vegetation and springs and seepage.

seasonal drops in water levels in wells and the drying up of wells in summer season; and [iii] increase in salinity of groundwater; [iv] land subsidence; [v] enormous increase in cost of groundwater extraction; and [vi] reduction of groundwater dependent vegetation and springs and seepage.

Custodio (2000), however, argues that though undesirable consequences appear when abstraction exceeds recharge, often there is no clear proof of the same being the cause of these undesirable consequences. This is true in case of Gujarat and West Bengal. In case of Gujarat, increasing incidence of fluoride in groundwater is a major problem whose causes are not clearly known. Fluoride content in groundwater can increase due to leaching of fluoride containing minerals present in geological formations with groundwater - a phenomenon not directly linked to over extraction of groundwater. Similarly, in West Bengal, there were widespread incidences of high levels of arsenic in groundwater threatening drinking water supplies and public health (Mc Arthur *et al.*, 2001). Though there are many competing theories[3] , it is seldom attributed to over exploitation.

Thus, the concept of groundwater over development or aquifer over exploitation does not appear to be simple, merely linked to recharge and extraction balance, but is rather complex linked to various undesirable consequences. Therefore, an assessment of groundwater over development involves complex considerations such as fundamental rights, basic survival needs, health, and economic, ecological and ethical issues and hence it is not possible to capture its essence with simple definitions.

It is nevertheless important to mention here that there are fundamental differences in the way these undesirable consequences are perceived by various scholars. For instance, according to Custodio (2000), it is predominantly the point of view of over concerned conservationists, and people suffering from real or assumed damage, and not always of well-informed people. Collin and Margat (1992) have argued that this is an unconscious or incited over reaction to a given situation, while Custodio and Llamas (1997) and Llamas (1992a) assert that this is the result of deeply entrenched "*hydromyths*". Custodio (2000) further opines that the groundwater developers take the opposite position, which focus on beneficial use and use the concepts of safe yield, or rational exploitation and the economics side of sustainable development to present their viewpoints.

Such a logical framework for analyzing the various viewpoints does not hold in several situations, including ours. First of all, the framework assumes that there are conservationists and those who are suffering from the damage, which is real or assumed, are different from the developers. This is not true. In many situations including the one under consideration both are the same. It is the rural communities especially the farmers who are mostly engaged in groundwater development for irrigation, and the consequences or the damage are also primarily borne by them in terms of increased extraction costs, reduced well yields, and quality deterioration. Therefore, the argument that the concerns about over exploitation are an unconscious over reaction to a given situation or are the result of deeply entrenched hydromyths itself is questionable.

On the contrary, more systematic debates about groundwater over development mainly initiated by the researchers and scholars, including those from official agencies and NGOs, were driven by concerns of maintaining sustainable water use in drinking water sector and agriculture. Official agencies mainly looked at farmers as the main culprits behind uncontrolled exploitation of groundwater while researchers and scholars from development circles blamed the government policies and institutional framework. Several researchers from India have pointed to the need to integrate the concerns of intra-generational equity (Saleth, 1994), social development, fundamental rights and economic efficiency (Moench, 1995) and economics of well irrigation (Kumar *et al*., 2001) in assessing over development of groundwater.

In India, the official versions of over development were primarily based on estimates of recharge and extraction. Therefore, they continued to treat areas with recharge exceeding the extraction as areas suitable for further exploitation without worrying much about the consequent effects. Those areas, where the average annual extraction figures exceeded the annual recharge figures, were treated as over exploited areas without

[3] Three mechanisms were used to explain the release of arsenic to groundwater and are as follows: 1] reductive dissolution of FeOOH and release of sorbed arsenic; 2] oxidation of arsenic pyrite; and, 3] anion exchange of sorbed arsenic with phosphate from fertilizer. However, Mc Arthur and others (2001) postulated another hypothesis, which challenged the oxidation and anion exchange theories, that distribution of arsenic pollution is controlled by microbial degradation of buried peat deposits, rather than distribution of arsenic in aquifer formations, and the former drives reduction of FeOOH.

giving due considerations to factors such as absence or presence of static groundwater storage. Nevertheless, there have been some recent changes in the official perceptions about groundwater over development, as a result of the recognition of the need to integrate economic and social considerations in assessing degree of exploitation. This has come out of observation of field realities. For instance, in certain cases, regions which are declared as safe are facing acute drinking water scarcity. Similarly, in certain other cases, such regions are facing long term decline in water levels (GoI, 2006). This new recognition is also reflected in the methodology proposed by Ground Water Estimation Committee of 1997. But, how far such concerns are integrated in actual assessment is not clear. We would take up this issue for further discussions in the subsequent section.

Though groundwater scientists had emphasised the need for maintaining safe yields and sustainable levels of extraction to promote development with minimum negative ecological, economic and social consequences, the manifestations of over development appear much earlier in certain areas. Thus, such concepts have really not found any place in practical and policy debates. Part of the reason is the realization that ownership rights in groundwater are not well-defined and well development is highly decentralized under private initiatives and government does not have any control over the amount of groundwater that farmers pump. In sum, both the estimates based on field manifestations and official data (of recharge and extraction) are static and short-term interpretations of the situation. They do not capture the complex physical characteristics and behaviour of aquifer systems, including large static groundwater storage, long-term effects, salinity and water quality issues, leakage from aquitards, the system recharge and discharge changes and the uncertainty.

3.2 Definition and Assessment of Groundwater Over-exploitation

Several researchers have tried to define groundwater over exploitation and evolve criteria for assessing degrees of over development, which integrate some of the concerns or considerations discussed early. The 1986 Regulations of the Public Water Domain of the Spanish Water Act (1985), define overexploitation by its effects: an aquifer is considered over exploited or in the risk of exploitation, when the sustainability of existing uses is threatened as a consequence of abstraction being greater than one, or close to, the annual mean volume of renewable resources, or when they may produce a serious water quality deterioration problem (Custodio 2000). Young (1992) defined over exploitation from an economic point of view, de-linking pumping rates from mean recharge values, as the non-optimal exploitation.

Llamas (1992b) introduced the notion of strict over exploitation – leaving room for definitions with broader scope as groundwater abstraction producing effects whose final balance is negative for present and future generations, taking into account physical, chemical, economic, ecological and social aspects.

The concept of sustainability used in the context of natural resource development by the Bruntland commission (Bruntland *et al*., 1987) based on the principle of inter-generational equity is also used to define groundwater over exploitation[4] (Custodio 2000). However, Georgescu-Reogen (1971) and Custodio (2000) have argued that the concept is too broad and cannot be applied to local specific situations, as it does not take into account the impossibility of complete recycling of matter. Another point of contention of Custodio (2000) is that if one strictly follows the principle of sustainable development, as proposed by the Commission, the non-renewable resources like the large and deep confined aquifers of arid regions yield no benefit to anyone. Thus, there is need for improving or extending the definition of sustainable development, for it to be applicable to aquifers.

Finally, the way over exploitation is perceived depends on points of views of different stake-holders involved such as farmers, water development administrators, ecologists, conservationists, mass media, naturists, and citizens and professionals such as engineers, scientists, economists, management specialists, environmentalists, lawyers, sociologists and politicians (Custodio 2000).

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[4]The two major principles of sustainable development are: [a] the rate at which renewable natural resources are exploited should be less than the rate of regeneration; and [b] the waste flow into the natural environment should be kept less than its assimilative capacity.

For instance, one of the dominant perceptions of the farmers about the consequences of over development - falling water levels, drying up of wells etc. - is that it happens due to frequent failure of monsoons and the long term sharp declines in annual rainfalls, sharply affecting natural recharge rates. In fact, declining rainfalls is a hydromyth existing among millions of farmers in the region[5] . Nevertheless, the farmers seem not to see well proliferation and increased groundwater draft as major factors leading to over development. On the contrary, they see droughts as a major cause of depletion. Farmers fail to recognize that droughts are not a recent phenomenon, but a cyclic phenomenon.

On the other hand, the official agencies claim with the support of their data of recharge and extraction that there are no reductions in the quantum of recharge over time[6] . However, here we do not rule out the chances of bias in the estimates as they are often influenced by strong political interests. The direction of such a bias could change depending on the kind of vested interest. If the vested interests are for drilling more wells, the attempt will be to show lower rates of groundwater level drops and over estimate the recharge figures. If the vested interest is in large surface irrigation project in an area, which has considerable well irrigation, the attempt made would be to overplay the signs of over development and unsustainable nature of present use of groundwater. Custodio (2000) has also mentioned about this bias and manipulation as an important factor influencing the perception of over exploitation

The official perceptions of over development are driven by aggregate views. They tend to compare figures of recharge and extraction rates for administrative boundaries or natural boundaries of aquifers. In the process, they miss out several hidden phenomena such as excessive draw-downs in water levels due to large well-fields, groundwater pollution, and excessive rise in water levels causing water logging, which are often localized. Economists' perception of over exploitation is often based on consideration of the cost of abstraction of groundwater, including investment for hitting groundwater and the number of attempts farmers have to make to hit water table. Whereas, the politicians perceive scarcity of groundwater for meeting basic water needs of the communities as signs of over exploitation, and this does not have much to do with the level of groundwater draft against recharge.

In sum, defining and assessing groundwater over development are both difficult and complex and not amenable to simple formulations (Custodio, 2000). According to Custodio, the reasons for this are as follows:

- Varying perceptions of people concerned-for instance, in Gujarat, often, ordinary people and the media refer to problems related to physical availability of groundwater, availability of economically accessible groundwater resources, groundwater quality problems, and seasonal
- The arguments about long term declining trends in rainfall are also contested in the case of Gujarat (Bhatia 1992). However, the detailed analysis of the time series data on magnitude and pattern of rainfalls–including the number of rainy days, duration and intensity-are absent making it difficult to evaluate the impact of rainfall on groundwater recharge
- In fact, the official data for Sabarmati Basin shows that the recharge had gone up during 1992-97 as compared to the period 1987-91 (GoG 1992 and 1999)
- Drops in water levels as a groundwater over development problem. It is only in hydrology and geo-hydrology circles that such distinctions are ever made
- The terms used to define over exploitation vary with space and time
- Persistent draw down trend is not a clear indicator-groundwater behaviour being very complex in multi-aquifer systems-with several variables contributing to inflows and outflows - groundwater level trends are not always clear indications of over development and under-development
- Difficulty in calculating aquifer recharge and integrating water quality with quantity
- Difficulty in assessing long term trends in recharge rate that are very important
- Importance of localized effects in the overall picture
- Changing social perceptions and priorities

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[6]In fact, the official data for Sabarmati Basin shows that the recharge had gone up during 1992 1997 as compared to the period 1987-91 (GOG 1992 and 1999).

- Improvements in water use technology
- The need to consider the net socio-economic benefits
- Complex nature of cost-benefit calculations and
- Use of scarce, poor, and inappropriate data to define over development

Therefore, in this paper, we take some illustrative cases to demonstrate that the magnitude of groundwater resource problems in India is much different than what the official figures project if we try to integrate some of the complex considerations that determine the degree of over exploitation, in our assessment. They include long-term water level trends, detailed groundwater balance, seasonal water level trends, and negative social, economic, ecological and ethical consequences.

4. EXISTING METHODOLOGIES FOR GROUNDWATER RESOURCE ASSESSMENT: STRENGTHS AND WEAKNESSES

During the past nearly three decades, 4 committees were constituted to propose scientific methodologies for assessment of groundwater development by the Central Ground Water Board of the Ministry of Water Resources. The first committee was in 1979, named Groundwater Over-exploitation Committee (1979). The second committee was constituted in 1984 named the Ground Water Estimation Committee (GEC-84), and the third one was in 1997 named Ground Water Resource Estimation Committee 1997. For our discussions, we would consider the last 2 methodologies only.

4.1 GEC-1984 Criteria and Methodology for Assessing Groundwater Development

GEC 1984 proposed a simple criterion for assessing groundwater development, which is based on net groundwater draft against the gross groundwater recharge. It proposed 2 methodologies for assessing groundwater resources, for administrative units such as blocks and districts. The first is water level fluctuation approach. This is suggested when sufficient numbers of observation wells for monitoring water levels are available within a given administrative unit in question. In this approach, the average annual recharge (R_e)from precipitation is calculated by the following equation.

$$R_e = (A_s * W_f * S_y) + D_w \quad \text{.......................(1)}$$

Here " S_y" is the specific yield of the aquifer, W_f the average water level fluctuation during monsoon, A_s the area of the aquifer, and D_w the pumping during monsoon.

The 5 year average of the annual fluctuations in groundwater levels between pre- and post-monsoon time, multiplied by the specific yield values and the geographical area of the aquifer gives the total recharge.

A major limitation of the GEC-1984 is in the criterion used for assessing groundwater development. At best, it works for simple aquifer units, and cannot capture the groundwater dynamics in complex aquifer systems. Water level fluctuation is the net result of recharge, discharge, return-flows, leakage from across the system, lateral inflows and outflows. But, the water level fluctuation approach to estimating recharge - which often uses values of fluctuations in water levels within one or two layers of the aquifer system - does not allow any discounting for the contribution from the existing storage from other layers of the aquifer, which could be very significant in the cases of deep alluvial aquifer systems with several layers.

Also, in many basins, groundwater contribution to stream-flows in the form of base flow is significant, and constitutes the lean season flows of the rivers (Sohiquilo and Llamas, 1984). For instance, Kumar et al. (2006) found in the case of Narmada river basin that in spite of increase in groundwater draft, the annual rate of decline in groundwater levels had decreased over time. This could be explained by significant reduction in groundwater outflows into surface streams, resulting from lowering of water levels. Outflows are losses from the aquifer, and reduce the effective annual replenishable groundwater. But, GEC-1984 neither included base flow as a determining factor, nor suggested procedure for estimating it. These omissions can lead to an over estimation of the utilizable groundwater, implying negative consequences for stream flows.

Further, the criterion used in GEC-84 for assessing groundwater development use aggregate figures of recharge and extraction. But, recharge is often confined to certain layers within the aquifer system – most commonly the upper shallow aquifer. So far as abstraction is concerned, there could be layers of the aquifer system, which are tapped but do not get natural replenishment either from rainfall or from leakage. As a result, different layers of the aquifer can undergo different degrees of exploitation. It would be different from what the aggregate figures of recharge and abstraction show, and would be actually reflected in the water level fluctuations in the respective aquifer layer. Since the existing methodology treats the entire aquifer system as a single aquifer, it fails to assess the degree of exploitation in different aquifers under consideration.

Further, a simplified criterion can lead to large errors in estimation of groundwater recharge. For instance, the approach of estimating recharge also considers the abstraction during the monsoon period (see Equation 1). Though the abstraction could come from more than one layer, the entire amount is attributed to a single recharged aquifer whose water level fluctuation data are available. The error in the estimation of recharge will be inversely proportional to the contribution of the recharged aquifer in the total abstraction during the monsoon period.

One of the outcomes of using such simplistic criterion is that recharge-abstraction balance of the aquifer does not often correlate with water level trends, a variable which groundwater managers and users are equally concerned with. Maintaining abstraction levels far below annual recharge does not mean that draft is within safe limits. There could be continuous outflow of water into natural drainage systems due to which water levels can decline. On the other hand, a steady recharge-abstraction imbalance does not mean decline in water levels in the aquifer. The aquifer under study might receive the entire recharge from lateral inflows, as well as from top, while several overlying aquifers might be contributing to the abstraction from the system. But, the criteria used in GEC-1984 are too simplistic to capture the complex hydrological considerations, and therefore is not realistic.

In the second approach of GEC-1984, use of ad hoc norms is suggested for the following: a] recharge from rainfall; b] recharge due to seepage from unlined canals; c] return flow from irrigated fields; d] seepage from tanks; and, e] influent seepage from rivers and streams. Separate norms are used for estimating rainfall recharge for different types of geological formations, such as alluvium, semi-consolidated rocks, and hard rocks (see Table 1).

Table 1: GEC-84 Norms for Estimating Recharge from Annual Rainfall

Sl. No	Nature of Geological Formation	Recharge Rate as a percentage of Rainfall
1.	Alluvial formations I] Alluvial sandy areas II] Alluvium with clay content	 20-25 10-20
2.	Semi consolidated rocks	10-15
3.	Hard rocks	4-10
4.	Limestone and sandstone	3-10

Source: NABARD, 2006

Return flow from irrigated fields are estimated using the norm of 35% of the irrigation dosage for surface water, 40% for paddy fields irrigated by surface water; 30% of the water delivered at the outlet for well irrigation, except for paddy; and 35% for paddy fields irrigated by well water (NABARD, 2006). Use of such ad hoc norms can invite many sources of errors. For example recharge from rainfall is a function of not only the formation geology, but also rainfall pattern, soil type, vegetation cover, geo-hydrological environment and the hydraulic conductivity of the soil in the root zone and below. Again, many regions in India face extreme variability in rainfall and rainy days, and recharge from rainfall is not a linear function of rainfall magnitude. As a result, using normal values of rainfall for recharge estimation can lead to significant errors. Further, for a given crop, return flow from irrigations is a complex function of total quantum of irrigation water dosage; the irrigation schedule; and agro-hydrological variables that actually determine the return flows from irrigated fields, which are determined by soil hydraulic properties; drainage conditions; agro-meteorology; and crop characteristics (Jos van Dam, 2006).

4.2 GEC-1997 Criteria and Methodology for Assessing Groundwater Development

The GEC-1997's criterion for assessing groundwater development is far more realistic, and has a better scientific basis than that of GEC 1984. First of all, it proposes assessment of recharge for monsoon and non-monsoon periods separately. Also, the methodology proposes analytical approach for estimating specific yield using groundwater balance for non-monsoon period. It also proposes detailed analytical approach for estimating recharge during monsoon using water level fluctuation approach involving various components of groundwater balance such as storage change, the return flows from irrigation to groundwater, base flows from groundwater into streams and recharge from streams into groundwater, net lateral groundwater inflow into the area and groundwater draft.

The methodology for estimating base flow and lateral flows for administrative units, proposed by GEC-1997, however, is not robust. As one would expect, arriving at reasonably accurate figures of these two variables is essential to deduce figures of monsoon recharge. The reason is pre-post monsoon water level fluctuation, which the methodology banks on for estimating monsoon recharge, is a result of the storage change occurring in the groundwater system due to many inflows and outflows. They include rainfall recharge, net lateral inflows, contribution of stream-flows into groundwater system, return flows from irrigation, groundwater draft, and base flow into streams.

If the assessment unit is a watershed, a stream gauge station can provide data for calculation of base flows, and hence the challenges are less. But, only a few states are taking watershed as the unit for groundwater assessment, and even in these cases, reliable data on stream-flows are not available, as many lower order streams are not gauged.

While base flow during lean season for administrative units is estimated on the basis of groundwater draft during the season, and the water level fluctuation and the specific yield values, its reliability would depend heavily on the accuracy of estimation of groundwater draft figures. But, these figures are normally estimated using certain ad hoc norms. We would deal with the issues associated with groundwater draft in section 4.3. If data on specific yield are not readily available, it can be estimated using groundwater balance by taking watershed as the unit which would again involve the use of groundwater draft estimates for the watershed. In nutshell, estimation of base flow would involve a lot of errors. This is evident from the groundwater resource assessment for Madhya Pradesh provided by Central Ground Water Board (GoI, 2005) for the year 2005. It shows that the total groundwater outflow during lean season is only 1860 MCM. This is a sheer underestimation, when we look at the total amount of lean season flow (from December to May) in just one of the many river basins of Madhya Pradesh, i.e., Narmada alone is 1653.22 MCM (GoI, 2005), and that many perennial rivers are originating from the region.

Again, the figures of recharge so obtained include recharge from irrigation, water harvesting structures, and return flows as well. Here again, no scientific methodology is employed for estimating recharge from irrigation return flows. Instead some modified versions of the earlier norms of 1984 are used. The norm of return flow as a percentage of irrigation dosage, changes according to the depth to groundwater table. For areas with water table higher than 25 m, the norm is 5% of irrigation dosage; for water table depth between 10-25 m, the norm is 10% of irrigation dosage, and for depth to water table less than 5m, is taken as the recharge from irrigation return flows, against 40% and 35% considered in the earlier methodology (NABARD, 2006). In intensively canal irrigated areas of Punjab, Haryana, UP, Andhra Pradesh and Maharashtra, use of such methodologies can lead to highly erroneous estimates of not only return flows but also net natural recharge.

For estimating recharge from water harvesting structures, a uniform rate of 1.4 mm/day is assumed for tanks and ponds based on the average area of the pond (NABARD, 2006). But, in hard rock areas of Peninsular India with large number of tanks and ponds, such assumptions can be unrealistic, and can lead to over estimation of recharge from recharge structures. The reason is sustainability of recharge from tanks and ponds depends on the hydraulic diffusivity of the aquifers, which is very poor in hard rock areas. The creation of recharge mount in the aquifer underlying the recharge structure can prevent further percolation of water (Muralidharan and Athawale, 1998).

The criterion suggested by GEC-1997 for assessing the stage of groundwater development involves gross groundwater draft against net recharge. The net groundwater recharge takes into account the losses from groundwater system, and net gains from lateral flows. This is a major departure from the earlier methodology as that considered net draft against the gross recharge. As Kumar and Singh (2001) note, such an approach had led to over estimation of recharge and under-estimation of draft, as recharge from irrigation return flows is double counted. Hence, the new methodology had reduced the anomalies due to this. But, when it comes to estimating the net groundwater recharge, neither the state groundwater departments nor the Central Ground Water Board consider the groundwater losses while estimating the net recharge in lieu of the fact that these hydrological variables are difficult to quantify. This is well acknowledged in a recent review of the existing methodologies for groundwater assessment carried out by NABARD (NABARD, 2006). Nevertheless, it is not complex enough to realistically assess groundwater development in multi-aquifer systems, where aquifers which get replenished and aquifers which are subject to hydrological stresses could be different.

GEC-1997, however, recommended that hydrological data of recharge and abstraction estimated for the administrative units should be integrated with data on mid-term and long-term trends in water levels to make the final assessment about the stage of groundwater development in areas, which are showing continuous decline in groundwater levels. But, this is hardly done in actual practice by central and state agencies.

4.3 COMMON INADEQUACIES IN GEC-84 AND GEC-97

The biggest challenge posed by the methodologies proposed under both GEC-84 and GEC-97 is in estimating the specific yield values of aquifers to which the recharge estimates are highly sensitive. The issue is very crucial for hard rock areas, as specific yield values could vary widely within small geographical areas (NABARD, 2006). While groundwater balance during non-monsoon period can be used to estimate specific yield, this would require realistic estimates of groundwater draft during the season. Lack of reliable data on groundwater draft is a major factor affecting the reliability of the entire exercise of assessing the stage of groundwater development, as the inaccuracy in estimation of this parameter increases the inaccuracy in estimation of both denominator and numerator.

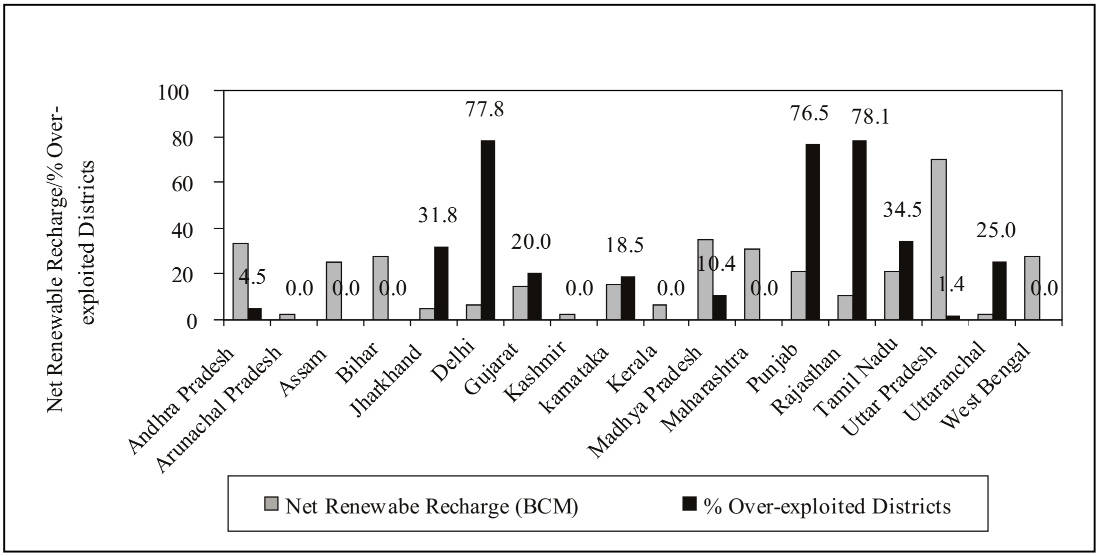
Both the committees proposed estimation of groundwater draft by three different methods: 1] using the well census and the norm of annual draft for different types of wells; 2] using electric power consumption, and the estimate of quantity of water pumped per unit power consumed; and, 3] using groundwater – irrigated area under different crops and the water requirement for each one. All these three approaches suffer from inadequacies. As regards the first one, it is hard to get the exact number of operational wells in a region at a given point of time, especially in hard rock regions, due to increasing incidence of well failures and farmers owning many wells at a time. Further, when it comes to quantifying the amount of water abstracted, wide variations in well outputs are seen within regions, and over the seasons. In case of the second method, it does not take into account the water abstraction by diesel wells that are in operation in many shallow groundwater areas in Orissa, Uttar Pradesh, Bihar, Assam, West Bengal, Madhyra Pradesh and some parts of Gujarat, Kerala and Andhra Pradesh. As regards the third one, the challenge is in getting reliable data on the groundwater-irrigated area under different crops, as data on source wise gross irrigated area are not compiled by most state governments.

In nutshell, both GEC-84 and GEC-97 suffer from problems in the criteria used for assessing the stage of groundwater development. The criteria used in GEC-1984 are only physical, involving only simple hydrological variables such as groundwater recharge and abstraction. Whereas in GEC-1997, the criteria used are a little more complex with the inclusion of base flows and lateral flows, and replacement of gross recharge by net recharge and net draft by gross draft. However, none of them involve complex hydro-dynamic, economic, social and ecological variables that help determine the negative consequences of groundwater over exploitation. Some of them are long-term trends in water levels, depth to water table, cost of abstraction of groundwater, and availability of water in wells during lean season. This apart there are issues of reliability in estimation of groundwater recharge and draft.

5. HOW SERIOUS ARE GROUNDWATER OVER-EXPLOITATION PROBLEMS IN INDIA?

The first set of alarms about groundwater over exploitation were raised almost three decades ago based on observations for a selected locations in India, including Mehsana in north Gujarat, coastal Saurashtra and Kachchh, Coimbatore in Tamil Nadu, Kolar in Karnataka, and Jaipur in Rajasthan. Several scholars had looked at the problem of groundwater depletion from many disciplinary angles (see Dhawan, 1997; Janakarajan, 1994; Moench, 1995; Phadtare, 1988).

Figure 1: Net Renewable Recharge Vs Stage of Groundwater Development



Dewas district located in Narmada valley in Madhya Pradesh was another region, about which a lot had been written (see for instance, Shah et al., 1998). Over the years, several new regions have been classified as falling under over exploited category. Punjab is one such region where many blocks were shown as experiencing falling water table conditions. There has been a lot of whistle blowing about the impending groundwater crisis in many arid and semi-arid regions based on anecdotal evidences from some of these regions on groundwater level trends.

But, if one goes by the official estimates of groundwater development in 2005 from CGWB, only 23.1 Million hecter meter out of the 43.2 Million hecter meter of renewable groundwater in the country is currently utilized (GoI, 2005). Again, if one goes by the most recent disaggregated data, only 15% of the groundwater basins in the country are over exploited; 7% critically exploited. Nearly 62% of the groundwater basins are still "safe" for further exploitation (GoI, 2005). Interestingly, as per the official statistics, it is Punjab is one of the states where over exploitation is most serious, next only to Rajasthan and is followed by Delhi and Gujarat. The number of over exploited districts in the hard rock areas of Andhra Pradesh, Tamil Nadu and Saurashtra in Gujarat, where high incidence of well failures is reported, is very low (see Figure 1).

Therefore, such "doomsday prophecies[7] " have not been based on rational view of the scenario using data on hydrological changes and hydrodynamics. This is not to say that groundwater over exploitation is not a cause for concern in India. In the subsequent section, we would examine how far these doomsday prophecies are correct.

[7]Collin and Margat (1992) have argued that this is an unconscious or incited over reaction to a given situation, while Custodio and Llamas (1997) and Llamas (1992a) assert that this is the result of deeply entrenched hydromyths. Custodio (2000) further opines that groundwater developers take the opposite position, which focus on beneficial use and use the concepts of safe yield, or rational exploitation and the economics side of sustainable development to present their viewpoints.

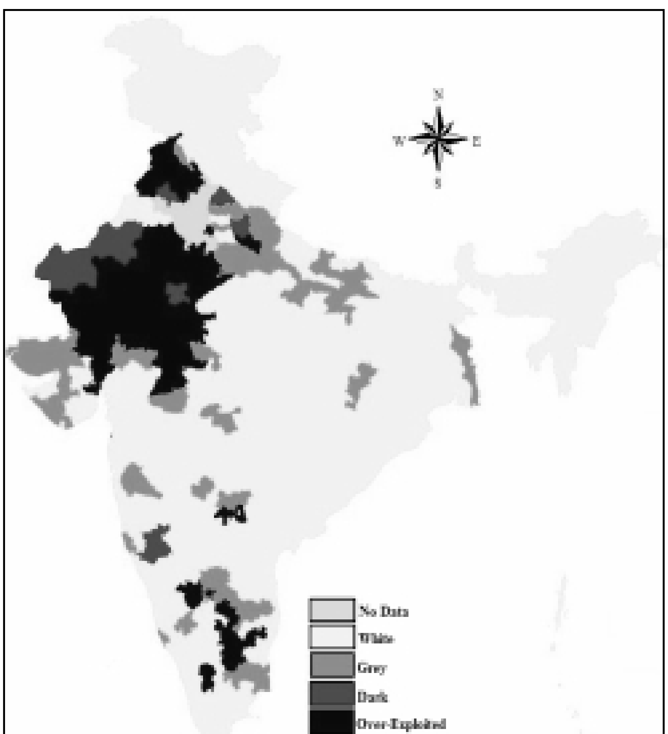
5.1 What Do Water Level Trends Really Mean?

Groundwater level trends are a net effect of several changes taking place in the resource conditions owing to recharge from precipitation, return flows from irrigated fields, seepage from water carriers (canals, channels etc.), abstraction or groundwater draft, lateral flows (either inflow or outflow) or outflows into the natural streams (Todd, 2003). In a region, where long term levels of groundwater pumping are less than the average annual recharge, the groundwater levels can experience short term declining trends as a result of drastic increase in groundwater pumping owing to monsoon failure. But, such a phenomenon does not represent the long term trends. It is important to note here that semi-arid regions in our country also experience significant inter-annual variability in rainfall (source: based on Pisharoty, 1990; Kumar et al., 2006). Further, it is not correct to attribute all changes in groundwater conditions to hydrological stressed induced by human action.

In a region where groundwater outflows into the surface streams are quite large due to the peculiar geo-hydrological environment, even if the net annual groundwater draft is far less than the net recharge, water levels can decline on an annual basis, as illustrated through a study of surface water groundwater interactions in Narmada river basin in India. This is because of the heavy outflows of groundwater into the surface streams. In such situations, increasing draft over time can actually reduce the rate of decline in water levels on a long time horizon (Kumar et al., 2005). In fact, this is the situation prevailing in many river basins of Central India, such as Mahi, Tapi, Krishna, Mahanadi and Godavari. Such situations also prevail in the western Ghats and north eastern hilly regions. This means in such areas, integrating environmental considerations such as maintaining lean season flows in rivers would limit the safe abstraction rates, to levels much lower than what is permissible on the basis of renewable recharge. Hence, in such regions, estimating the base flows would be very crucial in arriving at the net utilizable recharge, and therefore the actual stage of development of groundwater. We have already seen that the groundwater outflows are not properly accounted for in the estimates of the net recharge. Due to this reason, the estimates show a much lower stage of development than what the region is experiencing.

5.2 Can We Look at Groundwater Balance for Assessing Over-draft?

Figure 2: Groundwater over exploited regions in India



Ideally, in a region where lateral flows and outflows from groundwater systems are insignificant, groundwater over draft can take place if the total evapo-transpirative demand for water (ET) per unit area is more than the total effective rainfall, i.e., the portion of the rainfall remaining in situ after runoff losses, and the amount of water imported from outside for unit area. In many semi-arid to arid regions of India, cropping is intensive demanding irrigation water during winter and summer months. The ET demands for crop are much higher in comparison to the effective rainfall. The deficit has to be met either from local or imported surface water or groundwater pumping. Hence, the change in groundwater storage would be the imbalance between the total of recharge from rainfall and return flows from irrigation, and groundwater draft. In semi-arid and arid regions, natural recharge from precipitation is generally very low. In an area with intensive surface irrigation, a negative balance in groundwater indicates high levels of over draft or deficit in effective rainfall in meeting the ET requirements.

Punjab is a classical example. The region is intensively cultivated and irrigated. Most of Punjab is falling in semi-arid to arid climate. Both these factors make ET per unit area very high. Again effective rainfall is low. The water levels are falling throughout Punjab at a rate of 0.3m/annum (Hira and Khera, 2000). Let us examine the groundwater balance in an ideal situation like in Punjab. The change in groundwater storage (Δ_s) could be written as:

$$R_{rech} + RF_1 - NGD$$

$$\text{But, } NGD = ET + \Delta_{Dep} - (S_I + P_e - RF_I)$$

$$\Delta_s = R_{rech} + S_I + P_e - ET - \Delta_{Dep}$$

$$\Delta_s = R_{rech} + RF_1 - \{ET + \Delta_{Dep} - [S_I + P_e - RF_I]\}$$

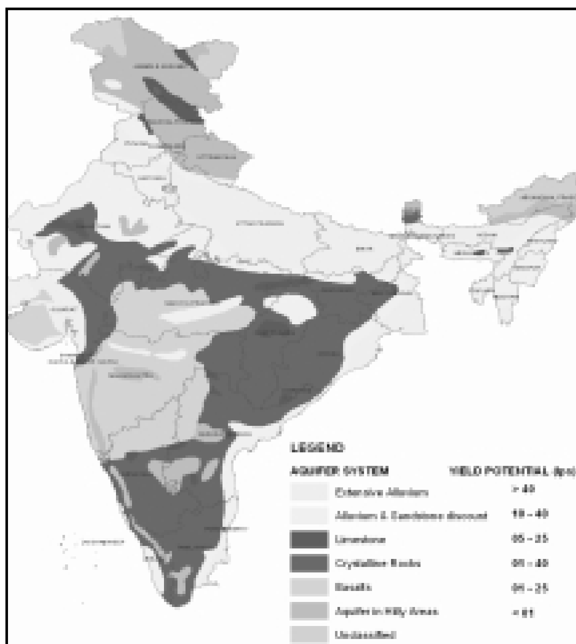
Here, R_{rech} is rainfall recharge; RF_I is irrigation return flow; NGD is the net groundwater draft; Δ_{Dep} is the total of water depleted from the soil during the fallow period and the water stored in the soil profile below the root zone; is the surface irrigation water applied; and P_e is effective rainfall.

Going by the above groundwater balance equation, if is removed, then the change in groundwater storage would become negative if the entire land is cultivated, which is the condition in almost throughout Punjab. This is because rainfall (P) is less than ET requirement, and as a result, P_e+Recharge also, as P_e+ Recharge would always be less than the total rainfall (P). Hence, surface irrigation's role in maintaining groundwater balance is more than that of the return flows from it, and equals the actual amount of surface water applied. This also means that if water levels are falling even with canal irrigation inputs, then the storage depletion and drop in water levels without exogenous water inputs would be much larger.

S_I

5.3 How Do Geological Conditions Matter?

Figure 3: Major Aquifer Systems in India



Under what geological conditions drops in water levels occur is also important in assessing the extent of groundwater over draft conditions. Many semi-arid and arid areas in the country fall under hard rock conditions. Examples are Peninsular India except the western Ghat region, Saurashtra in Gujarat, western parts of Madhya Pradesh, almost the entire Maharashtra and most parts of Orissa (see Figure 3). In these regions, the specific yield of aquifers is very small, 0.01-0.03. Large seasonal drops in water levels are a widespread phenomenon in these areas. During monsoon, sharp rise in water levels is observed and after the monsoon rains, water levels start receding. Many open wells get dried up during summer. Often the drop in water levels between pre and post monsoon is in the range of 5-6 m. So, one should make a clear distinction between seasonal depletion and annual depletion. Further, in hard rock areas, a unit volume of groundwater pumped from the aquifer results in up to 12-13 times the annual drawdown that occurs in alluvial areas for the same amount of over draft. A fall in water level of 1m in alluvial Punjab should be a cause for much greater concern than a 1m fall in water levels in hard rock areas of Tamil Nadu, or Saurashtra or Karnataka given the fact that the specific yield of alluvium in Punjab is in the range of 0.13-0.2. This will be evident from the data on recharge-abstraction balance for 2 distinct regions. This is not to say that magnitude of water level drop is not important. In fact, a sharp fall in water level would also have serious implications for the investment required for pumping groundwater, and also efficiency with which groundwater could be abstracted. Hence, what is more important is at what rate water levels fall on a long term basis.

5.4 Integrating Negative Consequences of Over-exploitation in Assessing Groundwater Development

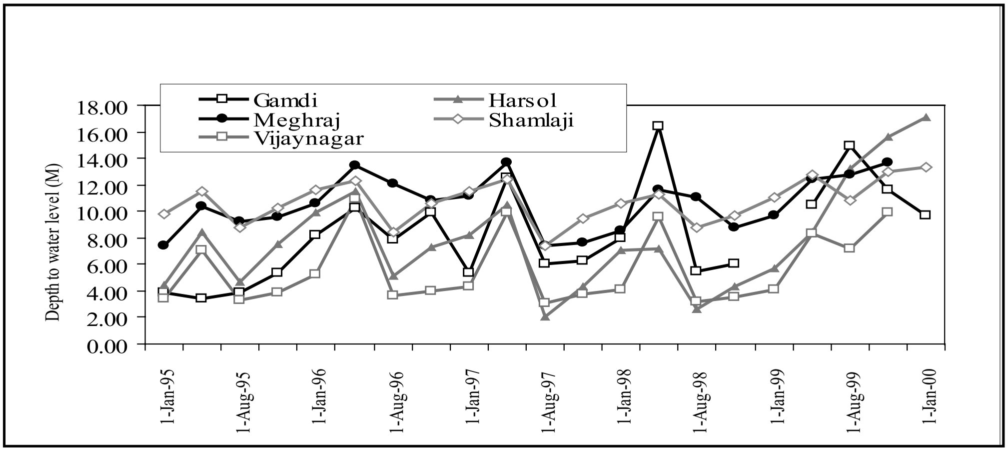
As Custodio (2000) notes, there are many complex considerations involved in assessing groundwater over exploitation in terms of various undesirable consequences. They are hydrological, hydro-dynamic, economic, social and ethical in nature. However, some of the most important ones are: groundwater stock available in a region; water level trends; net groundwater outflows against inflows; the economics of groundwater intensive use, particularly irrigation which takes lion’s share of the groundwater in most semi-arid and arid areas; the criticality of groundwater in the regional hydro-ecological regime; ethical aspects and social impacts of groundwater use. Let us examine how the use of these complex considerations in assessing groundwater over draft would change the groundwater scenario in India.

First of all, as regards the groundwater stock, a region with huge amount of static groundwater resources may experience over draft conditions, with resultant steady decline in water levels. The region which can be cited is alluvial plains of the Ganges, whose groundwater stock is many times more than the average annual replenishment (source: based on GoI, 1999). In such regions assessing over draft conditions purely in terms of average annual pumping and recharge may not make sense. In such regions, the long term sustainability goal in groundwater use can be realized even if one decides to deplete certain portion of the static groundwater resources along with the renewable portion, annually (Custodio, 2000). Limiting groundwater use to renewable resources, with the aim of benefiting future generations, can mean foregoing large present benefits.

As regards the influence of water level trends, a region may not experience over draft when pumping is compared against recharge. But, partial well failures could be an area of concern due to the seasonal drops in water levels. Such steep seasonal drops in water levels are characteristic of hard rock areas. For instance, historical data of water levels in 11 watersheds falling in Mulla-Mutha-Pawana shows levels of groundwater development below 20% in 8 watersheds. But fluctuations in water levels between post and pre monsoon were very high in many wells. For instance, in an observation well in watershed no. BM-42 in Dhanori village in Haweli taluka of Pune district shows a decline of 6.4 m during the period from October 1991 to May 1992. Again, during the period from September 1996 to May 1997, a decline in water level of 6.35 m was observed in water levels in the same well. In several years, the drop in water levels during the same period (between October and May) is in the range of 2.75 m - 3.75 m (source: Groundwater Survey and Development Agency, Pune Regional Office, Pune, 2001).

Similar water level trends are found in hard rock area of Sabarkantha district inside the Sabarmati river basin. The water level data of open observation wells obtained from the Central Ground Water Board were also analyzed to understand the dynamics of water level in the shallow aquifers. The analysis of data for the observation wells located within Sabarkantha district available for the 5 year period from 1996 - 00 shows declining trends in water levels from season to season as well as from year to year (Figure 4). For instance, in the case of Vijayanagar well, the water level dropped by 7.71 m from August 1995 to May 1996 owing to pumping; but recovered by 7.27 m during May 1996-August 1996 owning to the recharge from rainfall. More or less a similar trend continued in the next year. The water level dropped by 6.2 m during August 1996-May 1997; then rose by 6.8 m during the monsoon. It is very likely that the shallow wells may have dried up. On the other hand, the water level fluctuation over a 4year period was found to be only 1.27 m an average annual drop of 0.32 m. This is one of the characteristic features of hard rock areas. Large seasonal drops in water levels (upto 25m) can have significant impact on water availability in the wells during dry seasons.

Figure 4: Water Level Trends in Open Wells in Sabarkantha, Gujarat, India



As per official estimates many such regions are still categorized as white and grey, though these areas face severe groundwater scarcity during summer (Kumar et al., 2001). Table 2 shows the data on wells which have failed, and well which are not in use, available from minor irrigation census of 2001 for 12 Indian states. The total number failed wells include both wells which have permanently gone dry and wells which are temporarily not in use. The second category essentially refers to wells which are seasonal, due to seasonal depletion of groundwater. The data shows that the states which are mostly underlain by hard rock formations, both the percentage of wells that have failed and which are not in use are high. For instance, in Orissa, even as per 2005 official data, the stage of groundwater development was only 18% (GoI, 2005). But, a large percentage of dug wells (21.5%), and a much large percentage of deep tube wells (51.8%) have failed. In terms of numbers, a total of more than 79518 dug wells had failed in Orissa by 2001. Likewise, a significant percentage of open wells (17.3%) in Andhra Pradesh have failed by 2000-01, though the level of groundwater development in the state was only 45% even as per 2005 estimates (GoI, 2005). The number of wells, which have failed, is also very large (204761). Similar trend is found in Tamil Nadu and Madhya Pradesh.

Table 2: Well Failures in Different Categories from 8 Major Indian States (2001)

Sr. No	Name of the State	Percentage of Wells which have failed/(Not in Use)		
		Dug wells	Shallow Tube well	Deep Tube well
1.	Andhra Pradesh	17.3/(20.2)	2.4/(2.9)	1.6/(2.2)
2.	Bihar	18/(32.5)	2.7/(4.8)	36.7/(44.9)
3.	Gujarat	19.3/(22)	12/(14.2)	8.5/(12)
4.	Madhya Pradesh	16.2/(18)	14.7/(15.1)	13.9/(16.2)
5.	Maharashtra	9.3/(10.9)	4.3/(7.9)	10.7/(13.6)
6.	Orissa	21.0/(25)	16.5/(19.3)	51.8/(62.8)
7.	Punjab	0/(0)	0/(0)	1.2/(1.6)
8.	Rajasthan	24.9/(27.9)	3.3/(3.5)	7.4/(7.8)
9.	Tamil Nadu	20/(22.1)	7.5/(8.1)	19.7/(20.4)
10.	Uttar Pradesh	4.4/(9.5)	0.80/(1.2)	3.7/(5)
11.	West Bengal	6.3/(10.3)	3.5/(4.4)	9.8/(12.2)

Source: Authors' own analysis based on Minor Irrigation Census data 2001

Note: the figures in brackets show the percentage of wells which are currently not in use due to several reasons.

Similarly, the current district-wise assessment of groundwater development does not take into account the long-term trends, as the latest methodology suggests. A region might have experienced long term decline or rise in water levels; but a few years of abnormal precipitation (either drought years or wet years), may change the trends in the short run. Hence, assessment of over draft conditions should integrate hydro-dynamics, i.e., the way groundwater levels behave.

Another dimension of groundwater over exploitation is economic. The cost of production of water should not exceed the benefits derived from its use, or the cost of provision of water from alternative sources. Drops in water levels beyond certain limit cause negative economic consequences, by raising the cost of abstraction of unit volume of water, not only in irrigation but also in other sectors like municipal uses. Though there could be plenty of water in the aquifers, the fixed cost and variable costs of abstraction of water could be prohibitively high. In alluvial north and central Gujarat and arid Rajasthan, groundwater irrigation is viable due to heavy electricity subsidies. An analysis by Kumar et al. (2001) in Sabarmati river basin of north central Gujarat showed that groundwater irrigation would be economically unviable if the full cost of energy used for pumping groundwater is borne by the farmers.

In many hard rock areas underlain by basalt and granite, the highly weathered zones in the geological formations, which yield water, have small vertical extent-up to 30 m. When the regional groundwater level drops below this zone, farmers would be forced to dig bore wells tapping the zone with poor weathering. The reason is tapping groundwater from strata below this depth using open wells would be not only technically infeasible, but also economically unviable. These bore wells have poor yields, unlike the deep tube wells in alluvial areas such as north Gujarat, alluvial Punjab, Uttar Pradesh and Haryana. For instance, analysis of census data (Table 3) show that as high as 40% of the nearly 85,601 deep bore wells (that are in use) in Andhra Pradesh were not able to utilize their potential due to poor discharge. The figure was nearly 19.1% for Rajasthan, which had sedimentary and hard rock aquifers. The figure was 59.9% for Maharashtra, which has basalt formations. One could see that the percentage of deep tube wells which suffer from poor discharge was very low in alluvial areas of Punjab (0.3%) and West Bengal (0.3%). While the number is very high for alluvial Bihar, the total number (430) is negligible.

Table 3: Percentage of Dug Wells and Deep Tube Wells Suffering from Poor Discharge in Selected Indian States

Sr. No	Name of the State	No. & Percentage of Wells in Use Which Face Discharge Constraints	
		No. of Deep Tube Wells	% of Deep Tube Wells
1	Andhra Pradesh	34216	40.0
2	Bihar	430	12.6
3	Gujarat	20282	24.5
4	Madhya Pradesh	17841	58.5
5	Maharashtra	39958	59.9
6	Orissa	132	7.7
7	Punjab	10	0.10
8	Rajasthan	10010	19.1
9	Tamil Nadu	22838	34.1
10	Uttar Pradesh	3110	9.3
11	West Bengal	15	0.30

Source: Authors' own analysis based on Minor Irrigation Census data 2001

Withdrawal of groundwater from these bore wells creates excessive draw-downs as specific yield and transmissivity values of these hard rock formations are very low. Due to excessive draw-downs and high well interference, well failures become widespread. Therefore, before a farmer hits water in a successful bore well, he/she would have sunk money in many failed bore wells. Due to this reason, the actual cost of abstraction of groundwater becomes very high. The command area of wells is also on the downward trend. For instance, in the case of five districts falling in the basaltic area of Narmada river basin in Madhya Pradesh, the average command area of energized wells were found to be declining almost consistently from 1974 till 2000 (see Table 4). In Betul district, the average area irrigated by a well reduced from 6.97 ha to 2.18 ha during the 26 year period. In Chhindwara, it reduced from 4.56 ha to 2.75 ha. So investment for well construction, compounded by reduction in command area reduces the overall economics of well irrigation. But, this aspect has been captured in the criteria for assessment of over exploitation. As per the official data, these five districts are still in the white category, and safe for further exploitation (GoI, 2005).

Table 4: Reduction in Average Command Area of Wells over Time in Narmada Basin, Madhya Pradesh

Name of District Falling in Narmada Basin	Average Area Irrigated by a Well in ha					
	1974-75	1980-81	1985-86	1991-92	1995-96	2000-01
Balaghat	4.50	2.25	2.35	2.57	1.73	1.96
Chhindwara	4.56	2.58	2.26	1.42	1.50	1.75
Shahdol	2.04	0.18	0.50	0.70	0.99	0.47
Jhabua	2.93	1.87	0.89	1.20	1.26	0.57
Betul	6.97	3.37	3.02	1.98	2.06	2.18

Source: Authors' own estimates based on primary data as provided in Kumar (2007)

Interestingly, the economics of groundwater use is not a function of depth to water table alone, as often perceived. Even in areas with shallow water table conditions the cost of abstraction could be enormously high due to high cost of energy. In Bihar, due to poor rural electrification, farmers are forced to use diesel and kerosene pumps for lifting water from wells. Though the depth to water table is nearly 15-20 feet, it costs them Rs.50 /hour for pumping water with an output of nearly 15 lt/sec. The unit variable cost comes to Rs. 1/m^3 of water. This is higher than the variable cost farmers incur in north Gujarat (Rs.0.50/m^3) for pumping out water from a depth of 400-500 ft.

The economics of groundwater use is not static. Economic viability of groundwater abstraction can change under 2 circumstances: 1] opportunities for using the pumped water for more productive uses emerge with changing times; and 2] the cost of abstraction of groundwater changes due to improvements in pumping technologies, or changing cost of energy for pumping groundwater. With massive rural electrification, cost of groundwater abstraction in Bihar could come down to negligibly low levels. On the other hand, adoption of new high yielding varieties or high valued crops can increase the gross returns from farming.

Social consequences of groundwater use are equally important. One serious issue associated with groundwater intensive use is that it excludes resource poor farmers from directly accessing the resource when water levels start falling. Equity in access to resource (aquifer) should be an important consideration in assessing the degree of over exploitation of aquifers. In many areas, it is only the rich farmers, who are able to pump groundwater, owing to astronomical rise in cost of digging/drilling wells, and they enjoy unlimited access to the resource. While the well owners of Mehsana incur an implicit cost of nearly Rs.0.5/m^3 of water , they charge to the tune of Rs.1.5/m^3 to Rs. 2/m^3 from the buyers. Similar trends were found in Kolar district, in which case the well owners charge up to Rs. 6.5/m^3 of water (source: based on Deepak et al., 2005), against a close to zero

[8] This is based on the capital investment of 10 lac rupees amortized over the life of the tube well (12 years), the annual operation and maintenance costs of Rs. 50,000 and the average volume of 2.5 lac cubic metre of water pumped during a year at a rate of 100m3/hour.

marginal cost of pumping groundwater. In many areas, groundwater intensive use leads to water quality deterioration, causing scarcity of safe water for drinking. In such situations, the draft does not necessarily exceed the recharge. Examples are Saurashtra and Chennai coast, alluvial north and central Gujarat, Gangetic alluvium of West Bengal. While the issue is of salinity in coastal Saurashtra and Chennai, it is arsenic content in deep aquifers in West Bengal (Kumar and Shah, 2004).

Groundwater over use, like the use of other natural resources involves ethical considerations (Custodio, 2000). The ethical considerations concerning water use mainly revolve around the distribution of benefits and costs of water use and risks associated with it (Llamas and Priscoli, 2000). The extent to which wasteful use practices are involved in major sectors of water use and the degree to which water abstraction practices reduce the opportunities of users neighbouring farmer, individual himself, and others are the major issues to be investigated (Kumar, Singh and Singh, 2001). In a water-scarce region, physically and economically inefficient uses should be discouraged. But, in reality, even in regions where acute scarcity of groundwater exists, farmers use traditional irrigation methods that are wasteful; and allocate water to economically inefficient uses (source: based on Kumar, 2005; Deepak et al., 2005). In hard rock areas, competitive drilling by powerful farmers causes reduction in yield of neighbouring wells due to well interference, depriving resource-poor farmers (Janakarajan, 2002; Deepak et al., 2005). In sum, the current assessment of groundwater over exploitation does not give a clear picture of actual intensity of over exploitation in both absolute and relative terms. It tends to underestimate the magnitude of groundwater over exploitation in India, which can be assessed from the negative social, economic and ecological consequences of over development.

6. SUMMARY AND CONCLUSIONS

There are many conceptual issues in defining groundwater over development. First of all, the concept of groundwater over development or aquifer over exploitation is complex linked to various undesirable consequences which are physical, social, economic, ecological, environmental, and ethical in nature. Further, there are varying perceptions of the undesirable consequences. As Custodio (2000) notes, defining and assessing groundwater over development are both difficult and complex and not amenable to simple formulations. The reasons are as follows: varying perceptions of people concerned; the terms used to define over exploitation vary with space and time; difficulty in calculating aquifer recharge and integrating water quality with quantity: difficulty in assessing long term trends in recharge rate that are very important; importance of localized effects in the overall picture; changing social perceptions and priorities; improvements in water use technology; the need to consider the net socio-economic benefits; complex nature of cost-benefit calculations; and use of scarce, poor, and inappropriate data to define over development.

The criteria adopted by official agencies in India for assessment of groundwater over development are inadequate for complex aquifer conditions, and at best give aggregate scenarios of recharge and abstraction for simple aquifer conditions. But, there were some improvements in the criteria and methodologies proposed by various expert committees since 1984. The most significant improvement in the criteria is the inclusion of base flows and lateral flows to determine the net groundwater recharge. The second significant improvement is in the criteria for assessing the stage of groundwater development. GEC-1997 suggests the use of gross groundwater draft against the net recharge, instead of the net draft against the gross recharge. It had recommended the inclusion of all hydrological variables in the estimation.

But, the methodology proposed for estimation of these variables becomes inadequate when the assessment is to be made for administrative units. This is because of the absence of analytical procedure for estimation of base flows during monsoon season, and questionable reliability of the estimates of lean season base flows. Even the CGWB's own assessment of groundwater development takes into account only base flows during lean season (estimated). So, all these can induce major errors in estimation of recharge. But, the challenge becomes mounting when data on specific yield of aquifers are not available. When assessment is to be made for watersheds, the gauge data of stream flows can be used to estimate the base flows during monsoon. Also, the lean season flow can be directly measured.

Leaving aside the issue of doing reliable estimates of recharge and abstraction, the criteria for assessing aquifer over exploitation in India are too simplistic, based on net recharge and gross draft. They not take into account the complex hydrological, geological, hydro-dynamic, economic, social and ecological variables that determine the physical, social, economic, ecological and ethical consequences such as the safe yield of the aquifer, drinking water scarcity during lean season, poor economics of groundwater use, water quality deterioration, equity in access to water, and the efficiency with which water is used.

We have used selected illustrative cases to demonstrate how combining official statistics of groundwater development in the country, with information on detailed water balance, geology, water level fluctuations, and socio-economic, ecological and ethical aspects would cast an altogether different scenario of the degree of over exploitation problems in India. The available assessments of groundwater over exploitation provide a highly misleading picture of groundwater exploitation scenario in India. As per the most recent official estimates, many hard rock regions which are facing problems of reduction in well command, frequent well failures and enormous increase in cost of groundwater abstraction, and seasonal scarcity are shown as safe areas. Many areas in central India, which are facing problems of water level decline, are still categorized as under-developed areas.

To get the assessment of aquifer over exploitation that reflects the concerns of the stakeholders, two steps are important. The first step is improving the reliability of groundwater recharge and draft estimates. The most important challenge is accurate estimation of groundwater draft and natural outflows from and lateral flows in the groundwater system. The accuracy in estimation of groundwater recharge would depend on the availability of reliable data on specific yield values for the aquifer under consideration. The second step is broadening the criteria for assessing aquifer over exploitation to capture the complex hydrologic, hydro-dynamic, economic, social and ecological variables that reflect the negative consequences of over development. For this, a lot of data on socio-economic and ecological aspects of water use need to be generated and combined with the official data.

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WELLS AND ILL-FARE: IMPACTS OF WELL FAILURES ON CULTIVATORS IN HARD ROCK AREAS OF MADHYA PRADESH

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Abstract

Over exploitation of groundwater water resources is causing progressive decline in water table in the arid and semi arid parts of India. The socio-economic impacts of these phenomena range from increased cost of well irrigation to reduced returns from irrigated agriculture, to growing inequity in access to groundwater depending on the aquifer conditions and the overall socio-economic conditions of the communities. In hard rock areas, over exploitation is leading to decline in yield and drying up of open wells. This forces farmers to go for either well deepening or drilling new bore wells. But due to the poor success in hitting water through bore well drilling in hard rock areas and the consequent increase in costs of setting up a bore-well based irrigation scheme, small cultivators are the worse affected. This paper focus on the phenomenon of well failure in the hard rock areas of Dewas in Madhya Pradesh. It highlights the causes of well failure and related welfare impacts on the cultivators especially small landowners. The major impacts were found to be on the cropping pattern, extent of well irrigation, crop yields, net returns and food security in the surveyed region. In addition, discussion is centered on power subsidies in the state which have promoted indiscriminate use and further depletion of groundwater from the already low yielding aquifers.

1. INTRODUCTION

In India, groundwater irrigation has emerged as a major source of irrigation since mid 1970's. This was the period when most of the country's rural population was involved in extensive agriculture as an outcome of green revolution. At present groundwater is sustaining nearly 60% of the country's net irrigated area (Source: Indiastat 2004-05). The importance of the groundwater resource in India can further be realized by the fact that about 60% of irrigated food production depends on irrigation from groundwater wells (Shah et al., 2000). Nearly all major agricultural states in India have heavy dependence on groundwater for irrigation. In states such as Tamil Nadu, Maharashtra, Madhya Pradesh, Rajasthan, Uttar Pradesh, Punjab, and Gujarat, 60-87% of the net irrigated area is through groundwater (Source: Indiastat 2003-04). A study revealed that crop yield in groundwater irrigated areas is higher by one third to one half then those irrigated by surface sources (Dhawan, 1995).

Thus in order to optimize crop yields and maximize profits from agriculture, farmers make intensive use of groundwater. This has led to overdraft of groundwater beyond the recharge potential, and lead to water scarcity across many regions in India. The first set of concerns regarding groundwater over-exploitation at various locations across India, were raised almost three decades back (Kumar and Singh forthcoming). As per central groundwater board report (2006), 37% of the total assessed *talukas* in Karnataka, 37% of the total blocks in Tamil nadu, 49% of total blocks in Haryana, 59% of the total blocks in Rajasthan and 75% of the total blocks in Punjab are overexploited. These figures are much above the 15% of the total blocks/*talukas,* which are overexploited in the country. Such a mass scale overexploitation has serious consequences for a country like India where hard rocks such as granites, gneisses, basalt etc. cover almost 75% of the total area of the subcontinent. In these hard rocks areas, recharge of aquifer is a comparatively slow process and often occurs at places having fissure or cracks in the rock. Therefore, overexploitation in hard rock areas seriously affects the groundwater availability in these regions.

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Lack of well-defined ownership rights in groundwater has also resulted in its unsustainable use. In India, groundwater ownership is attached to land rights. This means anybody owning a land can drill or dig a well in his land and utilize as much groundwater as required. Along with such ownership status, one of the major factors, which promoted the indiscriminate use of groundwater is the policy of heavy subsidy on electricity supply by government to farmers for agriculture use (Janakarajan and Moench 2006). This has accelerated groundwater abstraction, with farmers now using more advanced devices and techniques to pump water. Across many regions, farmers kept on excavating deeper wells and drilling deeper bore wells in order to have more water for irrigation. This resulted in further lowering of water table in various parts of the country. 23 districts in Andhra Pradesh, 45 districts in Madhya Pradesh, 26 districts in Karnataka, 27 districts in Tamil nadu and 34 districts of Maharashtra have groundwater level declining at the rate of 20 cm/annum (*Source: Ministry of Water Resources*).

2. GROUNDWATER OVER-EXPLOITATION AND WELL FAILURES IN HARD ROCK REGIONS.

Figure 1: Net Irrigated Area from different sources

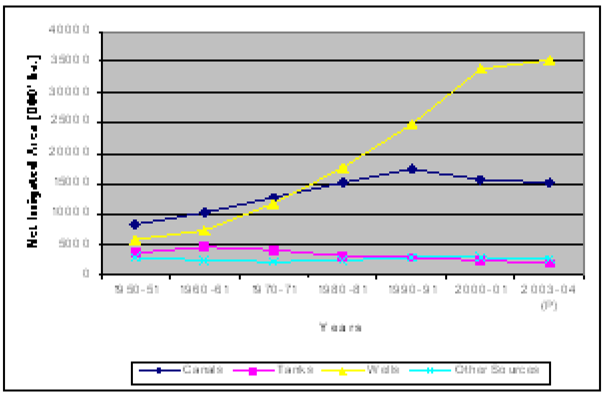
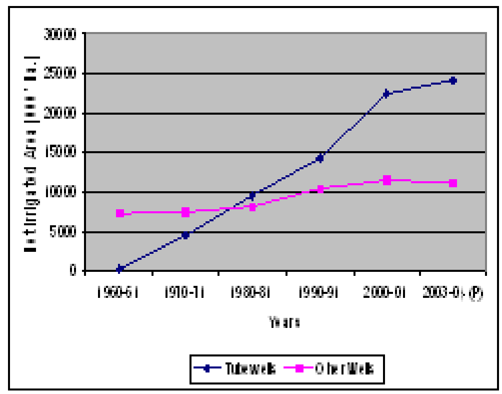


Figure 2: Net Irrigated area through wells

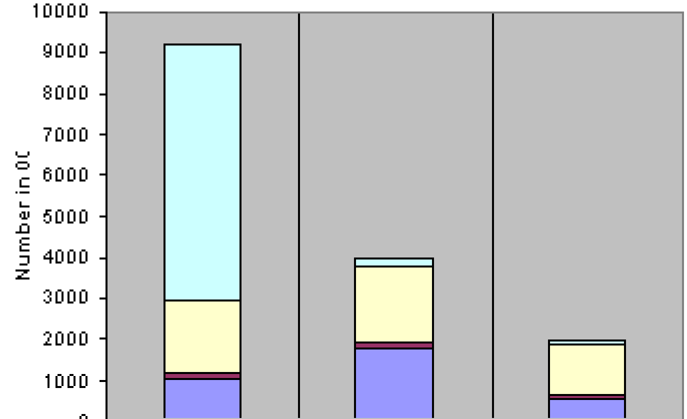


There is no doubt that groundwater use for irrigation in India is growing steadily and has overtaken the canal irrigation way back in the early 1970's (Figure 1). Since mid 1960's, energized irrigation i.e. through tube wells and bore wells has increased by much greater extent than the dug-wells irrigation (Figure 2). This increased dependence on groundwater has resulted in overexploitation of groundwater resources and caused significant increase in the number of well failures especially in the hard rock regions of the country. In fact, the problem of groundwater overexploitation has been reported by many researchers from different regions of India. These regions include parts of Andhra Pradesh (Chandra et al., 2006), Karnataka (Premchander et al., 2003), Maharashtra (Pathak et al., 1999), north Gujarat (Ranade and Kumar, 2004) and Tamil Nadu (Palanisami, 2002).

2.1 Hard rock areas Aquifer and well failures

Major source of irrigation in the hard rock region of our country i.e. Tamil Nadu, Karnataka, Maharashtra, Madhya Pradesh, and Andhra Pradesh is groundwater. Over the years, dependence on this sub-surface resource has only increased. In these hard rock areas where groundwater availability is highly dependent on degree of natural recharge through rainfall (which is only 4-10% of total rainfall, NABARD 2006) and percolation (Diwarka *et. al*., 2007), overdraft of groundwater can have serious affects on the water availability which may lead to well failures. Well failures put a range of social and economical impacts on the cultivators especially small landowners. Because of limited resources with these small landowners, these consequences include increased extraction costs, reduced well yields and quality deterioration (Kumar and Singh forthcoming).

Figure 3: Total Irrigation Wells and Well Failures



	Madhya Pradesh (1990-91 & 1999-00)	Tamil Nadu (1997-98 & 2002-03)	Maharashtra (1961-62 & 1994-95)
Year 2 Failed/Abandoned Wells (in 000')	6236	204	103
Year 2 Total Irrigation Wells (in 000')	1763	1844	1197
Year 1 Failed/Abandoned Wells (in 000')	175	148	105
Year 1 Total Irrigation Wells (in 000')	1018	1779	557

Wells failure is a common phenomenon in hard rock regions of country (Nagaraj and Chandrakanth 1997; NIH 1999; Ballukraya and Sakthivadivel 2002). The reason can either be overexploitation of water from existing wells or failure in identifying the exact water bearing zones or aquifers. Over the years, total number of irrigation wells in the hard rock regions has increased but there is simultaneous increase of abandoned or failed wells (Figure 3). In some states, increase in number of wells has not contributed to corresponding increase in groundwater irrigated area. For example in Tamil Nadu, it was found that with the increase in number of wells there is no major increase in groundwater irrigated area after 1980's (Janakarajan and Moench, 2006). Similarly, in 5 districts of Madhya Pradesh namely Balghat, Chhindwara, Shahdol, Jhabua and Betul, the average command area of energized wells was found to decline almost consistently between 1974 and 2000 (Kumar, 2007). These studies confirm that hard rock states are undergoing mass overexploitation of groundwater resource without much beneficial affect on the irrigators.

2.2 Situation in Madhya Pradesh

From the period 1992-93 to 2001-02, surface irrigated area (from both canals and tanks) in Madhya Pradesh has declined while irrigation through groundwater sources has increased. Even though this was the period of investments on surface irrigation systems and involvement of end users in irrigation management, still there was a decline in the net irrigated area by surface sources. The net groundwater irrigated area in state increased to 3.70 million ha in 2003-04 as compared to only 2.23 million ha in 1991-92. Irrigation wells in the state have increased from 1.02 million in 1990-91 to 1.8 million in 1999-00. In the same period number of sprinkler devices in the state increased to 13,865 from just 150. Tube well dependence[4] in 1992-93 itself was as high as 83% in Indore, 58% in Durg, 46% in Ujjain, 41% in Dewas and 38% in Raipur, which are all hard rock districts of MP (Shah et al., 1998).

[4] Tube well Dependence Index= Gross Irrigated Area by Tube wells*100/Gross Irrigated Area

Power subsidies in the state also promoted indiscriminate use of groundwater. Between 1985- 2001, free electricity was supplied by the state to the farmers. The period 1986-2001, saw a tremendous increase in number of tube wells in the state. From the total of 29534 in 1986-87 it increased to 315422 in 2000-2001, nearly 11 times increase (Source: Minor Irrigation Census, 1993-94 and 2000-01). However, after the pricing of electricity in 2001, the growth in number of irrigations wells has ceased. From the total of 1.53 million in 2001-02, the number of irrigation wells in 2004-05 was 1.39 million, a decrease of 9% in just 3 years.

The foregoing analysis confirms that groundwater is becoming an important source of irrigation in the state. But the main problem which is emerging and may be one of the reasons (along with electricity reforms) for decrease in number of irrigation wells is the increasing number of irrigation well failure in the past decade. The number of abandoned wells in the state has increased to 6.2 million (1999-00) in comparison to only 0.17 million in 1990-91. There are increasing evidences of reducing average command area of individual energized wells in Madhya Pradesh (Kumar, 2007). As per water resource department Madhya Pradesh estimates (1998), groundwater condition is safe in 24 districts, semi critical in 12 districts, critical in 4 districts and over-exploited in 8 districts. Critical districts identified are Dewas, Khargoan, Shajapur, Tikamgarh and over-exploited districts are Badwani, Chhindwara, Dhar, Indore, Mandsour, Neemuch, Ratlam, Ujjain. These increasing well failures in hard rock areas pose serious questions of not only sustaining the recent growth in well irrigation, but also sustaining the current level of use.

3. STUDY PURPOSE AND METHODOLOGY

With this overall picture of groundwater abstraction in the country, the following research was carried out in the hard rock areas of Madhya Pradesh (MP) state. The foremost objective of the study was to analyze the impact of well failures on the socio-economic condition of the farmers.

For the purpose, block *Bagli* from district *Dewas*, MP was selected as a study site. *Dewas* was selected as this is one of the districts in the state facing serious groundwater exploitation problem. Selection of *Bagli* was more because of convenience in carrying out the field work in that block. Two villages - *Nayapura* and *Chhatarpura* were chosen from the block for the survey. As the focus of the study was on irrigation well failures, farmers owning wells (open or bore wells or both) were selected. Random sampling was followed for selecting 101 farmers from the two villages. Sample consisted of 11 small and marginal farmers, 31 semi-medium farmers, 50 medium farmers and 9 large farmers. For taking responses from the farmers, a schedule was developed. Besides this, focus group discussions were carried out with some progressive farmers to get a deeper understanding of the problem. Discussions were also done on the importance of agriculture in farmers livelihoods, with the NGO members working in *Dewas* district. Various research papers related to groundwater overexploitation and the state government reports on the hydrogeology of the regions were consulted as a reference and background material for the research study.

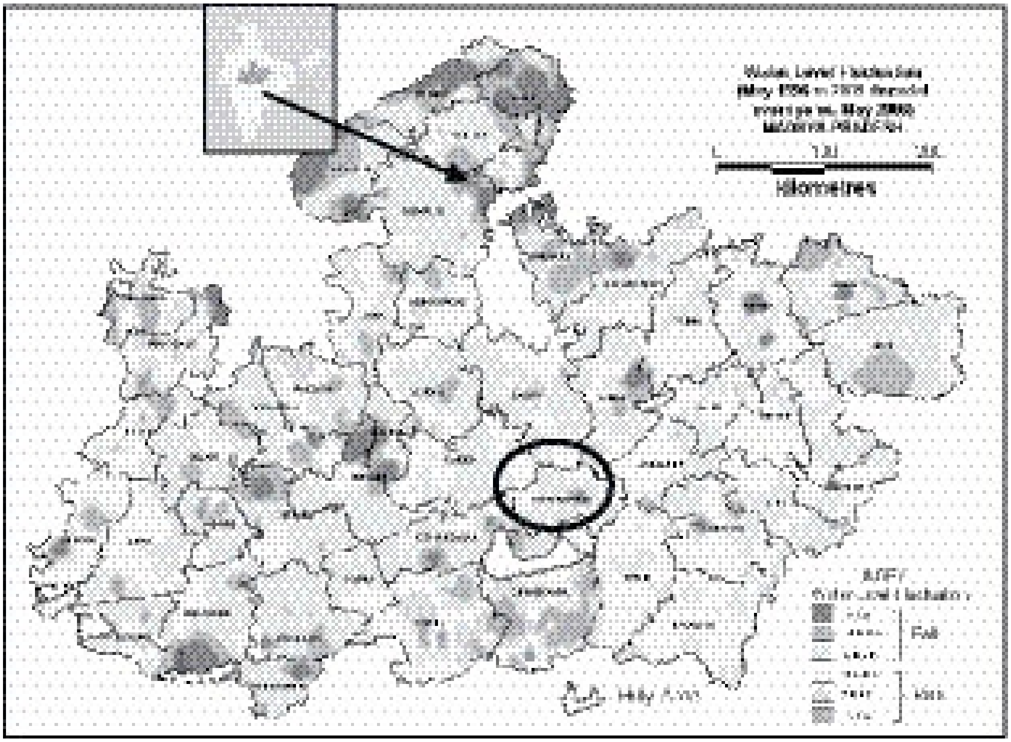
4. GENERAL FEATURES INCLUDING GROUNDWATER DEVELOPMENT IN *DEWAS*

Dewas is situated between 75º55’ and 77º09’ longitude and 22º19’ and 23º19’ latitude. The population of the district is 1.3 million (2001 census) which is roughly 2.15% of total population of Madhya Pradesh. Total area of the district is 7020 sq. kms. and it has 6 blocks or *tehsils*. The average rainfall in the district is 1067 mm. But owing to impervious nature of the soil (predominantly black soil) in most of the area, rainwater does not percolate. Also because of the topography (rolling terrain) of the region, most of the rainwater drains away into rivers. Major crops grown in the area include soyabean, cotton, wheat and gram.

The district has 0.43 million hectares of land under agriculture, out of which 0.17 million ha is covered by irrigation facilities. About 83% of this agricultural area covered under irrigation, is irrigated through groundwater sources i.e. dug wells and bore wells. There has been a rapid and progressive increase, both in number and depth of bore wells in the region (Shah et al., 1998). Number of bore wells in the district increased from only 3887 in 1990 to 14172 in 1998. Increased number of wells, impervious nature of soil and the rolling terrain topography of the area has resulted in depletion of groundwater table at the rate of 2 cm/annum (Figure 4).

Because of overexploitation and decrease of groundwater level at such an alarming rate, the district has been identified as “critical” (groundwater development >90% but <100%) by the Central Groundwater Board.

Figure 4: Groundwater Level Fluctuations, Madhya Pradesh
(Source: Central Groundwater Board)



4.1 Groundwater situation in Bagli block

Bagli lies in the *Malwa plateau* region of Madhya Pradesh. Majority of the agricultural land is irrigated through groundwater resources. The hydro-geological set up of the region is such that groundwater occurs in two distinct aquifer layers i.e. shallow and deep. Shallow aquifer layer is between 12-18 m deep and gets recharged with the rain water in the monsoon season. On the other hand, deep aquifer layer varies between 60-200 m and its occurrence depends mainly upon the location of the fissures in the rock. Rate of recharge in this deeper zone is a gradual and slow process. Groundwater is mainly tapped by the construction of open wells (to a depth of 12-18 m) and deep bore wells (maximum boring depth going up to 213 m). As per CGWB (1998), groundwater development in the block is within safe limits. However, because of irregular rainfall and increasing over exploitation of groundwater in the last few years, the block faces acute shortage of water during the later part of Rabi (winter) and whole of summer season. Also, there is increasing number of well failures in the block mainly because of seasonal variations (mostly in case of open wells) and failed drillings (mostly in case of bore wells). Major crops cultivated in the block include soyabean (in Kharif or monsoon season), wheat and gram (in Rabi season). A decade back, sugarcane was grown as the major perennial crop. But less availability of groundwater especially in summer season, have forced farmers to discontinue with cultivating sugarcane.

Collected data from the block indicates that about 91% of small farmers have joint ownership of wells as compared to only 31% of semi-medium and medium farmers and nil for large farmers (Table 1). Thus larger the size of landholding, lesser the incidence of joint well ownership. Also, the average number of wells owned by small farmers (1.09/farmer) is less than large land owners (3.9/farmer). This implies that number of owned wells is a direct function of land size.

Table 1: Details of Selected Farmers from the two Villages

	Selected Villages							
	Chhatarpura				Nayapura			
	Small & Marginal Farmers (Land <2 ha.)	Semi-Medium Farmers (Land 2-4 ha.)	Medium Farmers (Land 4-10 ha.)	Large Farmers (Land 10 ha. or above)	Small & Marginal Farmers (Land <2 ha.)	Semi-Medium Farmers (Land 2-4 ha.)	Medium Farmers (Land 4-10 ha.	Large Farmers (Land 10 ha. or above)
Total Number of Selected farmers	8	17	16	6	3	14	34	3
Farmers with only Individual Wells(IW)	1	9	14	5	0	4	13	2
Farmers with only Shared Wells (SW)	7	5	1	0	3	7	12	0
Farmers with both IW & SW	0	3	1	1	0	3	9	1
Major Crops Grown								
Kharif	Wheat, Gram, Garlic, Potato				Wheat, Gram, Garlic, Potato			
Rabi	Soyabean				Soyabean			

5. MAIN REASONS OF WELL FAILURE IN THIS REGION

Over the years, there has been tremendous increase in groundwater pumping for irrigation in *Dewas* district. From 50% in 1996-97, groundwater irrigated area increased to 87% of the total net irrigated area by 2004-05. There was increase of 14% in the number of irrigation pumps in the district between 1998-99 and 2002-03. Groundwater development in *Dewas* increased to 66% in 2004 (an increase of over 100%) as compared to only 32.9% in 1988 (Source: CGWB). This increase is significant considering that relatively lower level of groundwater development in hard rock areas can have significant impacts than the similar level of groundwater development in other areas.

In the selected block, shallow aquifers are the most common source of irrigation (i.e. irrigation by extracting water through constructing open wells) until early part of the Rabi season. After that, most of the open wells dry up (as reported by 100% of the respondents). In the remaining half of the Rabi season, those having access to bore wells continue with irrigation by extracting water from deeper groundwater aquifer. Almost 100% of the respondents agreed that the major cause of well failure (referring to open wells here) is the seasonal drop of water levels in the wells. During monsoon, these wells fill up with water and most of them dry up by November-December. As these open wells are popular with the small farmers, they are affected most by such failures. Other most common type of well failure is during the drilling of bore well itself. Because of the presence of hard rock strata beneath sub-soil surface (below depth of 18-20m), it is very difficult to find exact water bearing zone. Water bearing zones in such settings will only occur at points where there are fissures or cracks in the rock. On an average, it requires nearly 4-5 drillings before finally hitting the water bearing zone.

Some farmers (only 2 respondents from the selected farmers) are of the view that well interference is also making impact on the availability of water and hence causing well failures. Well interference is a condition occurring when the area of influence of a water well comes into contact with or overlaps that of a neighboring well, as when two wells are pumping from the same aquifer or located near each other. However, the phenomenon is not making such a significant impact in *Bagli* block yet.

6. IMPACT OF WELL FAILURE ON COST OF WELL IRRIGATION

Well failures in the region have more pronounced effect on the small landowners most of who have shared wells (91% of the surveyed small farmers). Looking at the cost economic side, it costs approximately Rs. 114000 to dig open well (diameter 8m and depth 14m) with 3HP submersible pump. As most of these open wells are shared among small farmers, the cost to the farmers get reduced to Rs. 57000/open well. This cost is 65.6% less than the bore well installation (depth of 87m with 10HP submersible pump) which costs around Rs. 165800 (Table 2). But because of seasonal drying of the open wells, small landowners suffer from increased cost of irrigation, low crop yields and low net returns (discussed in next section).

In contrast, large landowners believe that investments in open wells are not putting pressure on them. They get water from these open wells in the early part of Rabi season. Bore wells are used to provide supplemental irrigation to the winter crops in the later part of the season. Because of limited resources with small farmers, even the seasonal water drop makes a big impact on their irrigation cost and crop yields. Since most of the surveyed small farmers do not have access to bore wells, in case of less rainfall and early drying of open wells these farmers either purchase water or do not irrigate their fields in the remaining part of the season. Purchase of water (average cost Rs.80/hr.) further increases their cost of cultivation and no irrigation affects their overall crop yields (up to 25% less than the irrigated crops as reported by farmers). Further, because of the less probability (0.2) of hitting the exact water bearing zone and less discharge (1-2 lt/sec), installation of workable bore well is a difficult process. Therefore, bore wells are not a popular option among small farmers for irrigation and they restrict themselves to getting water from open wells only.

Table 2: Cost of digging/drilling Wells

	Cost of Open Well in INR (dia. 8m and depth 14m)	Cost of Bore well in INR (depth of 87 m)*
Cost of digging (inclusive of labor)	100,000	78,300
Cost of casing (required up to 15m)	Nil	17,500
Cost of Pump (inclusive of pipe system)	14,000 (3HP Pump)	70,000 (10HP Pump)
Total	114,000	165,800

* Cost estimation also includes failed bore holes

Regarding the operational cost, at present two types of electricity connections are available for agricultural usage. One is the fixed line collection for which farmers need to pay under fixed rate year around and second is the temporary connection for 1-3 months. Under fixed line connection, a flat rate of Rs. 220/HP/month is given by farmers. Majority of bore well owners have fixed line connections as they use water for nearly 8 months. Under temporary connection, the amount of Rs. 1027 has to be given for one-month up to 3 HP water pump and amount of Rs. 2821 for the three months. The amount of Rs. 1625 is charged for the 5 HP water pump for one month and Rs. 4615 for three months. Electricity rate, electricity charge (tax) application fee, electricity line connection charge and disconnect charge have been included in the selected charge. These temporary connections are more popular among open well owners as they have water only for 3-4 months. But, the supply of electricity is of poor quality and untimely. Most of the block receives only 6 hours of 3-phase electricity (necessary for running pumps) and there is no fixed time of supply. Considering the discharge from the wells and quality of electricity, it takes around 15 hours to irrigate 1ha of land. Thus, most of the large farmers use diesel gensets as a backup to irrigate their fields in the absence of electricity supply. Only a few small farmers can afford gensets and it takes around 2-2.5 lt of diesel/hr of pump working which significantly increases the cost of irrigation.

In the event of seasonal well failure, farmers especially with small land holdings, have to bear additional cost of well irrigation besides their normal operational expenditure (Table 3)[5] . These extra costs can be expenditure on new well installations (refer Table 2), cost on well deepening's (Rs. 180/m), cost on purchase of water (Rs. 80/hr) or losses in crop yields if farmers decide to leave their field with no irrigation.

Table 3: Normal Operational Cost of Well Irrigation/Month for a hectare of land with Wheat Crop (in Rs.)

	Under Fixed Line Connection (10 HP Pump)	Under Temporary Connection (5 HP Pump)*
Electricity Charges	1150	1625
Diesel Charges	630	630
Total	1780	2255

* Majority of Fixed line connection are for bore wells and temporary connection for open wells

7. MEASURES ADOPTED IN RESPONSE TO WELL FAILURES

The seasonal well failures in the region have forced farmers to take some corrective measures. Majority of farmers (32 % of the respondents) have gone for open well deepening over the years to have more water storage. This deepening is both vertical and horizontal. Maximum vertical deepening was found to be up to 22.5m and maximum horizontal deepening up to 30m for the surveyed farmers. Farmers opting for horizontal deepening mainly restrict it to below their farm lands only. This plays a major role in avoiding any kind of conflict arising from such deepenings. Of those having bore wells, no one has attempted deepening and very few farmers (only 2 respondents) opted for drilling new bore well once their earlier bore well started to give less discharge.

All the farmers had undergone cropping pattern changes as a result of no or less availability of water in late Rabi and summer season. Sugarcane was the major perennial cultivated crop but now it has been replaced with soyabean in Kharif (monsoon season) and wheat in Rabi season. The main reason for such shift was water shortage and comparatively better return in soyabean and wheat in comparison to sugarcane crop. Few farmers (total of 5 respondents) purchased water from other farmers having bore wells in case their open wells ran dry. The rate of water is on average Rs. 80/hr. Although it created an extra input cost burden on buyer farmers but they were satisfied in getting comparatively better crop yields than the un-irrigated farmers. A small fraction of farmers (2 in our sample) have also adopted sprinkler irrigation mainly for irrigating wheat but that had little success. One farmer has dug a recharge pond in his field. He learned about recharge ponds in one of the demonstration sites under National Rural Employment Guarantee Act (NREGA). The farmer looked quite optimistic about the benefits of the recharge ponds in the years ahead.

8. SOCIO-ECONOMIC IMPACTS OF WELL FAILURES

Socio economic impacts were mainly analyzed with focus on agricultural livelihoods only. These are discussed in detail in this section.

8.1 Impact on Cropping Pattern

Farmers in the surveyed area were mainly found to grow soyabean in Kharif and wheat and gram in Rabi season. Most of the farmers leave their land fallow in summer months. Surveyed data shows that soyabean is sown in 100% of the cultivated area across all landholding classes in the Kharif season. But cropping pattern

[5]While inferring Table 3, it has to be kept in mind that farmers will be paying year around for the fixed line connection but for a temporary connection they have to either pay for a 1 month or for three months depending upon the duration for which connection is taken.

varies during the Rabi season. Almost equal proportion of the cultivated land is diverted for wheat and gram crop by small and large landowners. However, for potato and garlic crop, small farmers divert less land in comparison to large farmers. Large landowners divert 73% more land for potato and 37% more land for garlic crop than the small farmers do. For more details, refer to Table 4. This particular cropping pattern explains the measures adopted by small farmers in response to scarcity of groundwater. Since potato and garlic are more water intensive crops than wheat and gram, small landowners refrain from diverting their land for these crops. However, because of better access to groundwater, large landowners divert their land in more proportionate manner across all the four Rabi crops.

Table 4: Cropping Pattern Across different Landholding Classes

	Total Cultivated Area(in Ha.)	Sown Area for Different Crops (in Ha.)				
Farmer Class		Soyabean	Wheat	Gram	Potato	Garlic
Small Landowners	20.25	20.25	4.75	4.25	2	1.75
Semi-Medium Landowners	88	88	37.25	18.75	6.75	14.25
Medium Landowners	282.5	282.5	97.5	69.75	34	36
Large Landowners	103.75	103.75	28.75	14.5	17.75	12.25
Total	494.5	494.5	168.25	107.25	60.5	64.25

8.2 Impact on Well Irrigation

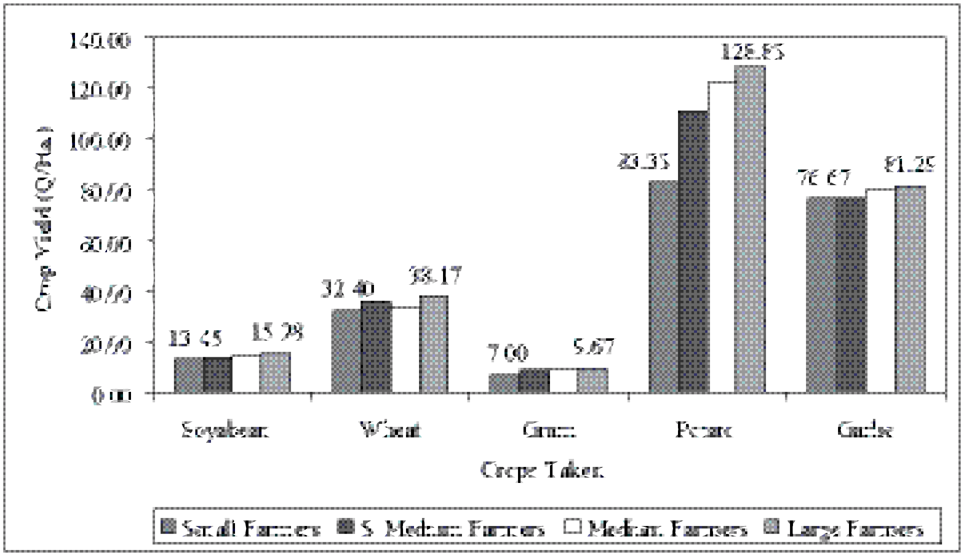
In absence of any surface irrigation source in the area, groundwater irrigation plays a major role especially for irrigating wheat. Irrigation is also required for other not so major crops like ginger and potato grown in the area. Well failures in these circumstances puts economical and social constraints on the farmers. Survey data shows that small farmers have more number of wells per unit of land (0.78) as compared to large farmers (0.32) but they irrigate only 3.25% of the total area. On the other hand, medium and large farmers own 68% of total number of wells, which are irrigating 78% of the total area. Since the average irrigated area per well is better in larger landholding classes (Table 5), the wells in these categories may be more productive as compared to small landowners. Thus, small landowners continue to suffer on account of less well irrigated area in comparison to the large landowners.

Table 5: Wells Ownership and Irrigated Area Across Different Categories of Surveyed Farmers

Farmer Class	Number of Well Owners	Total number of Wells Owned	Total Irrigated Area (in Ha.)	Average No. of Wells /farmer	Average Irrigated Area/ Well (in Ha.)	Average Irrigated Area /Well Owner (in Ha.)
Small Landowners	11	12	12.75	1.09	1.06	1.16
Semi-Medium Landowners	31	67	74	2.16	1.10	2.39
Medium Landowners	50	132	231.75	2.64	1.76	4.64
Large Landowners	9	35	73.25	3.89	2.09	8.14
Total	101	246	391.75	2.44	1.59	3.88

8.3. Impact on Crop Yields

Figure 5: Crop Yields (qtl/ha) for different group of Farmers



Crop yields (in qtl/ha) were different between small and large farmers. Yields for small farmers were 16% less for soyabean, 15% for wheat, 27% for gram, 35% for potato and 6% for garlic, in comparison to the large farmers (Figure 5). It might be possible that the current practice of well irrigation in this hard rock region is not able to provide significant support and benefit especially to small landowners. Also, less discharge from the bore wells, difficulty in installing successful bore well and seasonal nature of open well failures are putting extra burden on farmers. Now the question is - until what time farmers can continue to have the existing cropping pattern and afford the present irrigation sources, returning low yields and profits.

8.4. Impact on Net Returns

Similar story was observed in the net return from irrigated crops. Because of the hydro-geology and seasonal nature of well failures, the investment on irrigation is high. It costs on an average Rs. 15000/hectare as a cultivation cost for growing wheat. For open wells owners having temporary connection (5 HP Pump), 19% of cultivation cost is for getting irrigation and for farmers owning bore wells with fixed line (5 HP Pump), 19.5% of the cultivation cost is for irrigation[6] . Like crop yields (as discussed in section above), net return from crops were less for farmers with smaller landholdings. Aggregate net returns per farm for small landholders were 41% less than that of large landowners. Similarly aggregate net returns per well for small landholders were 39% less than for large landowners (Table 6). These differences were mainly due to the differential cropping pattern and well number between these two categories of farmers. Majority of these small landowners have only open wells (82% of the surveyed small farmers) with limited access to water and other resources. In fact because of recurring expenditure on well deepening and cost associated with drilling functional bore wells these returns further come down for both the small and large landowners.

8.5. Impact on Domestic Food Security

About a decade back sugarcane was grown as a major perennial crop in the surveyed area. But because of increasing well failures and thus low net returns, sugarcane crop no longer remained the feasible option.

[6] Considering that farmer with open well will do on average 3 watering and farmer with bore well will do 4-5 watering for wheat crop.

Consequently, there was shift in cropping pattern with soyabean emerging as a major Kharif crop and wheat as the major Rabi crop. This was surely an attempt by the farmers to overcome the groundwater scarcity problem and sustain their food security. Small landowners in particular give more importance to food crops like wheat and gram in their cropping pattern (Table 4). This indicates that they are more concerned regarding the availability of sufficient food and surplus crop for sale, which can sustain their other household requirements. Although the net returns for small landowners are much lower than the large landowners but they continue to have this cropping pattern to maintain their food sufficiency.

Table 6: Net Returns per Hectare (in Rs.) across Different Landholding Classes

	Wheat Small Landowners	Gram Large Landowners	Small Landowners	Large Landowners
Average Cost of Cultivation (Rs./Ha)	15000.00	15000.00	11350.00	11350.00
Yield (Q/ha)	32.40	38.17	7.00	9.67
Minimum Support Price 2006-07 (Rs./Q)	750.00	750.00	1445.00	1445.00
Gross Return (Rs./Ha)	24300.00	28627.50	10115.00	13973.15
Net Return (Rs./Ha)	9300.00	13627.50	-1235.00	2623.15

Table 7: Aggregate Net Returns for Wheat and Gram (in Rs./ha)

	Small Landowners	Large Landowners
Aggregate Net Returns/farmer	6058.46	10241.55
Aggregate Net Return/well	6290.00	10326.20

8.6. Other Social Impacts

In regards to equity and conflict over groundwater use, no problems were reported by the farmers. However, because of the current growth in the number of open wells and bore wells in the region, there are signs that equity in groundwater use may become an important issue. At present, good rainfall in the region (normal average of 984 mm/year) assure farmers of getting water from the open wells (till the early part of Rabi season), even if they carry on with deepenings of existing open wells. But certainly the horizontal drillings of open wells will have its impact in years of below average rainfall. These horizontal drillings may lead to well interference in the coming years. Less discharge and low probability of hitting exact water bearing zone, has limited the bore well installations to large farmers only. In the surveyed data, 89% of the large farmers had bore wells as compared to only 18% of small farmers. But, increase in the number of bore wells will definitely have an impact on the already low discharge from these wells. Surely net returns from agricultural practice in these hard rock areas are below that of other areas of the country where discharge from the wells and crop yields are comparatively better.

9. IMPLICATIONS

Increasing dependence on the groundwater, especially in context of hard rock areas has posed tremendous threat to the aquifer systems. A much lower level of groundwater development in the hard rock regions could be as serious as a higher level elsewhere (Vijayshankar and Shah, 1997). In fact because of some not so rational groundwater development assessments, number of over-exploited districts in hard rock areas where high incidence of well failures is found, are very low (Kumar and Singh forthcoming).

In the surveyed villages of *Bagli* block, over dependence on groundwater has started to pose problems in respect of depleting groundwater aquifer, lesser discharge and low crop yields. Also, the seasonal and geological nature of well failures has left farmers with little net returns. These impacts are more pronounced for the small landowners who have limited resources and access to groundwater. Further, free of cost electricity supplied to Madhya Pradesh farmers for nearly 16 years has promoted the growth in the number of wells, especially bore wells. However, this growth in number of wells does not resulted in increase in irrigated area per well (Kumar, 2007), only increase in incidences of well failures. In order to have maximum irrigation from the available resource, farmers resort to deepening of wells (both vertical and horizontal), which impacts the total cost associated with well irrigation. Well deepening has potential for inequity and conflict among well owners in the years ahead.

Although government has priced electricity for agricultural consumption from 2001 onwards, payments from rural areas remained low. As per one estimates, annual loss to the Madhya Pradesh State Electricity Board on revenue account alone until 2002 was between Rs.150 to Rs.250 crore. State government should place effective enforcement mechanisms, in order to check the non-payment of electricity bills, which will not only restrict the increase in well numbers but will also restrict groundwater use. There is also a big scope for constructing recharging structures and intervening with micro-irrigation techniques like sprinklers in the region. Few farmers had even gone ahead with them, but it requires more sincere and dedicated effort from the government to promote and make popular such water efficient systems among farmers. Future reforms in context of hard rock areas are required, which will promote the use of more water efficient practices and reduce the groundwater overdraft.

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GROUNDWATER GOVERNANCE IN THE INDO-GANGETIC BASIN: INTERPLAY OF HYDROLOGY AND SOCIO-ECOLOGY IN INDIA

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Abstract only

The Indus-Gangetic basin covers a very large tract of fertile agricultural lands in India and the production surplus from this basin meets food deficits of several other populous basins of the country. Though blessed with a vast network of dams, canals and strong irrigation bureaucracy, the surface irrigation systems have lost their historical supremacy to the more informal, demand-based and equitable groundwater irrigation. However, the development, the use, the sharing and groundwater markets and the agricultural production and social benefits produced by the groundwater resource are not uniform and seem to depend heavily upon the prevailing hydrology and socio-ecology of the given region/ state in this vast basin. IWMI lead 'Groundwater Governance in Asia' project through its cross cutting research component conducted a number of focussed studies in the varying agro-eco regions of Punjab (Hoshiarpur), and Haryana (Kurukshetra) of Indus basin, and Uttarakhand (Haridwar), Bihar (Vaishali) and West Bengal (Hooghly, Burdhwan, Bankura) states in the Ganges basin for better understanding of the groundwater governance issues and adaptations at the local level. In a hydrological setting where all the irrigation needs are met by groundwater (Hoshiarpur, Punjab) two distinct patterns of groundwater access, viz., shared wells and groundwater markets have evolved. Whereas a shared resource helped farmers to have equitable access to groundwater as well as improvement in crop and water productivity; even a very competitive groundwater market did not allow the water buyers to realize the same levels of water productivity as obtained by well owners who also made good profits by selling water from tube wells. The government policy of providing free electricity for the farm sector has provided incentives to the farmers to install additional tube wells leading to competitive exploitation by the farmers.

In most canal command areas, the inequitable and irregular canal water supply lead to shrinkage of canal irrigated area and groundwater irrigation is playing an important role (Kurukshetra, Haryana) and more so in tail end water courses (72-97 %). With the flat rate tariff regime of electricity the difference in cost of water for paddy and wheat is negligible, whereas amount of water used for paddy is 5-6 times higher than that of wheat. Compared to electric submersible pumps, the cost of water for diesel operated tubewells is higher by 7-11 times for paddy and 1.5 -2.0 times for wheat. The analysis showed that the gross margin was highest for basmati rice, followed by coarse rice and wheat and explained that under the prevailing flat rate of electricity and higher returns for paddy groundwater use shall continue to expand and water tables to further decline. There is an urgent need to look into this serious issue.

In the groundwater abundant state of Bihar, only about 36% of groundwater resources have been developed due to small and fragmented holdings, low number of water extraction mechanisms (WEM), high cost of energy and low investment capacity of small and marginal farmers (Vaishali district). Though the number of shallow tube wells has increased exponentially, the number of pump sets has not increased in proportion to the number of borings and economically backward farmers continue to extract groundwater through rented pumps, albeit at exorbitant costs. Further, most of the WEMs owners use purchased diesel as the motive power, the escalating diesel costs and high demand for irrigation has lead to rapid increase in water prices in the region. Even with abundant groundwater availability, inequity in ownership and access, non-existent rural electrification and rising energy costs have resulted in economic scarcity of groundwater and thus a very slow pace for its further mobilisation. Even the classical success stories of community tubewells in Vaishali is approaching its extinction due to weak institutional and policy support and overriding social dynamics.

Besides better understanding of these three widely varying interplay of groundwater hydrology and socio-ecology in the Indus-Gangetic basin the paper shall suggest suitable physical, socio-economic and policy and institutional mechanisms for sustainable groundwater governance in these settings of the basin.

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USING ENERGY PRICING AS A TOOL FOR EFFICIENT, EQUITABLE AND SUSTAINABLE USE OF GROUNDWATER FOR IRRIGATION: EVIDENCE FROM THREE LOCATIONS OF INDIA

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Abstract

This paper analyzes the potential impacts of energy pricing on efficiency, equity and sustainability in groundwater use. The analysis uses empirical data on water productivity in agriculture for crops, dairying and farms for north Gujarat, east US and south Bihar. For north Gujarat, the analysis uses data from well owners who pay flat rate tariff, and well owners who pay pro-rata tariff. For eastern UP and south Bihar, the analysis uses data from well owners and water buyers from diesel and electric well commands. The analysis also compares data from diesel well owners and electric well owners in south Bihar. The findings are as follows:

Introducing marginal cost for electricity motivates farmers to use water more efficiently at the farm level through careful use of irrigation water; use of better agronomic inputs; optimize costly inputs; optimize livestock composition and carefully select crops and cropping patterns, which give higher return from every unit of water and grow low water consuming crops. It also shows that higher cost of irrigation water (because of higher energy cost) will not lower net return from every unit of water used as the farmers will modify their farming system accordingly.

Further, change in the structure of power tariff from flat rate to pro-rata will not have any adverse effects on access and equity in groundwater use. Nor will it increase the monopoly power of well owners. The number of potential water sellers and not the number of potential buyers of water govern the price of water. Pro-rata pricing reduces cost of groundwater pumping per unit of land. It also reduces aggregate pumping, which is disproportionately higher than the reduction in net returns per unit of land. This leads to more sustainable groundwater use.

This means that in water scarce regions, it would be possible for farmers to maintain net farm surpluses at higher energy tariff by improving productivity of water use. The empirical evidence further reinforces that the arguments against pro-rata pricing are flawed. Raising power tariff in the farm sector to achieve efficiency, equity and sustainability in groundwater use is socially and economically viable.

1. INTRODUCTION

In arid and semi-arid regions of India, groundwater withdrawal for crop production exceeds the average annual recharge (Kumar, 2007). Uncontrolled withdrawal of groundwater for crop production, supported by subsidized electricity in the farm sector, leads to fast decline of water level in many parts of country. The alluvial areas of north Gujarat in western India, and hard rock areas of peninsular and central India are some such examples[3] .

As irrigation is the main user of groundwater in India, raising water productivity in the ground water irrigated areas is essential for reducing groundwater draft (Amarasinghe et al., 2004; Kumar, 2005; Kumar, 2007). Many Indian states are contemplating re-introduction of electricity metering in the farm sector, to manage groundwater demand. The basic premise is that at higher power tariff, with induced marginal cost of electricity and water, the farmers will improve water use efficiency (Kumar and Singh, 2001; Kumar, 2005) and enhanced

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[3] Groundwater situation in Mehsana district of north Gujarat is a classical example of the groundwater depletion where groundwater level dropping about 0.90m to 6.0 m/annum (CGWB, 1998).

water productivity. Such proposals face fierce resistance from farmers' lobby. Further, political parties and scholars alike argue that it will lead to a collapse of farmers in many water-scarce regions due to reduced net farm returns, making electricity metering in farm sector socially and economically unviable.

Agriculture accounted for almost 29% of the total power consumption in India in 2001-02 (GoI, 2002). Electricity to the farm sector in India is subsidised under both flat rate and pro-rata tariff systems. The subsidy in terms of sale to agricultural consumers is estimated to have increased from Rs. 15586 crores in 1996-97 to Rs. 30462 crores in 2000-01. This is because of increasing use of electricity for groundwater pumping, which in turn increase groundwater draft[4]. In most of the states, farmers pay electricity charges based on connected load and not on the basis of units of power consumed. Some of the Indian states are providing electricity to farm sector free of cost. Due to poor financial condition of the State Electricity Boards, they fail to supply good quality power to the agriculture sector. Pricing of electricity, in which the charge paid by farmers does not reflect actual consumption creates incentive for inefficient and unsustainable use of both power and groundwater (Kumar, 2005; Kumar and Singh, 2001).

While metering appears to be a solution to the problem, researchers question its viability on 3 grounds: 1] transaction cost of metering is very high, which increases the cost of supply of electricity, thereby reducing net social welfare (Shah et al., 2004); and 2] tariff levels at which electricity and water demand curve becomes elastic to price changes would be so high that it becomes socio-economically viable (Saleth, 1997); and 3] political opposition to metering is so high that governments shy away from the option.

A recent research by Kumar (2005) questions the validity of the first two arguments. Empirical evidence shows that with higher tariffs, the farmers use water more efficiently (by providing lower dosages to the crop), increase gross water productivity (Rs/m^3); and secure higher returns per unit of water used. They are motivated to allocate more water for less water-consuming water efficient crops, provided they receive high quality, sustained water supply.

Some scholars cite positive impact of flat rate pricing of electricity on access and equity of groundwater (for instance, Shah, 1993). They argue that with competitive water markets, water prices are kept low with the result that a major share of the electricity subsidy benefits are transferred to water buyers. However, the zero marginal cost of production of water from wells does not seem to influence the prices at which water is traded, in favour of buyers of water for irrigation. A recent research shows that flat rate pricing increases the monopoly power of large well owners (Kumar, Singh and Singh, 2001). Also, flat rate pricing leads to inequitable distribution of power subsidy benefits among well owners (Kumar and Singh, 2001; Howes and Murugai, 2003). Kumar (2007), on the basis of evidence from Mussafarpur in Bihar argued that the monopoly power enjoyed by water sellers cannot be reduced by pricing policies, but by improving the transferability of groundwater.

As a way to cope with the increasing financial burden due to revenue losses through subsidies and growing power deficits, the State Electricity Boards in many agriculturally prosperous states have introduced heavy cuts in power supply hours to the farm sector (GoI, 2002)[5]. They assume that this would reduce the energy use and groundwater draft for agriculture. There is no evidence to support this logic. The electricity boards have not analyzed the impact of such cuts on equity in access and efficiency in use of groundwater. On the contrary, with reduction in hours of power supply, the quality of irrigation can be adversely affected[6]. The economic prospects of irrigated farming are more elastic to quality of irrigation water rather than its cost (Kumar and Patel, 1995; Kumar and Singh, 2001). The rich well owners always find ways to overcome the crisis of power cuts. This can further increase their monopoly in water trading.

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[4] Due to subsidised power supply to agriculture sector, the annual losses to State Electricity Board are estimated to be Rs. 26000 crore and it is growing with a compound growth rate of 26 per cent per annum.

[5] In the hard rock areas of Gujarat, farmers are unable to run their pump for 6-8 hours continuously due to lack of water availability in the wells and higher rate of drawdown, resulting farmers are forced to run tube wells only for a 2-3 hours at a time and stop pumpfor 3-4 hours to accumulate water in the well.

[6] Due to interruptions in power supply accompanied by poor quality of power, farmers do not have absolute control over irrigation water. Under this situation, they show increasing tendency to over irrigate the crops when electricity is available. Water delivery often does not coincide with the critical stages of watering of crops. The result is that they are getting less output per unit of irrigation water.

Nevertheless, there are some positive developments in some states in the recent past. Since 2001, the government of Gujarat had only provided metered connections for agriculture. Nearly 12,000 farmers are already having metered power connections in north Gujarat alone. Here, farmers pay Rs.0.7/kwhr for electricity consumed. In Orissa, which is agriculturally one of the most backward states, electricity supply to farmers is through villages electricity co-operatives, known as *Vidyut Sanghs*, which does metering and billing. The agency does metering at the feeder level, and charges to the co-operatives. Studies on the impact of such policy interventions in promoting efficiency, access equity and sustainability in resource use are lacking.

2. OBJECTIVES AND HYPOTHESIS

The overall objective of the study is to analyze the socio-economic viability of pro-rata pricing of electricity in agriculture. Specific objectives are: 1] to study the impact of change in mode of electricity pricing on efficiency and sustainability of groundwater use by well owners; 2] to analyze the overall impact of electricity pricing on the farming system of well owners, including the economic prospects of farming; and, 3] to analyze the impact of change in mode of electricity pricing on the functioning of water markets.

The major hypothesis tested in this study is that with mounting cost of energy used for groundwater pumping, farmer would use energy and groundwater water more efficiently; shift their cropping system towards water efficient and high valued crops, take higher farming risks, thereby overcoming the potential negative impacts.

3. APPROACH AND METHODOLOGY

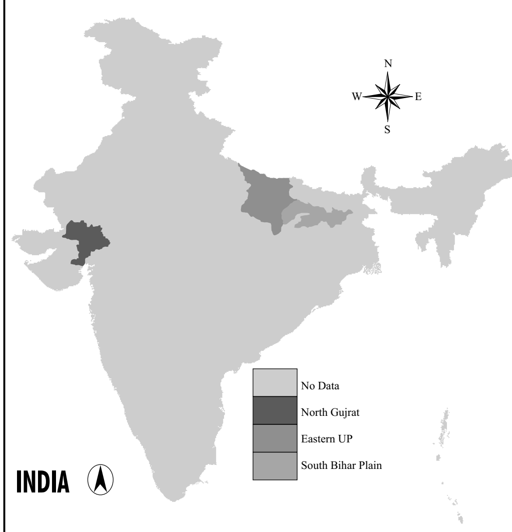
3.1 Study Area

North Gujarat, which is a water scarce region and the eastern plain regions of Uttar Pradesh and Bihar, which are water rich regions constitute the geographical area for the present study.

The semi arid north Gujarat region receives a mean annual rainfall of 735 mm. Grey brown, coastal alluvium types of soils are found in this regions The mean annual precipitation in the eastern plain region of Uttar Pradesh is about 1025 mm and the region's climate varies from dry sub-humid to moist sub-humid. The soil types in this sub-zone is light alluvial and calcareous clay.

The Patna district falls under the south Bihar plains; receives a mean annual rainfall of 1103 mm and climate condition of region varies from dry to moist sub-humid. The soil types found in the region are old alluvium sandy loam to clayey and the larger areas under the Tal and Diara.

Figure 1: Geo graphical Coverage of Study



3.2 Sampling Procedure and Data Collection

Primary and secondary data relating to crop and livestock production was obtained. The primary data included: quantum of crop inputs and outputs and their prices; cropping pattern; electricity prices; diesel consumption and price; well command area; number of water buyers and sellers; quantum of livestock inputs (dry and green fodder, feed, drinking water) and outputs, and unit price of inputs and outputs.

The districts of Mirzapur and Varanasi were selected from Bihar and Uttar Pradesh for the study. Five contiguous villages were selected for primary survey to draw the required sample for diesel and electric well owners, and water buyers. The sample size was 60 electric pump owners, 60 diesel pump owners, 60 water buyers from electric pumps and 60 water buyers from diesel pumps.

Two talukas - Palanpur and Vadgam of Banaskantha district were selected from north Gujarat. Samples of 120 farmers who have metered electricity connection were obtained from 29 villages for data collection. Of this, 60 electric pump owners who paid power tariff on the basis of the connected load, and remaining 60 electric pump owners paid power tariff on the basis of actual consumption of electricity.

In south Bihar, Patna, Maner and Danapur development blocks were selected for primary survey. From each block, one village was selected. Thus, the two villages selected were Baluan and Hathiyakand. The sample farmers of the Baluan village were dependent on diesel pumps whereas in Hathiyakand, farmers are dependent on electric pumps. From Baluan village, 60 diesel pump owners and 60 water-purchasing counterparts were selected. Likewise, from Hathiyakand, 60 electric pump owners and their water purchasing counterparts were selected. The detail of sample size is given in Table 1.

Table 1: Sampling Procedure and Sample Size

Name of the Regions	Name of the district	Types of Energy Tariff				Diesel pump		Total sample size
		Flat Rate		Unit Pricing				
		Well owner	Water buyers	Well owner	Water buyers	Well owner	Water buyers	
Water Scarce								
North Gujarat	Banaskantha	60	-	60	-	-	-	120
Water Rich Eastern UP	Varanasi and Mirzapur	60	60	-	-	60	60	240
South Bihar	Patna	60	60	-	-	60	60	240
Total		180	120	60	-	120	120	600

3.3 Methodology

3.3.1 Analysing the Efficiency and Sustainability Impacts of Change in Mode of Pricing

There are very few locations in India where farmers pay for electricity based on consumption. Gujarat is one such state. Therefore, to analyze the potential impacts of introducing pro-rata pricing of electricity in farm sector, with marginal cost of using groundwater, the farmers who are using diesel pumps for well irrigation and water buyers are used as proxy for pro-rata tariff.

The price of electricity used for pumping groundwater influences water productivity in many different ways (Kumar, 2005). The efficiency impacts change in mode of pricing by comparing water productivity of crops in physical terms. We can examine the impact of change in mode of pricing on economic viability of farming by comparing the overall water productivity of crops, livestock and farming system under the two conditions. The sustainability impacts of price changes can be analyzed by looking at the changes in groundwater withdrawal by well owning farmers.

In the study, we only consider the applied (pumped) water for estimation of water productivity at the field and farming system level, and not the depleted water that takes into account the contribution of rainfall to total water input to the crop and return flows into groundwater. This does not disturb the inferences drawn from the study due to three reasons: i] we are concerned with the changes in water productivity in the same field or farm, which means that the level of use of rainfall by the crop does not change. If rainfall use increases, it will not change the recharge to groundwater.

Return flows would be insignificant in semi-arid north Gujarat due to deep water table conditions. However, return flows from irrigation can be quite significant in both Uttar Pradesh and Bihar plains due to alluvial geology and sub-humid climatic conditions. The farmers in this region would be concerned with the total amount of water applied rather than the actual amount of water depleted. The reason is that applied water would determine the amount of energy required to pump groundwater, which is scarce in the regions. The farmers in these two regions will not be concerned with reducing the depleted water per se, as it is in abundance.

3.3.2 Estimating Water Productivity of Farming System

The physical water productivity for a given crop (kg/m^3) will be estimated using data on crop yield and the estimated volume of water applied for all sample farmers growing that crop. The combined physical and economic water productivity in Rs/m^3 is estimated using data on net returns from crop production in Rs/ha and estimated volume of water in cubic meter. To estimate the net income from a particular crop, the data on inputs for each crop was obtained by primary survey of farmers. This included cost of seed, labour, fertilizer, pesticides and insecticides, irrigation, ploughing, harvesting and threshing.

The physical productivity of water in milk production for livestock WP_{Milk} (lt/m^3) can be defined as:

$$WP_{Milk} = \frac{Q_{MP}}{\Delta_{Milk}} \quad \text{... (1)}$$

Where, Q_{MP} is the average daily milk output by one unit of livestock category over the entire live cycle (lt/animal/day). Δ_{Milk} is the total volume of water used per animal per day, including the water embedded in feed and fodder inputs, used in dairying for an animal in a day, worked out for the entire animal life cycle (m3/animal/day). It is estimated as:

$$\Delta_{milk} = \frac{Q_{cf}}{WP_{cf}} + \frac{Q_{df}}{WP_{df}} + \frac{Q_{gf}}{WP_{gf}} + \Delta_{DW} \quad \text{..................... (2) (Singh, 2004; Kumar, 2007)}$$

Where Q_{cf}, Q_{df} and Q_{gf} are the average quantities of cattle feed, dry fodder and green fodder used for feeding a livestock unit per day (kg/animal/day); WP_{cf}, WP_{df} and WP_{gf} are the physical productivities (kg/m^3) of cattle feed, dry fodder and green fodder, respectively; Δ_{DW} is the daily drinking water consumption by livestock (m^3/day). It is the average volume of water required by a dairy animal per day over its entire life cycle, including the water embedded in feed and fodder.

Q_{cf}, Q_{gf}, Q_{df} and Δ_{DW} for a given category of livestock would be estimated for the entire life cycle of the animal from the following: i] weighted average of the average daily figures of these inputs for each season for animals in different stages of the life cycle, viz., calving, lactation stage, dry stage; and ii] the time period in each stage of animal life cycle for that category of life stock.

Since all the farmers in the sample may not have animals that represent all the different stages of the life cycle in a particular category of livestock at a given point of time, the average values of inputs are worked out as value of above mentioned variables for the sample farmers. Likewise, the average values of physical productivity of water in green fodder and dry fodder are used for estimation. Q_{MP} (lt/animal/day) is estimated from: i] the weighted average of average daily figures of milk yield for different seasons; and ii] the ratio of time period in lactation and the average life span of the animal in that category.

WP_{gf} and WP_{df} is estimated by taking their respective quantities and the volume of water required for growing that crop. In the case of by-products of crops used as fodder, the water used for growing that crop is allocated as the main product and by product in proportion to the market prices of the respective (Singh, 2004).

The net return of milk production, NR_{milk} (Rs/animal/day) is estimated using values of Q_{MP}, the price of milk (Rs/litre) and the cost of production of the average amount of cattle inputs required in a day (Rs/animal/ day) estimated for the entire animal life cycle as proposed by Singh (2004) and Kumar (2007). It is important to mention here that with import of green or dry fodder in a farm, the cost of fodder input could also go up. This in turn would affect net water productivity in dairying WP_{dairy} (Rs/m^3). It can be estimated as:

$$WP_{dairy} = \frac{NR_{milk}}{\Delta_{milk}}$$ ……………………………….………. (3) (Singh, 2004; Kumar, 2007)

In the case of purchase of inputs market price is used. If the inputs are from the farmers' own fields, the actual cost of production is estimated. If farmer uses crop by-products for dairying, the total cost of production of the given crop is allocated among the main product and by-product on the basis of the potential revenues that can be earned from their sale. The quantity of inputs (feed and dry and green fodder) and milk outputs are worked out for the entire animal life cycle and not on the basis of the actual use of inputs and milk yield at the point under consideration.

The total volume of water used for milk production annually by one unit of livestock V_{dairy} (m^3/animal/ annum) is estimated by dividing the total annual milk production by one unit of livestock (Q_{AMP}) by the physical productivity of water in milk production (WP_{Milk}).

The water productivity of the farm WP_{farm} (Rs/m^3), including crops and dairy is estimated as:

$$WP_{farm} = \frac{\sum_{i=1}^{m} WP_{crop\,i} V_{crop,i} + \sum_{j=1}^{n} WP_{dairy,j} V_{dairy,j} N_j}{\sum_{i=1}^{m} V_{crop,i} + \sum_{j=1}^{n} V_{dairy,j}}$$ ……………………….…… (4)

Here, $WP_{crop,i}$ is the water productivity of main product of crop i; $V_{crop,i}$ is the total volume of water used for crop i; $WP_{dairy,j}$ is water productivity in dairy production for livestock type j ; and $V_{dairy,j}$ is the volume of water used for dairy production per animal for livestock category j . N_j is the total number of livestock in category j

3.3.3 Impacts of Different Modes of Energy Pricing on Equity in Access to Groundwater

The equity impact of different modes of energy pricing on groundwater use is analyzed by comparing the water charges (Rs/m^3) paid by the water buyers under the flat rate and unit pricing of electricity against the cost (Rs/m^3) farmers have to incur for access to groundwater if he decides to have his own well under both situations i.e., flat rate and unit pricing. For this, data was collected on: [i] water charges paid by water buyers under both the tariff regimes; [ii] cost of installation of bore/tube well; [iii] energy charges under flat and unit pricing paid by farmers annually; [iv] the land holding size; and, [v] well repair and maintenance cost.

4. RESULTS AND DISCUSSION

4.1 Distribution of Land Holdings

The average size of land holding of different categories of farmers in the study area is provided in Table 2. In north Gujarat, the average size of land holding is higher for tube well owner who are paying power tariff on connected load basis (3.79 ha) as compared to their counterparts having metered connection (3.28 ha). About 90% of the area is under irrigated crop production and remaining 10% area is cultivated under rain-fed condition.

In eastern Uttar Pradesh, the average size of land holding is larger for diesel well commands as compared to electric well commands. Differences are significant between well owners and water buyers. Diesel pump owners have average land holding size of 1.35 ha while their water buyers have landholding size of 0.94 ha. The average size of land holding for electric pump owner is 1.30 ha, whereas their water buyers have an average land holding size of 0.56 ha.

In south Bihar like eastern Uttar Pradesh, the average size of land holdings for both well owners and water buyers in the diesel pump commands is higher than that of their counterparts in electric pump commands. The well owners in electric well commands have larger sized holdings (0.73 ha) as compared to their water buyers (0.53 ha). In diesel pump commands, the differences are larger. The average size of land holding of well owner here is 1.26 ha, whereas for water buyers it is 0.57 ha.

From the data presented in Table 2, it is also clear that in the average size of land holding in water abundant eastern Uttar Pradesh and south Bihar plains is much smaller compared to water scarce north Gujarat. This is one of the important factors for utilizing available water resources. In case of water abundant region, the limited land availability should motivate farmers to maximize returns per unit of land. Against this, in water scarce region, water availability is a limiting factor for maximizing returns from crop production, and hence generally, they would be motivated to maximize the returns from every unit of water (Kumar et al., 2008). However, lack of resources for investing in wells and energizing devices is a limiting factor for many farmers in south Bihar and eastern Uttar Pradesh to access the water, which is available in plenty.

Table 2: Average Size of Land Holding of Sample Farmers in the three Locations

Name of the Regions	Name of the district	Electric Pump		Diesel pump	
		Unit Pricing	Flat Rate	Well owner	Water buyers
North Gujarat	Banaskantha	2.95 (0.33)	3.45 (0.34)	NA	NA
		Well Owner	Water Buyer		
Eastern Uttar Pradesh	Varanasi and Mirzapur	1.30	0.560	1.35	0.940
South Bihar Plains	Patna	0.730	0.530	1.260	0.570

4.2 Cost of Groundwater Irrigation

The cost of groundwater irrigation was estimated for well owners by taking into account the following: 1] cost of well construction and pump set installation; 2] cost of obtaining power connection; 3] cost of operational and maintenance of the well and the pump set; 4] life of the well and the pump set; 5] the average hours of groundwater pumping per year; and 6] discharge of the pump set. In the case of electric wells with metered connections, the hourly operation cost is worked out using the energy charges per kwhr of use. Similarly, in the case of diesel wells, the operation cost was worked out using the price of one litre of diesel and the amount of diesel consumption per hour of running. The cost of irrigation was finally worked out per cubic metre of water using well output data. In the case of wells with flat rate electricity connection, the implicit cost per hour of irrigation is worked out using the annualized cost, and the number of hours of irrigation per annum.

Based on the figures of well discharge, cost estimates were worked out for western Uttar Pradesh, northern Gujarat and south Bihar and are presented in the Table 3 The unit rates charged by diesel pump owners for irrigation services are much higher than that of electric pump owners. Check figures for Gujarat.

Table 3: Cost Estimates based on well discarge

Area	Water source	Average (rs/m^3)	Range (rs/m^3)
Western UP	Electric Pump owner	0.18	0.10 - 0.30
	Electric pump buyers	0.65	0.52 - 0.84
	Diesel pump owners	1.38	0.99 – 2.04
	Diesel pump buyers	2.81	2.07 – 3.63
North Gujarat	Metered connections	1.07	0.14 – 3.91
	Non metered connections	1.60	0.19 – 4.27
South Bihar	Electric Pump owner	0.77	0.17 – 3.39
	Electric pump buyers	0.70	0.31 - 0.92
	Diesel pump owners	1.87	1.51 – 2.95
	Diesel pump buyers	2.15	1.84 – 2.42

4.3 Area Allocated by Farmers for Different Crops in Eastern Uttar Pradesh

The cropping pattern of well owners and water buyers under different modes of energy pricing i.e., connected load (electric well) and unit consumption (diesel well) in eastern Uttar Pradesh is presented in Table 4. The crops grown in the study villages are food-grains, pulses, oilseeds, vegetables, cash crops and fodder crops. Paddy and wheat are the dominant crops. During the kharif season, well owners and water buyers under both energy regimes allocate larger portion their land holding under paddy. It is because of the high rainfall, which can meet a large part of the crop water requirement.

In diesel well commands, pump owners allocate about 26% of the gross cropped area under paddy cultivation, whereas in the case of water buyers, it is only 22%. In electric well commands, pump owners allocate 11.51% to paddy and water buyers allocate about 14.8% to paddy. Electric pump owners also grow groundnut. Water buyers in both electric and diesel well commands allocate larger portion of the gross cropped area under green fodder and other vegetables during kharif season as compared to pump owners. Water buyers in diesel well commands grow *Arhar.* Whereas water buyers in electric well commands grow lady’s finger.

Major crops grown during winter season are wheat and barley, potato, pea, gram, mustard, linseed and barseem. In electric well commands, the area allocated under wheat, potato, pea, barseem is lower for pump owners whereas gram, mustard, linseed and barley area allocation is higher for water buyers.

In diesel well commands, pump owners allocate larger share of their cropped area under winter crops as compared to water buyers. Such sharp difference is not seen in case of electric well commands. This could be because the hourly rate for irrigation water charged by diesel pump owners is four times higher than that charged by electric pump owners. During the summer season, major cops grown in electric pump commands are green fodder, sunflower and vegetables. While all these crops are grown by the electric pump owners, only green fodder is grown by water buyers. In diesel well commands, crops grown during summer season are green fodder and vegetables. Both diesel well owners and water buyers here allocate some area under green fodder.

4.4 Cropping pattern in North Gujarat

In the case of north Gujarat, major crops grown by the tubewell owners under both tariff regimes are green fodder (fodder bajra and alfalfa), foodgrain crops (jowar and bajra), pulses (black gram and green gram), groundnut and cash crops (cluster bean, cotton and castor). The farmers of this region allocate small area under

Table 4: Cropping Pattern of Well Owner and Water Buyers under Different Energy Regime, Eastern Uttar Pradesh

Name of the Crops	Electric Pump				Diesel Pump			
	Owner		Water Buyers		Owner		Water Buyers	
	Area (ha)	% to GCA	Area (ha)	% to GCA	Area (ha)	% to GCA	Area (ha)	% to GCA
Kharif Season								
1. Paddy	0.71	11.51	0.36	14.81	1.55	26.18	0.91	22.14
2. Bajra	0.32	5.15	0.14	5.85	0.23	3.85	0.13	3.25
3. Maize	0.24	3.97	0.12	4.78	0.23	3.81	-	-
4. Lady's Finger	0.32	5.18	0.23	9.53	-		-	
5. Other Vegetables	0.32	5.30	0.17	7.08	0.14	2.41	0.34	8.35
6. Arhar	-		-	-	-	-	0.30	7.42
7. Black gram	0.27	4.39	0.11	4.68	-	-	0.11	2.78
8. Green gram	0.37	6.06	-	-	-	-	0.11	2.78
9. Sesamum	0.08	1.30	0.06	2.34	0.23	3.85	0.11	2.78
10. Groundnut	0.33	5.34	-	-	-	-	-	-
11. Sugarcane	0.11	1.77	0.06	2.34	0.16	2.68	-	-
12. Chary (Green fodder)	0.16	2.60	0.08	3.20	0.11	1.89	0.10	2.38
Rabi Season								
1. Wheat	0.67	10.94	0.29	12.00	1.27	21.48	0.83	20.29
2. Barley	0.23	3.73	0.08	3.28	-	-	0.09	2.23
3. Pea	0.23	3.80	0.13	5.47	0.34	5.73	0.17	4.08
4. Gram	0.17	2.85	0.04	1.46	0.42	7.02	0.20	4.84
5. Mustard	0.70	10.06	0.53	4.45	0.27	4.55	0.14	3.50
6. Linseed	0.06	0.93	-	-	0.34	5.78	0.10	2.50
7. Potato	0.50	8.15	0.29	11.94	0.37	6.24	0.23	5.57
8. Barseem (Green fodder)	0.07	1.14	0.05	1.89	0.06	1.05	0.07	1.64
Summer Season								
1. Sunflower	0.10	1.58	-	-	-	-	-	-
2. Vegetables	0.11	1.86	-	-	0.11	1.93	-	-
3. MP chary (Green fodder)	0.15	2.38	0.12	4.89	0.09	1.55	0.14	3.48
Gross Cropped Area (GCA)	6.13	100.00	2.44	100.0	5.92	100.00	4.10	100.0

Source: Author's own estimate based on primary data

green fodder throughout the year (major crops are alfalfa, fodder bajra and chikudi). Table 5 gives the cropping pattern of well owners in north Gujarat.

During kharif, tube well owners under pro-rata tariff regime allocate slightly larger percentage of the cropped area under cotton, castor and fodder bajra. During winter, tube well owners under flat rate tariff regime are allocating more area under green fodder, wheat and mustard. The tube well owners under pro-rata tariff regime allocate slightly larger area under cumin, which is a high valued and sensitive cash crop. The major crops grown during summer season are green fodder (Kachchhi alfalfa[7] and fodder bajra) and bajra. The area allocated by flat and unit pricing tariff tubewells owners under the bajra crop is about 10% of the gross cropped area.

Table 5: Cropping Pattern of Well Owner under Different Energy Pricing Regime, North Gujarat

Season	Name of the Crops	Electric Pump Owner – Flat Rate		Electric Pump Owner – Unit Pricing	
		Area (ha)	% to GCA	Area (ha)	% to GCA
Kharif	1. Fodder Bajra	0.26	1.58	0.39	2.91
	2. Alfalfa (Green Fodder)	0.36	2.23	0.41	3.05
	3. Jowar	1.07	6.58	1.01	7.52
	4. Bajra	0.98	6.03	0.89	6.63
	5. Black gram	0.81	5.00	0.53	3.90
	6. Green gram	0.76	4.69	0.87	6.47
	7. Groundnut	0.95	5.82	0.51	3.81
	8. Cluster bean	0.85	5.24	1.06	7.87
	9. Cotton	0.63	3.87	0.61	4.52
	10. Castor	1.17	7.17	1.10	8.17
Rabi	1. Alfalfa (Green Fodder)	0.33	2.01	0.28	2.10
	2. Chekudi (Green Fodder)	1.33	8.15	0.23	1.69
	3. Wheat	1.27	7.82	0.96	7.14
	4. Barley	0.23	1.41	0.63	4.66
	5. Rajgaro	0.91	5.62	0.73	5.39
	6. Mustard	1.14	7.00	0.75	5.53
	7. Cumin	0.90	5.50	0.81	6.04
Summer	1. Alfalfa	0.38	2.35	-	-
	2. Fodder Bajra	0.25	1.55	0.41	3.01
	3. Bajra	1.69	10.37	1.29	9.58
	Gross Cropped Area (GCA)	16.27	100.00	13.49	100.00

Source: Author's own estimate based on primary data

4.5 Cropping Pattern in South Bihar

Cropping pattern of well owners and water buyers under different energy regimes and area allocated by the farmers under different crops in south Bihar are presented in Table 6. In the region, very high monsoon rain results in submergence of most of the cultivated land during kharif season. During this season, farmers grow two crops viz., paddy and green fodder, with larger area under paddy. Out of the gross cropped area, nearly 38% is under paddy and less than 3% is under green fodder. During winter, farmers grow wheat, gram, mustard, barseem (fodder), vegetables (potato, radish and carrot) and coriander. Largest area is under wheat. During summer, farmers grow onion, maize and green fodder.

[7] Two types of alfalfa are grown in the region: [1] the first one is sown during winter and is harvested by month of April i.e., the crop duration is about 6 months; and [2] the second one is Kachchhi alfalfa, which has a duration of nearly three years. Those farmers having good irrigation facility grow Kachchhi alfalfa get green fodder through out the year.

There is very little difference in Kharif cropping pattern found between well owners and water buyers in electric well commands or diesel well commands. During winter, water buyers in electric well commands cultivate gram and carrot. Diesel pump owners and water buyers in both diesel and electric well commands allocate larger area for potato. During summer, only diesel pump owners and water buyers in their commands cultivate green fodder. In general, electric pump owners allocate larger area under different crops as compared to electric pump water buyers. There is a similar trend in case of diesel pump command areas.

Table 6: Cropping Pattern of Well Owner and Water Buyer in Diesel and Electric Well Commands, South Bihar Plain

Name of the Crops	Electric Pump				Diesel Pump			
	Owner		Water Buyers		Owner		Water Buyers	
	Area (ha)	% to GCA	Area (ha)	% to GCA	Area (ha)	% to GCA	Area (ha)	% to GCA
Kharif Season								
1. Paddy	0.751	38.97	0.467	38.42	1.083	37.68	0.541	38.02
2. Masureya (Green fodder)	0.028	1.47	0.016	1.34	0.077	2.69	0.026	1.83
3. Maize (Green fodder)	0.004	0.22	0.002	0.17	-	-	-	-
Rabi Season								
1. Wheat	0.474	24.63	0.351	28.88	0.625	21.74	0.315	22.17
2. Potato	0.134	6.98	0.120	9.86	0.343	11.94	0.145	10.17
3. Barseem (Green fodder)	0.042	2.18	0.024	1.97	0.066	2.31	0.029	2.05
4. Mustard	0.059	3.05	-	-	0.207	7.21	0.077	5.39
5. Gram	-	-	0.011	0.89	-	-	-	-
6. Radish	0.025	1.32	0.023	1.85	-	-	-	-
7. Carrot	-	-	0.002	0.17	-	-	-	-
8. Coriander	-	-	-	-	0.019	0.65	-	-
Summer Season								
1. Onion	0.353	18.32	0.170	14.03	0.356	12.38	0.218	15.36
2. Maize	0.055	2.87	0.029	2.42	0.093	3.25	0.068	4.79
3. NP Chary (Green fodder)	-	-	-	-	0.005	0.16	0.003	0.22
Gross Cropped Area (GCA)	1.93	100.0	1.22	100.0	2.88	100.0	1.42	100.0

Source: Author's own estimate based on primary data

4.6. Irrigation Water Application and Crop Water Productivity

In this section, we present the estimates of irrigation water application, physical water productivity (kg/m^3) of main and by-products and net water productivity in economic terms (Rs/m^3) of different crops grown by electric/diesel pump owners and water buyers in their commands. Higher physical productivity of water use for a given crop indicates more efficient use of irrigation water through on farm water management or better farm management through better agronomic input.

Eastern Uttar Pradesh: Electric well commands

Table 7 presents the estimates of irrigation water dosage productivity of water in physical (kg/m^3) and economic terms (Rs/m^3) under electric pump ownership and irrigation water purchase for villages in eastern

Uttar Pradesh. In case of electric pump owner, total amount of irrigation water applied for crop production is higher as compared to irrigation water buyers. For most of the crops, both physical and economic productivity of water are higher for water buyers than their water-selling counterparts.

Table 7: Water Use, and Water Productivity in Physical and Economic Terms under Electric Pumps, Eastern Uttar Pradesh

Name of the Crops	Electric Pump – Owner				Electric pump – water buyer			
	Depth of irrigation water use (cm)	Water productivity (Kg/m^3)		Net water productivity (Rs/m^3)	Depth of irrigation water use (cm)	Water productivity (Kg/m^3)		Net water productivity (Rs/m^3)
		Main Product	By-product			Main Product	By-product	
Kharif Season								
1. Paddy	7.1	1.9	8.47	3.4	3.61	2.3	10.59	3.6
2. Chary (GF)	1.6	14.3	-	-	0.78	26.2	-	-
3. Vegetable	3.3	6.0	-	26.3	1.73	10.7	-	26.6
4. Lady's Finger	3.2	2.3	-	10.8	2.33	3.9	-	21.2
5. Maize	2.4	2.9	19.4	9.4	1.17	5.7	18.79	18.8
6. Sesamum	0.8	1.2	-	14.2	0.57	1.3	-	9.6
7. Sugarcane	1.1	12.4	-	6.7	0.57	10.6	-	8.1
8. Bajra	3.2	1.5	10.2	4.5	1.43	4.1	30.83	10.5
9. Black gram	2.7	1.9	-	39.1	1.14	2.4	-	46.3
10. Groundnut	3.3	2.6	-	31.7	-	-	-	-
11. Green gram	3.7	2.0	-	46.2	-	-	-	-
Rabi Season								
1. Wheat	6.7	2.4	11.3	7.8	2.93	2.6	12.36	7.6
2. Potato	5.0	5.7	-	8.6	2.91	6.0		9.6
3. Pea	2.3	1.9	-	13.5	1.33	2.1		15.0
4. Barseem	0.7	12.6	-	-	0.46	12.3		-
5. Gram	1.8	1.8	-	27.03	0.36	1.6		31.1
6. Mustard	1.6	1.4	-	10.8	1.20	1.4		11.4
7. Linseed	0.6	0.9	-	4.4	-	-	-	-
8. Barley	2.3	3.4	16.0	9.1	0.80	4.3	14.57	14.6
Summer Season								
1. MP chary	1.5	11.1	-	-	1.19	10.8	-	-
2. Sunflower	1.0	1.0	-	3.40	-	-	-	-
3. Vegetables	1.1	2.4	-	15.15	-	-	-	-

Source: Author's own estimate based on primary data

GF: Green fodder

Eastern Uttar Pradesh: Diesel well commands

Similar values for diesel pump owners and water buyers is presented in Table 8. The cropping pattern of pump owners and water buyers is almost the same, except that water buyers do not grow sugarcane and maize. To economize on irrigation water, water buyers cultivate water efficient crops such as arhar, black gram and green gram during kharif season. The cropping pattern during winter is same for diesel pump owner and water buyers. During summer season, only pump owners grow vegetables.

Table 8: Water Use, and Water Productivity in Physical and Economic Terms under Diesel Well Command, Eastern Uttar Pradesh

Name of the Crops	Diesel Pump – Owner				Diesel pump – water buyer			
	Depth of irrigation water use (cm)	Physical water productivity (Kg/m^3)		Net water productivity (Rs/m^3)	Depth of irrigation water use (cm)	Physical water productivity (Kg/m^3)		Net water productivity (Rs/m^3)
		Main Product	By-product			Main Product	By-product	
Kharif Season								
1. Paddy	15.53	1.86	8.50	2.62	9.09	2.39	8.49	2.92
2. Chary (GF)	1.12	18.44	-	-	0.98	29.74	-	-
3. Vegetables	1.43	0.77	-	0.37	3.43	1.94	-	25.26
4. Arhar	-		-	-	3.05	3.54	-	46.49
5. Maize	2.26	2.56	20.05	13.20	-	-	-	-
6. Sesamum	2.29	0.89	-	17.39	1.14	0.88	-	17.72
7. Sugarcane	1.59	10.13	-	2.50	-	-	-	-
8. Bajra	2.29	3.43	15.54	7.47	1.33	4.41	22.24	17.83
9. Black gram	-	-	-	-	1.14	1.30	-	28.69
10. Green gram	-	-	-	-	1.14	1.73	-	59.98
Rabi Season								
1. Wheat	12.74	2.57	13.34	6.22	8.33	3.50	14.40	7.80
2. Potato	3.70	7.23	-	17.87	2.29	7.40	-	-
3. Pea	3.40	1.56	-	12.19	1.67	1.74	-	12.36
4. Barseem (GF)	0.62	15.97	-	-	0.67	14.57	-	-
5. Gram	4.16	1.58	-	15.33	1.99	1.82	-	17.78
6. Mustard	2.70	1.56	-	10.87	1.44	1.15	-	11.99
7. Linseed	3.43	1.36	-	13.70	1.03	1.53	-	16.77
8. Barley	-	-	-	-	0.91	5.61	14.90	14.90
Summer Season								
1. MP Chary (GF)	0.92	10.68	-		1.43	11.77	-	-
2. Vegetable	1.14	2.41	-	17.49	-	-	-	-

Source: Author’s own estimate based on primary data

GF: Green fodder

Table 8 shows that the water buyers in diesel well commands apply less amount of water to their crops as compared to their water selling counterparts. Further, the physical productivity of water (kg/m^3) and water productivity in economic terms (Rs/m^3) is higher for water buyers as compared to diesel pump owners for all the crops.

North Gujarat: Flat and Unit energy Pricing Regimes

Table 9 presents similar data for different energy pricing regimes. Electric pump owners pay marginal cost for electricity and therefore maintain higher water productivity in both physical and economic terms for all the crops.

Table 9 Water Use, and Water Productivity in Physical and Economic Terms under Flat and Unit Energy Pricing Regime, North Gujarat

Name of the Crops	Electric Pump Owner – Flat Rate				Electric Pump Owner – Unit Pricing			
	Depth of irrigation (cm)	Physical water productivity (kg/m^3)		Net water productivity (Rs/m^3)	Depth of irrigation (cm)	Physical water productivity (kg/m^3)		Net water productivity (Rs/m^3)
		Main Product	By-product			Main Product	By-product	
Kharif Season								
1. Rajka Bajra	2.57	8.24	-	-	3.93	10.83	-	-
2. Alfalfa (GF)	3.63	5.42	-	-	4.11	5.64	-	-
3. Jowar	10.71	2.76	4.06	8.27	10.14	2.26	1.51	6.62
4. Bajra	9.81	1.00	3.48	5.13	8.94	1.45	2.14	6.39
5. Black gram	8.13	1.07	-	15.14	5.26	1.50	-	16.75
6. Green gram	7.62	0.91	-	10.85	8.73	0.98	-	11.20
7. Groundnut	9.47	0.58	-	3.58	5.14	0.56	-	4.68
8. Cluster	8.52	1.02	-	9.09	10.62	1.11	-	9.37
9. Cotton	6.29	0.41	-	5.34	6.10	1.15	-	19.28
10. Castor	11.66	0.59	-	5.06	11.02	0.62	-	6.52
Rabi Season								
1. Alfalfa (GF)	3.27	3.65	-	-	2.83	5.71	-	-
2. Chekudi (GF)	13.26	2.96	-	-	2.29	5.45	-	-
3. Wheat	12.72	0.82	2.64	4.64	9.63	0.91	2.08	5.17
4. Barley	2.29	0.47	9.33	0.70	6.29	1.11	2.89	6.17
5. Rajgaro	9.14	0.56	-	4.11	7.27	0.89	-	8.50
6. Mustard	11.38	2.86	-	22.25	7.46	2.10	-	23.50
7. Cumin	8.95	0.82	-	36.71	8.14	0.99	-	47.71
Summer Season								
1. Alfalfa (GF)	3.82	2.30	-	-	-	-	-	-
2. Rajka Bajra	2.53	3.27	-	-	4.06	8.15	-	-
3. Bajra	16.87	1.95	2.36	6.43	12.92	1.94	3.02	7.31

Source: Author's own estimate based on primary data GF: Green Fodder

The mean values of irrigation water dosage and water productivity in physical and economic terms for both pump owners and water buyers in electric pump command area in south Bihar plain for all crops are presented in Table 10. Water buyers apply less water to their crops, and maintain higher physical water productivity values for many crops in comparison to electric well owners (paddy, maize, barseem, onion and summer maize). However, they maintain lower water productivity in economic terms for most of the crops, except radish and onion. This could be due to the higher cost of irrigation water, which eventually reduces the values of numerator of water productivity. Table 11 presents figures of water use and water productivity of diesel well commands of south Bihar plains - both in physical and economic terms.

Table 10: Water Use, and Water Productivity in Physical and Economic Terms under Electric Well Command, South Bihar Plain

Name of the Crops	Electric Pump – Owner				Electric Pump – Water Buyer			
	Depth of irrigation water use (cm)	Physical water productivity (Kg/m^3)		Net water productivity (Rs/m^3)	Depth of irrigation water use (cm)	Physical water productivity (Kg/m^3)		Net water productivity (Rs/m^3)
		Main Product	By-product			Main Product	By-product	
	Kharif Season							
1. Paddy	7.51	2.5	12.90	6.35	4.67	2.69	12.60	8.4
2. Masureya	0.40	11.7	-	-	0.35	10.15	-	-
3. Maize (GF)	2.50	20.5	-	-	1.25	27.34	-	-
	Rabi Season							
1. Wheat	4.82	1.8	8.87	5.56	3.51	1.76	7.43	5.8
2. Potato	1.92	13.1	-	43.16	2.00	11.74	-	41.8
3. Barseem	0.56	10.4	-	-	0.40	11.91	-	-
4. Mustard	2.67	1.8	-	20.16	-	-	-	-
5. Gram	-	-	-	-	0.93	0.66	-	9.2
6. Radish	1.27	10.0	-	13.92	0.96	9.59	-	18.5
	Summer Season							
1. Onion	4.60	4.4	-	18.48	2.18	5.40	-	23.2
2. Maize	2.07	5.9	-	21.66	1.76	6.86	-	19.1

Source: Author’s own estimate based on primary data
GF: Green Fodder

Diesel pump owners and water buyers grow almost similar crops. For all crops except onion and summer green fodder, water buyers in diesel well commands secure higher physical water productivity as compared to pump owners. Again, for all crops except onion, the water buyers secure higher water productivity in economic terms as compared to pump owners.

Comparison of net water productivity (Rs./m^3) figures between well owners and water buyers in both electric and diesel well commands in two locations viz., eastern Uttar Pradesh and south Bihar planes and farmers with metered and farmers with non metered connections in north Gujarat show the following trends-

A) Net water productivity of water buyers from electric pumps is more both in east UP and south Bihar.

B) Net water productivity of electric pump owners under flat rate provision is comparatively less than those under unit price tariff.

C) Water productivity of electric pump owners in economic terms is less than that of diesel pump owners.

D) Economic water productivity of water buyers from electric pumps is less than those buying water from diesel pump sets.

Table 11: Water Use, and Water Productivity in Physical and Economic Terms under Diesel Well Command, South Bihar Plain

Name of the Crops	Diesel Pump – Owner				Diesel Pump – Water Buyer			
	Depth of irrigation water use (cm)	Water productivity (kg/m^3)		Net water productivity (Rs/m^3)	Depth of irrigation water use (cm)	Water productivity (kg/m^3)		Net water productivity (Rs/m^3)
		Main Product	By-product			Main Product	By-product	
	Kharif Season							
1. Paddy	8.96	2.40	15.13	7.50	5.41	2.98	19.77	9.56
2. Masureya	1.08	8.8	-	-	0.74	10.92	-	-
	Rabi Season							
1. Wheat	5.88	2.0	8.71	5.97	3.16	2.27	9.27	6.80
2. Potato	3.89	12.9	-	44.57	1.81	13.92	-	49.83
3. Barseem	0.89	12.7	-	-	0.60	16.03	-	-
4. Mustard	3.89	1.5	-	16.18	1.92	1.60	-	16.25
5. Coriander	2.81	2.3	-	38.72	-	-	-	-
	Summer Season							
1. Onion	3.70	5.8	-	21.50	3.06	5.34	-	21.27
2. Maize	2.24	5.3	-	17.05	1.64	7.65	-	31.84
3. MP Chary	0.92	8.9	-	-	0.94	7.46	-	-

Source: Author's own estimate based on primary data GF: Green Fodder

4.7 Livestock Water Productivity

4.7.1 Feed and Fodder Use

Farmers of eastern Uttar Pradesh keep buffalos, crossbred cows and indigenous cows. Most of the farmers in the region keep a combination of livestock i.e., buffalo with indigenous cow or buffalo with cross-bred cow. The reason behind this is that while buffalo milk fetches higher price, cow milk is used for domestic consumption. Green fodder includes chary, barseem and MP chary. *Bhusa* (which is a concentrate of barley flour and mustarg cake) is used as dry fodder. In general, farmers feed larger quantity of green fodder for milking animals.

Weighted average of feed and fodder input to livestock worked out for the entire animal lifecycle by farmers for west Uttar Pradesh are presented in Table 12.

Similar estimates for livestock inputs for farmers in diesel well command in eastern Uttar Pradesh were carried out. In case of pump owners, the average amount of feed and fodder fed to livestock were about 36, 43.35 and 31.71 kg/day/animal for buffalo, crossbred cow and indigenous cow, respectively. The corresponding numbers for water buyers were 37.5, 38.06 and 33.72 kg/day/per animal, respectively.

Table 12: Average Feed and Fodder Used Based on Lifecycle of Animal in eastern Uttar Pradesh

	Feed and Fodder Use (kg/day/animal)					
	Electric Pump – Owner			Electric Pump – Water Purchaser		
	Buffalo	Crossbred Cow	Indigenous Cow	Buffalo	Crossbred Cow	Indigenous Cow
Total Green Fodder	14.09	14.88	13.61	13.77	19.49	14.81
Total dry fodder	10.11	12.07	9.58	8.89	12.73	9.29
Total Concentrates	1.19	1.53	1.13	1.01	1.78	1.17

Source: Author's own estimate based on primary data

In north Gujarat, estimates of average feed and fodder input were made separately for farmers with metered and non-metered power connections. Farmers with metered power connection on average fed 13.68, 15.77 and 9.39 kg/day/animal of green fodder and 14.96, 16.32 and 12.13 kg/day/animal dry fodder to buffalo, crossbred cow and indigenous cow respectively. Quantity estimates were greater for farmers with non metered connections at 19.56, 23.18, and 9.25 kg/day/animal green fodder and 21.78, 25.64 and 20.95 kg/day/animal dry fodder to buffalo, crossbred cow and indigenous cow, respectively.

Similar estimates are available separately for farmers in the electric well commands and diesel well commands for south Bihar. The average amount of feed and fodder supplied by pump owner farmers in electric well commands to buffalo, crossbred cow and indigenous cow are 24.07, 24.75 and 16.09 kg/day/animal, respectively. The corresponding figures for water buyer-farmers in electric well commands are 21.92, 33.37 and 19.81 kg/day/animal, respectively. In case of diesel well commands, the average feed and fodder fed by diesel pump owner to buffalo, crossbred cow and indigenous cow are 35.34, 25.82 and 21.05 kg/day/animal, respectively. The corresponding figures for water buyers are 26.31, 27.56 and 29 kg/day/animal, respectively.

In general, in eastern Uttar Pradesh and south Bihar, water buyers (in both diesel and electric well commands) and farmers with non metered connections fed more input to their cattle.

4.7.2 Average Milk Production

The estimates of average milk production from dairy animals for electric well owners, worked out for the entire animal life cycle, are 2.91, 4.64 and 1.81 lt/day/animal for buffalo, crossbred cow and indigenous cow respectively. This is higher than that for water buyers, in whose case the figures are 2.64, 4.08 and 1.89 lt/day/animal. The corresponding estimates for farmers in the diesel well commands are; for well owners, 2.08, 4.01 and 1.95 lt and for water buyers, the values are 2.23, 3.23 and 2.01, for buffalo, crossbred cow and indigenous cow, respectively.

The estimates of average daily milk production in north Gujarat region are as follows. In case of farmers who have metered electricity connections, the average milk production from buffalo, crossbred cow and indigenous cow are 5.14, 7.5 and 1.91 lt/animal/, respectively. Same estimates for non metered connections are higher at 6.96, 9.32 and 6.43 lt. Such higher yields in the case of farmers with flat rate connections are due to the higher amount of feed and fodder that they are providing to dairy animals.

The estimates of average milk production for different dairy animals in electric well commands in South Bihar are as follows. For pump owners, the average milk production figures from buffalo, crossbred cow and indigenous cow are 2.0, 2.36 and 0.79 lt/day/animal, respectively. In the case of water buyers, they are 1.86, 2.97 and 0.88 lt/day/animal. The figures for farmers of diesel well commands are 1.69, 3.53 and 0.96 lt/day/animal respectively, whereas, in case of water buyers, the corresponding values are 1.68, 2.30 and 1.18 lt/day/animal.

4.7.3 Water Use for Milk Production

The estimates of the volume of water used for milk production and gross water productivity in milk production in economic terms for buffalo, crossbred and indigenous cows for the sample farmers in the electric well commands in Eastern Uttar Pradesh are presented in Table 13. Dairy farmers, who own pump-sets, use larger quantity of water for producing green and dry fodder, in comparison to water buyers. However, the amount of water embedded in the concentrate used for dairy production is higher for water buyers. The net result is that the gross water productivity for milk production is higher for electric pump owner as compared to irrigation water buyers.

Table 13: Water Use for Milk Production in Electric Pump Command Area, Eastern Uttar Pradesh (m^3/day)

Types of Feed & Fodder	Electric Pump – Owner			Electric Pump – Water Purchaser		
	Buffalo	Crossbred Cow	Indigenous Cow	Buffalo	Crossbred Cow	Indigenous Cow
Green Fodder	1.11	1.17	1.08	0.96	1.36	1.03
Dry Fodder	0.89	1.07	0.85	0.72	1.03	0.75
Concentrates	0.61	0.77	0.57	0.49	0.94	0.58
Drinking Water (m3)	0.018	0.019	0.013	0.018	0.019	0.013
Total Water Use (m3)	2.63	3.02	2.50	2.19	3.35	2.38
Milk Production (Lt)	2.91	4.64	1.81	2.64	4.08	1.89
Milk WP (Lt/m3)	1.11	1.54	0.72	1.20	1.22	0.79
Gross WP (Rs/m3)	11.95	15.52	6.72	12.97	12.31	7.35

Source: Author's own estimates based on primary data

For diesel well commands, the estimates of volume of water used for milk production by water sellers are 3.02 m^3, 3.48 m^3 and 2.68 m^3/day/animal for buffalo, crossbred cow and indigenous cow respectively, whereas in case of irrigation water buyers, the corresponding figures are 3.00 m^3, 3.21 m^3 and 2.64 m^3/day/animal. The physical productivity of water for milk production are 0.69, 1.15 and 0.73 lt/m^3, respectively for pump owner and 0.66, 1.08 and 0.58 lt/m^3 for water buyers. The average values of gross water productivity in milk production in economic terms from buffalo, crossbred cow and indigenous cow are Rs. 11.03/m^3, 16.13/m^3 and 10.95/m^3 respectively for pump owner and Rs 11.93/m^3, 14.06/m^3 and 11.38/m^3 for water buyers. In nutshell, the physical productivity of water for milk production, and water productivity in economic terms are higher for pump owners than that for water buyers.

For north Gujarat farmers, the estimates of embedded water used for milk production and the water productivity in physical and economic terms are as follows. In the case of farmers who have flat rate connections, average volume of water used for milk production from buffalo, crossbred cow and indigenous cow/day/animal are 9.77 m^3, 10.43 m^3 and 8.39 m^3, respectively. The corresponding average values of physical productivity of water in milk production (lt/m^3) are 0.53, 0.72 and 0.23, respectively and of gross water productivity in economic terms (Rs/m^3) are is 8.48, 10.43 and 2.96, respectively. In the case of well owner having metered connections, the average values of total volume of water used for milk production are 14.63 m^3, 17.39 m^3 and 10.90 m^3/day/animal for buffalo, crossbred cow and indigenous cow respectively. The corresponding values of physical water productivity for milk production (lt/m^3) are 0.48, 0.54 and 0.59, respectively and of gross water productivity in economic terms (Rs/m^3) are 7.39, 6.47 and 8.85, respectively for buffalo, cross bred cows and indigenous cows respectively.

The estimates of embedded water used in milk production in electric well commands for south Bihar plains are as follows. The electric pump owners use an average of 3.96 m^3, 4.92 m^3 and 2.81 m^3 of water per animal per day for buffalo, crossbred cow and indigenous cow, respectively. The corresponding figures for water buyers in their commands are 4.09 m^3, 5.36 m^3 and 3.37 m^3, respectively. The physical productivity of water used in milk production (lt/m^3) from buffalo, crossbred cow, and indigenous cow in the case of water buyers are 0.45, 0.48 and 0.28. The corresponding values of gross water productivity in economic terms (Rs/m^3) are 7.01, 6.66 and 3.95, respectively.

The estimates available for farmers in diesel well commands are as follows. The diesel pump owners use an average of 4.88, 3.96 and 2.73 m^3 of water/animal/day for buffalo, crossbred cow and indigenous cow, respectively. For water buyers, the corresponding figures are 3.62, 3.18 and 3.04, respectively. The physical productivity of water for milk production (lt/m^3) in case of pump owners for buffalo, cross bred cow and indigenous cow are 0.35, 0.90 and 0.50, respectively. The corresponding figures for water buyers are 0.46, 0.72 and 0.39, respectively. The average values of water productivity in milk production in economic terms (Rs/m^3) are 4.48, 10.60 and 7.00, respectively for buffalo, cross bred crow and indigenous cow. The corresponding figures for water buyers are 6.50, 8.52 and 5.45, respectively.

4.7.4 Net Water Productivity in Economic Terms

The net water productivity in economic terms for dairy production was estimated by considering the cost of milk production, which includes the cost of production of dry fodder, green fodder, cattle feed and other expenses for maintaining dairy animals in the water productivity analysis. In estimating the effective water productivity in milk production, the amount of water embedded in cattle feed used by farmers, which is imported, is subtracted from the value of denominator. The reason is that it is not counted in any water allocation decision taken by the farmers as a response to the pricing changes. The total cost of green fodder, dry fodder and concentrate, the income from milk and cow dung and total and effective water use for dairy production were estimated. Based on these data, both the net water productivity and effective net water productivity in economic terms were estimated for all the three locations (i.e., for well owners, and water buyers in electric and diesel well commands in eastern Uttar Pradesh and south Bihar and electric well owners with and without metered connections in north Gujarat).

The results for farmers in electric commands in Eastern Uttar Pradesh are presented in Table 14.

Table 14 shows that well owners secure higher net water productivity in milk production than water buyers for all types of livestock. Analysis of similar estimates for diesel well commands in eastern Uttar Pradesh shows the following. The values of net water productivity in economic terms for the pump owners are 1.74,

Table 14: Water Productivity in Economic Terms in Milk Production, Electric Pump, Eastern Uttar Pradesh

Sr. No.	Types of Feed & Fodder	Electric Pump – Owner			Electric Pump – Water Purchaser		
		Buffalo	Crossbred Cow	Indigenous Cow	Buffalo	Crossbred Cow	Indigenous Cow
1.	Green fodder (Rs.)	3.29	3.50	3.29	4.52	6.4	4.9
2.	Dry fodder (Rs.)	3.03	3.62	3.03	2.67	3.82	2.79
3.	Concentrates (Rs.)	6.51	8.39	6.51	5.54	9.58	6.38
4.	Total expenditure (Rs/day)	12.84	15.52	12.84	12.73	19.80	14.03
5.	Milk production (lt)	2.91	4.64	1.81	2.64	4.50	1.89
6.	Gross income from milk (Rs)	31.39	46.86	16.83	28.44	45.48	17.51
7.	Income from dung (Rs/day)	0.50	0.50	0.50	0.5	0.5	0.5
8.	Gross income (Rs/day)	31.89	47.36	17.33	28.94	45.98	18.01
9.	Net income (Rs/day)	19.05	31.84	4.50	16.21	26.18	3.98
10.	Net water productivity (Rs/m^3)	7.25	10.55	1.80	7.39	7.82	1.67

Source: Author's own estimate based on primary data

6.89 and 0.46 for buffalo, cross bred cow and indigenous cows, respectively. The corresponding values for water buyers are 0.43, 1.8 and -1.72. Comparing electric and diesel well commands, it appears that pump owners in electric well commands secure highest effective net water productivity in economic terms, followed by water buyers in their command, diesel pump owners and lowest for buyers of water from diesel pump owners.

In north Gujarat, the average values of effective net water productivity in economic terms for milk production from buffalo, crossbred cow and indigenous cow under flat energy pricing regime are Rs. 3.73/m^3, Rs. 5.88/m^3 and Rs. -1.85/m^3, respectively. In case of farmers under pro-rata pricing regime, the values are Rs. 3.31/m^3, Rs. 2.29/m^3 and Rs. 3.37/m^3, respectively. It is clear that over all effective net water productivity is higher under pro-rata pricing regime.

In south Bihar, the estimates of average effective net water productivity in milk production for electric well commands for electric pump well owner are Rs. 2.18/m^3, 1.96/m^3 and -1.0/m^3 and for water buyers are the values are Rs. 1.65/m^3, 3.89/m^3 and -0.64/m^3 for buffalo, crossbred cow and indigenous cow respectively. For diesel well commands, pump owner's effective net water productivity in economic terms (Rs/m^3) are -0.47, 5.68 and -250; and for water buyers are 0.07, 2.09 and -1.26, for buffalo, cross bred cow and indigenous cow, respectively.

4.8 Farm Level Water Productivity

Using more water means paying more for the pump rental services. Farmers should try and economize on the use of water, though it is not a scarce resource in eastern Uttar Pradesh and south Bihar. Farms are the unit for many investment decisions by farmers in agriculture including water allocation decisions. They try to optimize water allocation over the entire farm, rather than individual crops, to maximize their returns. Hence, the impact of power pricing on the efficiency with which water is used by farmers should be analyzed by looking at the water productivity for the entire farming system.

Our analysis clearly shows that the farm level water productivity is much higher for water buyers in diesel well commands in eastern Uttar Pradesh and south Bihar (Table 15). In electric well commands, the differences are not statistically significant. Here, the marginal cost of using water is too small for water buyers (Rs. 0.65/m^3), to create significant impacts on productivity. The farm level water productivity is much higher for farmers who are confronted with marginal cost of unit electricity in north Gujarat as compared to those who pay for electricity based on connected load. The water productivity improvement in highest in eastern Uttar Pradesh in the diesel well commands, where the water buyers' marginal cost of using irrigation service is Rs. 2.81/m^3. Water productivity difference is also quite substantial in north Gujarat between farmers with flat rate connection and those with metered connections.

Table 15: Farming System Level Water Productivity in Agriculture under Different Pricing Regimes

Name of the Regions	Name of the district	Electric Well Command		Diesel Well Command	
		Flat Rate	Unit Pricing	Well owner	Water buyers
North Gujarat	Banaskantha	6.20	7.90	NA	NA
		Well Owner	Water Buyer	Well Owner	Water Buyer
Eastern Uttar Pradesh	Varanasi and Mirzapur	10.95	11.18	8.67	12.89
South Bihar Plains	Patna	9.28	10.13	11.97	12.43

Further, comparison between electric well owners and diesel well owners in south Bihar also substantiates the earlier point that positive marginal cost promotes efficient use of water at the farm level. The data from eastern Uttar Pradesh does not corroborate with this. The reason is that the locations where electric well commands are located are not comparable with those of diesel well commands in terms of depth to groundwater table, soil conditions and moisture conditions. The diesel well commands are located in uplands with poor soils, whereas the electric well commands are located inside the flood plains of the Ganges with high water table depth, fertile soils and good moisture conditions during winter.

4.9 Impact of Different Modes of Energy Pricing on Equity in Access to Groundwater

As discussed in the methodology, the impacts of energy pricing on access equity in groundwater can be examined by studying how the increase in cost of production of groundwater influences the price at which water is traded. This can be studied by analyzing the changes in monopoly price ratios[8] for water traded in the market with change in mode of pricing. In the case of north Gujarat, we had a real life situation of farmers shifting from flat rate system to the pro-rata system of electricity consumption. However, these farmers are not into water trading. Hence, the water markets in electric and diesel well commands of eastern Uttar Pradesh and south Bihar were compared vis-à-vis the monopoly price ratios and the volume of water traded.

Through this analysis, we would test one dominant hypothesis by Shah (1993) that under flat rate system of pricing, well owners would have a strong incentive to pump out more water and as a result, the price at which water is traded in the market would come down, and come close to the cost of production of water. Kumar (2007) had challenged this hypothesis arguing that it is rather the number of potential sellers against the number of potential buyers citing evidences from Mussafarpur in Bihar.

Table 16 shows that in eastern Uttar Pradesh, the MPR (monopoly price ratio) was higher in the case of electric well commands than that in diesel pump well commands. While the price charged by electric pump owners was 3.6 times more than their cost of pumping, the price charged by diesel pump owners is only 1.8 times higher than their cost of pumping. In south Bihar, the trend is just the opposite. The average price charged by electric well owners is lower than the implicit cost of pumping water (Rs.0.70/m^3 against Rs. 0.77/m^3). Whereas the average price charged by diesel well owners (Rs. 2.15/m^3) is higher than the cost they incur for pumping groundwater (Rs.1.87/m^3).

Table 16: Selling Price of Well Water and the Monopoly Price Ratio under different Pricing Regimes

Name of the Regions	Name of the district	Selling Price of Water and Monopoly Price Ratio in			
		Electric Well Command		Diesel Well Command	
		Selling Price	MPR	Selling Price	MPR
North Gujarat	Banaskantha				
Eastern Uttar Pradesh	Varanasi and Mirzapur	0.65	3.50	2.81	1.85
South Bihar Plains	Patna	0.70	0.90	2.15	1.15

These are based on average figures of cost and price. A look at the cost and price figures for individual wells brings out a different picture. A few farmers have very high implicit cost of pumping groundwater, higher than the selling price. The reason is that the capital cost of the well and the pump set constitutes a major chunk of the cost, and the unit cost becomes high only because the wells run for fewer hours[9]. But, the monopoly price charged by many other farmers is higher under flat rate system for electric wells, as compared to those for diesel wells. These are farmers who have larger holdings due to which the pumping becomes very low.

Another interesting phenomenon found in both electric and diesel well commands is that the selling price of water is more or less same across the farmers, though the unit cost of pumping water varies across farmers.

[8] It is the ratio of the price of water and its actual cost of production incurred by the well owner.

[9] Such an approach to working out the unit cost, in which the capital cost is considered along with O & M, is valid only in long term marginal cost calculations. But, in reality the farmers do not consider this cost in their decision making framework is for short time duration. Therefore, the real marginal cost of pumping is very low, which means the MPR is high.

The selling price is decided by the market conditions irrespective of the cost farmers incur for pumping water (Kumar et al., 2001). Fewer numbers of potential sellers against a large number of potential buyers would increase the monopoly power of well owners. This is due to the poor transferability of water. Perhaps this is what is happening in the village with electric pumps in eastern Uttar Pradesh. On the other hand, presence of large number of sellers against a few buyers would reduce the monopoly power of well owners. They would be forced to sell water at prices conditioned by the market (Kumar, 2007). Perhaps this is what is happening in the village with electric pumps in south Bihar.

In nutshell, the mode of pricing of electricity does not influence the monopoly prices being charged by well owners in the market. On the other hand, the flat rate pricing puts large well owners in a very advantageous position as they could bring down their implicit unit cost of pumping groundwater.

4.10 Groundwater Pumpage

Often the distinction between efficiency and sustainability is not made (Moench and Kumar, 1993). Pricing would introduce efficiency, but may not ensure sustainability of resource use (Kumar, 2005). The total amount of groundwater pumpage per unit of cultivated area is determined by the cropping pattern and the cropping intensity. Increased allocation of cultivable area under highly water intensive crops would increase the demand for irrigation water by a farmer. Hence, total pumpage per unit cultivated area could be a good indicator of the sustainability impacts of change in mode of pricing on groundwater. However, farmers with very small land holding size are more likely to intensify cropping, which would increase the total pumpage. This would mean larger hours of pumpage per ha of cultivable area as value of numerator would increase and that of denominator would reduce.

But, the results from three locations (see Table 17) show that the pumpage of groundwater per unit area of cultivated land is lower for water buyers, in spite of them having lower sized holdings. The data for north Gujarat shows that in spite of having smaller sized land holdings (2.95 ha against 3.45 ha), the pump owners having metered connections use much less water per unit of land as compared to their counterparts having flat rate connections (303.88 hr/year against 443.88/year). The difference in aggregate pumping is much higher between farmers with meters and those without meters. Such a high reduction is water usage per unit of cultivated land, which a disproportionately higher than the reduction in net return per unit of land, is made possible through high improvements in water productivity in economic terms.

Table 17: Average Hours of Groundwater Use by Farmers under Different pricing Regimes

Name of the Regions	Name of the district	Groundwater Pumpage by Electric Pump Owners		Diesel pump	
		Unit Pricing	Flat Rate	Well owner	Water buyers
North Gujarat	Banaskantha	303.88	443.88	NA	NA
		Groundwater Use in Electric Well Command by		Groundwater Use in Diesel Well Command by	
		Well Owner	Water Buyer	Well Owners	Water Buyers
Eastern Uttar Pradesh	Varanasi and Mirzapur	175.38	183.93	222.23	148.00
South Bihar	Patna	329.97	249. 74	231.11	197.91

But, in spite of slight reduction in pumping, the net return from unit of land is higher for water buyers in eastern Uttar Pradesh and South Bihar plains (see Table 18). This is achieved through high enhancement in water productivity through selection of crops that are less water consuming and high valued.

Table 18: Net Income from Crop and Milk Production, three Locations

Type of Well Command	Type of farmer	Gross cropped area (ha)	Net income from crops (Rs.)	Net income from dairying (Rs/day)	Total Farm level Income (Rs.)	Farm level net income (Rs/ha)
Electric Well	Well owner	5.29	124587.3	7152.3	131739.6	24880
	Water buyer	2.21	54637.6	6165	60802.6	27570
Diesel Well	Well owner	5.66	74764.5	7429.5	82193.9	14528
	Water buyer	3.79	62323.1	6260.6	68583.7	18075
Electric Well	Flat Rate	13.35	369119.7	30048	768287.4	57531
	Metered	11.77	311806.9	45636	669250.2	56882
Electric Well	Well owner	3.14	120477	10292.6	130769.5	210345
	Water buyer	1.70	61517.7	8130.9	76023.9	190031
Diesel Well	Well owner	2.49	140105	9958.1	150063.6	191387
	Water buyer	1.60	71810	12232.2	84042.5	197895

Source: Author's own estimate based on primary data

5. MAJOR FINDINGS

The major findings emerging from the analysis of data from three locations are as follows:

1. Farmers who have metered power connection not only pay positive marginal cost of using well water, but also pay higher cost for every unit of irrigation water (Rs/m^3) as compared to their counterparts having flat rate connections. Similarly, farmers who are buyers of water from electric pump owners and diesel well owners in eastern Uttar Pradesh and south Bihar also pay positive marginal cost of using irrigation water pay higher unit costs of irrigation water compared to water selling counterparts.

2. Minor differences are found in the cropping pattern of well owners and water buyers in electric and diesel well commands; and between farmers with metered electricity connections and farmers with flat rate connections. The water buyers (in eastern Uttar Pradesh and south Bihar) and farmers who have metered electricity connections allocate some amount of land for highly water-efficient crops, which are also less water consuming.

3. Water buyers in diesel and electric well commands, and the farmers who have metered power connections in agriculture pay for water on volumetric basis. Our analysis suggests that they secure higher water productivity in physical terms (kg/m^3) for most crops as compared to water selling well owners through: careful use of irrigation water (as reflected in lower water application rates) and agronomic practices (as reflected in higher yield rates). This means that when confronted with positive marginal cost of irrigation water, farmers are encouraged to use water more efficiently.

4. Water buyers in diesel and electric well commands, and farmers who have metered electricity connections secure higher water productivity in economic terms for many crops as compared to water selling well owners through: careful use of irrigation water, optimizing costly inputs and obtaining higher yield rates through farm management. This means that when confronted with positive marginal cost of irrigation water, farmers would be encouraged to improve economic efficiency of water use.

5. The estimated values of net water productivity in economic terms estimated for dairy animals in case of water buyers in diesel and electric well commands, and the farmers who have metered power connections in agriculture are not higher than that of water selling well owners. This could be because the cost of

production of animal inputs are higher in the case of water buyers due to the higher cost of production of inputs in lieu of the higher cost of irrigation water. However, the water productivity in dairying is much lower than that of many crops grown by both well owners and water buyers in all the locations**.**

6. Water buyers in diesel and electric well commands, and the farmers who have metered power connections secure higher water productivity at the farm level as compared to water selling well owners through: careful use of irrigation water; agronomic inputs; optimizing costly inputs for crops; and through judicious selection of crops, cropping pattern and livestock composition, which give higher return from every unit of water consumed. The diesel well owners also secure higher water productivity at the farm level as compared to electric well owners, as shown by data from south Bihar. These results have two major implications for policy: 1] when confronted with positive marginal cost of irrigation water, farmers are encouraged to use water more efficiently over the entire farm from economic point of view; and 2] when confronted with higher cost of irrigation water, the farmers venture into adopting farming system and optimizing use of inputs to secure higher returns from every unit of water to offset the increase in costs of irrigation.

7. Higher net water productivity in economic terms (Rs/m^3) which farmers obtain even at high cost of irrigation water is indicative of the fact that it is possible to keep irrigation costs high enough to induce improved efficiency in water use in both physical and economic terms without compromising on farming prospects.

8. Comparison of water prices charged to water buyers in diesel and electric well commands against the cost of production of water clearly show that the monopoly price charged by well owners is not a function of the mode of energy pricing. The farmers who are confronted with zero marginal cost of using energy charge even higher monopoly rates for water as compared to diesel well owners. On the other hand, the flat rate pricing puts large well owners in a very advantageous position as they could bring down their implicit unit cost of pumping groundwater. The major policy implication of this analysis is that pro-rata pricing of electricity would promote equity in groundwater use, if many farmers from within the same area have access to electricity connections.

9. The water buyers in diesel and electric well commands are using much less water for every unit of net cultivated area as compared to the farmers who are well owners. In addition, the farmers who are using metered power connections are using less amount of water per unit of cultivated land. Such reduction in groundwater pumping, with a disproportionately lower reduction in net return from unit of land in the case of farmers with metered connections in north Gujarat, and no reduction in net returns in the case of eastern Uttar Pradesh and south Bihar plains, is possible through water productivity improvement in economic terms. This indicates that introducing marginal cost for water and electricity not only promotes efficient use of water, as manifested by higher farm-level water productivity, but also more sustainable use of water.

6. CONCLUSIONS AND POLICY IMPLICATIONS

The past one and a half decades have seen intense debate on the potential impacts of introducing electricity pricing in the farm sector on efficiency, equity and sustainability in groundwater use, and its overall socio-economic viability thereof. There is limited empirical work in India, which shows the potential impacts of pro-rata pricing of electricity on efficiency in groundwater. It showed that the levels of electricity tariff that encourage efficient and productive use of groundwater are socio-economically viable. However, the analysis was based on comparative analysis of crop water use and water productivity data from water buyers and well owners from a single location, rather than that of farmers who pay for electricity on pro-rata basis.

Introducing marginal cost for electricity motivates farmers to use water more efficiently at the field level from physical, agronomic and economic point of view through careful use of irrigation water, use of better agronomic inputs and optimizing costly inputs. Also, it would motivate farmers to use water more efficiently at the farm level through careful use of irrigation water in crops; better agronomic inputs; optimizing costly inputs for crops; careful selection of crops and cropping patterns, and livestock composition that give higher return from every unit of water and low water consuming crops. It also shows that higher cost of irrigation water affected by higher energy cost will not lead to lower net return from every unit of water used as the farmers modify farming system itself in response to increase in energy cost.

The analysis also shows that changing the power tariff structure from flat rate to pro-rata would not have any adverse effects on equity of access in groundwater in terms of increasing the monopoly power of well owners. This is because the monopoly prices are largely governed by the number of potential water sellers against the number of potential buyers of water in an area. In addition, pro-rata pricing has significant impact in reducing groundwater pumpage from every unit of irrigated land, which is disproportionately higher than the reduction in net return from unit of land. This shows positive impact on sustainability of groundwater use.

The empirical evidences further reinforce the fact that the arguments against pricing are flawed. One argument against price change is the higher marginal cost of supplying electricity under metered system, could reduce the net social welfare as a result of reduction in: 1] demand for electricity and groundwater; and 2] net surpluses individual farmers could generate from cropping. The second argument is that for power tariff levels to be in the responsive region of power demand curve, prices are often so high that it may become socially unviable.

The aggregate demand for electricity and groundwater in irrigation is a function of the demand rates (electricity and water requirements per unit of land), and the total area under irrigation. The empirical analyses from all locations show that the demand for water/energy per unit of land was lower for water buyers due to increase in unit price of water/energy. However, the net income surpluses from every unit of water/energy used increased.

Overall, the net returns reduced drastically per unit of land in south Bihar and eastern Uttar Pradesh, and marginally in north Gujarat. This is because in water-scarce regions like north Gujarat, farmers would not have constraint of land in maximizing returns. With higher water productivity (Rs/m^3), they would be able to maintain the same level of net farm return as in the past with much less amount of water by slightly expanding the irrigated area. This is more so because there is no need for regulating power supply under metered system of pricing, whereas it is compulsory under flat rate system of pricing to control the revenue losses to the electricity boards. Now, if one considers the positive externalities on the society due to energy and water saving due to their efficient use, the net social welfare would be even more under pro-rata pricing.

In spite of the higher prices, the net economic returns from farming are higher for water buyers as compared to water selling diesel and electric well owners. General argument against pro-rata pricing is that it raises the prices at which water is traded in the market. This is based on the assumption that introduction of marginal cost of energy, farmers would not have any special incentive to pump out extra water for sale, with the result that the monopoly power of well owners would increase. However, evidence provided in the paper suggests that the monopoly price charged by well owners is not dependent on whether well owners are confronted with marginal cost of using electricity or not.

In sum, the evidence provided in the paper corroborates with the earlier evidence provided by Kumar (2005) to the effect that raising pro-rata power tariff to levels that induce improvement in productivity of energy and water use would not have any adverse impacts on the economic viability of farming. This means that introducing high power tariff in the farm sector would be socio-economically viable.

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TOWARDS EVOLVING GROUNDWATER RIGHTS: THE CASE OF SHARED WELL IRRIGATION IN PUNJAB

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Abstract

Operationally, the water allocation arrangements found in the shared groundwater irrigation systems in the Bist Doab area of Punjab are identical to a "crude form" of water rights. Here, the individual farmer's access to well water is restricted in terms of number of days for which they could use the well. Also, these rights to use "water" can also be leased out. Hence, these entitlements can be treated as "tradable". Another important feature of this arrangement existing in the shareholder irrigation system is that the amount of water which the farmer can access through the well is rationed by restricted power supply. Hence, they are analogous to tradable water rights, with rationing. The potential impacts of such a rationing on efficiency of groundwater use can be examined by comparing the productivity parameters such as cropping pattern, land productivity (yield and net returns) and water productivity in crop production under shared irrigation systems with that under individual irrigation systems.

The learning from such a study can be used in drawing inferences on the potential outcomes of instituting water rights in groundwater. The study shows that under conditions of rationed water allocation, the farmers have high motivation to allocate more water to crops that are economically more efficient, and also use it more efficiently for the chosen crops than the farmers who have unrestricted access to groundwater by virtue of having wells under individual ownership. They generate greater returns from every unit of water used, without compromising on the prospects of farming. Hence, we can conclude that in semi arid and arid areas, establishing water rights in volumetric terms with due consideration to safe yield of the aquifer under consideration, and enforcing it would help promote efficiency and sustainability in groundwater use.

1.0 INTRODUCTION

The past few years have seen extensive academic debate on the range of institutional measures for promoting efficient, equitable and sustainable use of groundwater use in India (see Kumar, 2007; Moench, 1995; Shah et al., 2004b). These regulations and market instruments concern introduction of top-down state regulations on groundwater withdrawal (Sharma, 1995); introduction of groundwater withdrawal permits (Sharma, 1995); cooperative management of groundwater (Singh, 1995); introduction of tradable property rights in groundwater (Kumar and Singh, 2001; Kumar, 2007); intelligent rationing of electricity supplied to farm sector (Shah, 2004); and pro-rata power tariff in agriculture (Saleth, 1997; Kumar and Singh, 2001; Kumar, 2005); and community-based ownership and management of groundwater (Shah et al., 1998). These debates are, however, characterized by diametrically opposite view on the equity and productivity impacts of most of these instruments.

Many argue that pro rata pricing would have positive impacts on efficiency, equity (Kumar and Singh, 2001; Kumar, 2005) and sustainability (Singh and Kumar, 2008) in the use of groundwater in semi arid and arid regions. Some argue that the operational issues associated with introducing metering and pro rata pricing are many that it is almost impossible to do agricultural metering of electricity in the farm sector without causing

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negative welfare effects (Shah et al., 2004a; de Fraiture and Perry, 2004). On the other hand, some scholars have argued that rationing of water allocation is the best way to achieve enhanced productivity in agriculture water use (Perry, 2001; de Fraiture and Perry, 2004). Saleth (1997) argued that even the crudest form of water rights would be more effective in achieving equity, efficiency and sustainability in groundwater use, than evolving energy pricing policy which can achieve the goals of efficiency, equity and sustainability. While Shah et al (2004b) argue that instituting and enforcing groundwater rights or enforcing any regulations on the use of groundwater would be practically infeasible due to millions of wells and pump sets, Kumar (2007) suggests an institutional framework for enforcing tradable property rights in groundwater, with a three-tier hierarchy of institutions from local (village) level to the aquifer level to overcome such operational difficulties.

Kumar (2005) had illustrated with empirical evidences from semi arid north Gujarat that rationing groundwater allocation with volumetric water prices or pro rata pricing of electricity for pumping water would lead to positive outcomes on efficiency and sustainability of groundwater use with no adverse effects on farm returns. Whereas, Singh and Kumar (2008) based on empirical data from three locations in India, shows that pro rata pricing alone could bring about positive outcomes on efficiency, equity and sustainability. But, there is very little evidence on the potential impacts of volumetric rationing of water, wherein farmers have restricted access to groundwater, but do not incur any marginal costs of using it. Though the shareholders of tube well partnerships in north Gujarat have volumetric entitlements, they are also confronted with positive marginal cost of using water (Kumar, 2000; Kumar, 2005). Internationally, the only developing country where evidences of efficiency and equity impacts of tradable property rights in groundwater is Chile, where positive impacts on equity and water use efficiency were seen (Rosegrant and Gazmuri, 1994; Thobani, 1997).

Though theoretically not, practically, the water sharing arrangement in shared well irrigation of Punjab is quite identical to the crudest form of water rights. In this case, the farmers do not pay for well water on volumetric basis, neither their access to well water is defined in volumetric terms. But their access to the same is restricted in terms of number of hours/days for which they could use, which is directly linked to the size of share holding (Tiwari, 2007). Some scholars have argued that water rights without tradability would lead to wasteful use of the resource (Frederick, 1993; Howe et al., 1986), though this is not identical to the earlier case. Others fear that tradable water rights would lead to farmers allocating their water for high valued uses or using it for high valued crops, with negative consequences for equity, food security and water for basic survival needs (Rosegrant and Ringler, 1998). Understanding the potential impact of rationing water allocation can significantly contribute to deepening our understanding of crafting institutions and policies for sustainable use of groundwater.

2. OBJECTIVES

The study explores the impacts of rationed allocation of groundwater on efficiency and sustainability in groundwater use in agriculture. The specific objectives are to analyze the impact of volumetric rationing in water allocation on: 1] cropping pattern of the irrigators; and, 2] land and water productivity in irrigated crops.

3. THE STUDY AREA, METHODOLOGY AND SAMPLING

The area of our study was limited to the four districts of Doab region namely Jalandhar, Kapurthala, Nawanshahar, Ropar. This region falls between the two rivers Sutlej and Beas and as mentioned before, it is known as the heart of Punjab.

The district of Jalandhar is an intensively irrigated plain of Punjab between the Beas and Sutlej rivers. The district has semi arid climate. The mean annual rainfall in the district is 703.0 mm. The rainfall increases from the south-west towards the north-east, from 551.3 mm at Nakodar to 892.3 mm at Adampur. About 70 per cent of the annual normal rainfall is received during the period July to September, July being the rainiest month. The Nawanshahar district has a geographical area of 1258.33 sq. km with a population of 5.86 lac people. The average annual rainfall in the district is 700mm. About 70 % of the annual normal rainfall in the district is received during the period July to September.

Kapurthala District is situated in the Jalandhar Doab and comprises two non-contiguous parts, separated by a distance of 32 kilometres. According to the 1991 census, the population of Kapurthala District, covering a geographical area of some 1633 sq km., was 6.46 lac people. The district of Rupnagar falls between north latitude 30°-32' and 31°-24' and east longitude 76°-18' and 76°-55'. The district adjoins Nawanshahar, Mohali and Fatehgarh Sahib Districts of Punjab. The district comprises three Tehsils and 617 villages.

3.1 Methodology and Analytical Tools

The methodology used in the study involves comparing the cropping pattern; land productivity (yield and net returns) and water productivity (Rs/m3) under shared irrigation system with that of individual well commands. The efficiency impact of rationing water allocation is analyzed in terms of differences in water productivity of the crops in economic terms; and the cropping pattern. This approach is based on the premise that while the amount of water that can be accessed by individual well owners is unrestricted, it is restricted in case of shared well owners.

In order to collect detailed information regarding social dynamics of shareholders, history of system, dispute emergence and settlement, and to triangulate what information has been provided by the farmers, 15 Focussed Group Discussions were conducted with the farmers in all the study villages.

To estimate the land productivity (Rs/ha) the minimum support price has been taken as the price of output. It would help nullify the effect of any exaggeration made by the respondent or market volatility and only capture the effect of yield increase and change in cost of inputs. From the four districts in the Doab area, the villages and the respondents were selected using random sampling method for administering the structured questionnaire. The sample survey covered 81 individual well owners and 75 shared tube well systems from 20 villages in four districts. In case of shared tube wells, information about the entire tube well command was collected.

In order to understand how efficiently irrigation water is used for production of a particular crop, it is important to know the marginal productivity of irrigation water, wherein we should segregate the effect of soil moisture on crop yield or rain-fed component of crop yield. The detailed methodology for estimation of marginal productivity of applied water is provided in Kumar et al. (2008). However, it is assumed that the entire crop yield is due to the irrigation water, and rains do not contribute to the yield at all. The applied water productivity for crops in economic terms (θ_{crop}) was estimated by using the estimates of the total volume of water used for crop production (Δ_i) as the denominator against the net return from crop production (NR_i) in the numerator, as per equation 1.

The volume of water applied for crop (Δ_i) was estimated for each crop on the basis of the number of irrigations; hours of watering per irrigation and the well output. In order to ascertain the discharge of pump sets, discharge measurements were made for sample pump sets under each horsepower category from each district using bucket and stop watch. The discharge for the rest of the pump sets was then extrapolated using the estimated values of pump efficiency for each category of pump set.

$$\theta_{crop} = \frac{NR_i}{\Delta_i} \quad \text{.............................} \quad (1)$$

4. SHARED IRRIGATION SYSTEMS IN DOAB AREA OF PUNJAB

On the basis of ownership, irrigation systems can be classified into two major categories, viz., individual irrigation system, and shared irrigation system (Kumar, 2000; Tiwari, 2007). In shared irrigation system, the water extraction mechanism is owned or shared by at least more than one household. In simple terms, it is a type of arrangement where more that one household take water from a water source. These shareholders follow a specified system of turns to avail of the irrigation services. As found by Kumar (2000) in north Gujarat and later on by Tiwari (2007) in Punjab, generally, this mechanism of turns is based on the ratio of land owned by the particular household in the command area of the particular tube well. These shareholders do not have the liberty to avail of the irrigation services as per their wish. Instead, they need to plan about the selection and water requirement of crop keeping water availability in mind, and at times they do undertake discussions and mutually decide about the crops to be taken in command area.

There have been cases where shareholders take water intensive crops alternatively. However, this situation prevails only in limited number of cases. In majority of the cases, shareholders do protect themselves by taking only those crops which are less water-consuming and can provide better returns coupled with lesser risk with regard to water availability. In case of individual tube wells, owner enjoys full control over water application. Therefore, the availability of water does not become a constraint in crop selection.

The turns for irrigation are allocated on daily basis wherein during each turn water is available to the shareholder at least for a day. Those who have larger holdings (and share) would get each turn for proportionately more number of days. This is different from what was found in the case of north Gujarat where the allocation is on hourly basis for each watering. Except for Ropar, where there is electricity for 24 hrs, in other three districts electricity is available for about 8 hours in kharif and about 4 hours in winter. So if a farmer decides to grow rice then he has to se generator to fulfil the water requirement of the crop which increases the cost of cultivation to a very high level.

4.1 Illustrative Case Study

A clear illustration of shared groundwater irrigation system, and its operating principles and rules is provided below. Satnam singh had total land of 8 Acres which got divided between his two sons Raj and Banta in two equal parts. Their land was further divided in the next generation. Earlier both Raj and Banta singh were taking water on every alternate day. But, now with their off springs, Amar Singh's turn comes once in every 4th day, and similarly for other shareholders.

Figure 1: Demonstration of Shared irrigation system

	Satnam Singh (8 Acres)			
	Raj Singh		Banta Singh	
Land ←	4 Acres		4 Acres	
Turn ←	1 day		1 day	
	Amar Singh	Sohan	Pukkar	Kasmir
Land ←	2 Acres	2 Acres	2 Acres	2 Acres
Turn ←	1 day	1 day	1 day	1 day

Now if Amar singh decides to migrate abroad or to a city, then he can lease out his land to his brother or third party. In case he leases out his land to Sohan then, the turn earlier allotted to Amar gets transferred to Sohan Singh as shown in Figure 1. Now, though the command area remains the same, Sohan gets two consecutive turns.

Figure 2: Shared irrigation system in case of farmer leasing out land to his brother

Satnam Singh (8 Acres)			
Raj Singh		Banta Singh	
4 Acres		4 Acres	
1 day		1 day	
Amar Singh	Sohan	Pukkar	Kasmir
Lease out to Sohan	2 Acres + 2 Acres	2 Acres	2 Acres
	1 day + 1 day	1 day	1 day

Another possibility is that Amar Singh leases out his land to a third party and in that case the turn for water gets transferred to the lessee (Figure 2). In all the three cases discussed above, the command area of the tube well remained same. Also the irrigation schedule for the other three shareholder farmers remains the same. If Amar singh decides to cultivate crops in more area, then he will have to manage water to meet the crop water demand from his own fixed entitlement, decided earlier. But generally this does not happen as all the “leasing in” and leasing out” transactions in land occur along with transfer of water entitlements.

But, it is important to note that the farmer can use a generator or any other water extraction device for pumping water from the tube well to irrigate the extra piece of land within the allocated day. In this case, the command area of the tube well increases forms eight acres to nine acres. This clearly means that the farmers' "entitlement" is not defined in volumetric terms, but in terms of number of days for which he can use water from the tube well.

5. RESULTS AND DISCUSSION

5.1 Type of Tube Well

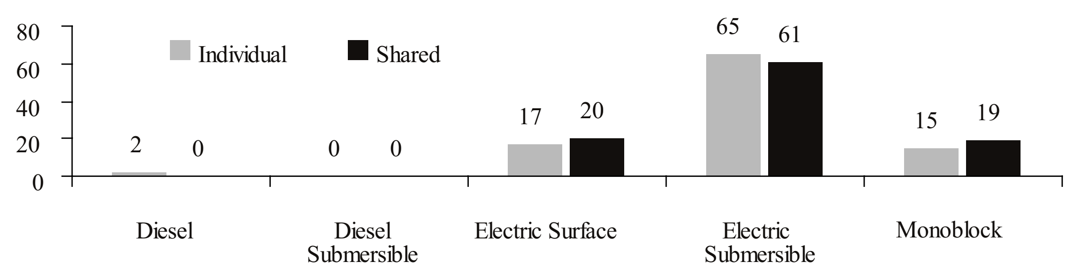
Figure 3 shows the percentage of farmers under the two categories, who own different types of water extraction devices. As regards pump ownership, nearly 60% of the tube wells both in shared and individual tube well systems were reported to have submersible pumps. One of the reasons for such a high percentage of submersible pump sets for tube wells was the prevalence of rice-wheat cropping pattern. Since irrigated paddy needs frequent heavy dozes of irrigations, farmers switch over from mono-block pumps to submersible pumps. One of the reasons for this is the drop in water table, experienced particularly during summer, due to which the outputs obtained from wells through the use of mono block pump sets are inadequate.

During the survey, it was found out that there was a trend of shifting from mono block pumps to submersible pumps. While mono-block pumps could operate at a depth of about 50-60 ft, a submersible pump can work at much higher depth with higher pump capacities. Also farmer makes a cushion for future and installs the pump at a greater depth considering the rapid decline in water table, which the region is experiencing. Table 1 shows the percentage of farmers under the two categories who have not shifted, and the percentage of farmers who have shifted due to one of the three reasons.

Table 1: Percentage of Farmers Shifting from Mono-block to Submersible Pump sets and the Reasons for Shifting

Particulars	Shared Wells (%)	Individual Wells (%)
No shift in pump sets	44	32
Increasing water table depth	23	41
Rice cultivation	17	21
Summer water shortage	16	6

Figure 3: Ownership of Groundwater Extraction Mechanisms by Different Categories of Farmers



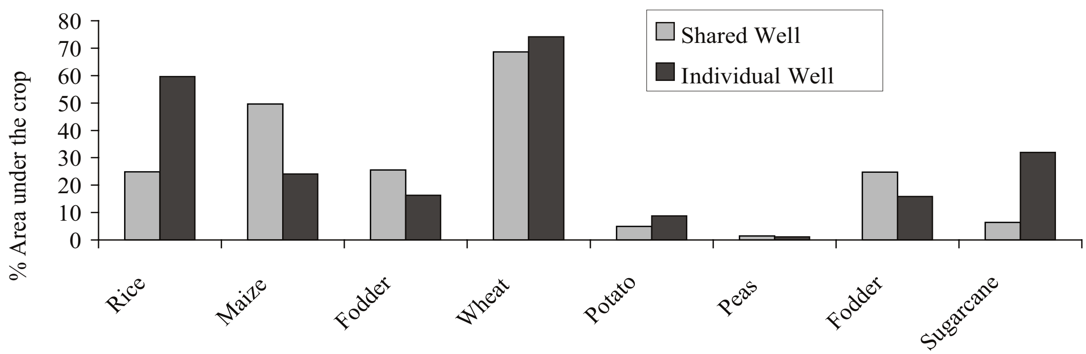
1. **N**o Shift in Pump Sets: Forty Four per cent of the shared wells and 31% of the individual wells did not change the pump sets due to the following reasons: 1] they are growing crops that do not require much water like maize, sugarcane. Water currently available is sufficient for these crops except rice; 2] water table at that particular place is still good enough for cultivation; 3] in shared well, since every decision regarding expenditure on the tube well is made with consensus of all the shareholders, many a times change of tube well is not supported if proposed by only one of the member because the cost of shifting is quite high approximately Rs. 87000.
2. Depth to Water Table: Water table depth is declining at an average annual rate of nearly 0.2 m. So, in the course of time, shift in pump sets become imperative. This phenomenon was more prominent in Ropar as the average bore depth was around 300 ft. In Ropar, all the pumps were submersible.
3. Rice Cultivation: In many areas such as Punjab (India), a traditional wheat belt, where rice-wheat is intensively grown, the water table receded on average 0.2 m per year during 1979-1991 (Singla 1992)[4] . The area under the critical water table below 10 m in central Punjab increased from 3% in 1973 to 25% in 1990 and 53% in 2000. Due to this decline in groundwater levels, there has been a shift from surface pump sets to submersible pumps.
4. Shortage of Water in summer: In summer, the temperatures soar up to 50°C in Doab area. The water requirement for paddy, which is transplanted in May-June, is very high during these months. Due to this reason, there is heavy pumping of groundwater. As a result, water table goes down, resulting in lowering of well yields. The crops suffer due to shortage of water. Hence, the farmers are forced to increase the depth of the tube well, to raise the well yields.

[4] Singla, T. L (1992) Groundwater recharge programme: present status and scope. Water Resources Day, Vol. I, Punjab Agricultural University. p 1169-1173.

5.2 Cropping Preferences in Shared and Individual Systems

Comparative analyses of cropping pattern of individual irrigation systems and shared irrigation systems show remarkable difference in the cropping pattern adopted in their command areas. In kharif, farmers in the commands of individual irrigation system are more inclined towards rice cultivation whereas in shared irrigation systems, majority of the cropped area in kharif is under maize (Figure 4). It should be kept in mind that maize grown during kharif takes much less water as compared to kharif paddy, which needs to be irrigated before the onset of monsoon, which arrives in the start of July. Though the cropped area figures of winter season do not differ much, the percentage area under wheat and potato, which are dependent purely on irrigation water, are slightly less in the shared irrigation system commands as compared to individual well commands. More interestingly, the percentage area under sugarcane is much less in shared irrigation commands (i.e., 32 per cent against 6.4 per cent). Here again, the tendency to go for highly water-intensive perennial crop is more among farmers having individual wells.

Figure 4: Cropping Pattern of Different Farmer Categories in Different Seasons



5.3 Crop Yields in Shared and Individual Irrigation System

Farmers mainly take two crops in a year in addition to the annual crop of sugarcane. These crops primarily include rice and maize in kharif and wheat in winter. There were instances, where vegetables such as potato and peas are also grown in winter. Water availability seems to have the biggest impact on the cropping pattern, and not on the agronomic inputs. Majority of the farmers follow the same agronomic practices suggested by the Agriculture University, irrespective of the amount of water they could access. The farmers who are members of shared irrigation systems manage their crop water demands by allocating less area for crops that are water intensive. This approach ensures optimum inputs, leading to more or less same level of crop yields. As Table 2 indicates, there is marginal difference in yield of crops, showing higher values in favour of individual well commands.

Table 2: Productivity of various crops in shared as well as individual system (qtl/acre)

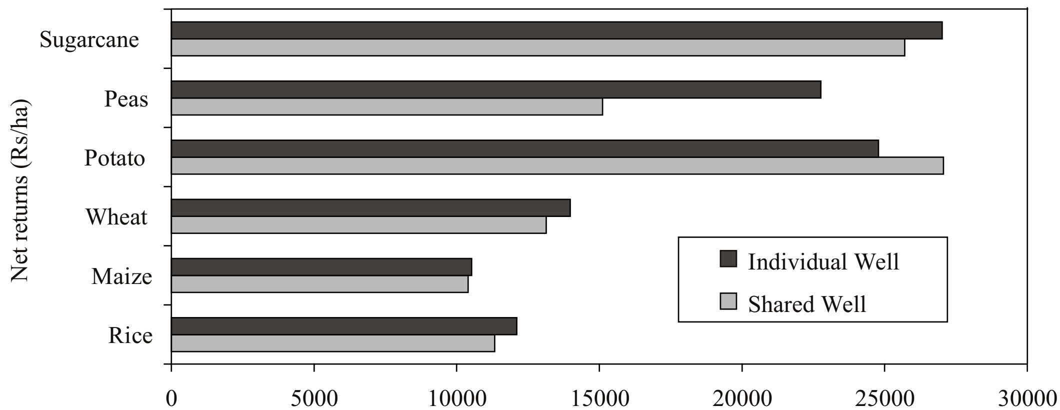
Crop	Shared Wells	Individual Wells
Rice	23.40	24.02
Maize	18.11	18.61
Wheat	20.17	19.80
Potato	65.00	64.79
Peas	25.29	29.75
Sugarcane	315.56	

Source: Authors' own estimates based on primary data

5.4 Net Returns from Crops in Shared and Individual Irrigation System

There was not much difference in both the systems as farmers irrespective of the tube well system adopt standard practices as recommended by Punjab Agricultural University, Ludhiana. The productivities as shown in the figure below (Figure 5)

Figure 5: Net Returns from Crops for different Categories of Farmers



Relatively higher values for returns from rice in the case of individual wells is mainly due to difference in use of generators. As discussed earlier, kharif rice in Punjab is a water intensive crop requiring daily irrigation till the onset of monsoon. If the field under rice gets dried then the productivity can fall drastically. At times, this can result in total loss of the crop also. In order to avoid such situations, farmers use generators to irrigate their land. Due to restricted availability of water and lesser control over timings, usage of generator is relatively higher in the shared irrigation systems in comparison to the individual systems.

Due to this reason, percentage of farmers taking rice in kharif is only 25% in shared irrigation system, as against 60% in individual well owners. Majority of the farmers under the shared irrigation system are inclined towards maize, percentage of farmers taking up maize is about 50% whereas same under individual is about 24% only. The focused group discussions revealed that this difference was due to differential water security. While individual owners were having greater water security, same is not the case with shared irrigation systems.

In cases where there were only two shareholders in the system, farmers were found to be growing rice as they could manage to provide watering at all critical stages of crop growth. However, in cases where shareholders were three or more, they prefer to grow maize only as taking rice in such circumstances would increase the cost of cultivation to a great extent, making it economically less viable as compared to other available options for the season. Also with large number of shareholders, the risk of yield reduction due to insufficient irrigation also increases.

5.5 Water Productivity

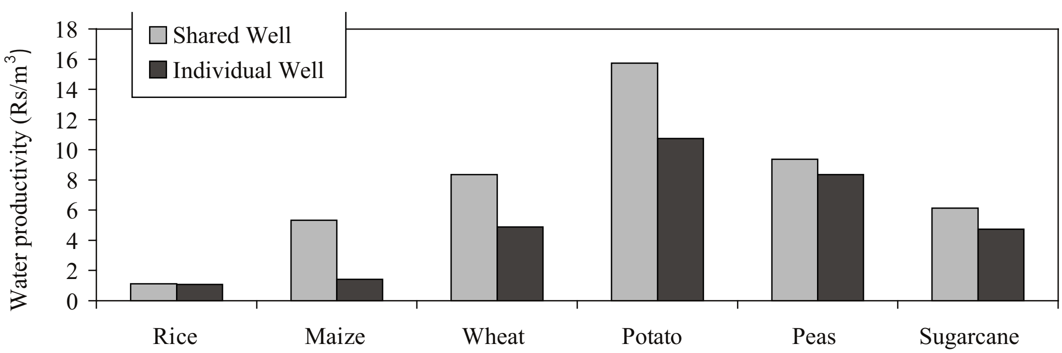
Water productivity in crop production can be defined as net return on per unit volume of irrigation water applied for crop production; in simpler words, it shows the average return on the applied water.

An analysis of water productivity can show the efficiency with which water is used in a particular crop. This analysis is relevant for areas where scarcity of water exists. However, Doab area of Punjab is a water rich region, and as a result generally farmers do not care about water use efficiency. While the electricity prices could motivate farmers to use water more efficiently, this is also available free of cost. Farmers do not have any special incentive to use electricity more efficiently as it won't help them cut down the cost of irrigation. But, in the case of shared irrigation systems (tube wells), the amount of water farmers are entitled to use in a season is limited.

Hence, ideally, they should have incentive to allocate their water for uses that yield higher returns, and as a result should obtain higher water productivity in crop production.

Figure 7 shows the difference in productivity of water for different crops between the two categories of farmers. It shows that there is no big difference between the water productivity of rice under both the systems. It is because of the natural tendency of farmer to keep the rice field submerged so that land does not get dried and risk with respect to loss in crop yield can be minimized. But for other crops, difference in water productivity figures between individual farmers and shareholders is significant. It shows the efficient utilization of water under the shared irrigation. These results were expected as under resource constraints, careful and judicious usage is resorted to. In this case, as the share holders get limited water, he/she plans irrigation schedules properly and provides only optimum dosage. Therefore, per unit return on water applied is higher in case of shared irrigation system.

Figure 6: Crop Water Productivity under different Irrigation Systems



5.6 Leasing of Land

There is a common trend in the area of leasing in or out the land because of many reasons. Some of the prominent reasons being: migration1[5] ; demise of the kin; and, outstation posting or government service. With the leasing of land in the shared system command, a farmer's entitlement for water also goes to the person who takes the land on lease. The rates of leasing out vary greatly, depending on whether the rights to use water from the well also get transferred or not. The lease charges may range from Rs. 16,000 to Rs. 17,000 per acre per annum. There were one or two cases where we found leasing out of land without rights to use water from the well. The rates in those cases were about Rs. 9000-1000/acre/annum.

In case of shared tube well systems, about 70% of the cases were of leasing of the land within the family i.e., between two brothers. As demonstrated earlier, if the lease out is to one's own brother, the person gets two consecutive turns. Whereas if the land is leased out to an outsider, the irrigation schedule for the kinship partners remain un-altered.

5.7 Mechanization

Mechanization is an important feature of Punjab's agriculture. Historically Punjab has been a region where modern agricultural practices have been followed; same is evident by proactive role and participation of

[5] Migration is very common in this region and because of that, the person migrating generally leases out his land to either his own brother or third party in the village itself. Earlier, people from the region used to migrate to Canada and USA but now they have started migrating to France, Britain and Spain. Also with the price of the land sky-rocketing, people do not sell off their land and therefore "land leasing" phenomena is on the rise.

the region in making green revolution a big success in India. Farmers in this region (mainly Doab region) are progressive, and with the support of Agricultural Universities, they have been able to achieve commendable crop yields and returns. These are clearly visible in the living standards of the inhabitants of the region.

In general, subsistence agriculture is characterised by low level of use of modern equipments or machinery and opposite is true for the commercial farming. In that respect, anything "shared" means a compulsive arrangement where the shareholders are seen to be under some kind of resource constraint, mainly financial. However, the same argument does not hold good for the members of shared well irrigation systems in Doab region. The farmers who are part of the shared irrigation system are well off and undertake all the modern agricultural practices as prescribed by Punjab Agriculture University. Concentration or usage of modern machinery is also very high. Table 3 shows the figure of farmers owning tractors and other kind of heavy agricultural machinery.

Table 3: Ownership patterns of farm equipments in both shared and individual systems

Particulars	Shared Wells	Individual Wells
Tractor owned	62.70	96.29
Tiller owned	64.32	98.76
Harvester	19.45	19.75

Source: Authors' own estimates based on primary data

As Table 3 shows, there is a significant difference in the percentage of farmers owning tractors and tillers falling under shared and individual irrigation systems. Although, figures of shared are relatively low, but these are higher in comparison of other states. This arrangement provides a clear indication that shared well irrigation is no where associated with subsistence agriculture, but is equally commercial like. The difference in ownership can be due to the smaller land holdings in case of farmers under shared irrigation systems. Those farmers, who do not own the farm machinery, rent or borrow them in to do the agricultural operations.

6. FINDINGS

1. In shared irrigation systems, farmers have greater motivation to grow less water consuming maize and peas as compared to water-intensive rice and sugarcane found in individual systems. The percentage of farmers growing rice under shared irrigation systems was about 25 as compared to 60 in the case of individual wells.

2. The income returns from unit area of the crop were slightly higher for farmers with individual irrigation systems. Such differences could be attributed to the higher yield these farmers get and the lesser cost they incur for irrigation.

3. Water productivity figures for all the major crops were higher for shared irrigation systems than that of individual systems. Overall, water productivity was higher for potato, peas, maize and sugarcane across the board. Though there wasn't much difference in water productivity of rice, in the case of wheat the difference was major. It was Rs.5.3/m^3 in shared systems, as against Rs.1.4/m^3 in individual systems. For maize, it was Rs. 8.36/m^3 in shared systems as against Rs. 4.89/m^3 in individual systems. This is in spite of the lower net returns from land, indicating lower dosage of irrigation water. Also, in the case of other crops viz., potato, peas, sugarcane it was higher in shared systems, though the differences were marginal. This improvement in productivity comes from careful and judicious use of irrigation water.

4. The farmers under shared irrigation systems tend to grow crops that give higher water productivity such as potato, peas and maize, and avoid crops that yield very low returns from every unit of water used. Hence, it could be inferred that these farmers secure much higher water productivity in rupee terms as

compared to individual well owners. Thus, under a regime of volumetric rationing of water, farmers maximize their returns from every unit of water used rather than land through careful use of irrigation water for a particular crop and careful selection of crops that give higher returns (in rupee terms) from every unit of water. Also, the limited access to water which the shareholders have, do not seem to have any impact on farm mechanization and land leasing.

5. Under shared irrigation systems, there is optimal use of farm machinery through renting and borrowing.

7. CONCLUSIONS

In the recent years, discussions on the management of groundwater in arid and semi arid areas have focussed on institutional interventions that influence the way groundwater would be accessed and used by the users (Kumar and Singh, 2001; Kumar, 2007; Shah et al., 1998). Enforcement of tradable property rights in groundwater is one of them, the others being community based management of groundwater (Shah et al., 1998) and cooperative management (Singh, 1995). This marks a major departure from quick fix solutions to deal with groundwater over-draft such as water harvesting and artificial recharge of aquifers. It is being argued that enforcement of tradable property rights in groundwater would promote efficient water markets, raise the price of water in the markets, and encourage farmers to use water more efficiently in their fields, and transfer the saved water to economically more efficient uses (Kumar and Singh, 2001; Kumar, 2007). There is hardly any empirical evidence available from within India on the outcomes of introducing water rights.

At the operational level, the shareholder irrigation systems in Punjab are identical to a crude form of groundwater rights, wherein the individual farmer's "entitlement" for well water are allocated in terms of number of days for which wells can be run, and also schedules pre-determined. Also, these rights to use "water" can also be leased out. Hence, these entitlements can be treated as tradable. Another important feature of this arrangement existing in the shareholder irrigation system is that amount of water which the farmer can access groundwater through the well is rationed by restricted power supply, given the high cost of obtaining diesel generators. Hence, they are analogous to tradable water rights, with rationing. Hence, the learning from such a study can be used to draw inference on the potential outcomes of instituting water rights in groundwater. The study shows that under such conditions, the farmers have high motivation to allocate more water to crops that are economically more efficient, and also use it more efficiently for the chosen crops than the farmers who have unrestricted access to groundwater by virtue of having wells under individual ownership. They generate greater returns from every unit of water used, without compromising on the prospects of farming.

That said, one needs to see whether the learning drawn from Punjab study can be extended to other semi arid regions of India. For that we need to understand the groundwater socio-ecology in other dry regions as against Punjab. In Punjab, owing to the good resource endowment and the good economic conditions of the farmers, access equity in groundwater is good. Due to this reason, the extent of water trading is extremely limited. Whereas in other semi arid and arid regions such as north Gujarat, north Karnataka, western Rajasthan and parts of Andhra Pradesh, Madhya Pradesh and Tamil Nadu, groundwater is really scarce, and the equity in access to the resource is very poor (Kumar, 2007). With the introduction of water rights, many farmers who were earlier having unlimited access to the resource would have to manage with limited rights due to re-distribution of rights. This would increase the need for water trading, thereby increasing the price of water in the market. For the water using well owner, this would indicate the opportunity cost of using it, and therefore he/she would have stronger incentive to enhance the productivity of water use to get returns higher than the market price of water. Hence, we can conclude that in semi arid and arid areas, establishing water rights in volumetric terms with due consideration to safe yield of the aquifer under consideration, and enforcing it would help promote efficiency and sustainability in groundwater use. This might eventually result in large-scale shift from cereals that give low returns per unit of water to high valued cash crops. This can create problems of and regional food security and rural employment depending on the type of crop which replaces the traditional ones.

But, the opportunities for such crop shifts and the extent of real shift in cropping pattern would depend on the agro-ecology of the region in question. For instance, sweet lime orchards were common in Nalgonda district for quite some time. But, with drip irrigation becoming very popular and the heavy subsidy made available from the government in the recent years, the area under orchards had also increased remarkably. Paddy has been the major traditional crop in the region prior to large-scale introduction of orchards. But, in spite of the fact that sweet lime gives much higher returns as compared to paddy, farmers still grow the wet land paddy though in slightly smaller area. This is because the land used for paddy cultivation (low-lying wetlands) is not suitable for cultivation of sweet lime. Hence, the impact of expansion in area under orchard on cereal production and local food security is almost negligible, and this growth has mainly comes at a cost of traditional rain-fed pulses such as gram. Here, the limited opportunities for farmers to divert the water to more efficient uses would also reduce the monopoly price of water in the market.

Hence, the concerns being raised by researchers about the impact of water trading are equity, access to water for basic survival and food security (Rosegrant and Ringler, 1998) become real only when there is large-scale transfer of water from rural areas to urban areas. But, it is important to keep in mind that such transfers take place during droughts when urban areas face water shortages. At these times, rural areas also face shortage of water to produce sufficient food. Hence, it would give opportunities for all segments of the farming community to earn good income from sale of water to urban areas, by which they could take care of their cash needs to purchase food. Hence, the negative effect will be on those in villages, who do not have access to land and water resources, but depend on farm labour. The effects would be lack of water for drinking and domestic uses within rural areas. This leads us to the need for allocating water rights also to those who do not have land. But, more important than creating water rights are the institutional structures for enforcing it. Future research on evolving institutional structures for enforcing water rights in arid and semi arid regions that are embedded in the specific groundwater socio-ecology of the regions is needed.

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FACTORS INFLUENCING FARMERS' WILLINGNESS TO PROTECT GROUNDWATER FROM NONPOINT SOURCES OF POLLUTION IN THE LOWER BHAVANI RIVER BASIN, TAMIL NADU

Sacchidananda Mukherjee[1]

Abstract

Pollution abatement strategies in India and other developing countries have given priority to point sources of pollution. However, it is increasingly evident that improvement of quality of surface and ground water will also require control of pollution from nonpoint sources (NPS). NPS pollution control is particularly crucial in rural areas where groundwater is an important source of drinking water. If pollution continues unabated it could pose serious risks not only for current generations but also for future generations to meet demand for safe drinking water at a reasonable cost. Regulatory approaches are not suitable to control pollution from NPS. Voluntary approach like collective action to adopt agricultural best management practices by the farmers could be a long-term solution within the existing institutional structure. Farmers' perceptions about groundwater and drinking water quality are important, which influence their willingness to adopt protection measures either individually or collectively. This study attempts to capture the factors influencing farmers' perceptions and their willingness to protect groundwater, and their willingness to support the local government to supply drinking water through alternative arrangements. Six villages are identified in the Lower Bhavani River Basin, Tamil Nadu, on the basis of their long-term groundwater nitrate concentrations and sources of irrigation. A pre-structured questionnaire survey (face-to-face interviews) has been administered to 395 farm-households across six villages during June-July, 2006. Results show that farmers' perceptions of risks related to groundwater nitrate pollution vary across the villages, and mimic the actual groundwater nitrate situation. Estimated results of binary choice Probit models show that farmers from comparatively high groundwater nitrate contaminated villages are willing to protect groundwater as compared to farmers from less affected villages. Demand for safe drinking water varies across the villages, based on the variations of socio-economic characteristics of the sample households and groundwater quality of the villages.

1. INTRODUCTION

Pollution abatement strategies in India and other developing countries have given priority to point sources of pollution. However, it is evident that improvement of quality of surface and ground water will also require the control of pollution from nonpoint sources (NPS). NPS pollution control is particularly crucial in rural areas where groundwater is an important source of drinking water. In several parts of India, growing access to irrigation facilities along with unbalanced and overuse of nitrogenous fertilisers, unlined and open storage of livestock wastes, and open defecation and urination has led to high concentration of nitrate in the groundwater. There is limited information on the level of pesticide contamination of water sources. However, there is substantial secondary information on the level of nitrate in surface as well as ground water.

Consumption of nitrate contaminated drinking water poses various short and long term health hazards to various age groups (Fewtrell, 2004; WHO, 2004). WHO has recommended that water used for drinking should have a nitrate (NO_3) concentration less than 50 milligram per liter (mg/l) (WHO, 2004). In India drinking water having nitrate levels greater than 100 mg/l are considered to be harmful to human health (ISI, 1991). Sustainability of safe sources of drinking water is a major challenge that developing countries like India are

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facing today. In India, a large section of the rural population still does not have access to safe drinking water. If the pollution from nonpoint sources continues unabated it could pose serious health risks not only for the current generations but also for future generations.

1.1 Environmental Sustainability of Sources of Drinking Water

One of the targets of the United Nations' Millennium Development Goals (MDGs) is to "halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation" (Target 10 of MDGs).[2] Pollution from nonpoint sources (NPS) makes groundwater resources unsuitable for drinking. Thus environmental sustainability of safe sources of drinking water for future generations is at stake.

Environmental and natural resources conservation from quantitative depletion and qualitative degradation, should be an integral part of any economic and development policy, which is also one of the targets of United Nations' Millennium Development Goals (Target 9).

Due to large number of sources and diffused entry points, it is technically difficult and financially infeasible to monitor the contribution of individual nonpoint sources to the ambient concentration (Dosi and Zeitouni, 2001). Though monitoring and taking regulatory measures to protect groundwater is the responsibility of the Pollution Control Boards (Trivedy, 2000), there is no legal provision to regulate individual polluters. As a result, pollution control of nonpoint sources is mostly neglected in India. Although several attempts have been made to control pollution from point sources, there is no substantial improvement in the quality of surface and ground water resources (Maria, 2003). Both qualitative and quantitative aspects of protection of drinking water sources need to be addressed to meet the drinking water needs of the people. Major challenges that rural water supply sector in India is facing today are not only to meet the large investment requirement to augment the water supply, but also additional investment burden to tackle the water quality related problems. Achieving equity and greater access to safe drinking water for a large section of the populace will remain a distant dream, if we cannot protect our drinking water sources from all possible sources of pollution. Since groundwater serves as a decentralised source of drinking water in rural areas, the rural population become vulnerable to various water-borne diseases when groundwater is polluted. And it is mostly the poor and marginal section of the population who suffer the most, as they cannot afford to protect themselves from the impacts of pollution.

Access to safe drinking water is vital for human well-being (UNDP, 2006). People exposed to polluted drinking water are vulnerable to various water borne diseases. Costs associated with mortality and morbidity of water-borne diseases are high. For example in India water borne diseases annually put a burden of USD 3.1 to 8.3 million in 1992 prices (Brandon and Hommann, 1995).

The Comptroller and Auditor General of India (2000) reports that about 10% of water sources in the state of Tamil Nadu are not potable due to excessive nitrate. The nitrate-affected belt is mainly in the western districts of Tamil Nadu. Foster and Garduño (2004) reported elevated concentration of nitrate in drinking water wells during dry season at numerous locations in Tamil Nadu. In Coimbatore and Dharmapuri districts of western zone, more than 20% of drinking water wells had nitrate concentration greater than 50 mg/l and in large number of wells nitrate concentration exceeded 100 mg/l. They attributed infiltration or leaching of nitrate from human and animal excreta as the major cause of groundwater nitrate in those areas. Controlling pollution from nonpoint sources will be the first step towards sustainable access to safe drinking water in rural areas. In this study, we use the Lower Bhavani River Basin in Tamil Nadu as a case study of nonpoint source pollution.

1.2 Nitrate Pollution in the Lower Bhavani River Basin, Tamil Nadu

The Bhavani river is the second largest perennial river of Tamil Nadu, and one of the most important tributaries of the Cauvery river. The Bhavanisagar Reservoir, the Bhavani river and three diversions from the river, viz., Arakkankottai, Thadapalli and Kalingarayan canals (known as the old system) and a canal from the reservoir known as the Lower Bhavani Project (LBP) canal, form the Lower Bhavani River Basin in Tamil Nadu (see

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[2] http://www.un.org/millenniumgoals/ – accessed on July 15, 2006.

Location Map in Appendix A). The Lower Bhavani River Basin is an extensively irrigated area, and farmers apply nitrogenous fertilisers way above the doses recommended by the Tamil Nadu Agricultural University (Shanmugam and Mukherjee, 2004). As a result high concentration of nitrate has been reported both in shallow and deep aquifers. Andamuthu and Subburam (1994) reported that on an average 36.43% of the groundwater samples in the LBP main canal command area had nitrate concentration more than the maximum limit of 45 mg/l fixed by the WHO in 1984. They attributed this to the usage of commercial fertilisers and high concentration of nitrate in the LBP canal water as the major source. Secondary data on groundwater quality indicates that the level of nitrates in the groundwater is high (> 100 mg/liter) in many pockets of Coimbatore and Erode districts of Tamil Nadu in which the basin is located. Due to growing incidence of groundwater nitrate concentration in the basin, the environmental sustainability of safe drinking water sources is at stake. In some instances the public water supply authority has provided drinking water from alternative sources to nitrate affected rural habitations.[2] However, a large section of the society is still dependent on decentralised drinking water systems and exposed to high nitrate contaminated drinking water. It is expected that drinking nitrate-contaminated water may have various short and long term health impacts. However, due to inadequate secondary health information it cannot be confirmed.

Community participation in environmental conservation is a new area of research and it is in this regard that this study attempts to capture the following factors:

(a) farmers' perceptions about groundwater and drinking water quality,

(b) farmers' willingness to protect groundwater quality, and

(c) farmers' willingness to support local government to supply safe drinking water (demand for safe drinking water).

2. NONPOINT SOURCE POLLUTION CONTROL OPTIONS

It is not possible to use regulatory instruments (command and control approaches, standard and charges approaches) to control NPS pollution due to the large number of sources and diffuse entry points (Dosi and Zeitouni, 2001; Shortle and Horan, 2002; Shortle and Abler, 1997). It is also difficult to monitor discharges by individuals at a reasonable cost. In the case of groundwater, there is also the problem of accumulation of pollutants over time. Economic instruments like nitrogen and pesticide taxes are not feasible in the Indian context at this time, although they have been used in some European countries (Zeijts and Westhoek, 2004 and Rougoor et al., 2001). In India, nitrogenous fertilisers have been subsidised to encourage use by farmers. This has led to overuse of fertilisers by farmers and the consequent problem of nitrate pollution of the groundwater (NAAS, 2005). Proper pricing of fertilisers may lead to more careful use (Chelliah et al., 2007). Voluntary approach like collective action to adopt best management practices (BMPs) by the farmers may be a long-term solution to control NPS groundwater pollution. Collective action is needed to ensure that restraint in the use of fertilisers is practised by all the farmers in a particular village or area.

3. LITERATURE REVIEW

Contingent valuation studies focused on either estimation of benefits of groundwater quality protection as a source of drinking water in general,[3] or estimation of benefits of reduction of nitrate in groundwater in particular[4] are mostly concerned with the amount that the beneficiaries are willing to pay to protect groundwater from nonpoint sources of pollution rather on the factors influencing their contingent behaviour.

Studies conducted by Napier and Brown (1993), Elnagheeb et al. (1995) and Nielson et al. (2003) give importance to the factors which influence either willingness to pay or willingness to protect groundwater quality from NPS pollution.

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[3] Mostly from the deep aquifers fitted with power pumps, mini power pumps and/or bringing water from the Bhavani River either directly or indirectly from infiltration wells. Dual water supply systems are also in operation in some regions.

Napier and Brown (1993) report that farmers who believe that pesticides and fertilisers in groundwater pose a threat to family health tend to perceive that groundwater pollution is an important environmental issue. The farmers are also more willing to force land operators to adopt groundwater protection practices. Authors argue that farm structure factors are less useful as compared to social learning factors in predicting attitudes toward groundwater protection.

Elnagheeb et al. (1995) studied the Georgia farmers' perceptions of groundwater pollution and their preferences for actions to protect groundwater. Results show that farmers who got more information from external sources (such as universities, agricultural extension agents, and TV) were more supportive of regulatory policies on fertilisers and pesticides. Authors report that farmers' knowledge about environmental impacts of agricultural practices of their own farm is poor and farmers act to guard their self-interest. If the farmers perceive that changes in practices to protect groundwater quality would lower net farm income, they become reluctant to support such a policy. If the adoption of practices to protect groundwater involves high costs, farmers who are under financial stress or debt become reluctant. Farmers who use their own well water for drinking and not sure about the safety and purity of the well water are more supportive. If the farmers perceive any risk from water consumption, they become supportive to adopt practices to protect groundwater.

Nielson et al. (2003) argue that knowledge of socio-demographic factors affecting attitudes and perceptions of risk is an important instrument in enhancing efficiencies of interventions. They found that socio-demographic factors like gender, education, place of residence and age influence individual's attitude to an environmental issue (securing future drinking water) and the extent to which individuals are willing to allocate present resources to alleviate a future problem.

Bergstrom et al. (2001), Boyle et al. (1994), and Poe and Bishop (2001) argue that in the absence of objective information, people form subjective perceptions about their water quality. Subjective perceptions of water quality are influenced by socio-economic background of the people and their access to general and specific information on water quality. General Information (GI) specific to groundwater nitrate contamination can be defined as the information related to sources of nitrates in groundwater, government standards, opportunities for mitigation, and the costs of adoption of those mitigation measures etc. Information that is specific to household's exposure to groundwater nitrate pollution - e.g., nitrate levels found in an individual's well or overall groundwater quality of the village - can be defined as Specific Information (SI). Based on socio-economic characteristics, and access to information, both general and specific information on water quality helps the households to draw a subjective assessment about water quality which mostly influences their willingness to adopt protection measures either individually (point of use purification of water) or collectively (protection of drinking water sources or willingness to support local government to set up community water treatment plant).

Ready and Henken (1999) demonstrate that a well owner's optimal self-protection from nitrate contaminated groundwater is subject to his/her subjective probability risk perceptions that the well is contaminated, which is supported by regular well test results. They show that in Kentucky, USA optimal self-protection could reduce a well owner's expected damage from nitrate contamination by 38%.

Bosch and Pease (2000) argue that producer's and consumer's risk perceptions and preferences can affect perceived costs and benefits of adoption of water quality protection measures. Uncertainty about pollution damages to water resources is likely to increase the perceived benefits of a given quantity of water quality protection practices. Public policies to reduce uncertainty about the costs and benefits of water quality protection practices may produce net social benefits.

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[4] For example, see Bergstrom and Dorfman, 1994; Caudill and Hoehn, 1992; Jordan and Elnagheeb, 1993; McClelland et al., 1992; Powell et al., 1994; Schultz and Lindsey, 1990; Sun et al., 1992; Stenger and Willinger, 1998; Lichtenberg and Zimmerman, 1999; and Boyle et al., 1994.

[5] For example, see Crutchfield et al., 1997; Edwards, 1988; Poe, 1998; Poe and Bishop, 1999; 2001; Epp and Delavan, 2001; Walker and Hoehn, 1990; Hanley, 1989.

Successful risk assessment and risk communications to the stakeholders is important to induce them to adopt measures to protect groundwater quality. Fessenden-Raden et al. (1987) argue that risk communication is neither simply one-way transfer of information nor it is a single or discrete event, but a process involving interactions over time between senders and receivers of information about a risk (vulnerability). Taking account of socio-economic characteristics, concerns and priorities of the information recipients are important aspects towards successful risk communication.

How effective provision of scientific information related to groundwater quality (laboratory water test results) could be to make farmers understand the prevailing groundwater quality situation in the sample villages – is a serious question. It is difficult for individual farmers to understand the scientific information related to nitrate concentration in their drinking water, due to lack of education, environmental awareness and also due to the fact that presence of nitrate does not change any perceptible characteristics of drinking water, like taste, colour, odour etc. On the contrary, testing of individual well for possible nitrate contamination and intimation of test results during questionnaire survey will not reveal the actual groundwater quality scenario prevailing in the village, as groundwater quality is dynamic process which varies over time and space. Therefore, instead of providing sample household specific nitrate concentration in drinking water we have provided general groundwater nitrate situation prevailing in the basin along with the sources of groundwater nitrate pollution and possible health hazards of consuming high nitrate contaminated drinking water.

4. CONCEPTUAL FRAMEWORK

Researchers argue that unless farmers foresee any positive distinctive private economic benefits in the adoption of environmentally benign agricultural practices, they will not adopt any of those practices to protect resources (groundwater) which is mostly under open access regime. Unlike other natural resources which fall under local common pool resources (like forestry, fisheries, grazing land, and irrigation water), private benefits of protecting groundwater are not distinct and cannot be parceled out to individuals involved in conservation. Since in India, groundwater falls mostly under free access regime and some of the services it provides have characteristics of a public good, farmers will not incur any private costs to ensure public benefits (safe drinking water).

Unlike in developed countries where small number of farmers having large land holding size and homogeneous cropping pattern, in developing countries like India, a large number of farmers having small land holding size and heterogenous cropping pattern dominate. In developed countries farmers are provided with economic incentives (conservation reserve program, countryside stewardship program etc.) to protect groundwater for comparatively large urban and semi-urban consumers. Therefore, polluter and victim (consumer) difference is distinct in developed countries and consumers' willingness to pay is often studied instead of polluters willing to pay (incur costs) to protect groundwater from farming activities. But in India, the difference between polluter and victim (consumer) is not clear, as the polluters (farmers) themselves are victims (consumers of groundwater). Therefore, we have treated individual farmers as consumer and not as producer and have studied their willingness to pay (incur costs) in terms of adoption of BMPs to protect groundwater. Our argument is that farmers will adopt environmentally benign farm practices to protect groundwater provided they perceive that their groundwater and drinking water is polluted and that could pose health hazards or risk to his/her own and family members. Farmers perceptions about groundwater and drinking water quality and possible health hazards are important which could influence their willingness to adopt measures to protect themselves individually (point of use purification) or collectively (groundwater protection or community water treatment plant).

Firstly, following Elnagheeb et al. (1995), Napier and Brown (1993) and Nielsen et al., (2003), factors influencing farmers' perceptions about groundwater and drinking water quality have been captured. In the second stage factors influencing the farmers' willingness to protect groundwater quality and willingness to support local government to supply safe drinking water have been captured through binary choice Probit models (Greene, 2003; Long, 1997). The underlying conceptual framework is as follows:

Following Hanemann's (1984) random utility framework, individual j's utility function can be written as:

$$U_j = U_j(Q_j, Y_j \mid H_j)$$

where

$U_j(.)$: utility function of j^{th} household
Q_j : groundwater / drinking water quality of j^{th} household
Y_j : income of j^{th} household
H_j : socio-economic characteristics of j^{th} household

Since the above utility function is unobservable to us, we estimate it as follows:

$$V_j = V_j(Q_j, Y_j \mid H_j) + \varepsilon_j$$

where, e is the error term, and e~N(0,1)

Following Boyle et al., 1994 and Bergstrom et al., 2001, individual j's estimated utility function can be written as:

$$V_j(Q_j(GI_j, SI_j), Y_j \mid H_j) + \varepsilon_j$$

$$V_j(Q_j^1(GP_j^1, SP_j^1), Y_j \mid H_j) + \varepsilon_j^1 \text{ and } V_j(Q_j^0(GP_j^0, SP_j^0), Y_j \mid H_j) + \varepsilon_j^0$$

where

$V_j(.)$: estimated utility function of j^{th} household

$Q_j(.)$: in absence of actual (objective) groundwater /drinking water quality information, j^{th} household forms a *subjective perceptions* about its water quality based on the access to *specific* and *general information*

GI_j: *general information* of j^{th} household

SI_j: *specific information* of j^{th} household

General Information (GI) are related to possible health effects and sources of nitrates in groundwater, government standards, opportunities for mitigation, costs of mitigation etc.

Specific Information (SI) are specific to household's exposure to groundwater nitrate pollution, includes nitrate levels found in an individual's well or overall groundwater quality of the village.

$Q_j^1 = Q_j^1(GI_j^1, SI_j^1)$ is j^{th} household's *subjective perceptions* about groundwater/ drinking water quality when it takes mitigation measures or adopts environmentally benign agricultural practices to protect groundwater quality

$Q_j^0 = Q_j^0(GI_j^0, SI_j^0)$ is j^{th} household's *subjective perceptions* about groundwater/ drinking water quality when it does not take mitigation measures or adopt environmentally benign agricultural practices to protect groundwater quality.

The probability that whether j[th] household will adopt agricultural practices or mitigation measures to protect groundwater quality or whether it will support local government to supply drinking water from alternative safe sources, can be written as:

$$\begin{aligned} Prob(Yes = 1) &= Prob(V_j(Q_j^1(GI_j^1, SI_j^1), Y_j - OP_j \mid H_j) + \varepsilon_j^1 \geq V_j(Q_j^0(GI_j^0, SI_j^0), Y_j \mid H_j) + \varepsilon_j^0) \\ &= Prob(\varepsilon_j^0 - \varepsilon_j^1 \leq (V_j(Q_j^1(GI_j^1, SI_j^1), Y_j - OP_j \mid H_j) - V_j(Q_j^0(GI_j^0, SI_j^0), Y_j \mid H_j)) \\ &= Prob(\eta_j \leq \Delta V_j) = \Phi_\eta(\Delta V_j) \end{aligned} \quad (2)$$

where $\eta_j = \varepsilon_j^0 - \varepsilon_j^1$ and e_js are iid, e_j~N(0,1)

Öh(.) is the standard normal cumulative density function of h

Where V = k(GI, SI, Y, H) for all j, and we estimate function k(.) through binary choice Probit and multinomial logit models.

OP_j represents individual j's cost of adoption of measures which could reduce the probability of groundwater contamination (e.g., agricultural practices to protect groundwater quality) and/or costs of averting practices (point-of-use purification or contribution to local government to supply water from alternative safe sources) or costs of mitigation of exposures to polluted groundwater e.g., costs of regular community monitoring of groundwater quality.

Prob (Yes) represents the probability that individual household will adopt - (a) measures to protect groundwater quality; (b) mitigation measures in terms of taking up regular monitoring of groundwater quality (individual or community monitoring); (c) averting practices such as installing individual home water filter; and/ or (d) support local government to supply water from alternative sources or setting up community water treatment plant.

5. METHODOLOGY AND DATA SOURCES

This study is based on both primary and secondary information collected from various sources.

5.1 Secondary Sources of Information

To understand the spatial, temporal and seasonal variations of groundwater nitrate concentration in the Lower Bhavani River Basin, secondary groundwater quality information (time series and cross section) have been collected from the Tamil Nadu Water Supply and Drainage (TWAD) Board, Chennai and analysed to identify "Nitrate Hot Spots" in the Basin. Information related to drinking water sources and access to drinking water was collected from the Rural Water Supply Division of the TWAD Board, Erode. Population and other demographic details were collected from the Regional Census office at Chennai.

5.2 Primary Household Questionnaire Survey

5.2.1 Characteristics of the Sample Villages

To capture the spatial variations across the basin, we have selected six villages on the basis of their sources of irrigation and long-term groundwater nitrate concentration. Among the 6 villages two are from the LBP command area – Elathur (ELA) at the head reach of the LBP canal and Kalingiam (KAL) at the middle reach of the LBP canal, two are from the old system – Kondayampalayam (KDP) depends on Arrakankottai canal for irrigation and Appakoodal (APP) depends on the Bhavani river for irrigation and two are from rain fed and groundwater irrigated are – Madampalayam (MDP) and Kembanickenpalayam (KNP) (**Location Map** in **Appendix A**). Apart from surface water sources, groundwater is also used extensively for irrigation in the study villages.

Apart from the sources of irrigation, villages differ with respect to their level of urbanisation and socio-economic status. Appakoodal, Elathur and Kembanickenpalayam are Town Panchayats (TP) and Kalingiam, Kondayampalayam and Madampalayam are Village Panchayats (VP). Out of six sample villages from three irrigation systems – old system, new system and rain fed area - one TP and one VP falls under each of the system (Table 1).

Appakoodal (APP), Kembanickenpalayam (KNP) and Madampalayam (MDP) are highly polluted with more than 50% of the regular observation wells' samples taken by TWAD Board during May 1991 to May 2005 having NO_3 concentration more than 50 mg/l. Elathur (ELA), Kalingiam (KAL) and Kondayampalayam (KDP) were moderately affected with less than 25% of the regular observation wells' samples have NO_3 concentration more than 50 mg/l (Table 1).

Table 1: Groundwater Nitrate Pollution in the Study Villages

Name of the Sample Location	Source(s) of Irrigation	NO_3 Concentration (in mg/l)		% of observation having NO_3 Concentration	
		Average	Range	>50 mg/l	> 100 mg/l
Kembanickenpalayam (KNP) (Town Panchayat)	Small dam, groundwater (open wells and bore wells) & river pumping	47.9	0 – 106	50.0	4.5
Madampalayam (MDP) (Village Panchayat)	Mostly rain fed and ground-water (open wells and deep bore wells)	128.7	0 – 320	77.3	54.5
Elathur (ELA) (Town Panchayat)	The Lower Bhavani Project (LBP) canal and groundwater (open wells and deep bore wells)	34.5	1 – 120	23.1	11.5
Kalingiam (KAL) (Village Panchayat)	The LBP canal and ground-water (open wells and deep bore wells)	24.3	0 – 134	13.0	4.3
Kondayampalayam (KDP) (Village Panchayat)	The Arakkankottai canal and groundwater (open wells and deep bore wells)	49.7	2.7 - 115	44.0	4.0
Appakoodal (APP) (Town Panchayat)	The Bhavani River and groundwater (open wells and deep bore wells)	50.0	10 – 105	53.8	3.8

Source: Census of India 2001; TWAD Board, Chennai and Primary Survey

5.2.2 Sampling Criteria

A pre-structured questionnaire survey was administered to 395 farm households spread across the six villages in the basin during June to July 2006. The survey involves collection of both quantitative and qualitative information from the sample households. We followed the random sampling procedure to select the sample households from the nitrate-affected villages. Since stratification requires at least any one of the criteria - background nitrate concentration of drinking water of individual households, income of the households, land holding size etc., which are absent at present at the household level from the secondary sources.

On an average 60 farm households were selected randomly from each of the six villages on the basis of their availability of own agricultural land and interest in the subject of our research. Voluntary participations of the farm households were sought for interviews, based on their availability of time. We have conducted face-to-face interviews with the head of the farm-household. Both the information leaflet and questionnaire were translated into Tamil, and a background of the objectives, scope and coverage of this study were described before starting the interviews.

The questionnaire was designed to include both qualitative and quantitative information to capture the farmers' perceptions about groundwater and drinking water quality, factors influencing farmers' willingness to protect groundwater quality from agricultural nonpoint sources of pollution and their willingness to support local government to supply safe drinking water. Socio-economic background, sources of agricultural information/ consultation /membership in participatory social institutions, willingness to adopt Best Management Practices (BMPs), existing agricultural and farm-management practices, details of crops and chemical use, animal waste management practices and access to sewage and sanitation were collected.

5.2.3 Basic Sample Characteristics

Our sample households (395) constitute 3% of the total households (13,278) of the selected villages according to 2001 Population Census, which varies from 2.3% in Appakoodal to 6.2% in Madampalayam (Table B.1 in Appendix B). Our sample population constitute 3.4% (2.6 to 6.9) of the total population of the villages. Average family size is 4.2, which is comparatively higher than population census figures.

The sample households hold 695.01 hectare of agricultural land which is 12.4% of total agricultural land of our study villages (5592.3 hectare), which varies from 8.2% in Elathur to 25.7% in Kondayampalayam. Total cropped area as a percentage of total geographical area varies from 56% in Appakoodal to 92% in Madampalayam, with an average 69%. Average land holding is 1.8 hectare which varies from 1.2 hectare for APP to 2.6 hectare for KDP (Table B.1 in Appendix B). A list of descriptive statistics is provided in Table B.2 and Table B.3 of Appendix B.

6. BASIC FINDINGS

6.1 Secondary Data Analysis

6.1.1 Sources of Drinking Water

Deep bore wells fitted with mini power pump (MPP) and power pump (PP), serve as the major sources (> 86%) of drinking water under the centralised drinking water system across the rural habitations in the basin. Since the local panchayats are not equipped to test water quality, taking curative measures are overruled; as a result people get unmonitored and unregulated quality of drinking water. Only 12% of the habitations get drinking water from surface sources, which is comparatively safe with respect to nitrate concentration.

6.1.2 Access to Drinking Water

Access to drinking water varies significantly across the blocks in the basin. Access to 40 litre of water per person per day (lpcd) is considered as the basic minimum requirement (UNDP, 2006). A large part of the basin, the rural population still do not have access to basic minimum amount of safe drinking water. When access is meagre and quality of drinking water is unmonitored and unregulated, population becomes vulnerable to various water-borne diseases. Pollution from agricultural nonpoint sources makes it more difficult to supply safe drinking water to all the rural habitations.

6.1.3 Groundwater Nitrate Pollution in the Lower Bhavani River Basin – Status

<u>TWAD Board's Hand Pump Data: 2001-2002</u>

Out of 3,129 groundwater samples (hand pumps) tested in the Basin during 2001-2002, 1,305 samples (approximately 41.7%) had nitrate concentration greater than 50 milligram per litre (mg/l). Of which 8.9% of the samples had nitrate concentration more than 100 mg/l. Out of 12 blocks in the basin, 4 blocks had average nitrate concentration more than 50 mg/l, which shows that in several pockets of the basin groundwater (drinking water sources) are polluted.

TWAD Board's Power Pump Data: 2001-2002

Out of 1,217 groundwater samples from bore wells and open wells fitted with power pump and mini power pump, 437 samples (35.9%) had nitrate concentration more than 50 mg/l which confirms that deep aquifers is also polluted in several pockets in the basin.

TWAD Board's Regular Observation Wells Data: May 1991 to May 2005

Data analysis shows that - a) post-monsoon average nitrate concentrations are higher than pre-monsoon average concentrations, which show that nitrate leaches to the groundwater during rainy seasons and b) different blocks are affected by different level of groundwater nitrate contamination, Karamadai, Bhavanisagar and Erode blocks are highly polluted.

6.2 Primary Household Questionnaire Survey

6.2.1 Sources of Drinking Water

In study villages 27.95% (11.62% in KAL to 60.29% in KNP) of the sample households depend on their open wells to meet drinking water needs. Only 49% of the households are covered with supplied water, either through house connection (only 10.53%) or through stand posts (38.5%). Table 2 shows that 50% of our sample households depend on groundwater (shallow or deep) to meet drinking water needs. More than 82% of the households in Kembanickenpalayam depend on groundwater for their drinking water. Though it is a Town Panchayat, it cannot supply drinking water through supply network due to sparsely settled population and inadequate supply network. Since Appakoodal has its Independent Water Supply Scheme (IWSS), which draws water from the Bhavani River (1.6 million litre per day), as a result the dependence on groundwater as a source of drinking water is comparatively less, 23%. However, almost 5% of households are dependent on water tanker

Table 2: Sources of Drinking Water (in Percentage of Sample Households)[@]

Village Name	Own Hand Pump (sdwohp)	Own Power Pump (sdwohp)	Own Open Well (sdwohp)	Supply Water – House Connection (sdwohp)	Supply Water – Sand Post (sdwohp)	Public Hand Pump (sdwohp)	Community Well (sdwohp)	Water Tanker (sdwohp)	Number of Respondents (sdwohp)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Appakoodal (APP)	0.00	3.59	19.74	0.77	71.28	0.00	0.00	4.62	65
Elathur (ELA)	2.43	16.20	23.26	14.93	36.69	2.08	4.40	0.00	72
Kalingiam (KAL)	31.06	1.52	11.62	36.36	0.00	14.14	2.78	2.53	66
Kembanickenpalayam (KNP)	2.21	18.38	60.29	0.00	17.65	0.00	1.47	0.00	68
Kondayampalayam (KDP)	1.30	11.72	32.03	9.11	42.71	2.08	1.04	0.00	64
Madampalayam (MDP)	3.89	8.89	19.44	0.83	66.39	0.56	0.00	0.00	60
All Villages	**6.81**	**10.21**	**27.95**	**10.53**	**38.46**	**3.16**	**1.69**	**1.18**	**395**

Note: [@] - implies adjusted for multiple responses
Source: Primary Survey

provided by the local industry, as they are not covered under centralised drinking water network.

6.2.2 Farmers' Perceptions about Groundwater and Drinking Water Quality

Respondents were asked to rank their drinking water quality according to their perceptions. A five point Likert-type scale was constructed on the basis of five categories of perceptions, viz., very good (5), good (4), fair (3) bad (2) and very bad (1). The average drinking water quality scores with respect to the farmers' perceptions are presented in Table 3 into three categories, viz., drinking water quality of supplied water (DWQSW) - where both house connection and sand post are taken into consideration, drinking water quality of their own sources (DWQOS) - which covers own hand pump, power pump, open well; and drinking water quality of public hand pump (DWQPHP). The average score of supplied water quality is 3.9 (3.6 - 4.0), which implies that supplied water quality lies in between fair (3) to good quality (4). However in four out of six villages some farmers also reported that drinking water quality is bad (2), for example in Appakoodal – 72% and Madampalayam – 67% of the respondents though are dependent on supplied water, still their water quality satisfaction is not that much higher than the average (84 percent, Col. 6 in Table 3). Average score of own source drinking water quality varies from 2.9 to 3.9, which implies that it lies between bad (2) to good quality (4), depending on the place of residence. For example, in Kembanickenpalayam 66% of the respondents collect water from alternative sources as their own sources of drinking water are polluted (CLCTWAT). On an average 46% of the respon-

Table 3: Farmers' Perceptions about Drinking Water Quality

Village Name	Drinking Water Quality of Supplied Water (dwqsw) *	Drinking Water Quality of Own Source (dwqos)*	Drinking Water Quality of Public Hand Pump & Public Wells (dwqphp)*	Percentage of Respondents Collect Water as their Own Source(s) of Drinking Water is Polluted (clctwat)	Percentage of Respondents are Satisfied with their Drinking Water Quality (wqs)	Percentage of Respondents think their Groundwater Quality is Polluted (gwqp)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Appakoodal	3.9 (2 - 4)	2.9 (2 - 4)	—-	42	85	43
Elathur	3.8 (3 - 5)	3.2 (2 - 4)	2.5 (2 - 4)	54	81	25
Kalingiam	3.9 (2 - 4)	3.9 (2 - 5)	3.8 (3 - 4)	21	100	8
Kembanickenpalayam	3.6 (2 - 5)	3.4 (1 - 5)	3.5 (2 - 5)	66	60	44
Kondayampalayam	4.0 (3 - 5)	3.8 (2 - 4)	5.0 (5 - 5)	30	92	11
Madampalayam	3.9 (2 - 4)	3.0 (2 - 4)	—-	46	84	28
All Villages	3.9 (2 - 5)	3.4 (1 - 5)	3.3 (2 - 5)	46	84	28

Note: *-Respondents were asked to rank their drinking water quality according to their perceptions into five Likert-type scale, e.g., very good =5, good quality =4, fair=3, bad quality = 2, and very bad=1.
Figures in the parenthesis show the range for the corresponding average value
Source: Primary Survey

dents collect water, as their own drinking water sources are not potable.

Through four different questions we attempt to capture individual farmers' perceptions (subjective) about groundwater and drinking water quality. An agreement with the second question and disagreement with the other questions as shown in Table 4, show that water quality is polluted according to the farmers' perceptions. On an average 84% of the sample households are satisfied with their drinking water quality (WQS), and on an average only 28% of the sample households think that their groundwater quality is polluted (GWQP). However, in case of APP, KNP and MDP more than 40% of the sample households responded affirmatively to ground water quality being polluted. On an average 45% of the households collect water as their own source(s) of drinking water is polluted. In case of ELA, though it is moderately polluted, 54% of the sample households collect water due to water quality problem. In KNP and MDP, more than 60% of the households collect water. In APP, 43% of the sample households collect water, which goes against the actual groundwater quality perceptions as revealed to us. It is mainly due to the fact that respondents are sceptical to reveal the actual groundwater quality situation to us for the fear of intimidation from the local industry. Farmers' perceptions vary significantly across the study villages.

On an average 24% of the sample households purify water after collection for drinking and cooking purposes. In KAL only 8% and KNP 34% of the households purify water. Table 5 shows that after adjustment for multiple responses, 14% of the households boil water. However, boiling water further increase the concentration of nitrate, and is not recommended. Using plain cloth and candle type filter cannot remove nitrate

Table 4: Farmers' Perceptions about Water Quality

Criteria	APP	ELA	KAL	KNP	KDP	MDP	ALL	F-stat
Do you think groundwater quality is polluted? (GWQP) (1 if 'Yes', 0 otherwise)	0.43	0.25	0.08	0.44	0.11	0.40	0.28	9.5638*
Are you satisfied with your drinking water quality? (WQS) (1 if 'Yes', 0 otherwise)	0.85	0.81	1.00	0.60	0.92	0.88	0.84	10.2054*
Do you collect water due to quality problem of your own drinking water source? (CLCTWAT) (1 if 'Yes', 0 otherwise)	0.42	0.54	0.21	0.65	0.30	0.60	0.45	8.7589*
Do you purify/treat water after collection for drinking and cooking purposes? (PURIWATR) (1 if 'Yes', 0 otherwise)	0.18	0.26	0.08	0.34	0.27	0.28	0.24	3.2172*

Note: * - implies F-stat for mean equality test across the villages is significant at 0.01 level (2-tailed)
Source: Primary Survey

Table 5: Farmers' Water Purification Practices (in percentage of total number of sample farmers)

Methods of Water Purification	APP	ELA	KAL	KNP	KDP	MDP	ALL
Filter - Plain Cloth (Y=1, N=0)	5	12	2	11	0	7	6
Boil Water (Y=1, N=0)	10	14	4	21	25	11	14
Water Filter - Candle Type (Y=1, N=0)	3	0	2	1	2	11	3
Water Filter - Others (Y=1, N=0)	0	0	0	1	0	0	0
Chemical Treatment (Chlorination, Camphor, Alum, Lime etc.) (Y=1, N=0)	0	0	0	0	0	0	0
No Purification (in %)	82	74	92	66	73	72	76

Source: Primary Survey

from water.
Since different agricultural practices have different implications for groundwater quality, farmer's perceptions about agricultural practices and their impacts on groundwater quality have been captured through a set of variables where the farmer's responses are categorized into four groups, i.e., agree, disagree, undecided (neither agree nor disagree) and no response. Using Principal Component Analysis method of Factor Analysis, composite indices are constructed to capture farmer's perceptions on different aspects of nonpoint source groundwater pollution (e.g., BPERCEPT, AGRIPRAC, PROENV).

7. RESULTS

7.1 Factors Influencing Farmers' Perceptions about Groundwater Quality

To understand the farmers' perceptions about groundwater water quality of their area, in primary questionnaire survey the respondents were asked to reveal their opinion for the following binary choice question:

Do you think groundwater quality is polluted? (GWQP)
GWQP = 1 if "Yes"
0 otherwise

On an average only 28 per cent of the sample households think that their groundwater quality is polluted (GWQP), which varies significantly across the villages from minimum 8 per cent in KAL to maximum 44 per cent in KNP. In case of APP, KNP and MDP more than 40 per cent of the sample households responded affirmatively for GWQP.

To understand the factors influencing farmers' subjective risk perceptions about groundwater quality (GWQP), binary choice Probit models are estimated following the econometric specification as follows:

$$\Pr ob(GWQP = 1) = \Phi(x'\beta)$$

where, Φ is the cumulative distribution function of the standard normal distribution, and

$$x'\beta = \beta_0 + \beta_1 age + \beta_2 edu + \beta_3 eap + \beta_4 bpercept + \beta_5 agriprac + \beta_6 lpclandh + \beta_7 fagr\inf o$$
$$+ \beta_8 childn + \beta_9 knowbmp + \beta_{10} proenv + \beta_{11} sdwoow + \beta_{12} sdwopp + \beta_{13} sdwshc + \beta_{14} sdwssp$$
$$+ \beta_{15} dwqos + \beta_{16} dwqphp + \beta_{17} dwqsw + \beta_{18} app + \beta_{19} knp + \beta_{20} mdp$$

The results show that apart from various socio-economic characteristics of the respondent and his/her household, the characteristics of the natural resource of our concern (groundwater) - captured through various dummy variables, e.g., sources of drinking water, drinking water quality and village dummy – significantly influence the perceptions (see Table C.1 and Table C.2 in Appendix C).

Households with larger per capita landholding (lpclandh) are more likely to perceive that their groundwater quality is polluted. Per capita land holding is a measure of household's income, which shows that higher income households perceive greater risk of groundwater pollution (gwqp). Farmers having knowledge about impacts of agricultural practices on groundwater quality (agriprac) are more likely to perceive that their groundwater quality is polluted. Farmers' knowledge about agricultural and environmental best management practices (knowbmp) positively influences their perceptions. However, farmers who have latrine, use bio-fertilisers, practice organic farming, and have biogas plants - as defined as pro-environment farmers (proenv) - are less likely to accept that their groundwater quality is polluted. Irrespective of sources of drinking water, farmers perceive that their groundwater quality is polluted. Farmers having access to better drinking water quality from either their own sources (i.e., own open well, own hand pump and own power pump) or water supply sources (house connection and stand posts) are less likely to perceive that their groundwater is polluted. Households having higher number of children, less than 5 years of age, are less likely to accept that their groundwater quality is polluted. Sample households from comparatively highly nitrate affected villages, viz., APP, KNP and MDP, are more likely to accept that their groundwater quality is polluted, the opposite is true for other villages, viz., ELA, KAL and KDP. The results show that farmers' subjective perceptions about groundwater quality mimic the actual groundwater nitrate situation of the villages.

7.2 Factors Influencing Farmers' Perceptions about Drinking Water Quality

To understand the farmers' perceptions about drinking water quality of their own sources, in primary questionnaire survey the respondents were asked to reveal their opinion for the following binary choice question:

Do you collect water due to quality problem of your own drinking water source? (CLCTWAT)

CLCTWAT = *1 if "Yes"*
0 otherwise

On an average 45 per cent of sample households collect drinking water as their own sources are polluted. The percentage varies significantly across the villages, from minimum 21 per cent in KAL to maximum 65 per cent in KNP.

To understand the factors influencing farmers' perceptions about drinking water quality of their own sources, binary choice Probit models are estimated (Table C.3 and C.4 in Appendix C). The results show that:

- Farmers' perceptions about groundwater quality positively influence their decision to collect drinking water. Collection of drinking water from alternative sources and purification of water are the major coping mechanisms adopted by the households. Farmers who purify drinking water are more likely to collect water as their own sources are polluted.
- Irrespective of sources of drinking water, farmers agree that they collect water as their own sources are polluted. Farmers who are satisfied with their own drinking water quality are less likely to collect water from alternative sources
- Households having higher number of children (less than 5 years of age) and more economically active persons are less likely to collect water. Therefore, those families are more vulnerable to groundwater pollution, as they don't collect water from alternative safe sources.
- Sample households from KNP and MDP are more likely to collect water as their own sources are polluted. In ELA, households collect water because access to safe drinking water is limited.
- Farmers from KAL and KDP are less likely to collect water, as their own source(s) of drinking water comparatively are less polluted. In APP, households collect drinking water from stand posts as their own sources are polluted; however due to fear of facing intimidation from the local industry, households are sceptical to reveal that to us.

7.3 Factors Influencing Farmers' Willingness to Protect Groundwater Quality

To capture farmers' willingness to protect groundwater from nonpoint sources of pollution, in primary questionnaire survey the respondents were asked to reveal their opinion for the following binary choice question:

Since groundwater is a major source of drinking water in this area, it should be protected from agricultural chemicals (WTPGWQ)

WTPGWQ = *1 if "Yes"*
0 otherwise

On an average 56% of the respondents revealed that they are willing to protect groundwater as a source of drinking water. Willingness to protect varies significantly across the villages, minimum 38% in KAL and KDP to maximum 78% in KNP.

To understand the factors influencing farmers' willingness to protect groundwater quality from agricultural nonpoint sources (WTPGWQ), following the theoretical model as developed in equation (2), we have estimated binary choice Probit models using the following econometric specification:

$$Prob(WTPGWQ = 1) = \Phi(x'\beta)$$

where, Φ is the cumulative distribution function of the standard normal distribution, and

$$x'\beta = \beta_0 + \beta_1 age + \beta_2 edu + \beta_3 eap + \beta_4 bpercept + \beta_5 agriprac + \beta_6 fmember + \beta_7 fagrinfo + \beta_8 app + \beta_9 knp + \beta_{10} mdp$$

The results (see Table C.5 and C.6 in Appendix C) show that:

- Farmers having better knowledge about impacts of agricultural practices on groundwater quality (agriprac) are willing to protect groundwater from nonpoint sources
- Farmers who are staying for long time in the sample villages and having larger per capita land holding are reluctant to protect groundwater quality
- Farmers' membership in participatory social institutions (e.g., Cooperative Milk Producers' Association, Farmers' Association etc.) positively influences their WTPGWQ, whereas sources of agricultural information (fagrinfo) negatively influence WTPGWQ across all the villages. However, when the model is corrected for the presence of heteroskedasticity, fagrinfo shows positive relationship with WTPGWQ for ELA, KAL and KDP.
- Farmers having knowledge about agricultural best management practices and their environmental impacts (benefits) are more likely to protect groundwater quality
- In all comparatively nitrate affected villages (APP, KNP and MDP), farmers' are willing to protect groundwater quality, whereas in other villages farmers are reluctant to protect groundwater quality.

7.4 Factors Influencing Farmers' Willingness to Support Local Government to Supply Safe Drinking Water

To capture farmers' willingness to support (WTS) local government to supply safe drinking water (demand for safe drinking water) through alternative arrangements, in primary questionnaire survey the respondents were asked to reveal their opinion for the following binary choice question:

Since you collect drinking water due to quality of your own drinking water sources are problematic, will you support local government to supply water from alternative safe sources or to set up state-of-the-art water treatment plant, by contributing, supporting and taking initiative? (WTSGOVCW)

$$WTSGOVCW = \begin{cases} 1 \text{ if Yes} \\ 0 \text{ otherwise} \end{cases}$$

The results show that on an average 38% (minimum 20% in KAL to maximum 58% in MDP) of the sample farmers are willing to support local government, which varies significantly across the sample villages.

To understand factors influencing farmers, binary choice Probit models are estimated. The results (see Table C.7 in Appendix C) show that:

- Irrespective of sources of drinking water, farmers are willing to support local government in terms of initiatives and contribution to supply safe drinking water
- Farmers having access to relatively good quality drinking water are reluctant to support the local government. Farmers' perceptions about their groundwater quality influence their WTS, and the households who purify water are also WTS.
- Households from APP, KAL and KDP are less likely to support government, as their own sources of groundwater quality are comparatively less polluted (KAL and KDP) or they already have good access to supplied water (APP).
- Households from ELA, KNP and MDP are willing to support government, as their own sources of drinking water is comparatively polluted (KNP and MDP), and they want to improve the access to supplied water (ELA).

8. CONCLUSIONS AND POLICY IMPLICATIONS

In many parts of India, intensive agricultural activities are mostly supported by excessive and unbalanced application of nitrogenous fertilisers, resulting in nonpoint source groundwater pollution. Apart from fertilisers, unlined and open storage of animal wastes and open defecation and urination has led to high concentration of nitrate in the groundwater. Protection of groundwater quality from nonpoint source pollution is crucial for sustainable access to safe drinking in rural areas. Since 90% of rural population depends on groundwater for drinking purposes, protection of groundwater will be the first step towards ensuring water security to the rural populace. Large-scale community participation is required to protect groundwater from quantitative depletion and qualitative degradation. Collective action in the adoption of agricultural best management practices is required for sustainability of safe sources of drinking water.

In India water supply authorities mostly prefer curative measures (e.g., *ex post* treatment) at a higher incremental cost of water supply from alternative safe sources as compared to precautionary measures (e.g., *ex ante* protection of drinking water sources), as a result demand for investment in infrastructure to supply drinking water to rural populace is growing astronomically. For example, Government of India (GoI)'s allocation of fund under Accelerated Rural Water Supply Programme (ARWSP) alone has gone up from Rs. 1299.91 crore in 1997-98 to Rs. 4816.66 crore in 2006-07, which shows 271% increment. GoI allocated Rs. 1039.98 crore to states during 2006-07 to tackle water quality related problems under ARWSP, which is 21.6% of total allocation of fund to states under ARWSP. According to the estimate released by the Rajiv Gandhi National Drinking Water Mission (RGNDWM) on 31st March 2004, in India 13,958 habitations are affected by drinking water nitrate pollution (RGNDWM, Personal Communication).

Unlike developed countries, developing countries like India cannot afford (technically and financially) to rely solely on curative measures; therefore it should protect drinking water sources by controlling pollution from all possible sources. Since, groundwater is a major source of drinking water, protection of groundwater quality from agricultural NPS should be an integral part of environmental management programmes to meet the demand for safe drinking water at a reasonable cost.

In the Lower Bhavani river basin in Tamilnadu, incidence of growing concentration of nitrate in the groundwater shows that environmental sustainability of safe drinking water sources is at stake. Similar situations also prevail in several other parts of India and other developing countries.

This study tries to understand (in *ex ante*) individual farmer's willingness to protect groundwater and the factors which influence his/her individual decision. This is the first step to study the possible emergence of collective action. The decision to cooperate in collective action is an individual's decision where his/her economic motives, socio-economic background and other factors play a crucial role. Apart from individual specific factors, social connectivity (social capital) and factors like information/consultation sources play a crucial role in his/her decision. The results show that:

- Farmers from comparatively high groundwater nitrate contaminated villages correctly perceive (subjective) their groundwater quality and they are willing to protect groundwater quality as compared to farmers from less affected villages. Therefore, it shows that any groundwater quality protection programme from nonpoint sources of pollution should take into consideration the site characteristics and socio-economic characteristics of the stakeholders.
- Farmers' groundwater quality perceptions vary across the villages and mimic the actual groundwater nitrate situation. Households depending on their socio-economic characteristics, social- and information-network and the characteristics of the resource (alternative sources and quality of drinking water) derive a subjective risk assessment of their groundwater quality. Regular monitoring of groundwater quality, assessment (objective) of risks of consuming contaminated groundwater and communication of risks to the stakeholders could help the farmers to take measures/initiatives either individually or collectively to protect groundwater from NPS pollution.

- Demand for safe drinking water varies across the villages, based on the variations of socio-economic characteristics of the sample households and groundwater quality. However, with reference to farmers' willingness to protect groundwater quality, their willingness to support local government shows different results. For example, farmers in Appakoodal and Kembanickenpalayam, having higher concentration of groundwater nitrate, are willing to protect groundwater quality and reluctant to support local government. However, adoption of demand driven approach for provision of drinking water may not be suitable specifically when the risk of consuming contaminated drinking water is not commonly perceived by the consumers, as the presence of nitrate does not change the taste, odour, colour or any other commonly perceivable quality/characteristics of drinking water.
- Farmers' knowledge about impacts of agricultural practices on groundwater quality significantly influences their perceptions about groundwater quality and willingness to protect groundwater. Therefore, provision of agricultural information and education along with basic agricultural extension services could induce the farmers to protect groundwater from NPS Pollution.
- Both socio-economic characteristics of the households and the characteristics of the subject (groundwater or drinking water) significantly influence the farmers' perceptions. Knowledge of agricultural BMPs and their impacts on environment positively influences farmers' perceptions and willingness.
- Farmers' perceptions about groundwater quality influence their willingness to support local government to supply safe drinking water. Irrespective of sources of drinking water, farmers are willing to support local government
- Memberships in social participatory institutions and sources of agricultural information, significantly influences farmers perceptions and willingness.

The role of stakeholders and their voluntary participation in agro-environmental management in general and water resources conservation/management in particular is a new area of research, at least for a developing country like India. The study will be useful for policy since there are many areas in India and other developing countries which are facing similar groundwater pollution problems. The issue of groundwater pollution from nonpoint sources is a growing concern not only for a relatively water scarce country like India, but also for water abundant countries around the world.

9. LIMITATIONS OF THE STUDY

The present study is based on individual's response, therefore it cannot predict with certainty what will be the collective initiative to protect groundwater quality or the adoption of agricultural BMPs

Ex ante this study cannot predict with certainty –

- What will be the actual adoption of groundwater protection measures by individuals?
- How many farmers will practically implement it and what will be the intensity of adoption? and
- What will be the actual impact of the adoption of measures on groundwater quality?

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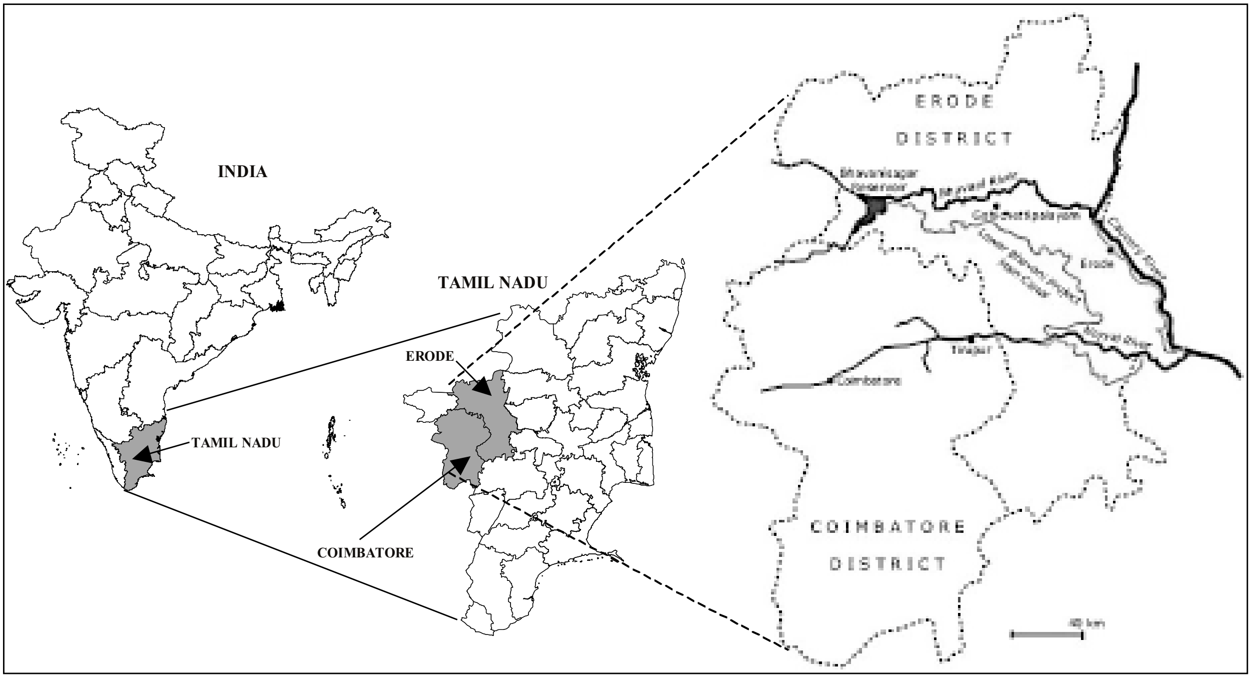
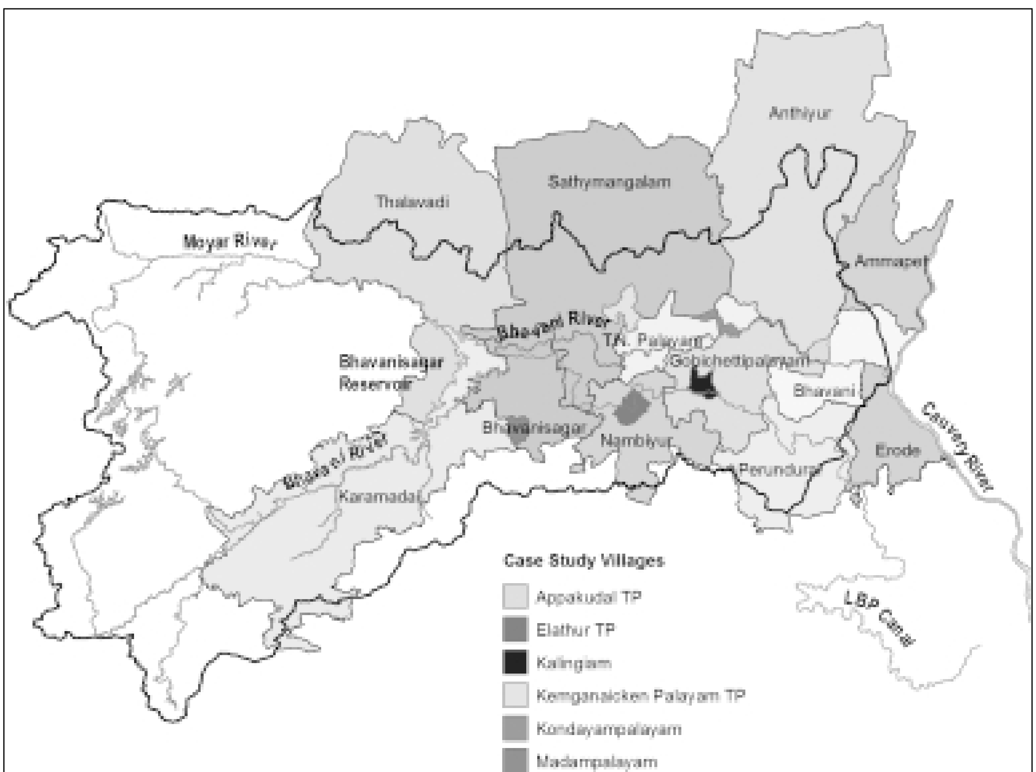
APPENDIX A

Location Map 1: The Lower Bhavani River Basin, Tamil Nadu



Location Map 2: Location of the Case Study Villages in the Lower Bhavani River Basin, Tamil Nadu



Source: GIS, TWAD Board, Chennai and Mats Lannerstad

APPENDIX C

Table C.1: Factors Influencing Farmers' Perceptions about Groundwater Quality

Dependent Variable: GWQP										
	Homoscedastic Probit Estimation				Heteroscedastic Probit Estimation					
Explanatory Variables	Coeff.	z-stat	Marg. Effect	z-stat	Coeff.	z-stat	Coeff.	z-stat	Marg. Effect	z-stat
constant	-0.5675	-1.01			-1.0724	-2.77 ***				
age	-0.0106	-1.47	-0.0030	-1.47 *	0.0043	0.83			0.0008	0.83 *
edu	0.0078	0.37	0.0022	0.37 *	-0.0011	-0.06			-0.0002	-0.06 *
eap	0.0423	0.53	0.0121	0.53 *	-0.0407	-0.64			-0.0078	-0.63 *
lpclandh	0.2282	1.93 *	0.0654	1.91 *	0.2093	3.19 ***			0.0404	3.24 ***
bpercept	0.0034	1.35	0.0010	1.36 *	0.0234	4.97 ***	-0.0136	-4.33 ***	0.0013	1.69 *
agriprac	0.0084	2.76 ***	0.0024	2.75 ***	0.0112	4.33 ***			0.0022	4.45 ***
fagrinfo	-0.0051	-2.14 **	-0.0015	-2.13 **	-0.0037	-2.02 **			-0.0007	-1.92 *
sdwoow‡	0.9358	3.13 ***	0.2805	3.11 ***	0.6913	2.71 ***			0.1437	2.27 **
sdwopp‡	1.2952	3.82 ***	0.4522	3.74 ***	1.1310	4.84 ***			0.3130	3.75 ***
sdwshc‡	0.7243	2.08 **	0.2401	1.88 *	0.4227	1.58			0.0950	1.34 *
sdwssp‡	1.1297	3.17 ***	0.3062	3.32 ***	0.6198	2.00 **			0.1165	1.94 *
dwqos	-0.3724	-4.40 ***	-0.1068	-4.48 ***	-0.3253	-4.49 ***			-0.0627	-3.58 ***
dwqphp	0.4358	3.65 ***	0.1250	3.61 ***	0.4655	5.50 ***			0.0897	4.68 ***
dwqsw	-0.2213	-2.66 ***	-0.0635	-2.61 ***	-0.1698	-2.93 ***			-0.0327	-2.63 ***
childn	*-0.5528*	*-3.74 ****	*-0.1585*	*-3.72 ****	*-0.6114*	*-5.24 ****			*-0.1179*	*-4.54 ****
knowbmp	*0.0085*	*3.49 ****	*0.0025*	*3.50 ****	*0.0126*	*4.93 ****			*0.0024*	*4.61 ****
proenv	*-0.0085*	*-3.64 ****	*-0.0024*	*-3.59 ****	*-0.0029*	*-1.50*	*-0.0198*	*-3.82 ****	*-0.0052*	*-4.94 ****
app‡	*0.7167*	*2.97 ****	*0.2393*	*2.70 ****	*0.6184*	*2.06 ***			*0.1498*	*1.68 **
knp‡	*0.9514*	*3.63 ****	*0.3256*	*3.33 ****	*0.3585*	*1.17*			*0.0792*	*1.02 **
mdp‡	*0.9328*	*3.77 ****	*0.3215*	*3.47 ****	*0.7738*	*3.21 ****			*0.1984*	*2.51 ***
Number of Obs:	*395*				*395*					
Wald chi² (df):	*99.78*	*(20) ****			*114.04*	*(20) ****	*26.43*	*(2) ****		
Pseudo R²:	*0.2717*									
Log pseudo-likelihood:	*-171.53*				*-155.06*					
Predicted Probability (at mean):			*0.2082*						0.1139	

Note: ‡- implies that marginal effect is for discrete change of dummy variable from 0 to 1
***, ** & * - implies that estimated z - stat is significant at 0.01, 0.05 and 0.10 level respectively

Table C.2: Factors Influencing Farmers' Perceptions about Groundwater Quality

Dependent Variable: GWQP										
	Homoscedastic Probit Estimation				Heteroscedastic Probit Estimation					
Explanatory Variables	Coeff.	z-stat	Marg. Effect	z-stat	Coeff.	z-stat	Coeff.	z-stat	Marg. Effect	z-stat
constant	0.653	1.18			-0.6267	-1.66 *				
age	-0.0124	-1.68 *	-0.0035	-1.68 *	0.0038	0.83			0.0007	0.85 *
edu	0.0021	0.1	0.0006	0.1 *	0.0039	0.23			0.0008	0.23 *
eap	0.0285	0.36	0.0079	0.36 *	-0.0429	-0.76			-0.0083	-0.75 *
lpclandh	0.2751	2.3 **	0.0764	2.26 **	0.2154	2.87 ***			0.0417	3.11 ***
bpercept	0.0043	1.8 *	0.0012	1.8 *	0.0242	4.92 ***	-0.0137	-4.15 ***	0.0015	2.06 **
agriprac	0.0076	2.71 ***	0.0021	2.67 ***	0.0099	4.17 ***			0.0019	4.38 ***
fagrinfo	-0.0052	-2.16 **	-0.0014	-2.15 **	-0.0039	-2.07 **			-0.0008	-2.08 **
sdwoow‡	0.8398	2.72 ***	0.2443	2.66 ***	0.7348	3.12 ***			0.154	2.69 ***
sdwopp‡	1.1438	3.27 ***	0.3908	3.04 ***	1.1382	4.67 ***			0.3164	3.77 ***
sdwshc‡	0.9959	2.45 **	0.334	2.25 **	0.4968	2.14 **			0.1148	1.8 *
sdwssp‡	1.2427	3.46 ***	0.3245	3.65 ***	0.7564	2.91 ***			0.1423	2.82 ***
dwqos	-0.3457	-3.87 ***	-0.096	-3.93 ***	-0.3277	-4.65 ***			-0.0634	-3.8 ***
dwqphp	0.4845	4.06 ***	0.1345	4.13 ***	0.4514	4.81 ***			0.0874	4.05 ***
dwqsw	-0.2953	-3.3 ***	-0.082	-3.25 ***	-0.1657	-3.12 ***			-0.0321	-2.99 ***
childn	-0.568	-3.73 ***	-0.1577	-3.76 ***	-0.6015	-5.49 ***			-0.1165	-4.97 ***
knowbmp	0.0093	3.78 ***	0.0026	3.84 ***	0.0122	4.64 ***			0.0024	4.35 ***
proenv	-0.0081	-3.35 ***	-0.0022	-3.35 ***	-0.0036	-2.23 **	-0.0196	-3.44 ***	-0.0053	-4.36 ***
ela‡	-0.5668	-2.59 **	-0.133	-3.06 ***	-0.6325	-2.92 ***			-0.0958	-3.13 ***
kal‡	-1.5751	-3.39 ***	-0.263	-6.72 ***	-0.4276	-0.83			-0.0695	-0.97 *
kdp‡	-1.222	-4.65 ***	-0.2264	-6.8 ***	-0.5488	-2.24 **			-0.0845	-2.47 **
Number of Obs:	395				395					
Wald chi² (df):	98.17	(20) ***			116.43	(20) ***	20.82	(2) ***		
Pseudo R^2:	0.2861									
Log pseudo-likelihood:	-168.14				-155.68					
Predicted Probability (at mean):			0.1973						0.1146	

Note: as in Table C.1.

Table C.3: Factors Influencing Farmers' Perceptions about Drinking Water Quality

Dependent Variable: CLCTWAT								
Explanatory Variables	Coeff.	z-stat	Marg. Effect	z-stat	Coeff.	z-stat	Marg. Effect	z-stat
constant	-1.7866	-3.99 ***			-1.0819	-2.36 **		
age	0.0081	1.20	0.0032	1.20	0.0055	0.80	0.0021	0.80
edu	-0.0007	-0.04	-0.0003	-0.04	0.0203	1.16	0.0080	1.16
eap	-0.2043	-2.82 ***	-0.0802	-2.82 ***	-0.1697	-2.36 **	-0.0667	-2.36 **
pcincact	0.0000	-1.68 *	0.0000	-1.68 *	0.0000	-1.34	0.0000	-1.34
gwqp‡	1.1713	6.40 ***	0.4408	7.34 ***				
puriwatr‡	0.5541	2.78 ***	0.2181	2.84 ***	0.4900	2.63 ***	0.1934	2.67 ***
wqs‡					-0.5913	-2.83 ***	-0.2324	-2.93 ***
proenv	0.0031	1.49	0.0012	1.49	0.0012	0.62	0.0005	0.62
sdwwti‡	1.7285	4.23 ***	0.5178	8.93 ***	1.9361	3.95 ***	0.5379	10.40 ***
sdwohp‡	0.5869	2.05 **	0.2308	2.12 **	0.5679	2.30 **	0.2235	2.38 **
sdwphp‡	1.1701	3.72 ***	0.4233	4.87 ***	1.0685	3.57 ***	0.3931	4.44 ***
sdwssp‡	1.0926	4.87 ***	0.4055	5.39 ***	1.2178	5.96 ***	0.4474	6.75 ***
childn	-0.3496	-2.21 **	-0.1372	-2.22 **	-0.4450	-2.95 ***	-0.1750	-2.96 ***
ela‡	0.9590	4.45 ***	0.3658	4.99 ***	0.8062	3.94 ***	0.3120	4.25 ***
knp‡	1.5343	5.27 ***	0.5337	7.51 ***	1.6184	5.93 ***	0.5521	8.72 ***
mdp‡	0.6547	2.88 ***	0.2563	3.02 ***	0.7104	3.10 ***	0.2768	3.29 ***
Number of observations:	395				395			
Wald chi^2 (df):	124.98	(15) ***			94.68	(15) ***		
Pseudo R^2:	0.3071				0.2358			
Log pseudo-likelihood:	-188.51				-207.89			
Predicted Probability (at mean):			0.4285				0.4324	

Note: as in Table C.1.

Table C.4: Factors Influencing Farmers' Perceptions about Drinking Water Quality

Dependent Variable: CLCTWAT								
Explanatory Variables	Coeff.	z-stat	Marg. Effect	z-stat	Coeff.	z-stat	Marg. Effect	z-stat
constant	-0.4545	-1.09			0.3615	0.87		
age	0.0067	1.03	0.0026	1.03	0.0032	0.48	0.0013	0.48
edu	0.0003	0.02	0.0001	0.02	0.0183	1.04	0.0072	1.04
eap	-0.2119	-2.89 ***	-0.0832	-2.88 ***	-0.1892	-2.66 ***	-0.0743	-2.66 ***
pcincact	0.0000	-1.88 *	0.0000	-1.88 *	0.0000	-1.45	0.0000	-1.45
gwqp‡	1.2016	6.56 ***	0.4507	7.59 ***				
puriwatr‡	0.5160	2.71 ***	0.2034	2.75 ***	0.4562	2.57 **	0.1802	2.60 ***
wqs‡					-0.6130	-2.95 ***	-0.2407	-3.06 ***
proenv	0.0041	2.01 **	0.0016	2.01 **	0.0027	1.39	0.0010	1.39
sdwwti‡	1.6343	3.84 ***	0.5048	7.54 ***	1.7407	3.75 ***	0.5188	8.14 ***
sdwohp‡	0.6427	1.70 *	0.2519	1.78 *	0.6617	2.11 **	0.2589	2.22 **
sdwphp‡	1.3133	3.68 ***	0.4610	5.18 ***	1.2592	3.59 ***	0.4470	4.88 ***
sdwssp‡	0.7341	3.89 ***	0.2803	4.08 ***	0.8115	4.59 ***	0.3083	4.85 ***
childn	-0.2953	-1.96 *	-0.1159	-1.97 **	-0.3770	-2.59 ***	-0.1480	-2.61 ***
app‡	-0.9216	-4.47 ***	-0.3176	-5.36 ***	-0.7693	-3.65 ***	-0.2736	-4.26 ***
kal‡	-1.5011	-3.64 ***	-0.4518	-5.82 ***	-1.5840	-4.15 ***	-0.4674	-6.91 ***
kdp‡	-0.8913	-3.80 ***	-0.3088	-4.63 ***	-1.0112	-4.72 ***	-0.3417	-5.97 ***
Number of observations:	395				395			
Wald chi^2 (df):	132.78	(15) ***			97.94	(15) ***		
Pseudo R^2:	0.2950				0.2210			
Log pseudo-likelihood:	-191.80				-211.92			
Predicted Probability (at mean):			0.4284				0.4293	

Note: as in Table C.1.

Table C.5: Factors Influencing Farmers' Willingness To Protect Groundwater Quality

Dependent Variable: WTPGWQ										
	Homoscedastic Probit Estimation				Heteroscedastic Probit Estimation					
Explanatory Variables	Coeff.	z-stat	Marg. Effect	z-stat	Coeff.	z-stat	Coeff.	z-stat	Marg. Effect	z-stat
Constant	0.2559	0.66			0.0850	0.83				
Age	-1.1E-05	0.00	-4.4E-06	0.00	0.0006	0.53			0.0006	0.54
Edu	0.0150	0.84	0.0059	0.84	0.0058	1.42			0.0063	1.69 *
Pclandh	-0.1813	-0.87	-0.0711	-0.87	-0.1039	-1.87 *			-0.1138	-2.35 **
Eap	0.0517	0.79	0.0202	0.79	0.0118	0.63			0.0129	0.70
Reside	-0.0073	-3.50 ***	-0.0029	-3.50 ***	-0.0034	-3.03 ***	-0.0135	-3.22 ***	-0.0045	-6.68 ***
Bpercept	0.0110	5.30 ***	0.0043	5.30 ***	0.0085	2.35 **	-0.0277	-2.78 ***	0.0076	3.84 ***
Agriprac	0.0071	2.75 ***	0.0028	2.75 ***	0.0021	2.46 **			0.0024	3.53 ***
Fmember	0.0034	1.65 *	0.0013	1.65 *	0.0004	0.99	-0.0082	-2.61 ***	-0.0001	-0.12
Fagrinfo	-0.0045	-2.19 **	-0.0018	-2.19 **	-0.0001	-0.18			-0.0001	-0.18
app‡	0.7608	3.72 ***	0.2698	4.35 ***	0.1954	1.66 *			0.2138	2.52 **
knp‡	0.6172	2.69 ***	0.2251	3.01 ***	0.0959	1.67 *			0.1057	1.87 *
mdp‡	0.9065	4.35 ***	0.3105	5.35 ***	0.1722	1.79 *			0.1890	2.83 ***
Number of observations:	395				395					
Wald chi^2 (df):	85.18	(12) ***			14.08	(12) ***	19.10	(3) ***		
Pseudo R^2:	0.1876									
Log pseudo-likelihood:	-219.944				-204.54					
Predicted Probability (at mean):			0.5750							

Note: as in Table C.1.

Table C.6: Factors Influencing Farmers' Willingness To Protect Groundwater Quality

Dependent Variable: WTPGWQ										
	Homoscedastic Probit Estimation				Heteroscedastic Probit Estimation					
Explanatory Variables	Coeff.	z-stat	Marg. Effect	z-stat	Coeff.	z-stat	Coeff.	z-stat	Marg. Effect	z-stat
Constant	1.0776	2.64***			0.2326	1.76 *				
Age	-0.0014	-0.22	-0.0005	-0.22	0.0005	0.49			0.0006	0.49
Edu	0.0126	0.69	0.0049	0.69	0.0045	1.31			0.0058	1.60
Pclandh	-0.1325	-0.60	-0.0519	-0.60	-0.0880	-1.63			-0.1135	-1.98 **
eap‡	0.0518	0.81	0.0203	0.81	0.0078	0.54			0.0101	0.59
reside	-0.0072	-3.55***	-0.0028	-3.55 ***	-0.0031	-2.49 **	-0.0156	-3.69 ***	-0.0048	-6.55 ***
bpercept	0.0113	5.58***	0.0044	5.56 ***	0.0069	2.31 **	-0.0303	-2.23 **	0.0074	2.97 ***
agriprac	0.0059	2.34**	0.0023	2.35 **	0.0015	2.43 **			0.0019	3.03 ***
fmember	0.0031	1.58	0.0012	1.58	0.0003	0.82	-0.0077	-2.39 **	0.0000	-0.05
fagrinfo	-0.0039	-1.95*	-0.0015	-1.95 *	0.0001	0.15			0.0001	0.15
ela‡	-0.5616	-2.96***	-0.2211	-3.04 ***	-0.1142	-1.83 *			-0.1434	-2.38 **
kal‡	-0.8427	-4.20***	-0.3252	-4.57 ***	-0.1139	-1.55			-0.1428	-2.21 **
kdp‡	-0.9681	-4.76***	-0.3683	-5.36 ***	-0.1471	-1.76 *			-0.1820	-2.76 ***
Number of observations:	395				395					
Wald chi^2 (df):	85.58	(12)***			12.17	(12) ***	16.58	(3) ***		
Pseudo R^2:	0.1916									
Log pseudo-likelihood:	-218.875				-204.83					
Predicted Probability (at mean):			0.5743						0.4517	

Note: as in Table C.1.

Table C.7: Factors Influencing Farmers' Willingness to Support (Demand for) Local Government to Supply Safe Drinking Water

Dependent Variable: WTSGOVCW								
	Homoscedastic Probit Estimation				Heteroscedastic Probit Estimation			
Explanatory Variables	Coeff.	z-stat	Marg. Effect	z-stat	Coeff.	z-stat	Marg. Effect	z-stat
constant	-0.4028	-0.89			-1.3667	-3.01 ***		
age	0.0064	0.92	0.0024	0.91	0.0062	0.87	0.0023	0.86
edu	-0.0089	-0.46	-0.0033	-0.46	-0.0128	-0.66	-0.0047	-0.66
eap	-0.1480	-1.97 **	-0.0540	-1.97 **	-0.1585	-2.10 **	-0.0579	-2.10 **
pcincact	0.0000	-1.63	0.0000	-1.63	0.0000	-1.53	0.0000	-1.53
proenv	0.0054	2.58 **	0.0020	2.59 **	0.0059	2.83 ***	0.0022	2.84 ***
childn	-0.4150	-2.57 **	-0.1514	-2.60 ***	-0.3954	-2.46 **	-0.1445	-2.49 **
puriwatr	0.6648	3.57 ***	0.2528	3.54 ***	0.6815	3.62 ***	0.2595	3.59 ***
gwqp‡	0.9056	5.08 ***	0.3410	5.13 ***	0.9136	5.16 ***	0.3442	5.25 ***
wtpgov	0.2018	2.37 **	0.0736	2.37 **	0.2137	2.49 **	0.0781	2.49 **
dwqos	-0.1041	-1.99 **	-0.0380	-2.00 **	-0.1018	-1.91 *	-0.0372	-1.91 *
dwqphp	-0.3965	-1.80 *	-0.1446	-1.81 *	-0.3963	-1.77 *	-0.1448	-1.78 *
dwqsw	-0.2281	-3.12 ***	-0.0832	-3.12 ***	-0.2374	-3.13 ***	-0.0867	-3.14 ***
sdwcw‡	1.0575	1.76 *	0.4023	1.99 **	1.0119	1.71 *	0.3867	1.91 *
sdwohp‡	0.9496	2.46 **	0.3636	2.58 **	0.7266	2.51 **	0.2798	2.52 **
sdwphp‡	1.6851	4.21 ***	0.5825	6.43 ***	1.5383	4.44 ***	0.5471	6.23 ***
sdwssp‡	1.5040	5.07 ***	0.4962	6.05 ***	1.5844	5.10 ***	0.5190	6.21 ***
sdwwti‡	1.3879	2.54 **	0.4989	3.52 ***	1.2992	2.48 **	0.4748	3.25 ***
app‡	-1.0328	-4.65 ***	-0.3008	-6.17 ***				
kal‡	-1.3905	-3.20 ***	-0.3674	-5.28 ***				
kdp‡	-0.7816	-3.23 ***	-0.2429	-4.03 ***				
ela‡					1.0923	4.83 ***	0.4141	5.22 ***
knp‡					0.9286	3.33 ***	0.3554	3.45 ***
mdp‡					0.9204	4.03 ***	0.3530	4.21 ***
Number of observations:	395				395			
Wald chi^2 (df):	130.87	(20) ***			131.75	(20) ***		
Pseudo R^2:	0.3073				0.3047			
Log pseudo-likelihood:	-182.33				-183.02			
Predicted Probability (at mean):			0.3361				0.3376	

Note: as in Table C.1.

APPENDIX B

Table B.1: Sample Villages and Basic Sample Characteristics

Name of the Sample Location	Total Number of 2001 Census House holds	Number of Sample House holds	Percentage of Census House holds	Total Population (Population Census 2001)	Sample Population	Percentage of Census Population	Census Family Size	Average Sample Family Size	Agricultural Area (in hectare)	Total Land Holding of Sample Households (in hectare)	Percentage of Agricultural Area of the Village (in hectare)	Average Land Holding of the Sample Households (in hectare)
Kembanickenpalayam (KNP)	2,752	65	2.4	10,308	273	2.6	3.7	4.2	1,477.4	85.4	5.8	1.3
Madampalayam (MDP)	1,164	72	6.2	4,348	301	6.9	3.7	4.2	742.3	126.1	17.0	1.8
Elathur (ELA)	2,166	66	3.0	7,678	275	3.6	3.5	4.2	708.3	104.2	14.7	1.6
Kalingiam (KAL)	2,580	68	2.6	9,386	299	3.2	3.6	4.4	1,058.8	141.9	13.4	2.1
Kondayampalayam (KDP)	2,042	64	3.1	6,988	260	3.7	3.4	4.1	584.5	163.5	28.0	2.6
Appakoodal (APP)	2,574	60	2.3	9,522	248	2.6	3.7	4.1	1,021.0	73.9	7.2	1.2
Total	13,278	395	3.0	48,230	1,656	3.4	3.6	4.2	5,592.3	695.0	12.4	1.8

Source: Census of India, 2001 and Primary Survey

Table B.2: Descriptive Statistics

	APP	ELA	KAL	KNP	KDP	MDP	ALL	F-stat	Prob.
No. of Obs.	65	72	66	68	64	60	395	(df: 5, 389)	
	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev		
Age (in completed years) (age)	44 ± 13 (23 - 66)	50 ± 12 (25 - 80)	42 ± 13 (21 - 71)	44 ± 12 (20 - 82)	47 ± 13 (22 - 76)	51 ± 12 (28 - 80)	46 ± 13 (20 - 82)	5.3844	0.0001
Education (in years) (edu)	7.5 ± 5.6 (0 - 18)	6.9 ± 5.1 (0 - 18)	6.7 ± 4.9 (0 - 17)	8.5 ± 3.4 (0 - 15)	7.6 ± 5 (0 - 16)	5.1 ± 4.7 (0 - 15)	7.1 ± 4.9 (0 - 18)	3.6340	0.0032
Economically active person in a family (eap)	1.9 ± 1.3 (1 - 9)	1.9 ± 1.1 (1 - 5)	1.9 ± 1.1 (1 - 7)	1.6 ± 0.7 (1 - 3)	1.9 ± 1 (1 - 4)	1.5 ± 0.7 (1 - 4)	1.8 ± 1 (1 - 9)	2.1789	0.0558
Per capita land holding (in hectare) (pclandh)	0.34 ± 0.27 (0.03 - 1.82)	0.42 ± 0.31 (0.05 - 2.02)	0.4 ± 0.32 (0.08 - 1.35)	0.49 ± 0.42 (0.1 - 3.04)	0.63 ± 0.53 (0.1 - 3.04)	0.33 ± 0.25 (0.04 - 1.42)	0.44 ± 0.38 (0.03 - 3.04)	5.9585	0.0000
Per capita income (in Rs./Year) (pcincact)	7,613 ± 5,764 (1,000 – 33,333)	8,688 ± 11,505 (1,000 – 66,667)	10,699 ± 8,865 (250 – 41,149)	9,239 ± 9,512 (1,250 – 60,400)	11,706 ± 10,124 (1,667 – 58,796)	8,235 ± 9,123 (375 – 40,000)	9,362 ± 9,403 (250 – 66,667)	1.7781	0.1163
Residing in the village (in years) (reside)	83 ± 32 (1 - 100)	80 ± 29 (1 - 100)	81 ± 33 (4 - 100)	57 ± 42 (10 - 200)	68 ± 41 (1 - 100)	89 ± 24 (5 - 100)	76 ± 36 (1 - 200)	7.9073	0.0000
Having children (below 5 years of age) in the family (child)	0.05 ± 0.21	0.15 ± 0.36	0.12 ± 0.33	0.28 ± 0.45	0.11 ± 0.31	0.13 ± 0.34	0.14 ± 0.35	3.3616	0.0055
Number of children (below 5 years of age) in the family (childn)	0.06 ± 0.30 (0 - 2)	0.21 ± 0.53 (0 - 2)	0.20 ± 0.59 (0 - 3)	0.50 ± 0.97 (0 - 4)	0.13 ± 0.38 (0 - 2)	0.22 ± 0.61 (0 - 3)	0.22 ± 0.62 (0 - 4)	4.1491	0.0011
Area under sugarcane cultivation (in hectare) (areasugar)	2.50 ± 1.75 (0 - 8)	0.89 ± 1.36 (0 - 6)	2.29 ± 2.69 (0 - 18)	1.69 ± 2.42 (0 - 13)	2.29 ± 2.58 (0 - 10)	0.00 ± 0.00 (0 - 0)	1.62 ± 2.20 (0 - 18)	14.7348	0.0000
Herd Size (in cows/ buffalo/bullock unit) (animal)	3.0 ± 2.7 (0 - 10)	3.4 ± 2.2 (0 - 9)	4.1 ± 3.2 (0 - 15)	5.3 ± 3.9 (0 - 21)	3.1 ± 1.7 (0 - 7)	2.0 ± 1.8 (0 - 8)	3.5 ± 2.9 (0 - 21)	10.9970	0.0000

Note: Figures in the parenthesis show the range for the corresponding average value.

Table B.2: Descriptive Statistics

	APP	ELA	KAL	KNP	KDP	MDP	ALL	F-stat	Prob.
	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev	Mean ± Stdev		
Factor Score of Farmers' Source of Agriculture Related Information (fagrinfo)	6.48 ± 41.25 (-59.36 - 66.83)	-2.59 ± 34.56 (-59.36 - 66.83)	-4.81 ± 38.71 (-61.01 - 66.83)	-5.40 ± 27.88 (-59.36 - 66.83)	20.21 ± 37.98 (-59.36 - 66.83)	-14.05 ± 33.56 (-59.36 - 42.91)	0 ± 37.2 (-61.01 - 66.83)	6.9473	0.0000
Factor Score of Farmers' Sources of Consultations related to Agricultural Practices (fconsult)	-24.16 ± 13.87 (-34.18 - 38.88)	-0.96 ± 27.6 (-34.18 - 68.43)	-8.28 ± 24.8 (-34.18 - 45.36)	41.49 ± 32.76 (-34.18 - 106.74)	-9.77 ± 19.65 (-34.18 - 48.98)	-0.18 ± 27.88 (-34.18 - 66.29)	0.00 ± 32.42 (-34.18 - 106.74)	51.8694	0.0000
Factor Score of Membership in Social and Community Institutions (fmember)	-14.57 ± 29.29 (-36.43 - 40.41)	6.64 ± 39.77 (-36.43 - 141.18)	-0.38 ± 39.81 (-36.43 - 131.59)	6.44 ± 18.06 (-36.43 - 55.32)	6.32 ± 42.88 (-36.43 - 131.59)	-5.81 ± 33.79 (-36.43 - 88.2)	0.00 ± 35.61 (-36.43 - 141.18)	3.9903	0.0015
Factor Score of Farmers' Knowledge on Farm Management Practices (knowbmp)	4.76 ± 43.65 (-78.35 - 49.59)	-13.84 ± 42.26 (-92.69 - 49.59)	2.84 ± 43.48 (-92.69 - 49.59)	6.96 ± 38.94 (-92.69 - 49.59)	27.24 ± 30.82 (-55.74 - 49.59)	-28.62 ± 37.81 (-92.69 - 49.59)	0.00 ± 43.14 (-92.69 - 49.59)	14.5786	0.0000
Factor Score of Farmers' Adoption of Agricultural Best Management Practices (BMPs)(proenv)	-5.20 ± 46.82 (-43.31 - 135.33)	-9.25 ± 36.68 (-43.31 - 99.05)	-4.33 ± 44.92 (-43.31 - 135.33)	15.84 ± 45.58 (-43.31 - 135.33)	28.37 ± 45.9 (-43.31 - 135.33)	-26.73 ± 26.65 (-43.31 - 90.02)	0.00 ± 45.1 (-43.31 - 135.33)	13.7812	0.0000
Factor Score of Farmers' Willingness to Participate in Government Sponsored Training Programme (wtpgov)	-0.11 ± 1.01 (-2.95 - 0.64)	0.14 ± 0.92 (-3.32 - 0.64)	-0.48 ± 1.26 (-3.32 - 0.64)	0.37 ± 0.69 (-3.32 - 0.64)	0.06 ± 0.9 (-3.32 - 0.64)	0.00 ± 0.97 (-3.32 - 0.64)	0.00 ± 1.00 (-3.32 - 0.64)	5.7051	0.0000
Area under sugarcane cultivation (in hectare) (areasugar)	2.50 ± 1.75 (0 - 8)	0.89 ± 1.36 (0 - 6)	2.29 ± 2.69 (0 - 18)	1.69 ± 2.42 (0 - 13)	2.29 ± 2.58 (0 - 10)	0.00 ± 0.00 (0 - 0)	1.62 ± 2.20 (0 - 18)	14.7348	0.0000
Herd Size (in cows/ buffalo/bullock unit) (animal)	3.0 ± 2.7 (0 - 10)	3.4 ± 2.2 (0 - 9)	4.1 ± 3.2 (0 - 15)	5.3 ± 3.9 (0 - 21)	3.1 ± 1.7 (0 - 7)	2.0 ± 1.8 (0 - 8)	3.5 ± 2.9 (0 - 21)	10.9970	0.0000

Note: Figures in the parenthesis show the range for the corresponding average value.

DIESEL PRICE HIKES AND FARMER DISTRESS: THE MYTH AND THE REALITY

M. Dinesh Kumar[1], O. P. Singh[2] and M.V. K. Sivamohan [3]

Abstract

The issues being addressed in this paper are as follows. Has there been significant change in cost of groundwater pumping due to diesel price shock in regions where it matters? If so, how that has impacted millions of irrigation water buyers? How farmers respond to increase in irrigation costs? Such responses include: how the well owning farmers change their farming enterprise, including the farming system itself; how their willingness to take risk changes, and finally, how the economic prospects of irrigated farming itself changes as a result?

It is found that the impact of diesel price on irrigation cost incurred by diesel well owners is not significant. One reason for this is that the regions which are heavily dependent on diesel pumps for irrigation have shallow groundwater table. Also, this burden is not passed on to the water buyers owing to increasing competition and reducing monopoly power of pump owners. The analysis of the farming enterprise of irrigators under differential cost (irrigation) regimes presented here shows that farmers would be able to cope with very high rise in irrigation costs through irrigation efficiency improvements and allocating more area under crops that give higher returns per unit of land and water, that enhance the farming returns from every unit of water and energy used. By doing this, they are able to maintain almost the same net returns from farming as in the past. This means, that the rise in cost of diesel in real terms had not made any negative impact on economic prospects of diesel well irrigators, including water buyers.

1. INTRODUCTION

While in many arid and semi-arid regions of India, the water management issue is of growing physical shortage of water, and in some water-abundant regions, it is economic scarcity of water. Here, due to poor state of rural electrification, high cost of diesel engines, and the small size of land holdings, investment in irrigation is very poor. The resource poor, small and marginal farmers pay exorbitant prices for the water they buy from well owners, making irrigated agriculture an unattractive proposition.

Many scholars argue that the recent hikes in diesel prices across the country had badly hit the regions with poor rural electrification facility.. Their argument is that growing economic scarcity of water, occurring due to this, cause sweeping changes in agriculture, especially of small and marginal farmers in India. This they attribute as a cause of widespread farmer distress in the countryside. This is based on the premise that regions such as eastern UP, West Bengal, Assam and Bihar depend heavily on diesel power for lifting groundwater, and increase in price of diesel is likely to impact on cost of irrigation and also millions of rural livelihoods in these regions, as agricultural productivities are already very low. Over the period of 17 years, the price of diesel has also gone up from Rs. 5 per litre to Rs. 34.84 per litre.

The available empirical works on impact of energy price hike on irrigated farming are based on respondent surveys. Such works have little relevance for practical policy formulation in the sense that the perceived

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"impacts of price changes" are an outcome of the whole range of changes happening with the farming system level, including that on the market front. Such analyses fail to segregate the response of farmer to input price changes, and their subsequent implications for prospects of farming, especially by small and marginal farmers.

In this paper, certain fundamental questions are raised concerning Indian agriculture. First: has there been significant change in cost of groundwater pumping due to diesel price shock in regions where it matters? If so, how that has impacted on millions of irrigation water buyers? How farmers respond to increase in irrigation costs? Such responses include: how the well owning farmers change their farming enterprise, including the farming system itself; how their willingness to take risk changes, and finally, how the economic prospects of irrigated farming itself changes as a result?

2. A CONCEPTUAL FRAMEWORK FOR ANALYZING THE IMPACT OF ENERGY PRICE ON FARMING ENTERPRISE

The rise in diesel price might affect the diesel well owners and water buyers in diesel well commands in different ways. First of all, the rising diesel price (Rs/litre) would raise the marginal cost of using irrigation water for crop production unless the farmers put in systems to improve the efficiency of the pump that reduce the diesel consumption per hour of pumping, and increase the well outputs. This would encourage the well owners to improve the efficiency of use of irrigation water in the field to cut down the cost of irrigation. This can result in lower irrigation dosage, higher yield, higher physical productivity of water (kg/m^3), and perhaps higher water productivity in economic terms also (Rs/m^3), with net returns remaining the same.

But, there might be crops where the cost of irrigation itself would be a significant chunk of the production cost. In such situations, with diesel price hike, the irrigation cost could become so high even with efficiency improvement, when compared against the gross returns from the crop. This would eventually make the net returns too low, making the crop itself unviable. In such situations, the farmers might respond by replacing the existing crops by new crops that yield much higher income returns (Rs/ha of land) so as to offset the increase in cost of irrigation water. This can also include crops that are highly water-intensive. Hence, analysis should be based on farming system returns rather than return from crops.

On the other hand, the impact of rising diesel price on water buyers would be a little more complex. The reason is that over time, along with increasing cost of production of water, the monopoly price of water itself could also change in favour of water buyers with increasing number of privately owned wells as found in Muzaffarpur in Bihar (Kumar, 2007). If that happens, then the water price may not increase in proportion to the cost of production of water. Hence, taking the actual price paid by water buyers would nullify the impact of real change in diesel prices in areas where situation had not improved. To sum up, while diesel price hike can impact on cost of groundwater irrigation, the price fluctuations are not true reflections of the actual impact of diesel price increase.

While this can happens on the cost front, on the price front, the market price of many agricultural produce also can change significantly over time. For instance for many cereals, the prices in real terms had not increased in real terms, and on the contrary, had reduced in certain cases. Hence, comparing the time series data on income returns from farming would distort the picture with respect to impact of input prices by wrongly attributing the declining returns to the increase in input costs. This means for capturing the "response to and impact of input price changes", it is essential to compare the farming systems under different price regimes for irrigation water. The major attributes to be covered in such analysis include: 1] irrigation dosage; 2] physical productivity of water in crops; 3] net returns from crops and livestock; 4] net water productivity in economic terms for crops and livestock; and, 5] the returns and water productivity in farming.

2.1 Differential Cost of Groundwater for Irrigation across Different Categories of Farmers

The average cost of pumping irrigation water for the diesel pump owners is Rs.1.38/m^3 and the range is Rs.0.99/m^3 to Rs.2.04/m^3. The average price at which diesel well owners sell water is Rs.2.81/m^3 and the individual values range from Rs.2.07/m^3 to Rs. 3.63/m^3. Against this, the average price of at which irrigation water is sold by electric pump owners is Rs 0.65/m^3 and the individual values range from Rs 0.52/m^3 to Rs 0.84/ m^3.

The average price at which groundwater is being sold by electric well owners is Rs 0.70/m^3 and the individual values range from Rs.0.31/m^3 to Rs 0.92/m^3. The average cost of pumping groundwater using diesel pump is Rs.1.87/m^3 and individual values range from Rs. 1.41/m^3 to 2.93/m^3. The average price at which groundwater is being sold by diesel pump owners is Rs 2.15/m^3 and the individual values range from Rs.1.84/m^3 to Rs.2.42/m^3 (Table 1).

Table 1: The Average Costs and Cost Range in Irrigation Water for Diesel Well Owners, and Water Buyers in Diesel and Electric Well Commands

Name of the Region	Cost of Irrigation Water					
	For Diesel Well Owners		Water Buyers in Diesel Well Command		Water Buyers in Electric Well Command	
	Average	Range	Average	Range	Average	Range
South Bihar	1.87	1.41-2.93	2.15	1.84-2.42	0.70	0.31-0.92
Eastern UP	1.38	0.99-2.04	2.81	2.07-3.63	0.65	0.52-0.84

3. OBJECTIVES

The overall objective of the study is to analyze how the small and marginal farmers in water abundant regions respond to diesel price hike, and to assess the overall impact on the economic prospects of farming. The specific objectives are:

- To analyze the actual change in cost of irrigation water for diesel well owners and water buyers due to rise in diesel prices
- To analyze the response of diesel well owners to potential hike in irrigation costs and its overall impact on economic prospects of farming
- To study the response of water buyers in diesel well commands to diesel price hike and its overall impact on economic prospects of their farming;

3.1 Hypothesis

Increase in cost of diesel would encourage farmers to use water and other inputs for crop and livestock production more efficiently; but might also adopt high valued crops which require more water, to sustain the net returns from crop production.

4. METHODOLOGY

4.1 Geographical Coverage

The geographical coverage of present study includes eastern plain region of Uttar Pradesh and south Bihar plains .

4.2 Climatic Condition of the Study Area

The average annual precipitation in the eastern plain region of Uttar Pradesh is about 1025 mm. The region's climate is dry sub-humid to moist sub-humid. The soil types in this sub-zone are light alluvial and calcareous clay. Patna district falls under the south Bihar plains region of Bihar state receives average normal annual rainfall of 1103mm and climate condition of region is dry to moist sub-humid. The soil types found in the region are old alluvium sandy loam to clayey and the larger areas under the *Tal* and *Diara*.

4.3 Methodology

4.3.1 Overall Methodology

At the outset an analysis is made here, of the actual increase in cost of irrigation water for the diesel well owners and water buyers over time on the basis of the time series data on cost of diesel; energy (diesel) use per hour of pumping; and the well outputs. This is adjusted to inflation. The price water buyers pay in hourly terms is converted into unit charges using data on well outputs, and then adjusted to inflation to obtain the prices in real terms.

The potential response of diesel well owners to increase in irrigation cost is analyzed by comparing the cropping pattern; irrigation water dosage; and productivity of irrigation water in crops, dairying and at the farm level of the diesel well owners with that of water buyers from electric well owners. This is in view of the fact that the water buyers in electric well commands are incurring much lower cost for irrigation water as compared to diesel well owners, and water buyers in diesel well command. Whereas overall agro-climatic conditions governing the demand for water for a particular crop, and the ecological viability of crops would remain the same. Subsequently, the potential response of water buyers to rise in irrigation cost is analyzed by comparing the above attributes and compared with water buyers in electric well commands.

The overall economic impact of rise in irrigation cost on farming enterprises is analyzed by estimating the net return from the entire farm for diesel well owners and their water-purchasing counterparts, and then comparing it with that for water buyers from electric well owners in the same region. Further, based on the actual rise in cost of irrigation water felt by diesel well owners over the years due to diesel price hike, and the potential response of the irrigators to irrigation cost rise, the actual impact of diesel price hike on farming enterprises of diesel well owners and their water buyers is assessed.

4.3.2 Sampling Plan

Sixty well owners and water buyers from electric and diesel well commands in Eastern Uttar Pradesh (Varanasi and Mirzapur) and South Bihar plain (Patna) were selected for the study.

4.3.2 Analytical Procedure

The net economic return from farming would be assessed by adding up the net return from crops and dairy production.

The net return from crop production NI_{crop} for those crops which by-products does not used for the dairying will be estimated as:

$$NI_{Crop} = \left[\left(Y_{MP} * FHP_{MP} \right) + \left(Y_{By-P} * FHP_{By-P} \right) \right] - C_{Input} \quad \ldots\ldots\ldots (1)$$

For the estimation of net return NI_{cropi} for those crops, which by-product is used as an input of milk production (dry fodder) , in such situation we will allocate total cost of production between the main product and by-product using their ratio of market value. The net return from such crops we will be estimated as:

$$NI_{Crop\,i} = \left[\left(Y_{MP} * FHP_{MP} \right) - C_{Main\ product} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Here, Y_{MP} is the yield of main product (Quintal); FHP_{MP} is the farm harvest price of main product (Rs/kg);Y_{By-P} is the yield of by-product (Quintal) and FHP_{BY-P} farm harvest price of by-products (Rs/kg); C_{input} is the cost of all inputs used for crop production and is the cost of inputs for main production.

The net income from livestock NI_{Dairy} production based on life cycle we will estimate as:

$$NI_{Dairy} = \left[\left(Y_{milk} * P_{milk} \right) + \left(Y_{Dung} * P_{Dung} \right) \right] - \left[\left(P_{gf} * Q_{gf} \right) + \left(P_{df} * Q_{df} \right) + \left(P_{cf} * Q_{cf} \right) + P_{oi} \right] \ldots\ (3)$$

Here, Y_{milk} is the milk yield per animal per annum; Y_{Dung} is the yield of dung per animal per annum; P_{milk} and P_{Dung} is the price of milk and price of dug received by the farmer; Q is the quantum of inputs used per cattle unit per annum. The suffixes , *gf, df, cf* and *oi* stand for green fodder, dry fodder, cattle feed, and other expenses respectively. The price of *gf* and *df* will be the unit cost of production (total input costs divided by total production). The price of *cf* and *oi* is the actual market price.

The net income at farm level (Rs) would be estimated as:

$$NI_{farm} = \sum_{i=1}^{m} NI_{crop\,i} + \sum_{j=1}^{n} NI_{Dairy} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

Where, $\sum_{i=1}^{n} NI_{Crop\,i}$ is the net income from all the crops grown by the farmers on his farm and $\sum_{n=1}^{n} NI_{Dairy}$ is the net income from dairy farming.

The detailed methodology for estimating water productivity in crops, dairying and farm level water productivity are discussed in Singh and Kumar (2008).

Table 2: The Cost of Pumping and Sale Price of Groundwater in Diesel Well Commands of eastern UP and south Bihar villages

Name of the Region	Price Details	Cost of Pumping Groundwater (Rs/m^3)				Selling Price of Groundwater (Rs/m^3)			
		1990	1995	2000	2006	1990	1995	2000	2006
South Bihar Plans	Average	0.41	0.51	0.95	1.60	1.16	1.40	1.75	2.11
	Minimum	0.22	0.31	0.75	1.38	0.90	1.10	1.44	1.81
	Maximum	0.95	1.04	1.46	2.09	1.67	1.88	2.08	2.50
Eastern UP	Average	0.47	0.56	1.00	1.64	0.98	1.31	1.63	2.67
	Minimum	0.14	0.21	0.54	1.02	0.84	1.11	1.39	1.96
	Maximum	1.51	1.62	2.10	2.82	1.62	2.34	2.52	3.51

Assumption: We assume that the diesel consumption, discharge rate of the pump and hours of diesel pump running per year is same for 2006

5. RESULTS AND DISCUSSIONS

5.1 Actual Impact of Diesel Price Hike on Cost of Pumping Well Water and Water Prices in the Market

The actual cost of groundwater pumping and the price at which water is traded in the diesel well commands of eastern UP and south Bihar are given below. It shows that in the case of south Bihar villages, the average cost of pumping went up by nearly 300 per cent from Rs. 0.41/m^3 to 1.16/m^3, whereas the selling price of water went up by only 90% from Rs.1.16/m^3 to Rs. 2.11/m^3. This means that the monopoly price ratio had declined from 2.8 to 1.3. In the case of eastern UP villages, the average cost of pumping went up by nearly 280% from Rs.0.47/m^3 to Rs.1.64/m^3, where as the sale price of water went up by 170%. This means, the decline in monopoly price of water is (from 2.1 to 1.6) is not as sharp as in the case of south Bihar. This is quite understandable, as the rate of growth in number of diesel wells and pump sets has been much higher in south Bihar than in eastern UP. In nutshell, the impact of diesel price change on the water buyers is different from that of eastern Utter Pradesh.

But, the price increase shown above does not mean that the actual price of irrigation water has gone up. If one wants to see how the price has changed in real terms, one should correct the price to the inflation rates. We have used an annual inflation rate of 7% to estimate how the cost of pumping and cost of irrigation water (sale price) have changed over the years from 1990-2006. It shows that in the case of eastern UP, the cost of irrigation in real terms has gone up by 18%, whereas the actual price of irrigation water from diesel well owners had gone down by 7.5%. In South Bihar while the cost of irrigation in real terms has gone up by 32%, the price of irrigation water had gone down by 38%.

5.2 Cropping Patterns in the Study Area under different Energy Pricing Regimes

Cropping patterns of farmers in electric and diesel pump command area under different crops in different seasons for eastern Uttar Pradesh is dominated by the paddy and wheat. During summer, most of the agricultural lands remain fallow, farmers grow only green fodder. The water buyers in diesel well commands allocate some portion of their land for pulses viz., arhar, black gram and green gram, which are normally rain-fed, but require one or two irrigations in case of long dry spells, thereby cutting down the cost of irrigation.

The cropping pattern of water buyers in electric well commands and farmers in diesel well commands in south Bihar plans is similar to that obtaining in the eastern Uttar Pradesh viz., paddy and wheat cropping system. Due to high rainfall and poor drainage of land in the region, the agricultural land remains waterlogged during monsoon, and in this situation farmers are forced to take paddy. Farmers allocate a very small area for fodder crops to sustain dairy farming. During winter, they allocate larger area for wheat followed by potato, which gives high returns. During summer, farmers allocate larger are for onion, which again provides cash income

5.3 Irrigation, Net Return from Crops and Crop Water Productivity

The estimates of irrigation dosage, water productivity in physical and economic terms for selected crops for diesel well owners and their water buyers in eastern Uttar Pradesh are presented in Table 3 Comparison of the estimates for diesel well owners and their water buyer counter parts (Table 3) shows the following: 1] the average depth of irrigation is slightly lower for water buyers in diesel well command as compared to their well-owning counterparts; and, 2] the water buyers in diesel well commands secure higher physical productivity of water and water productivity in economic terms for all the crops.

Comparison between diesel well owners and water buyers in electric well commands however shows a different trend. The average dosage of irrigation is much lower for farmers who buy water from electric well commands as compared to diesel well owners, in spite of the fact that they are confronted with much lower

Table 3: Water Use, Physical and Net Water Productivity under Diesel Pump, Eastern Uttar Pradesh

Name of the Crops	Diesel Pump – Owner		Diesel Pump –Water Buyer				Electric Pump –Water buyer		
	Depth of irrigation (mm)	WP (kg/m^3)	Depth of irrigation (mm)	WP (kg/m^3)	Net WP (Rs/m^3)	Net WP (Rs/m^3)	Depth of irrigation (mm)	WP (kg/m^3)	Net WP (Rs/m^3)
Paddy	15.53	1.86	9.09	2.39	2.92	2.62	3.61	2.29	3.64
Sesamum	2.29	0.89	1.14	0.88	17.72	17.39	0.57	1.25	9.58
Sugarcane	-	-	-	-	-	-	0.57	10.62	8.11
Bajra	2.29	3.43	1.33	4.41	17.83	7.47	1.43	4.05	10.52
Wheat	12.74	2.57	8.33	3.50	7.80	6.22	2.93	2.63	7.57
Potato	3.70	7.23	2.29	7.40	-	17.87	2.91	5.96	9.58
Pea	3.40	1.56	1.67	1.74	12.36	12.19	1.33	2.14	14.95
Gram	4.16	1.58	1.99	1.82	17.78	15.33	0.36	1.62	31.12
Mustard	2.70	1.56	1.44	1.15	11.99	10.87	1.20	1.39	11.44
Linseed	3.43	1.36	1.03	1.53	16.77	13.70	-	-	-

GF: Green fodder
Source: Author’s own estimate based on primary data

Table 4: Water Use, Physical Productivity of Water and Net Water Productivity in Economic Terms under Diesel Pump, South Bihar Plain

Name of the Crops	Diesel Pump – Owner			Diesel Pump –Water Buyer			Electric Pump –Water buyer		
	Depth of irrigation (cm)	WP (Kg/m^3)	Net WP (Rs/m^3)	Depth of irrigation (cm)	WP (Kg/m^3)	Net WP (Rs/m^3)	Depth of irrigation (mm)	WP (kg/m^3)	Net WP (Rs/m^3)
Paddy	8.96	2.40	7.50	5.41	2.98	9.56	4.67	2.69	8.35
Wheat	5.88	1.98	5.97	3.16	2.27	6.80	3.51	1.76	5.78
Potato	3.89	12.93	44.57	1.81	13.92	49.83	2.00	11.74	41.78
Mustard	3.89	1.54	16.18	1.92	1.60	16.25			
Onion	3.70	5.84	21.50	3.06	5.34	21.27	2.18	5.40	23.15
Maize	2.24	5.26	17.05	1.64	7.65	31.84	1.76	6.86	19.05

GF: Green Fodder
Source: Author’s own estimate based on primary data

marginal cost of irrigation. Further, the water buyers in electric well command secure much higher values of water productivity in both physical and economic terms as compared to diesel well owners. This is due to the fact that the electric well commands are located in the flood plains of the river, with high soil moisture content, fertile soils. These reduce not only the irrigation water requirement of the crops, but also the need for fertilizer inputs also, minimizing the input costs. As a result, the irrigation dosage and water productivity values are higher for water buyers in electric well command.

As regards the net income from crop production, the comparative figures for eastern Uttar Pradesh are presented in Figure 1. Here, the electric well owners secure higher income per ha in paddy, wheat, pea and gram as compared to farmers in diesel well commands. Whereas, the diesel pump water buyers secure higher net income in bajra, mustard and linseed.

The estimates of irrigation dosage, water productivity in physical and economic terms for selected crops for diesel well owners and their water buyers, and water buyers in electric well commands in south Bihar plains are presented in Table 4. Comparison of the estimates for diesel well owners and their water buyer counterparts shows a similar trend as that of eastern Uttar Pradesh. Comparison of corresponding figures between diesel well owners and water buyers in electric well command show a similar trend. The figures of irrigation dosage and water productivity (in both physical and economic terms) are higher for diesel well owners who have to pay a much higher price for irrigation water in volumetric terms, as compared to those who buy water from electric well owners.

As regards the net income from different crops, the comparative figures are presented in Figure 2. In south Bihar plans, the electric well owners obtain higher net income per ha in wheat, potato, mustard and onion crops whereas, diesel pump water buyers get higher net income per ha in maize cultivation. The diesel pump owners are receiving second highest per hectare net income from onion, mustard, potato and wheat and highest per hectare net income from the paddy crop.

Figure 1: Net Income from Crop Production, Eastern UP

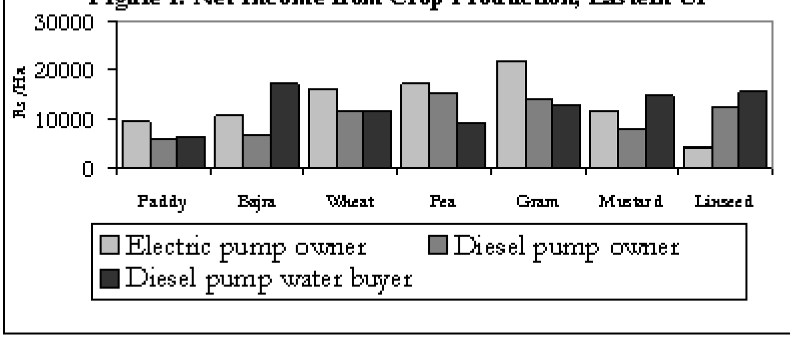

Figure 2: Net Income from Crop Production, South Bihar Plains

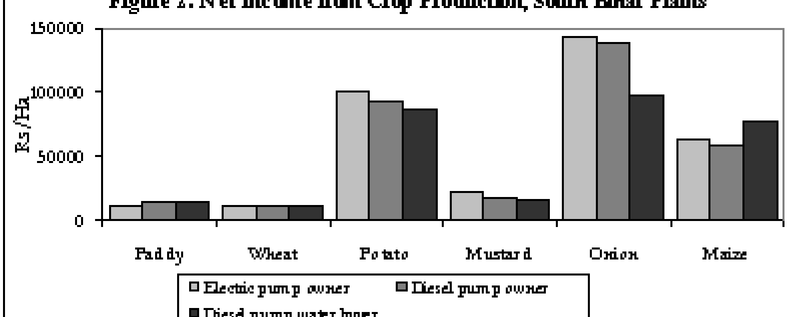

Table 5: Average Feed and Fodder Used Based on Lifecycle of Animal, Diesel Pump, Eastern Uttar Pradesh

	Feed and Fodder Use (kg/day/animal)								
	Diesel Pump – Owner			Diesel Pump – Water Buyer			Electric Pump-Water Buyer		
	Buffalo	CBCow	Ind. Cow	Buffalo	CBCow	Ind. Cow	Buffalo	CBCow	Ind. Cow
G. Fodder	19.6	24.3	17.1	19.2	16.7	13.4	13.8	19.5	14.8
Dry Fodder	15.1	17.5	13.2	17.1	19.6	19.1	8.9	12.7	9.3
Concentrate	1.5	1.5	1.4	1.3	1.8	1.3	1.0	1.8	1.2

Note: CBCow implies Cross Bred Cow; Ind. Cow implies Indigenous Cow

5.4 Net Income and Water Productivity in Milk Production

The net income from milk production is dependent on the amount of fodder and feed provided to the dairy animals; cost of production of these inputs, and milk yield and the price of these outputs. Whereas the determinants of water productivity in milk production are: the milk yield and its price; the total amount of water embedded in the animal feed and fodder; and the cost of production of animal feed and fodder.

Table 6: Average Feed and Fodder Used Based on Lifecycle of Animal, Diesel Pump, South Bihar Plains

	Feed and Fodder Use (kg/day/animal)								
	Diesel Pump – Owner			Diesel Pump – Water Buyer			Electric Pump-Water Buyer		
	Buffalo	CBCow	Ind. Cow	Buffalo	CBCow	Ind. Cow	Buffalo	CBCow	Ind. Cow
G. Fodder	14.85	15.29	10.77	9.87	11.46	9.82	9.90	8.19	6.18
Dry Fodder	18.68	9.13	9.49	14.70	14.86	18.07	10.36	23.15	12.36
Concentrate	1.81	1.40	0.79	1.74	1.24	1.11	1.66	2.03	1.27

5.4.1 Feed and Fodder Use

Table 5 presents the estimates of average quantum of green fodder, dry fodder and animal feed provided to the three different types of livestock, viz., buffalo, cross bred cow and indigenous cow for diesel well owners; the farmers who purchase irrigation water from them; and those who purchase water from electric pump owners for eastern UP villages. Comparison across the different categories of farmers shows that generally, the dairy inputs are highest for water buyers of diesel well owners, followed by diesel well owners and lowest for water buyers in electric well command. The exception is for cross bred cow in which case the green fodder input is much lower for water buyers of diesel well command as compared to other categories of farmers.

Table 6 presents the estimates of average quantum of green fodder, dry fodder and animal feed provided to the three different types of livestock, viz., buffalo, cross bred cow and indigenous cow for diesel well owners and the farmers who purchase irrigation water from them; and farmers who purchase water from electric well owners for south Bihar villages. Comparison across the different categories of farmers shows no general trend unlike what has been found in the case of eastern UP. Nevertheless, for buffalo, the quantum of green and dry fodder input is highest for diesel well owners.

5.4.2 Water Use for Milk Production, Physical Productivity of Water and Gross Water Productivity in Economic Terms

The water required for milk production includes that embedded in the dry and green fodder and cattle feed provided to the animals, in addition to the direct water use by cattle for drinking. They are estimated for the

Table 7: Water Use for Milk Production in Diesel Pump Command Area, eastern UP (m^3/day)

	Diesel Pump – Owner			Diesel Pump – Water Purchaser			Electric Pump – Water Buyer		
	Buffalo	CBCow	Ind.Cow	Buffalo	CBCow	Ind.Cow	Buffalo	CBCow	Ind.Cow
Total Water Use (m^3)	3.02	3.48	2.68	3.00	3.21	2.64	2.19	3.35	2.38
Milk Production (litres)	2.08	4.01	1.95	2.23	3.23	2.01	2.64	4.08	1.89
WP (Lt/m^3)	0.69	1.15	0.73	0.75	1.00	0.76	1.20	1.22	0.79
Gross WP (Rs/m^3)	11.03	16.13	10.95	11.93	14.06	11.38	12.97	12.31	7.35

entire animal life cycle by using the standard formula used in Singh (2004) and also in Kumar (2007). Using the figures of average daily milk production per animal per day, the gross return from dairying was worked out. The physical productivity of water in milk production (litres/m^3) and the gross water productivity in economic terms (Rs/m^3) were estimated using the figures of total water use per animal per day and the gross returns. The estimates for eastern UP are presented in Table 7.

Comparison of the figures of physical productivity of water in milk production shows that the figures are highest for water buyers in electric well commands. Between diesel well owners and water buyers in their

Table 8: Water Use for Milk Production in Diesel Pump Command Area, eastern UP (m^3/day)

	Diesel Pump – Owner			Diesel Pump – Water Purchaser			Electric Pump – Water Buyer		
	Buffalo	CBCow	Ind.Cow	Buffalo	CBCow	Ind.Cow	Buffalo	CBCow	Ind.Cow
Total Water Use (m^3)	4.88	3.93	2.73	3.62	3.18	3.04	4.09	5.36	3.37
Milk Production (litres)	1.69	3.53	1.37	1.68	2.30	1.18	1.86	2.97	0.88
WP (Lt/m^3)	0.35	0.90	0.50	0.46	0.72	0.39	0.45	0.55	0.26
Gross WP (Rs/m^3)	4.85	10.60	7.00	6.50	8.52	5.45	6.35	7.69	3.6

command, no major differences were noticeable. As regards gross water productivity in economic terms, the water buyers in electric well command obtain the highest values in buffalo milk production. Again, no major differences were noticeable between diesel well owners and those who buy water from them in gross water productivity. But, in case of cross bred cows, diesel well owners secure the highest water productivity, followed by water buyers in diesel well commands and lowest by water buyers in electric well commands. In the case of indigenous cows, the water buyers in diesel well commands obtain highest water productivity in rupee terms.

The estimates for south Bihar are presented in Table 10. Comparison of the figures of physical productivity of water in milk production shows that the figures are highest in case of water buyers in diesel well commands for buffalo milk; and highest in case of diesel well owners for cross bred cow, and indigenous cow. The water buyers in diesel well command secure highest gross water productivity in economic terms in buffalo milk production, while diesel well owners secure highest gross water productivity in cross bred cow and indigenous cow milk production. The farmers in electric well commands obtain the lowest figures of physical productivity of water and gross water productivity in economic terms in cross bred cow and indigenous cow milk production.

5.5 Expenditure, Net Income and Net Water Productivity in Milk Production

The total average expenditure for milk production per animal per day was estimated using the standard formula provided in Singh (2004) and Kumar (2007). Table 9 contains total expenditure in dairy production and net income from dairying per animal per day, and net water productivity in economic terms for different types

Table 9: Physical Water Productivity and Net Water Productivity in Economic Terms in Milk Production, Diesel Pump, Eastern Uttar Pradesh

	Diesel Pump – Owner			Diesel Pump – Water Purchaser			Electric Pump – Water Buyer		
	Buffalo	CBCow	Ind.Cow	Buffalo	CBCow	Ind.Cow	Buffalo	CBCow	Ind.Cow
Total expenditure (Rs/day)	17.71	20.12	17.71	20.02	22.73	18.43	12.73	19.80	14.03
Milk production (Lt)	2.08	4.01	1.95	2.23	3.23	2.01	2.64	4.50	1.89
Income (Rs)	33.34	56.18	29.32	35.74	45.17	30.09	28.44	45.48	17.51
Income from dung (Rs/day)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Gross income (Rs/day)	33.84	56.68	29.82	36.24	45.67	30.59	28.94	45.98	18.01
Net income (Rs/day)	16.13	36.56	12.10	16.22	22.94	12.15	16.21	26.18	3.98
Net WP (Rs/m^3)	5.33	10.50	4.52	5.41	7.14	4.60	7.39	7.82	1.67

Table 10: Net Water Productivity in Milk Production, Diesel Pump, South Bihar Plain

	Diesel Pump – Owner			Diesel Pump – Water Purchaser			Electric Pump – Water Buyer		
	Buffalo	CBCow	Ind.Cow	Buffalo	CBCow	Ind.Cow	Buffalo	CBCow	Ind.Cow
Total expenditure (Rs/day)	20.57	16.52	20.57	17.05	14.95	14.38	19.35	11.20	16.77
Milk production (Lt)	1.69	3.53	1.37	1.68	2.30	1.18	2.36	0.79	1.86
Income (Rs)	23.65	41.60	19.11	23.53	27.06	16.57	32.76	11.11	25.98
Income from dung (Rs/day)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Gross income (Rs/day)	24.15	42.10	19.61	24.03	27.56	17.07	33.26	11.61	26.48
Net income (Rs/day)	3.58	25.57	-0.96	6.98	12.61	2.69	13.91	0.41	9.70
Net WP (Rs/m^3)	4.98	4.06	2.84	3.62	3.18	3.04	4.92	2.81	4.09

of livestock. Comparing the estimates for the three different categories of farmers show some definite trends. For instance, the expenditure on dairy production is highest for water buyers in diesel well command, who are confronted with highest marginal cost of irrigation water, followed by diesel well owners and lowest for water buyers in electric well commands. The net income from milk production does not show any definite trends. Water buyers in electric well commands secure highest net water productivity in milk production in buffalo milk production; diesel well owners obtain highest water productivity in cross bred cow milk production; and water buyers in diesel well commands obtain highest water productivity in production of indigenous cow milk.

The estimates of daily expenditure on dairying; the net income from milk production per animal per day; and the net water productivity in rupee terms for different categories of livestock are provided for the three different categories of farmers in south Bihar villages in Table 10. Comparing the figures, no definite trend vis-à-vis expenditure, incomes and water productivity is seen to emerge.

5.6 Impact of Differential Cost of Irrigation on Water Productivity at the Farm Level

Table 11: Comparison of Water Productivity at the Farm Level at Different Irrigation Costs in Eastern UP and south Bihar

Name of Region	Farmer Category	Overall Water Productivity in Crops(Rs/m^3)	Water Productivity in Dairying (Rs/m^3)	Farm level Water Productivity (Rs/m^3)
Eastern UP	WB in Electric well	16.72	2.84	9.78
	Diesel Well Owner	10.35	3.03	6.73
	WB in Diesel well	20.06	0.17	10.20
South Bihar	WB in Electric well	17.97	1.64	9.81
	Diesel Well Owner	21.62	0.90	11.27
	WB in Diesel well	22.59	0.30	11.45

Source: authors' own estimates

Having estimated water productivity values for crops and dairying, the water productivity values for the entire farming system were worked out using the estimates of the total volume of water annually allocated to different crops and the estimated volume of water used up in dairy production as per the equations provided in Methodology. The final figures for water productivity for the crop combinations; water productivity in dairying and farm level water productivity for the locations, viz., eastern UP and south Bihar are provided in Table 11. It shows that water productivity figures are higher for the farmers who are confronted with the higher cost of irrigation water, i.e., the water buyers in diesel well commands. The exception is the water buyers in electric well commands. This is due to the inherent advantage with the location.

The higher values of farm level water productivity for water buyers in diesel well commands is mainly due to the reduced application of irrigation water for the crops, which enhances both physical productivity and

Table 12: Net Income from Crop and Milk Production, Eastern Uttar Pradesh

Type of pump	Type of farmer	Gross cropped area (Ha)	Net income from crop production (Rs)	Net income from milk production (Rs/annum)	Farm level net income (Rs)	Farm level net income (Rs/Ha)
Diesel Well	Well owner	5.29	124587.3	7152.3	131739.6	24880.2
	Water buyer	2.21	54637.6	6165.0	60802.6	27570.1
Electric Well	Well owner	5.66	74764.5	7429.5	82193.9	14528.1

Source: Authors' own estimate based on primary data.

Table 13: Net Income from Crop and Milk Production, South Bihar Plains

Type of pump	Type of farmer	Gross cropped area (ha)	Net income from crop production (Rs)	Net income from milk production (Rs./day)	Farm level net income (crop + milk) (Rs.)	Farm level net income (Rs/ha)
Diesel Well	Well owner	3.14	111736.7	10292.6	130769.5	210345.8
	Water buyer	1.70	61517.7	8130.89	76023.9	190031.1
Electric Well	Well owner	2.49	140105.5	9958.09	150063.6	191387.5

Source: Authors' own estimate based on primary data.

water productivity in economic terms for the crops. But, the improvement in physical productivity of water does not get converted into higher water productivity in rupee terms in dairy production. This is because the cost of production of dairy inputs is higher for water buyers in diesel well commands and diesel well owners.

5.7 Impact of Differential Cost of Irrigation on Farm Incomes

Overall impact of electricity and diesel price change on the farming system is analysed by considering the net return from crop and dairy farming is discussed in subsequent section. Analysis shows that the impact of cost of irrigation on farming prospects is not at all significant. While in the case of eastern UP, the water buyers in diesel well commands, who incur the highest cost of irrigation water, are earning highest income per unit of land, the electric well owners, who incur the lowest cost of irrigation water, obtain the lowest net return from unit of land (Table 12). In south Bihar, the diesel well owners are found to be obtaining highest income from every unit of land, even higher than what the water buyers in electric well commands obtain (Table 13). The difference in net returns between diesel well owners and their water purchasing counterparts is also not significant.

6. MAJOR FINDINGS

1. The impact of rising cost of diesel on the diesel well owners (in terms of cost of diesel well irrigation in real terms) is nearly 32% in south Bihar and 18% in eastern UP. But, this did not have any positive impact on the price at which water is sold by diesel well owners due to the reducing monopoly power of diesel well owners over time. The actual price at which water is available to the water buyers came down by 38% in south Bihar and 7.5% in eastern UP. The fact that the cropping pattern of diesel well owners and water buyers did not undergo any significant change over the past one and a half decade testifies this.

2. In order to analyze the potential impact the rise in diesel price would have on the farming enterprise of diesel well owners and water buyers in their command, a comparative analysis of irrigation water use, income from crops, dairying and entire farm; and water productivity in crop and milk production and at the farm level of three different categories of farmers, viz., water buyers in electric well commands, diesel well owners and water buyers in diesel well commands was carried out. It shows that higher cost of irrigation water motivates farmers to use irrigation water more efficiently from a physical point of view to minimize the cost of irrigation.

3. Ever since the Green revolution period irrigated farming has been getting transformed as a commercial proposition by the farmers. Farmers prefer crops yielding more returns and in the process reasonable price hikes in diesel do not find much importance by the farmers in their farming economies.

4. Further, the farmers who are paying higher cost for irrigation water use it more efficiently also from agronomic and economic points of view, as reflected by higher values of water productivity in both physical and economic terms they obtain.

5. The farmers who are paying higher cost for irrigation water use it more efficiently from economic point of view at the farm level than those who pay lower cost, by optimizing crop and dairy inputs; and allocating more area under crops that give higher returns. This is reflected in the highest cropping system water productivity and farm level water productivity in economic terms for the water buyers in diesel well commands.

6. The net income return farmers obtain from irrigated farming is found to be inelastic to the cost of irrigation water. The water buyers in diesel well commands, who pay the highest cost for irrigation water, get as much net returns per ha of land as the water buyers in electric well commands, who incur the least cost for irrigation water in volumetric terms. They manage to sustain the net returns by minimizing the input costs and maximizing the returns, and selecting crops that give higher returns per unit land.

7. It is clearly found that the impact of diesel price on irrigation cost incurred by diesel well owners is not significant. Also, this burden is not passed on to the water buyers due to the increasing competition, and lowering monopoly power of pump owners. Further, the analysis of the farming enterprise of irrigators under differential cost (irrigation) regimes shows that farmers would be able to cope with steep rise in irrigation costs through irrigation efficiency improvements and allocating more area under crops that give higher returns from unit of land and water, that enhance the farming returns from every unit of water and energy used. By doing this, they are able to maintain almost the same net returns from farming as in the past. This means, that the rise in cost of diesel in real terms cannot make any negative impacts on economic prospects of diesel well irrigators, including water buyers.

7. CONCLUSIONS AND POLICY IMPLICATIONS

An attempt is made to answer two important questions concerning India's farm livelihoods in this paper. They are: 1] what has been the actual impact of the rising price of diesel on millions of India's small and marginal farmers in water abundant regions who depend on irrigation pumps energized by diesel directly or indirectly vis-à-vis the cost of irrigation water?, and 2] what is likely to be the potential impact of rise in cost of irrigation water on the farming enterprise of small and marginal farmers, who are either well owners or water buyers?

Contrary to the popular perception and belief that diesel price rise causes a lot of distress among farmers, it is found that the impact of diesel price on irrigation cost incurred by diesel well owners is not significant. One reason for this is that the regions which are heavily dependent on diesel pumps for irrigation are having shallow groundwater table. Also, this burden is not passed on to the water buyers due to the increasing competition and lowering monopoly power of pump owners. One needs to keep in mind the fact that over the past two decades, there has been an explosion in irrigation pump sets in eastern India, and this had drastically reduced the monopoly power of diesel pump owners.

The analysis of the farming enterprise of irrigators under differential cost (irrigation) regimes presented here shows that farmers would be able to cope with very high rise in irrigation costs through irrigation efficiency improvements and allocating more area under crops that give higher returns from unit of land and water, that enhance the farming returns from every unit of water and energy used. By doing this, they are able to maintain almost the same net returns from farming as in the past. This means, that the rise in cost of diesel in real terms had not made any negative impact on economic prospects of diesel well irrigators, including water buyers.

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WASTEWATER TREATMENT AND REUSE: AN INSTITUTIONAL ANALYSIS FOR HYDERABAD, INDIA

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Abstract

The current paper presents an institutional analysis of wastewater (non) treatment and reuse scenario using the case study of Hyderabad, India. The objective of the institutional analysis in the current study is to determine the extent and the character of an observed gap between declared rules (formal) and rules-in-use (informal practices) in the context of wastewater disposal, use and its adverse impact on environment and people of Hyderabad. The analysis shows that there is a wide gap between the declared rules and rules-in-use due to: insufficient organizational capacity to implement and monitor the rules, lack of awareness among people, poor water and sewerage pricing system, insufficient attention and budget towards environmental issues of water pollution and the fact that the rules have not kept pace with the changing socio-economic realities of the society. This gap has been used as an indicator to suggest that a change in the existing institutional framework of wastewater treatment and reuse scenario is essential. The suggested changes include: increase awareness among people on the need to protect our rivers and other fresh water sources; need to increase the general efficiency of the water boards; increased allocations of budgets for wastewater treatment and to improve the quality of our rivers; need to change the pricing strategy for the water supply and increase the sewerage cess; make efforts to increase the trust of people on the water boards; ensure solid waste management of the city; ensure treatment of industrial wastes before they are released into the river.

1. INTRODUCTION

"Institutions are the humanly devised constraints that shape human action (North. 1990)". They set the ground rules for resource use and establish the incentives, information, and compulsions that guide economic outcomes. Institutions evolve with changes in the society and its priorities. From an economist's viewpoint, institutions affect the performance of an individual, group, organization, a country or its economy, through the effect they have on the costs of exchange and production. Together with technology, the institutions determine the transaction and transformation (production) costs (North, 1990). The current paper presents an institutional analysis of wastewater treatment and reuse scenario.

For more than 30 years now, wastewater from the Hyderabad city has been flowing into Musi river untreated. A couple of decades ago, when the population of Hyderabad was quite small, it was not considered an issue of river pollution. However in the last ten years (1991-2001), the population of Hyderabad has increased by 19.3% (JNNURM, 2005) resulting in increased wastewater flows into the Musi river leading to further deterioration. The Musi river receives fresh water from rains during June, July and August and would have remained dry, but for the 700 million liters of untreated wastewater released into it every day from the city drains. This water is extensively used for irrigation of leafy vegetables on a small scale, para grass and paady. About 2100 ha of para grass and 10,000 ha of paddy is cultivated with un-treated wastewater (Mekala, 2006).

Initial estimates show that more than 7000 households depend directly or indirectly on para grass grown in urban and peri-urban areas for income generation and food security and about 58000 households in 16 villages further downstream of Musi river depend on wastewater irrigation for paddy cultivation for their food security (Mekala. 2006). However, since the wastewater is untreated, its use in agriculture is associated with certain

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The analysis presented in this paper forms a part of the research, which is being carried out for the PhD thesis by the first author.

health and environmental risks. Untreated wastewater caries helminthes, protozoa, bacteria and viruses (arranged in order of highest risk to lowest risk), which can cause number of health problems among farmers and consumers, if no proper precautions are taken. One study by Jeroen Ensink of IWMI on helminth infections among wastewater farmers shows that a number of other factors like sanitation facilities and defecation practices influence the health of people more than wastewater irrigation. Diarrhea and retarded growth among young children is also very common in wastewater irrigated areas. Soil contamination and groundwater pollution are the major environmental problems of wastewater. It was found that, in all wastewater irrigated areas, the groundwater is so saline that it cannot be used for potable purposes (Buechler and Mekala, 2003). Also, paddy yields have decreased by 40-50% over the years due to soil contamination by continuous wastewater irrigation (Buechler and Mekala, 2005). The socio-economic impacts include – loss of work days due to bad health, expenses incurred on medication and reduction in yields.

The challenge is to improve the river health and minimize the negative effects of wastewater irrigation without compromising on the livelihoods of the people dependent on it. International Water Management Institute (IWMI) has identified certain options to minimize these ill effects which include - community based decentralized treatment systems; regular monitoring of irrigation water quality; prevent mixing of household wastewater with industrial wastewater; change in cultivation and cropping practices; awareness and education to farmers, vendors and consumers of wastewater products on health, hygiene and sanitation and regular anti-helminthic medication programs. However, very little understanding is gained on the overall institutional framework of wastewater markets.

The objective of institutional analysis in the current study in the Hyderabad context is to determine the extent and the character of the observed gap between declared rules (formal) and rules-in-use (informal practices) in the context of wastewater disposal, use and its adverse impact on environment and people. This gap has been used as an indicator to suggest that a change in the existing institutional framework of wastewater treatment and reuse scenario is essential. The results of this analysis are used to formulate recommendations for possible change such that performance can be better and transaction costs are less in the new institutional framework. The current paper presents part of this analysis and recommendations for change using Hyderabad as a case study.

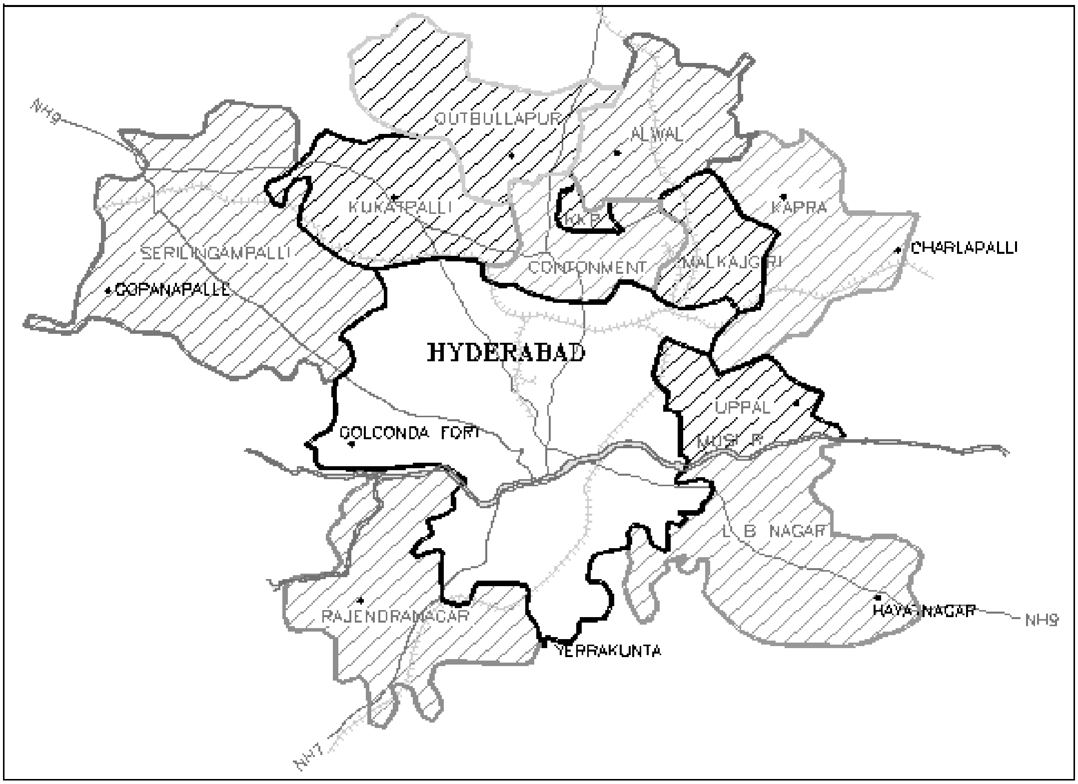
The data and information for the institutional analysis is collected from primary survey (100 respondents), personal interviews and secondary sources from different documents, institutions and government organizations concerned with and related to wastewater law, policy and administration in Hyderabad. The scope of this paper is restricted to the analysis of the gaps between the declared rules of the Hyderabad Metro Water Supply and Sewerage Board and the current rules-in-use.

2. PHYSICAL SETTING

Hyderabad is the fifth largest city in India and has lately become an information technology hub creating thousands of new jobs. The 625 sq km area under the Greater Hyderabad Municipal Corporation (GHMC), which has a population of 67 lakhs (The Hindu newspaper. April 16, 2007). The population projections for 2011 for the twin cities (Hyderabad and Secunderabad) range from 9.5 to 11.3 million people (HUDA, draft master plan for 2011). The Musi river, which is a tributary of Krishna river flows from west to east right through the heart of Hyderabad and all the wastewater from the main city area flows into Musi river and more than 90% of it is untreated. The natural drainage area (see figure 1) of river Musi within the limits of twin cities covers Municipal Corporation of Hyderabad, Osmania university, Secunderabad cantonment area and three surrounding municipalities viz., Uppal, Malkajigiri and Gaddiannaram and partially covers five surrounding municipalities viz., L.B.Nagar, Rajendranagar, Kukatpally, Quthbullapur and Kapra. All the domestic and industrial sewage currently flows into Musi river polluting it completely.

The inflow of domestic and industrial wastewater into the Musi river is currently more than 700 million litres per day of which more than 90% is untreated and used for irrigation in the downstream areas (see figure 2). With no/decreasing fresh water inflows from the upstream areas, Musi river has mainly become a natural sewage drain for Hyderabad with detrimental effects on the environment and people downstream of the city. Table 1 indicates the quality of Musi river water at various locations [A is in the city, B is on the fringe of the city, C is peri-urban and D & E are in the rural areas along the river downstream of Hyderabad].

Figure 1: Hyderabad City with Surrounding Municipalities



Source: HMWSSB, 2006

Table 1: Results of Monthly Water Samples Collected from November 2005 to July 2006

Sample locations	Mean Total nitrogen mg/L	Mean BOD mg/L	Mean EC μs/Cm	Mean DO mg/L
A [Amberpet)	35.78	151.55	1367	0.122
B (Peerzadiguda)	32.9	98.22	1636	0.162
BC (between B & Gowrelli)	34.35	62.55	1636	0.318
D (Pillaipally)	30.97	40.55	1705	2.9
E (Battugudam)	18.325	27	1753	3.722

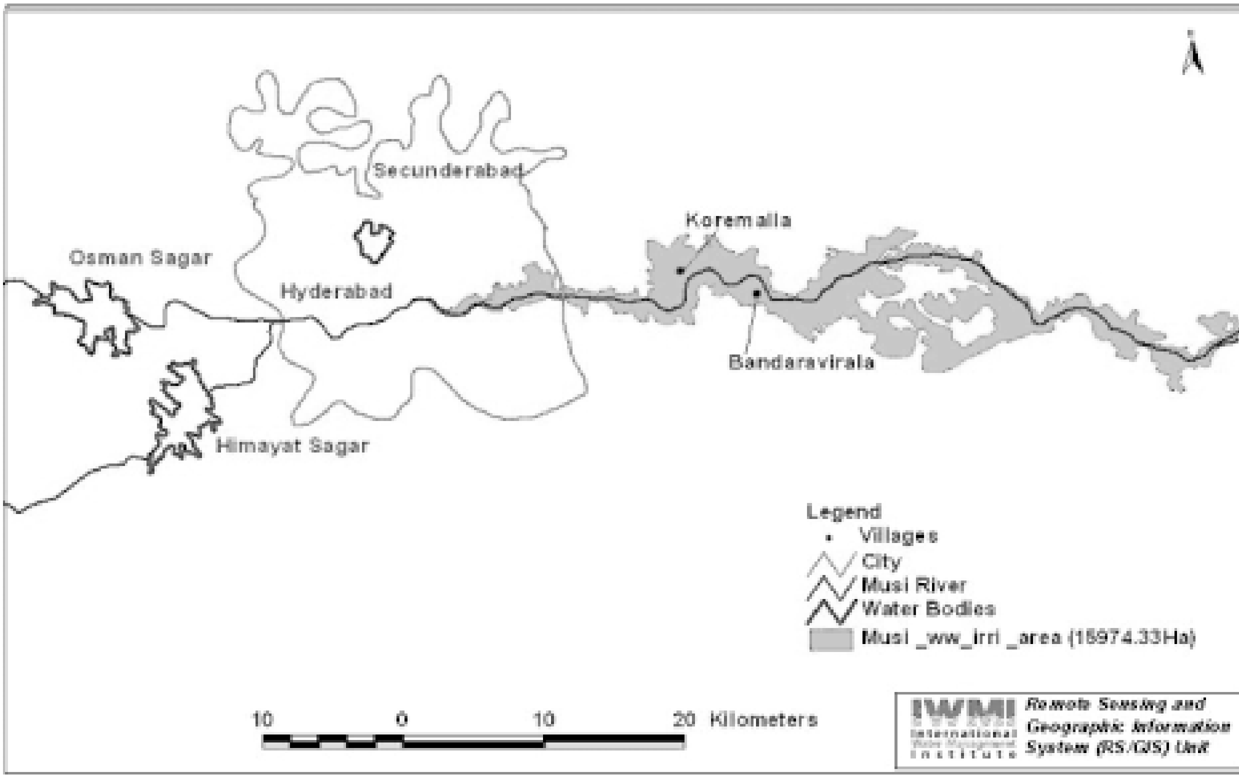
Source: Dr. Robert Simmons & team [IWMI] as part of a BMZ project & reproduced here with permission.

3. RESULTS AND DISCUSSIONS OF THE INSTITUTIONAL ANALYSIS

Institutions can be both formal and informal. In addition to written laws, rules and protocols, informal procedures, norms and practices accepted by society and followed over several years become part of the institutional framework. According to Merrey (1993), certain patterns of norms and behaviors persist because they are valued by people for practical and other reasons. In such cases, informal rules have a tendency to override formal rules. This is common in many developing societies, making the enforcement of formal rules very difficult and thereby affecting performance (Bandaragoda and Firdousi, 1992). Formal and informal institutions coexist in many societies. Informal rules and practices, which replace declared laws, rules and regulations, are referred to as "rules-in-use" by Bandaragoda (2000). A number of such rules-in-use exist in the current wastewater disposal and reuse situation in this case study which are discussed in this section.

This section presents the gaps between the declared rules and rules-in-use, reasons for these gaps and consequences of non-compliance.

Figure 2: Wastewater Irrigated Agriculture Along Musi River



Source: Landsat Image. 2005. IWMI Hyderabad, India Office.

3.1 Gaps between Declared Rules and Rules-in-Use

The Hyderabad Metropolitan Water Supply and Sewerage Act No 15 of 1989 make provision for water supply, sewage and sewage treatment in the Hyderabad Metropolitan Area and for matters connected therewith. The current section presents the declared rules and the actual rules-in-use, the magnitude of the gap between the two and the reasons for such a gap. As mentioned earlier, this gap is used as an indicator to analyse the current institutional set up and the requisite change required to make the system of wastewater disposal, treatment and use more efficient and less harmful to the environment and humans.

3.1.1 Declared Rule - Chapter V: Sewerage and sewage treatment works

Section 54: Certain matters not to be passed into the Board sewers and sewage treatment works: Save as otherwise provided in the Water (Prevention and Control of Pollution) Act, 1974, relating to discharge and disposal of industrial effluents and other objectionable effluents, no person shall throw empty, or turn into any board sewers,

a) any matter likely to damage or interfere with the free maintenance or execution or otherwise to effect prejudicially the progress of work; or
b) any roof water; or
c) any chemical, refuse or wastewater or stream or any other industrial effluent from any type of industry, trade and business which may cause danger or nuisance or may be prejudicial to the health or;
d) any dangerous petroleum or petroleum products.

3.1.1.1 Rule-In-Use

a) In Hyderabad, disposing of solid waste in the public open drains is a common practice and no penalties are imposed on people who commit such an offence. Many times, sewage drains have been seen to overflow due to blockages causing public nuisance and creating an environment congenial for germs to thrive. The main reason for this is that there is no provision for proper solid waste disposal in the city. Only in some areas, the municipality is active in collection and disposal of waste and in most parts of the city, people have to make their own provisions for solid waste disposal. Households who cannot or do not want to pay for their solid waste disposal, blindly dump their waste into sewerage drains or river (people living close to the river).
b) Most houses and apartment buildings in Hyderabad do not have rain water harvesting systems and hence most roof water ends up in drains mixing with the sewage water and finally enters the Musi river. Old buildings were not mandated by law to have rain water harvesting structures and do not intend to invest in them now. New builders have got away with this rule for various reasons (see section 64 below in point 3.1.3).
c) A number of small and large industries have been known to illegally dump their effluents either directly into the sewage drains or into the river resulting in severe pollution and adverse impact on the fish and crops in the areas down stream of Hyderabad. There are a number of probable reasons for this kind of behavior (greed, lack of treatment facilities, expensive treatment facilities, lack of concern for nature, lack of monitoring and strict enforcement of rules), but no detailed studies are available to pin-point the reasons.
d) In a number of personal interviews with farmers in the peri-urban areas of Hyderabad, farmers have complained about the dumping of various kinds of unknown chemicals and petroleum products in the river causing severe crop losses to farmers.

3.1.2 Declared Rule - Section 60. New premises not to be erected without drains or sewers:

(1) In area in which board sewers are provided, it shall not be lawful to erect or to re-erect any premises or to occupy any such premises unless,
    (a) a sewer be constructed of such size, materials and descriptions at such level and with such fall as shall appear to the board to be necessary for the effectual sewerage of such premises;
    (b) there have been provided and set upon such premises such appliances and fittings as may appear to the board to be necessary for the purpose of gathering or receiving the filth and any other polluted and obnoxious matter from and conveying the same off, the said premises and of effectually flushing the drain of the said premises and every fixture connected therewith.
(2) The sewer so constructed shall empty into a board sewer.
(3) The provisions of this section shall be applicable to premises any part of which is situated within a distance of thirty-five meters from a board sewer.

3.1.2.1 Rules-In-Use

Builders and people in general have violated this rule time and again. New houses and buildings are erected with no sewerage in place often emptying their sewage into the next/nearest vacant plot or fresh water lake polluting the groundwater or lake. The reason for this is that it takes initial investment on the part of the builders to layout a sewerage network and they save money and effort by not laying out the network and in turn sell the plots for a little less price to people who are more than willing to buy it even without a sewer network in place because of the high demand for space. Often people construct their own sewer drains during the construction of their house, but if there is no house constructed in the neighboring plot, and if the owner of the neighboring plot does not intend to construct a house for a long time, then, the continuity of the sewer line is broken and often the empty plots are filled with sewage water creating mosquito problems and bad odour and an unsightly view to all those around. Community sense is often lacking in urban areas and collective action is often not possible due to varying interests of the people.

3.1.3 Declared Rule - Section 64. Sewage and rainwater for drains to be distinct

Whenever it is provided in this chapter that steps shall or may be taken for the effectual drainage of any premises, it shall be competent to the board to require that there shall be one drain for filth and polluted water and an entirely distinct drain for rain water and unpolluted sub-soil water or both rain water unpolluted sub-soil water each emptying into separate Board sewer or Corporation drain or other suitable places.

3.1.3.1 Rules-In-Use

With a sudden increase in the population, the existing sewerage network of Hyderabad became inadequate to carry all the sewage of the city, hence emptying sewage into the storm water drains and finally releasing the untreated sewage water into the Musi River. Also, most households do not have rainwater harvesting structures in place and hence all the rainwater from rooftops ultimately ends in the sewage channels and finally drains into the river. Many of the new houses now install rainwater-harvesting structures to comply with the rules but often these rainwater structures go into dis-use after sometime because of lack of maintenance of the structures and lack of interest and awareness of the people. There are a number of reasons why people do not have rainwater harvesting structure viz., lack of interest, lack of technical know-how, lack of space and lack of awareness of the value of rainwater among the people.

3.1.4 Declared Rule - Section 65. Appointment of places for the emptying of sewers and disposal of sewage

The board may cause any or all the board sewers to empty into, and all the sewage to be disposed of at such places either within or outside Hyderabad metropolitan area or in any places in the state, as it considers suitable:

a. Provided that no place which has not been before the commencement of this chapter used for any of the purposes specified in this section shall, after such commencement, be used therefore without the approval of the Board;
b. Provided further that on and after such date as may be appointed by the Board in this behalf, no sewage shall be discharged into any water-course until it has been treated in such manner as may be prescribed in the by-laws made in this behalf.

3.1.4.1 Rule- In-Use

Currently there are only two sewage treatment plants in Hyderabad. One at Necklace road with a treatment capacity (upto secondary level) of 20 mld and another at Amberpet with a treatment capacity (upto primary level only) of 113 mld. More than 90% of wastewater undergoes no treatment and is directly discharged into the Musi river. The main reason for this is that wastewater treatment is an expensive process and most municipalities and water boards could not afford to set up new treatment plants with increase in wastewater supply without outside help. As per the rule, water boards can charge only 35% of the water supply charges as a sewerage cess and often this money is not enough to actually treat the wastewater.

However, a new project called "Abatement of Pollution of River Musi" has been launched in a drive to clean the river. Government of India and Government of Andhra Pradesh will share the capital cost of the project. It is proposed that the National Rivers Conservation Directorate (NRCD) under the 10th Plan will provide funds to the state government to the tune of 70% of the total capital cost and remaining 30% of the capital costs will be paid by the state government itself. In addition to their share in the capital cost, NRCD will also share operation and maintenance costs of the plant for first six months. The assets created under the project will be property of the state government and the state government will be responsible for its proper operation and maintenance then after.

Table 2: Location and Capacities of Proposed Sewage Treatment Plants

Plant	2007 (mld)	2021 (mld)
Amberpet	339	815
Nagole	172	366
Nalla-cheruvu	30	134
Attapur	51	121
Total	592	1436

Source: HMWSSB Master Plan, January 2008

The current status of the completion of different STPs under the Abatement of Pollution of River Musi project [under the NRAP assistance] is shown in Table 3.

Table 3: Status of the STP Under the Abatement of Pollution of River Musi Project

STP location	Capacity	% completed	Date of completion
Amberpet	339 mld	85% completed	31-12-2007
Nagole	172 mld	77% completed	31-03-2008
Nalla-cheruvu	30 mld	55% completed	31-03-2008
Attapur	51 mld	Tender stage	31-12-2008

Source: HMWSSB. January 2008

3.1.5 Declared Rule - Section 75: Regulations regarding sewage:

The board may with the previous approval of the government, make regulations to carry out the purposes of this chapter. In making any regulation under this section, the board may provide that a breach thereof shall be punishable with fine, which may extend to one thousand rupees and in case of continuing breach with an additional fine which may extend to hundred rupees per day during which the breach continues after receipt of a notice from the Board to discontinue such breach.

3.1.5.1 Rules-In-Use

From personal interviews with people, it is seen that often people do not pay fines even after repeated warnings from the water board officials. At the same time, a field study conducted in Hyderabad, India by Raghavendra (2006) suggests that households were actually unhappy with the poor performance (poor measurement of domestic water consumption and institutional indifference towards improving the quality of service) of the HMWSSB. Some households in Hyderabad receive municipal water supply once every other day and some others once in a week even though both pay the same monthly flat rate (depending upon the diameter of the supply pipes. This difference in quantities of water supplied also de-motivates people and reduces trust on authorities. Hence, the problem lies both with people's attitude and the water board's performance.

3.1.6 Declared Water Quality Guidelines

Table 4 presents the water quality guidelines for different uses as per the Central Pollution Control Board.

Table 4: Water Quality Criterion for Designated Use as Per CPCB

Designated-Best-Use	Criteria
Drinking water source without conventional treatment but after disinfection [Drinkable quality]	1. Total coliforms organism MPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 6 mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 2 mg/l or less
Outdoor bathing (Organized) [Swimmable quality]	1. Total coliforms organism MPN/100ml shall be 500 or less pH between 6.5 and 8.5, Dissolved Oxygen 5 mg/l or more 2. Biochemical Oxygen Demand 5 days 20°C 3 mg/l or less
Drinking water source after conventional treatment and disinfection [Drinkable quality after treatment]	1. Total coliforms organism MPN/100ml shall be 5000 or less pH between 6 to 9, Dissolved Oxygen 4 mg/l or more 2. Biochemical Oxygen Demand 5 days 20°C 3 mg/l or less
Propagation of wild life and fisheries [Fishable quality]	1. pH between 6.5 to 8.5, Dissolved Oxygen 4mg/l or more 2. Free Ammonia (as N) 1.2 mg/l or less
Irrigation, industrial cooling, controlled waste disposal [Boatable quality]	1. pH betwwn 6.0 to 8.5 2. Electrical Conductivity at 25°C max., 2250 micro mhos/cm 3. Sodium absorption ratio max., 26 4. Boron max., 2 mg/l

Source:http://www.cpcb.nic.in/Water/waterqualitycriteria.html

3.1.7 Current Practice

Table 1 and Table 5 clearly indicate that Musi river water downstream of Hyderabad is not fit for any uses as mentioned by the Central Pollution Control Board (CPCB) (see Table 5) and yet, Musi river water has been extensively used for irrigation of more than 10,000 ha of para grass and paddy in peri-urban Hyderabad. In many countries of the developing world, farmers use wastewater out of necessity and it is a reality that cannot be denied or effectively banned (Buechler *et al*. 2002). The main reason for the non-compliance of farmers with the prescribed guidelines for water quality is lack of alternate sources of irrigation and benefits derived from the crop production. In the rural areas downstream of Hyderabad which use Musi wastewater, it was found that wastewater irrigated paddy contributes almost 43% of household food consumption and that households with more than one acre of land and more than five household members grow vegetables like tomatoes, chillies, eggplant and corn for household use on part of their land (Buechler and Mekala. 2003).

Table 5: Quality of Water in River Musi at Various Points as it Passes through Hyderabad.

S.No	Composite Samples at	pH	DO (mg/l)	TDS (mg/l)	BOD (mg/l)	COD (mg/l)	TKN (mg/l)	Faecal Coliform MPN/100ml x10 ^{5}
1.	Nagole Bridge	6.90	Nil	1102	112	219	14	2.9
2.	Musoorambagh	6.86	Nil	962	97	156	13	3.1
3.	Chadarghat Br	6.80	Nil	930	105	187	12	2.8
4.	Imliban Station	6.74	Nil	970	74	143	11	4.00
5.	Puranapul	7.20	0.8	808	86	174	12	2.70
6.	Attapur Bridgel	7.22	2.0	740	65	139	13	1.80
7.	Bapughat	7.42	2.1	620	46	87	10	1.60

Samples tested: November 2001

Source: Reproduced from the project report prepared by MWH India Private Limited on the Musi River Conservation Project. Volume 1, January 2002.

4. CONCLUSIONS

The mismatch between declared rules and rules-in-use and the reasons for the gap suggest that the institutional framework is weak and does not actually support or facilitate the implementation of all the declared rules. The key conclusions that can be drawn from the above analysis are:

1. The declared rules are too idealistic and ambitious considering the available capacity of the organizations who are supposed to ensure their implementation. (the relevant organizations and their roles is not within the scope of this paper).
2. The rules have been declared two decades ago (1987) and have not kept pace with the changing socio-economic condition of the city, rapid population growth and the people and hence there is a big gap between the declared rules and rules-in-use.
3. The cost of water supply, treatment of wastewater and others have increased tremendously. However, the pricing of water and sewerage services has not kept pace with this price rise.
4. The government and water boards have always concentrated on ensuring the water supply to the cities, but wastewater treatment and disposal have always been given low importence on the agenda and hence never provided enough budget outlay for the same.
5. Often, urban people are not aware of the gravity of problems associated with the wastewater disposal and treatment and hence apathy towards such issues.

5. CHANGES REQUIRED IN THE INSTITUTIONAL SET-UP

There is an urgent need to make certain changes in the current institutional set-up to improve the wastewater situation in Hyderabad and minimize the adverse effects before it gets too expensive for the society in general. The following actions are recommended based on the above analysis:

1. Increase awareness among people on the need to protect our rivers and other fresh water sources. Most people surveyed (100 respondents) in the study were not even aware how much they paid for their water and sewerage services.
2. Need to increase the general efficiency of the water boards to cater to the needs of the people and also cope with the increasing demand for high quality water and better urban quality of life. There is a need for dynamic leaders in water related institutions / organizations who could improve the general efficiency of

these organizations to deliver the outputs at a lesser cost.

3. The budget allocations for environment have been very poor (0.02 % of the total outlay) and there is a case for increased allocations for wastewater treatment and improve the quality of our rivers.

4. Need to change the pricing strategy for the water supply and increase the sewerage cess (currently 35% of the water supply charges) to cover the maintenance costs for the new treatment plants.

5. Of the 100 respondents surveyed in this study, more than 40% of them said that they were willing to pay for wastewater treatment provided they were given the guarantee that their money would be used to right use and with high efficiency. Therefore, to gain the trust of the people, before the water boards actually increase the sewerage cess in the water bills, it is essential that they first invest (loan money from central and state governments) in treatment plants and start treating the wastewater. Once people can clearly see change in the quality of river water, then government can increase the sewer cess.

6. In addition to liquid waste management, the solid waste management of the city also needs to be improved to prevent illegal dumping of solid waste into the city drains and river. Otherwise, the very purpose of treatment of wastewater would be defeated.

7. Until and unless the industrial wastes are pre-treated before release into the river, the river can never be made clean. Strict monitoring and high penalties are essential to prevent illegal dumping of industrial wastewater into the river.

Finally, it is concluded that there is a need for change in the behaviors of different stakeholders, organizations and adapt existing rules to bring the desired changes in the overall institutional set-up.

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ECONOMICS OF DRIP IRRIGATED COTTON: A SYNTHESIS OF FOUR CASE STUDIES

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Abstract

Studies on different crops confirm that drip method of irrigation saves substantial amount of water, increases productivity of crops as well as reduces cost of cultivation. However, detailed studies are seldom available about the economics of cotton cultivation under drip method. Therefore, an attempt is made here to find out the impact of drip irrigation on various parameters including its economic viability. The study shows that cultivating cotton under drip irrigation provides a number of different benefits to farmers over the conventional flood method of irrigation. Drip irrigation reduces cost of irrigation by about 50% and helps reduce the cost on weeding, interculture and preparatory works. Water saving in drip irrigation in cotton cultivation is estimated to be about 45% of flood irrigation. This also saves the consumption of electricity by about 140 Kwh/acre compared with flood irrigation. The productivity of drip-irrigated cotton is about 114% higher than the corresponding flood irrigation harvest. The profit of the cotton crop cultivated using drip irrigation is higher by about Rs. 20601/acre than the corresponding profit realised by flood irrigation. The net present worth and benefit-cost ratio estimated using discounted cash flow technique shows that the investment in drip irrigation is economically viable even without subsidy. The analysis also shows that the farmers would be able to repay the whole capital cost of drip system from the income generated in the very first year of raising the crop.

1. INTRODUCTION

The intensification of agriculture along with increased demand for water from other sectors has put tremendous pressure on the limited water resources in recent years in India. An estimate by the Central Water Commission (CWC) shows that by 2050, the annual requirement of water from all sectors (1447 BCM) would exceed the annual utilisable water from both surface and groundwater sources in India (1122 BCM) (CWC, 2005).[1]

While the available fresh water supplies for future use have been declining at a faster rate, the requirement of food and other agricultural commodities has been on the rise because of continuous population growth and feed requirement for livestock (see, Bhalla, et al., 1999; Amarasinghe, et al., 2007; Chand, 2007). Since irrigation contributes substantially to the gross production of agricultural commodities, the fast increase in demand for irrigation water puts enormous pressure on policy makers to find ways to improve agricultural production while economising irrigation water. The conventional method throughout the world for crop cultivation is flood irrigation. It is inefficient in terms of field application efficiency and eventually the overall water use efficiency as it allows heavy losses of water through conveyance and distribution (Shreshtha and Gopalakrishnan, 1993; Rosegrant and Meinzen-Dick, 1996; Rosegrant, et al., 2002; Postal, 2001). Quite a few supply side efforts have been made to increase the water use efficiency under flood irrigation method (FIM) in India and elsewhere in the world. However, those efforts and strategies have not made any significant impact on the overall water use efficiency in both canal and groundwater irrigation.

Drip irrigation method (DIM) is a technical measure introduced about two decades back to increase the water use efficiency in Indian agriculture[2]. Under this method, water is delivered directly to the root zone of the crops using pipe network and emitters. This method is entirely different from the conventional method,

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where water is dispersed to the whole cropland, instead of exclusively to the crop. Since water is supplied at the required time and the required quantity using pipe network, excess irrigation as well as water losses occurring through conveyance and distribution are eliminated. Experiment based studies show that the water use efficiency can be achieved upto 100% under DIM, whereas the same is possible only in the range of 35-40% under flood method of irrigation (INCID, 1994; Sivanappan, 1994). Besides saving water, DIM is also capable of enhancing crop productivity at low cost of cultivation (Narayanamoorthy, 1997, 2004 and 2005; Dhawan, 2002).

DIM is a relatively new method of irrigation. It entails relatively large amount of fixed capital investment. Therefore, several studies have been carried out to find out the impact of DIM on different parameters of crop cultivation including its economic viability in different crops, using both experimental and field level data (see, INCID, 1994, Narayanamoorthy, 1997; 2003, 2004; Dhawan, 2002). Studies especially carried out using field survey data on crops such as banana, grapes and sugarcane have showed that the DIM saves water by about 30-40%, increases productivity by 30-45% and considerably lowers the cost of cultivation compared to the same crops cultivated under FIM with similar environment. Studies have also showed that investment in drip irrigation is economically viable for farmers even without subsidy (see, Narayanamoorthy, 1997, 2004 and 2005).

Though studies on the impact of DIM on many other crops are available, studies on cotton cultivation under DIM using field level survey data are seldom available especially on the Indian context.[3] Cotton is an important commercial crop cultivated in India covering an area of about 8.68 mha in 2005-06 (GoI, 2007). Though cotton is predominantly cultivated as a rainfed crop, about 33% of the cotton area is cultivated under surface irrigation method in India. Because of inherent problems associated with the surface irrigation and increased water scarcity, farmers are not able to supply water at the required time interval for cotton, which increases the moisture stress on crops. As a result, farmers are not able to increase the productivity of the crop despite using required yield-increasing inputs, The productivity of cotton crop is one of the lowest in the world.[4] The experimental data based studies carried out in different locations show that cotton cultivated under DIM increases productivity by about 25% and water saving by 60% (INCID, 1994). Realising the importance of DIM on water saving and productivity, farmers in different parts of India have started adopting it especially in the recent years. Why do farmers cultivate cotton crop under DIM? What is the main driving force for the increased adoption of DMI in cotton cultivation? What is the impact of DIM on water saving and productivity of cotton? Is the investment in drip irrigation economically viable for farmers without subsidy? What is the pay back period of drip investment in cotton cultivation? Since studies focusing on these issues using field level survey data are not available, this study makes an attempt to fill this void using the data collected from farmers cultivating cotton in Maharashtra state. The specific objectives of the study are: (1) To find the operation-wise cost saving due to drip method of irrigation in cotton cultivation. (2) To estimate the water and electricity saving due to DIM in cotton cultivation. (3) To study the impact of DIM on the productivity of cotton crop. (4) To study the relative economics of drip and non-drip irrigated cotton crop. (5) To estimate the economic viability of drip investment with and without capital subsidy under different discount rates assuming different life periods of the system.

2. EMPIRICAL SETTINGS AND METHOD

This paper is a synthesis of in-depth case studies[5] of four individual farmers selected from Jalgaon district of Maharashtra, an important cotton-growing state accounting for about 33% of India's total cotton area during 2005-06. Severe groundwater scarcity along with frequently interrupted supply of electricity have forced the farmers to cultivate cotton under drip method of irrigation in certain parts of Maharashtra state in the recent years. Jalgaon, a district in the north-western part of Maharashtra has been selected for this study to capture the impact of drip irrigation on various parameters of cotton cultivation. From three different villages[6], we have selected four farmers each with different land holding sizes cultivating uniform variety (Bt cotton) of cotton under both drip and flood method of irrigation. This is done to moderate the impact of soil and other environmental factors on water consumption and productivity of crop. In addition to in-depth discussions with the selected farmers on the cultivation of cotton under drip irrigation, all the data associated with cotton cultivation pertaining to the agricultural year 2006-07 have been collected from the farmers to carry out a detailed analysis and make a comparison between the crops under drip and flood irrigation.

In order to find out the economic viability of investment in drip irrigation in cotton cultivation, both net present worth (NPW) and benefit-cost ratio (BCR) are estimated using discounted cash flow technique (Gittinger, 1984). INCID (1994) study assumed 5 years as a life period of the drip set for computing the benefit-cost ratio of cotton crop under DIM. However, the experiences of the farmers cultivating cotton in the study area under DIM and the sources from drip industry seem to suggest that the drip system can last up to 15 years without incurring any heavy cost on operation and maintenance. Therefore, NPW and BCR are computed separately treating 5, 10 and 15 years as life period of the drip system. Though the rate of interest for institutional credit is currently around 10%, we have estimated NPW and BCR separately keeping 10% and 15% discount rates.

The NPW is the difference between the sum of the present value of benefits and that of costs for a given life period of the drip set. It collates the total benefits with the total costs taking into account items such as cost of capital and depreciation costs of the drip set. As per the NPW criterion, the investment on drip set can be treated as economically viable if the present value of benefits is greater than the present value of costs. The BCR is closely related to NPW as it is obtained by dividing the present worth of the benefit stream with that of the cost stream. If the BCR is more than one, then the investment on any project can be considered as economically viable. Obviously, a BCR greater than one implies that the NPW of the benefit stream is higher than that of the cost stream (Gittinger, 1984). The NPW and BCR are mathematically defined as follows:

$$\text{NPW} = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad \ldots\ldots (1)$$

$$\text{BCR} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}} \quad \ldots\ldots (2)$$

[Where, B_t = benefit in year t; C_t = cost in year t; t = 1, 2, 3,…….n; n = project life in years;i = rate of interest or the assumed opportunity cost of the investment]

Drip irrigation involves fixed capital and thus, it is necessary to take into account the income and cost stream for the whole life span of drip investment. However, it is difficult to uncover the actual cash flows for the entire life span of drip investment because of the absence of observed temporal information on benefits and costs. So, we have made a few realistic assumptions to estimate both the cash inflows and cash outflows for drip investment. These assumptions are:

1. The life period of the drip set is assumed to be 5, 10 and 15 years, and on that basis, three different NPW and BCRs are worked out.
2. The cost of cultivation and income generated using drip method of irrigation is assumed constant during the entire life period of drip set.
3. Two different rates of discount (interest rates) are considered to understand the sensitivity of investment to the change in capital cost. They are assumed at 10 and 15% as alternatives representing different opportunity costs of capital.
4. The cultivation technology of cotton crop is assumed to remain constant during the entire life period of drip set.

3. COST OF CULTIVATION

While saving water and increasing productivity of crops, DIM reduces the cost of cultivation especially in operations like irrigation, weeding, ploughing and preparatory works. To understand the impact of DIM on various operational costs of cultivation, we have compared the costs of each of the operations for drip and flood irrigated crop. The data on operation-wise cost of cultivation presented in Table 1 show only a marginal difference in the total cost of cultivation[7] between the two methods. However, when we exclude the harvesting cost from the gross cost of cultivation, the overall cost saving due to DIM comes to nearly 17% over FIM. Harvesting cost is directly associated with the yield of cotton, and as the yield of crop cultivated under DIM is substantially higher, cost incurred by the farmers on account of harvesting is necessarily higher for DIM crop.

Table 1: Operation-wise cost of cultivation of drip and flood irrigated cotton (Rs/acre)

Sr. No.	Operation	DIM	FIM	Gain over FIM	
				Amount	Percent
1.	Preparatory works	950.00	1537.50	587.50	38.20
2.	Seed and seed sowing	1020.00	1020.00	0.00	0.00
3.	Fertilisers	2042.25	1868.50	-173.75	-9.30
4.	Farm yard manures (FYM)	2750.00	2750.00	0.00	0.00
5.	Pesticides	3750.00	4750.00	1000.00	21.05
6.	Weeding and interculture	290.00	490.00	200.00	40.80
7.	Irrigation	864.60	1773.10	912.50	51.40
8.	Harvesting	5200.00	2500.00	-2700.00	-108.00
9.	Others	537.50	500.00	-37.50	-7.50
	Total cost	17404.40	17193.10	-211.20	-1.20
	Total excluding harvesting cost	12204.40	14693.10	2488.80	16.90

Source: Case study data.
Note: Operation-wise cost includes both inputs and labour cost (i.e., cost A2+FL).

As confirmed by earlier studies on other crops, among the various operations, substantial cost saving is noticed in operations like irrigation[8] (51%), weeding and interculture (about 40%) and preparatory works (about 38%). While the reduced consumption of water under DIM reduces the cost on irrigation, relatively fewer requirements of ploughing and other preparatory works for cultivating crop under DIM. Since water is supplied only at the root of the crops and not to the non-crop zone, weed growth is reduced substantially, which eventually reduces the labour requirement for weeding and interculture operation in cotton cultivation. Interestingly, we did not observe substantial difference in the use of yield increasing inputs such as fertilisers, FYM and pesticides between the two methods of irrigation. This seems to suggest that the farmers are not discriminating the crops in terms of adoption of yield-increasing inputs while cultivating cotton under FIM or DIM. There is little difference in the gross cost of cultivation for drip and non-drip irrigated crop.

4. WATER AND ELECTRICITY SAVING

Applied water saving and electricity saving are two significant advantages of drip method of irrigation. Since water is supplied directly to the root zone of the crop under DIM, substantial amount of water losses occurring due to conveyance, distribution and application at the field level are reduced. Under experimental based studies, water consumption is usually estimated as depth of water applied (in terms of cm or mm). But, the same method is difficult to follow at the farmers' field because of changes in the horse power (HP) of the pumpset, water level in the well, varying level of delivery pipes, condition of the water extraction machineries, distance between place of water source and field to be irrigated, quality of soil and terrain condition. In view of this, we have measured water consumption in terms of horsepower (HP) hours of irrigation. HP hr of water consumption is computed by multiplying HP of the pump-set with hours of water used by each farmer.[9]

The data presented in Table 2 illustrates that water saving is substantial due to the use of drip method of irrigation in cotton cultivation. Though the number of irrigation used for drip irrigated crop (57.50) is substantially higher than that of flood irrigated crop (8.50), the hours used for each turn of irrigation is less than 1 hr (only about 0.48 min.) under DIM as against the use of 9.45 hr/acre under FIM. As a result, the total water used for drip-irrigated cotton comes to about 228 HP hours/acre, whereas the same comes to about 415 HP hours for non-drip irrigated cotton crop. This means that farmers are able to save about 187 HP hr of water per acre, which is about 45% saving over FIM. The main reason for substantial water saving under DIM is that the farmers are able to supply required quantity of water at the required time exclusively at the root zone of the crop. This, the farmers are unable to accomplish when cotton is cultivated under flood method of irrigation. Though the water used under the FIM is much higher than under the DIM, farmers following FIM reported that they were not able to supply adequate quantity of water during the time of crop growth mainly due to water shortage in the well and frequent interruptions in electricity supply. Therefore, their cotton crop had to face either moisture stress or excess wetting throughout the crop season, which has significant impact on crop growth. In fact, all farmers reported frequent interruptions in electricity supply and water scarcity as 2 of the prime reasons for adopting the DIM for cotton cultivation.

Table 2: Water and electricity consumption in drip and flood irrigated cotton (Rs/acre)

Sr. No.	Particulars	DIM	FIM	Gain over FIM	
				Amount	Percent
1.	Pumpset HP	5	5	—	—
2.	Number of irrigation/acre	57.50	8.50	-49.00	-576.50
3.	Hours per irrigation/acre	0.48	9.45	8.57	94.92
4.	HP hours of water used/acre	228.10	415	186.90	45.00
5.	Electricity consumption (kwh/acre)	171.10	311.25	140.15	45.00

Source: Case study data.
Note: Operation-wise cost includes both inputs and labour cost (i.e., cost A2+FL).

The water saving estimated here is the applied water saving at the field level. However, to what extent this gets converted into real water saving depends on what portion of the applied water in the case of FMI which gets depleted. As Kumar et al., (2008) noted, the real water saving at the field level through micro irrigation systems would be determined by the crop type, groundwater environment and the climate. It would be significant for row crops in semi arid and arid climatic conditions, with deep groundwater table. This is because the non-beneficial evaporation from soil (not covered by canopy), and non-recoverable deep percolation would be substantial. In our case study, the cropped area not covered by canopy cover is large, especially during growing season, the area has semi arid climate, and groundwater table is deep. Therefore, the applied water can be treated as very close to depleted water in case of FMI.

The irrigated area can be expanded using the saved water by the drip method of irrigation. Farmers have reported that they have brought additional area under irrigation by adopting drip irrigation. An important policy related question associated with DIM is how much additional area can be brought under cotton cultivation from the water saved in using DIM. Our estimate suggests that the water saving gained from an acre of cotton cultivated using DIM will enable a farmer to bring additional 0.82 acre under cotton cultivation.

The reduced consumption of water by drip-irrigated crop obviously curtails the working hours of pumpset reducing the required quantum of electricity. We have attempted to estimate the electricity saving in cotton cultivation. It is calculated that 0.750 kwh of power is used per HP for every hour of pumpset operation (see, Shah, 1993). So, we have multiplied the HP hr of the pumpset with assumed power consumption to estimate the electricity requirement for an acre of cotton cultivation (see, Table 2). As per our estimate, the consumption of electricity under DIM is only about 171 kwh/acre as against 311 kwh/acre under FIM, a saving of 140 kwh/acre.

Table 3: Productivity of drip and flood irrigated cotton (Rs/acre)

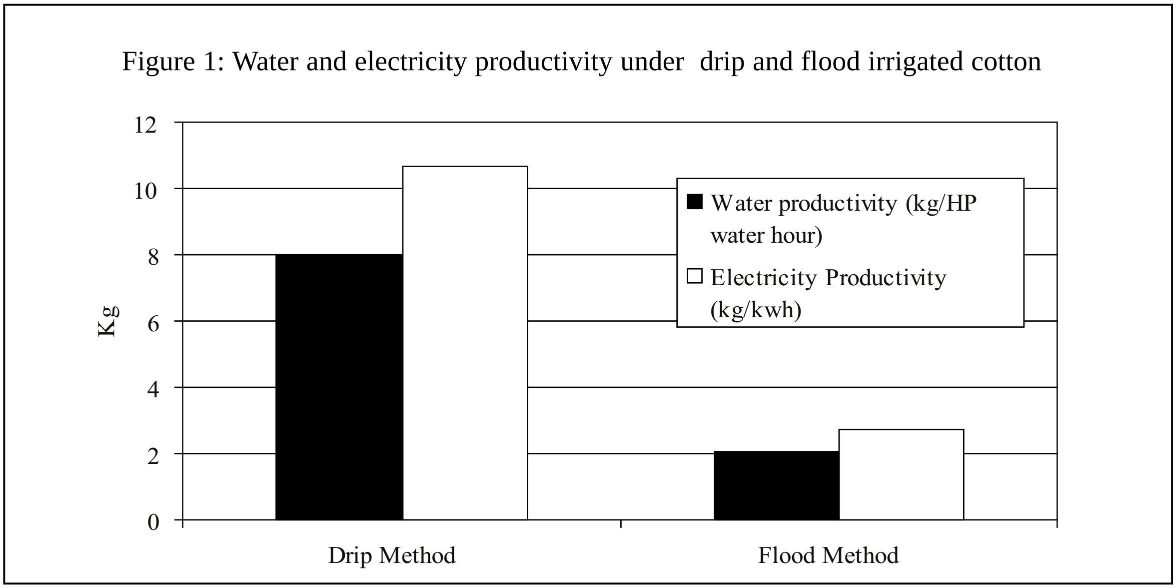
Sr. No.	Particulars	DIM	FIM	Gain over FIM	
				Amount	Percent
1.	Productivity (qtl/acre)	18.25	8.50	9.75	114.70
2.	Cost of production (Rs/qtl)	953.70	2022.70	1069.00	52.85
3.	Water productivity (kg/HP hour of water)	7.99	2.05	5.90	289.75
4.	Electricity productivity (kg/kwh)	10.67	2.70	7.90	290.80

Source: Estimated using case study data.

5. PRODUCTIVITY GAINS

DIM is primarily introduced to increase water use efficiency. In addition, it considerably increases the productivity of crops by reducing their moisture stress. Data presented in Table 3 shows that productivity of cotton cultivated under DIM (18.25 qtl/acre) is about 114% higher than under FIM (8.50 qtl/acre). What are the causes for this increased productivity of cotton under DIM? The farmers attribute yield increase to the following four reasons. First, under DIM the moisture stress for crop is avoided because of its ability to supply required quantity of water at the required time. This has increased the plant growth, increasing the number of canopies from which more flowers and bolls are produced. Second, supply of water only at the root zone of the crop prevents water flow to other zones where the weeds grow and therefore, weed growth is reduced. Third, the supply of water at regular intervals also allowed the crop to absorb the fertilisers without any big losses through leaching and evaporation. Fourth, pre-mature dropping of bolls is reported to be less under drip method because of the absence of moisture stress as compared to FIM. We have not attempted to study the contribution of each factor on the productivity of cotton crop. However, taking into consideration the insignificant difference in the use of yield-increasing inputs between the crops cultivated under drip and flood method of irrigation, one might be inclined to attribute the whole productivity gain to drip irrigation.

The availability of water and electricity is becoming a serious constraint in countries like India in view of their intensifying demand. Therefore, along with land productivity, there is an urgent need to increase the productivity of these inputs (see, Kijne, et al., 2003). Since land productivity of cotton cultivated under DIM is very high over FIM, we have tried to estimate whether DIM also increases the productivity of water and electricity together with a reduction in cost of production. In order to identify the water and electricity productivity of cotton, we have estimated per unit productivity per HP hours of water, as well as per unit productivity per kwh of electricity. Under DIM, cotton productivity is 8 kg/HP hours of water whereas the same is only 2.05 kg for FIM crop. Similarly, electricity productivity (kg/kwh) is 10.67 for DIM crop and it is only 2.70 kg for FIM crop (see, Figure 1). The improved productivity due to DIM also enhances the cost efficiency significantly (the cost required to produce one unit of output). These results clearly indicate that DIM not only increases the land productivity but also increases productivity of water and electricity.



6. RELATIVE LEVELS OF PROFIT OF COTTON CULTIVATION

Let us now turn our attention to the relative profit levels of cotton cultivated under the two methods of irrigation. While calculating profit of cotton per acre, the total cost is calculated considering only the variable cost and not fixed costs like interest rate and depreciation. The gross income from cotton is calculated by multiplying total yield with the price (which varied from Rs. 2000-2300/qtl) received by the farmers. In order to calculate the profit, the corresponding total cost of cultivation is subtracted from the gross value of production under DIM and FIM. The estimated profit per acre comes to Rs. 21283 for DIM, but is only Rs. 681 for FIM cotton.[10] So the profit of drip-irrigated cotton is higher by Rs. 20601/acre than flood irrigated cotton (see, Table 4)[11]. One may be interested to know whether higher profit is due to the effect of productivity or due to the effect of price. As mentioned in the methodology section, farmers selected for this study have cultivated uniform variety of cotton (Bt. cotton). Therefore, those farmers could get same price for the cotton harvested from drip and flood irrigated fields. This higher profit is purely because of yield effect under DIM and not because of price effect. Farmers can repay the whole capital cost of the drip system (which is about Rs. 21375/acre without subsidy) from the profit of a single crop in a year. This could be an important reason why farmers in the study area want to switch to DIM.

Table 4: Relative profit levels of drip and flood irrigated cotton (Rs/acre)

Sr. No.	Particulars	DIM	FIM	Gain over FIM	
				Amount	Percentage
1.	Gross cost of cultivation	17404.40	17193.10	-211.20	-1.20
2.	Gross value of production	38687.50	17875.00	20812.50	116.40
3.	Profit (farm business income)	21283.10	681.90	20601.25	3021.30
4.	Capital cost of DIS (without subsidy)	21375.00	—	—	—
5.	Subsidy for DIS (Rs/acre)	10631.25	—	—	—
6.	Capital cost of DIS (with subsidy)	10743.75	—-	—	—

Source: Case study data.
Note: DIS – drip irrigation system

7. BENEFIT-COST ANALYSIS

Gross profit (farm business income) of cotton cultivated under DIM is significantly higher than the gross profit under FIM. However, this gross amount cannot be treated as the effective (real) profit of cotton cultivated under DIM, since it does not take into account the capital cost of the drip set, its depreciation and interest accrued on the fixed capital. For calculating the net profit, they should all be taken into account. The longevity (duration of service) of drip-set is an important variable to determine the net present value, which in turn is a determinant of per hectare profit. DIM is a capital-intensive technique and therefore, the initial high investment needed for installing drip systems remains the main disincentive for the widespread adoption, especially in crops which are not water-intensive like cotton. To what extent this disincentive effect is real and to what extent such effect can be counter balanced by government subsidy are important policy issues. Therefore, there is a need to find out the economic viability of drip investment in cotton cultivation under different settings. For that purpose, both the Net Present Worth (NPW) and the Benefit-Cost Ratio (BCR) are estimated using the discounted cash flow technique.

The required capital investment is one of the critical factors, which determines the economic viability of the drip irrigation in any crop. Therefore, a brief discussion about the requirement of capital for drip irrigation is done before getting into the aspects of economic viability of the system. Depending upon the nature of crop, the capital investment required for DIM varies. While narrow spaced crops need higher fixed investment, wide spaced crops require relatively low fixed investment. This is because of relatively less requirement of tube length, emitters and drippers. States like Maharashtra are providing nearly 50% of the capital cost as subsidy through a sponsored scheme to encourage the adoption of drip irrigation for different crops. The capital cost of drip set comes to Rs. 21375/acre for the case study farmer without subsidy, and it goes down to Rs. 10631/acre with 50% subsidy.

Let us now analyse benefit-cost pattern of drip investment using discounted cash flow technique. We have computed both the NPW and the BCR separately by including subsidy and by excluding subsidy in the total fixed capital cost of drip set. Financial viability analysis under different rates of discount would indicate the efficacy of investment at different opportunity costs of investment. Although the BCR is sensitive to discount rate and the degree of such sensitivity depends on the pattern of cash flows, it is interesting to observe the sensitivity of the BCR when there is simultaneous change in both subsidy and discount factor. Therefore, we have attempted to find out answers specifically to the following four important issues namely (1) Whether investment in drip system for cotton cultivation is economically viable to farmers? (2) Can farmers meet the expense of investment in drip irrigation to cultivate cotton without subsidy? (3) To what extent do NPW and BCR change, when the assumed longevity of the drip system is increased from 5 years to 10 years and further to 15 years? and (4) What is the pay back period of drip investment, assuming the current cost and price of the equipment?

Table 5: NPW and B-C ratio of drip irrigated cotton under different scenarios

Subsidy category	Life period assumed	Discount rate	NPW (Rs/acre)	BCR
With subsidy	5 years	15%	60280	1.868
		10%	68965	1.888
	10 years	15%	94894	1.956
		10%	117852	1.983
	15 years	15%	112104	1.982
		10%	148207	2.015

Subsidy category	Life period assumed	Discount rate	NPW (Rs/acre)	BCR
Without subsidy	5 years	15%	51035	1.649
		10%	59301	1.679
	10 years	15%	85650	1.789
		10%	108187	1.835
	15 years	15%	102859	1.834
		10%	138542	1.889

Source: Case study data
Note: Computed using discounted cash flow technique.

The results of net present worth and the benefit-cost ratio estimated, assuming different discount rates and with varying life periods of the system are presented in Table 5. Both the NPW and BCR computed under different scenarios show that the drip investment in cotton cultivation is economically viable for farmers. As expected, the NPW of the investment with subsidy is marginally higher than that under 'no subsidy' option under all scenarios used for analysis. For instance, the NPW at 10% discount rate computed assuming 10 years as life period of the system, increases from Rs.108187/acre without subsidy to Rs. 117852/acre with subsidy. This means that the subsidy enables the farmers to get an additional benefit of Rs. 9665/acre. Similar trend is observed when the NPW is computed assuming 5 and 15 years as life period of the system.

The BCR computed with different discount rates clearly suggests that drip investment is economically viable for cotton farmers under all scenarios. The minimum BCR is 1.649 and maximum is 1.889 when one estimates the same without considering subsidy. The same increases from 1.868 to 2.015 when subsidy is included. The relatively higher BCR realised with subsidy indicates the vital role of subsidy in enhancing the economic viability of drip irrigation. The minimum BCR of 1.649 without subsidy highlights the fact that the investment in drip irrigation in cotton cultivation is economically viable even in the absence of subsidy.[12]

The NPW and BCR are also sensitive to the endurance period of the drip system assumed for calculation. The BCR is expected to be relatively less when one estimates the same assuming relatively less number of survival years as compared to the longer period because of higher density of the capital investment. Though the ideal life period of the drip system for cotton cultivation is 10 years, the experiences of the farmers suggest that the system may work up to 15 years with proper maintenance.[13] In the worst case situation, the system may be expected to work only upto 5 years. We have attempted to see to what extent the NPW and BCR are sensitive to varying life period of the drip system. Table 5 shows that the values of BCR and NPW increase significantly when one estimates them assuming 15 years as life period, as compared to 10 and 5 years period. Interestingly, when we estimate the BCR treating 15 years as life period of the system with 10% discount rate, the value is as high as 2.015. This is expected because the density of capital is thinly distributed between the years when one considers relatively longer life period for computing the BCR.

How many years are needed for the farmer to fully recover the capital investment in drip adoption is an important issue in the context of DIM adoption in cotton cultivation? The year-wise NPW estimated under various scenarios (different discount rates along with different life period of the system) indicates that farmers may be able to recover the entire capital cost of the drip set from the income of the very first year itself when 50% subsidy is availed. However, the farmers will just be short of about Rs. 500/acre to completely recover the whole capital cost of drip system in the very first year when 50% subsidy is not granted for cotton cultivation.

In the context of cotton cultivation under drip method of irrigation, the system is assumed to be used only for one season (for about six months) in a year. In this aspect, it differs from the annual crops like grapes and banana where the system is under use throughout the year. Farmers also report that the system used for cotton cultivation can also be used for cultivating vegetable, pulse and oilseed crops after finishing the cultivation of cotton crop.[14] The gross income generated due to drip system would be enhanced, if income from others crops is included for calculation. As we have not considered income generated from the other crops, private benefit-cost analysis taking into account those benefits would increase substantially.

8. CONCLUDING REMARKS

The present study shows that cultivating cotton under drip method of irrigation provides a number of benefits to farmers over FIM. While reducing the cost of irrigation to the tune of about 50%, drip method of irrigation also helps reducing the cost on weeding, interculture and well preparatory works. Water saving due to the adoption of drip method of irrigation in cotton cultivation is estimated to be about 45% more. Reduced withdrawal of water under DIM also helps to reduce the consumption of electricity to the tune of about 140 Kwh/acre over the conventional irrigation method. The productivity difference between drip irrigated cotton (18.25 qtl/acre) and flood irrigated cotton (8.50 qtl/acre) comes to about 9.75 qtl/acre, which is about 114% higher than the same harvested using flood method of irrigation. Increased productivity with reduced consumption of water under DIM has increased water and electricity productivity substantially. The profit (farm business income) of the cotton crop cultivated using DIM is also higher by about Rs. 20601/acre than that realised from FIM. The net present worth and benefit-cost ratio estimated using discounted cash flow technique shows that the drip investment in cotton cultivation is economically viable under both 'with' and 'without' subsidy conditions. The analysis also shows that the farmers would be able to repay the whole capital cost of drip system from the crop's income of the very first year.

The results of the study suggest that cultivation of cotton crop under drip method of irrigation would greatly benefit the farmers. Farmers in Maharashtra and elsewhere in India are unable to increase the productivity of cotton mostly because of inadequate water supply necessary for flood method of irrigation. Most of the times farmers are unable to recover even the cost of cotton cultivation due to poor yield under FIM. Our study also confirms that farmers cultivating cotton using flood method of irrigation are barely able to recover the cost of cultivation because of low productivity. They are thus unable to repay their institutional or non-institutional loans, and in many cases commit suicide. Therefore, promoting drip method of irrigation could possibly reduce the distress of the cotton-growing farmers in Maharashtra as well as in other parts of India. Both the Central and State governments are currently working on implementing various special programmes to improve the agricultural sector in Vidharbha region. While planning such programmes, the governments can allocate a portion of these funds to promote cotton cultivation under DIM.

Though cultivation of cotton under DIM has been picking up in Maharashtra and Gujarat, most farmers in other parts of India are yet to know that cotton cultivation under drip method is economically viable even in the absence of government subsidy. In various parts of the country, severe water scarcity and interrupted power supply are increasingly becoming common. Farmers are able to increase the productivity of cotton significantly under drip irrigation even with these constraints. Farmers are also able to expand the irrigated area with the same amount of water utilized for flood method of irrigation by the adoption of drip method of irrigation. Therefore, the benefits of cultivating cotton under DIM needs to be propagated through quality extension network and special programmes broadcast on a continuous basis through electronic media.

Is there any justification in continuing with the subsidy for drip method of irrigation if it is economically viable even without subsidy? Our study confirms that investment in drip system is economically viable even without subsidy. Nevertheless the case-study farmers were not in favour of immediate scaling down of subsidy mainly for two reasons. First, subsidy gives enormous incentive to the small and marginal farmers to adopt this technology without any hesitation. Second, any reduction in subsidy may hamper the adoption rate which is now only in the initial stage. The enormous subsidy burden on the exchequer can also be justified since drip irrigation saves enormous amount of water and electricity, both of which are becoming increasingly scarce in India. If more accurate estimates of the benefits from the saving of water and electricity in monetary terms for the whole life of the drip system are made, the benefits would be much larger than the cost of subsidy to the government. Therefore, this subsidy should be treated as a reward to motivate the farmers for saving these

2 scarce resources. The debate on whether or not to give subsidy to farmers would continue because of various socio-political reasons. Nonetheless, cultivating cotton under DIM is certainly a “win-win opportunity” for both the individual farmers and for society as a whole.

Notes:

1. CWC (2005) estimate shows that demand for water for other sectors is likely to grow much faster than that of the agricultural sector. As per the estimate, while the demand for water in industry and domestic sector would increase about 7.80 times and 2.40 times respectively between 2000 and 2050, the same would increase only about 1.98 times in agricultural sector. The increased demand for water from other sectors is expected to reduce the availability of irrigation water in the future. More discussion on this issue can be seen from Saleth, (1996); Vaidyanathan (1998) and MOWR, (1999).

2. Drip method of irrigation is one of the methods of micro-irrigation, which was initially introduced in the early seventies by the agricultural universities and other research institutions in India with the aim to increase the water use efficiency in crop cultivation. The development of drip irrigation in terms of area coverage was very slow in the initial years, but significant development has been achieved, especially since 1990s. Due to various promotional schemes introduced by the government of India and states like Maharashtra, area under drip method of irrigation has increased from 1500 ha in 1985 to 70589 ha in 1991-92 and further to 246000 ha in 1997-98 (INCID, 1994; AFC, 1998; GoI, 2004). As of 2005-06, the area under DMI is estimated to have been increased to about 6.25 lac ha (www.indiastate.org).

3. Though cotton is one of the important commercial crops of the country and it can be cultivated under drip method of irrigation, there is a vacuum in the literature on this subject. To our knowledge, no study has been published on the economics of cotton cultivation under drip method of irrigation, especially in India’s premier journals like Indian Journal of Agricultural Economics and Economic and Political Weekly.

4. Unlike major foodgrain crops, the productivity of cotton has not increased appreciably since the introduction of green revolution in India. Between 1980-81 and 2000-01, its productivity increased only from 152 kg/ha to 190 kg/ha. This is very low when compared to the productivity of cotton in countries like USA, China, etc. Predominant cultivation of cotton under rainfed condition in India is considered to be the important reason for this.

5. A crucial reason for carrying out these case studies is that it allows the researcher to clearly understand every aspect of cotton cultivation under drip method of irrigation. This may not always be possible in a sample survey. Whether the results arrived from a case study is sufficient enough to make a solid policy decision is a major question that has been debated by the economists over the years.

6. These farmers are selected from three different villages namely Shingola, Nari and Palaskheda, all of which are located in Jamner taluka of Jalgaon district.

7. This cost is A2+FL. By the definition of Commission for Agricultural Costs and Prices (CACP), cost A2+FL includes all actual expenses in cash and kind incurred in production by the farmer plus rent paid for leased-in land as well as imputed value of family labour. The CACP uses nine cost concepts for cost calculation, the definition of which is available in CACP (2005).

8. Irrigation cost includes both human labour cost used for irrigation purpose and the electricity cost. Since farmers in Maharashtra State pay the electricity tariff on flat-rate basis, it is difficult to get the actual unit cost of electricity. Therefore, we have estimated the electricity cost of irrigation using the average unit cost of power supply, which prevailed in the State during the year 2006-07 (Rs. 3.30/kwh) and multiplying it by the hours of irrigation of the cotton crop.

9. Alternatively, one can also estimate water volume applied by multiplying average discharge of the pumpset by number of pump operating hours. However, since it requires a device to measure the discharge of each pumpset that is also expected to change depending upon the water level of the well, we have not followed this method in estimating the water consumption.

10. Analogous to the findings of our study, data from the CACP also suggests that the income from cotton cultivation is tending to be very low because of increased cost of cultivation and low productivity. For instance, in Maharashtra State, the ratio of value of output from cotton crop to cost C2 has declined from 1.195 in 1975-76 to 0.799 in 2001-02, indicating that farmers are unable to meet even the cost of cultivation from the crop's income. More discussion on this issue can be seen from Narayanamoorthy (2006 and 2007).

11. This profit is the difference between gross value of production from cotton and cost A2+FL, and should ideally be called as farm business income.

12. Results of this study are also in conformity with some of the earlier studies carried out on three crops namely grapes, banana and sugarcane utilising field survey data from Maharashtra (see, Narayanamoorthy, 1997; 2003 and 2004).

13. There is no ideal life period of drip system. For instance, Dr. S. N. Kulkarni of ICID, an expert in micro-irrigation, argues that the drip set designed for cotton crop can seldom work for 15 years under field condition. This view does not coincide with the argument of the leading manufacturers of drip set and also with the perceptions of farmers adopting drip system for cotton crop.

14. One may tend to argue that the drip system designed for cotton crop may not be suitable for cultivating other crops because of variations in spacing followed for cultivating the stated crops. However, the farmers seem to be able to adjust the spacing of these crops keeping in view the drip set designed for cotton.

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IMPACT OF ORGANIC SUGARCANE FARMING ON ECONOMICS AND WATER USE EFFICIENCY IN MAHARASHTRA

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Abstract

This study examines the impact of organic farming on economics and water use efficiency in sugarcane cultivation in Maharashtra. The study is based on primary data collected from both certified organic sugarcane (OS) and inorganic sugarcane (IS) growing sample farmers in the water scarce and groundwater dependent district of Jalgaon in Maharashtra. The study finds that OS cultivation increases human labour employment by 20.2% and its overall cost of cultivation is also lower by 14.67% than IS farming. Although the yield from OS is 6.2% lower than the conventional crop, it is more than compensated by the price premium received and yield stability observed on OS farms. The OS farming gives 15.72% higher profits and profits are also more stable on OS farms than the IS farms thereby enhancing the economic well-being of OS farmers. Crucially, OS farming substantially enhances the water use efficiency (WUE) measured by different indicators. Thus, OS farming offers ample opportunities for enhancing farmers' income and improving water use efficiency in the cultivation of a highly water-consumptive and important sugarcane crop in the state. Finally, the paper discusses the emerging issues and outlines the task ahead for advancing OS farming in Maharashtra.

1. INTRODUCTION

India occupied second position in world in both sugarcane area and production. It shared 21.45% of the total area and 23% of the total sugarcane production in the world during triennium ending (TE) 2002-03 (GoI, 2005)[a]. Sugarcane contributes about 7.5% to agriculture GDP from only 3% of the cultivated area and provides sustenance to about 45 million farmers, their dependents and a large mass of agricultural labours for their livelihood (GoI, 2004). Maharashtra, the study state, is the second largest sugarcane growing state in the country. It contributed 0.58 mha (13.53%) to total area and 45.78 million ton (15.06%) to total production of sugarcane in the country in TE 2002-03 (GoI, 2005)[a]. The potential of Maharashtra has been shown by the steady growth in area and production of sugarcane over the years. However, the unceasing decline in productivity in recent decades is a cause of great concern.[1]

Sugarcane is the second most important cash crop covering less than 3% of the total cropped area of the state but it utilizes more than 60% of the total water available for irrigation in the state. This has already exerted a considerable strain on the limited water resources of the state[2]. The demand of water for sugarcane irrigation has led to an increase in number of tube wells and had resulted into the decrease of water table by more than 4m over the past decade in several areas in the districts of Jalgaon, Ahmednagar and Aurangabad (World Bank, 2003). This has significantly enhanced the number of open wells going dry over the years. The excess use of water combined with higher doses of chemical fertilizers is observed to be resulting in enhanced rate of degradation of water and land resources in certain parts of the state. This is reflected in the secular decline of sugarcane productivity in recent decades in Maharashtra (Samui et al., 2005).

Organic farming is a holistic agricultural production management system that sustains and ameliorates the health of agro-ecosystem encompassing biodiversity, nutrient bio-cycles and soil microbial and bio-chemical activities. It avoids the use of chemo-synthetic fertilizers and pesticides and emphasizes socially and environmentally beneficial practices such as crop rotations, intercropping, green manuring, use of organic

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manures, vermi-compost, bio-fertilizers and bio-pesticides in preference to the use of off-farm inputs considering that regional conditions require locally adapted systems. Thus, organic farming prohibits the use of harmful synthetic chemicals and promotes the use of renewable organic resources for sustainable agriculture.

The organic farming is the fastest growing sector in both land use and market size in the world. It is being cultivated in more than 120 countries covering about 31 mha of area in the world (Willer and Yussefi, 2007). The global market for organic food products was valued at US $ 25 billion in 2003, US $ 50 billion in 2006 and is estimated to reach to more than US $ 100 billion in 2010. Europe is the largest market for organic foods followed by North America. These two markets together share more than 95% of the global market for organic food products. Although the Indian market for organic food products is relatively miniscule, it has great potential to grow in near future and to reap the benefits of the rapidly growing lucrative market for organic products.

Organic farming is as old as agriculture in India. But presently it is being cultivated on relatively very small area. For example, the certified area under organic farming was only 76,326 ha during 2003, which is about 0.05% of the total cultivated area in the country (Willer and Yussefi, 2007). This is negligible when compared with the top 10 countries in organic farming in the world.[3] However, organic farming had received better attention in recent years in India and concerted efforts are being made by the state and central governments, NGOs, farmers and other organizations to promote it in the country. For example, the states of Uttaranchal and Sikkim have been declared as organic states by their respective governments. These initiatives may help in boosting the area under organic farming in near future in the country.

Maharashtra is an important organic farming state. It is at the forefront in developing, adopting and spreading organic farming technologies in the semi-arid regions of the country. Different parts of Maharashtra have developed their own local organic farming systems for various crops. Recognising the importance and potential of organic farming, Government of Maharashtra (GoM) has implemented the centrally sponsored scheme for promotion of organic farming in the state since 2003-04. The provision of Rs. 73 million and Rs. 154.50 million were made during the year of 2004-05 and 2005-06 for promotion of organic farming in the state (GoM, 2007). These efforts have helped in increasing the awareness about the organic farming, reducing the use of chemicals, and enhancing the area under organic farming and boosting the organic production in the state. It has been reported by the GoM (2007) that the area registered for organic certification in the state was 51,000 ha in 2006-07. The GoM intends to convert about 650,000 ha of area to organic farming in the state in near future. Organic sugarcane is an important crop grown in the study district. The practice of organic farming is very popular in Jalgaon district and the registered area to be converted to organic farming in the study district increased from 42,696 ha in 2004-05 to 49,000 ha in 2006-07 (GoM, 2007). Thus, the area under organic farming is rapidly expanding in study state as well as in study district.

The findings of several previous studies have shown that excessive use of chemicals in agriculture results in adverse effects on human health, animals, biodiversity and contributes to degradation of water, soil and environmental resources (Ghosh, 2003; Pachauri and Sridharan, 1998; Parrott and Marsden, 2002; Singh et al., 1987). On the other hand, organic farming had beneficial effects on human health, animals, biodiversity, water, soil and environmental resources (Blaise, 2006; Gareau, 2004; Rahudkar and Phate, 1992; Rajendran et al., 2000; Schwank et al., 2001; Singh and Swarup, 2000; Thakur and Sharma, 2005). It is recognized that the results of these studies are valuable to understand the harmful effects of intensive chemical farming and the benefits of various practices followed under the organic farming. However, a keen perusal of these studies indicates that there is dearth of systemic studies probing into the impact of organic farming on economics and water use efficiency (WUE) of sugarcane cultivation in Maharashtra.[4] Therefore, the present study is designed to assess the impact of organic sugarcane (OS) farming on input use, costs, yields, risks, returns and WUE in relation to conventional inorganic sugarcane (IS) farming in the state. The paper also explores the emerging issues and suggests policy measures for advancing organic farming for sustaining the sugarcane cultivation in Maharashtra.

The paper is organized in 7 sections. The next section provides brief information on study area, sampling design, data and its sources. Section 3 delineates the salient characteristics of sampled farmers. The impact of

OS farming on input use, costs, yields, risks and returns is analysed in Section 4. Section 5 examines the impact of OS farming on WUE. Section 6 discusses the emerging issues and outlines the task ahead. Concluding comments are made in the final section.

2. DESIGN OF THE STUDY

The importance of organic farming is steadily growing in Maharashtra. Organic sugarcane is an important crop grown in the state. Jalgaon, the only district in the state that has the largest number of "certified" OS growing farmers was selected for this study. Moreover, the district is also facing the serious problems of water scarcity and sustainability due to sugarcane cultivation. We selected only those certified OS farmers who have obtained certification from nationally accredited and internationally designated and recognized certification agency for their organic sugarcane. These certified OS growing farmers were few in selected villages. Therefore, purposive sampling technique was used for the selection of certified OS sample farmers. The organic and inorganic sugarcane growing sample farmers were selected from the same villages to minimize the edaphic and other agro-economic differences between the two groups of sample farmers. The sample included 72 farmers, 38 certified OS growing farmers and 34 IS growing farmers.

The study is based on primary data collected from OS and IS farmers through personal interviews with the help of a specially designed questionnaire. The questionnaire covered information on household resource base, cropping pattern, input use pattern, cost of sugarcane cultivation, yield, etc. Moreover, farmers perceptions on different parameters of OS and IS cultivation were also elicited. The data pertains to the sugarcane crop, both organic and inorganic, planted and harvested during the 2004-05 agricultural year.

3. IMPORTANT FEATURES OF SAMPLE FARMERS

There are wide differences in the resource endowments across the sample groups. The average family size of OS households was found to be smaller (4.18) than IS households (4.94) in the selected district (Table 1). The heads of OS households are younger and better educated than their counterparts from IS households. Generally, the large land holding is associated with higher and early adoption of agricultural technologies in India. Therefore, it was expected that the size of land holding of OS sample farmers would be larger than IS sample farmers. This notion was found to be valid as the average size of land holding of OS farmers was found to be 6.93 ha compared to 6.43 ha for IS farmers.

Most of the sample farmers used well irrigation for their sugarcane crop. The well irrigation has some advantages over the surface irrigation sources. The well irrigation is relatively less affected by vagaries of monsoon and farmer has better control over water supply. However, the use of wells for sugarcane irrigation in Jalgaon district is now often being associated with certain negative externalities due to over exploitation of groundwater resources. The excessive mining of groundwater for irrigation had jeopardized the sustainability of limited water resources in this district. The issue of equity is also not less important as resource rich farmers are found to be exploiting this resource rampantly.

The livestock position given in Table 1 reveals that OS farmers not only owned more number of livestock but the value of livestock owned by them was also higher than IS farmers. The better livestock position of OS farmers may be attributed to their higher demand for manures and other livestock products for cultivation of organic crops. Sugarcane and cotton, the most important cash crops of the state also prevailed over the cropping pattern on sample farms. From the point of view of present study, it is important to note that the OS crop occupied largest coverage at 17.19% of gross cropped area (GCA) on sample farms in the study district. The percentage area under high value fruit and vegetable crops and low water intensive chickpea crop was substantially higher on OS farms than the IS farms.

Table 1: Important Features of Organic and Inorganic Sample Farmers

Sr. No.	Characteristics	Organic Sugarcane Growing Farmers	Inorganic Sugarcane Growing Farmers
1.	Family Size (No.)	4.18	4.94
2.	Age of Family Head (Years)	42.35	43.50
3.	Education of Family Head (Edu. Years)	10.55	9.88
4.	Average Size of Land Holding (ha)	6.93	6.43
5.	Average Net Irrigated Area (ha)	5.60	5.48
6.	Per cent of Well Irrigated Area	90.74	88.08
7.	Livestock (No./Household)	12.41	10.05
8.	Value of Livestock Owned (Rs. '000' / Household)	70.67	56.21
9.	Major Crops Grown (Percentage of GCA)		
	● Organic Sugarcane	17.19	0.00
	● Inorganic Sugarcane	0.00	15.72
	● Cotton	16.90	28.27
	● Wheat	13.95	16.43
	● Fruit crops	11.59	6.49
	● Sorghum	9.75	11.91
	● Chickpea	7.82	2.37
	● Vegetable crops	3.13	2.15

4. IMPACT OF ORGANIC FARMING ON ECONOMICS OF SUGARCANE CULTIVATION

Even if OS farming is found to be superior in the context of the water use efficiency, it is necessary to examine its performance in terms of its economics which ultimately influences the adoption. Therefore, this section examines the impact of organic farming on the economics of sugarcane cultivation with specific focus on input use pattern, cost of cultivation, yields, gross returns and profits. The results of this analysis are presented in Tables 2 - 4 and are discussed in the following sub-sections.

4.1 Impact on Input Use

The sugarcane sector is one of the important employment generating sector employing over 7.5% of total rural population in India (GoI, 2004). The data presented in Table 2 also indicates that sugarcane cultivation, especially the OS cultivation, needs large number of human labour days. For example, on an average, the per hectare human labour use was found to be 247.80 days on OS farms and 206.15 days on IS farms, showing 20.20% higher use on OS crop than the IS crop. This is mainly attributed to increased labour requirement for carrying out operations such as preparatory tillage, manuring, green manuring and managing the weeds, pests and diseases on OS farms. Furthermore, the intercropping typically found on OS farms, with crops having various planting and harvesting schedules, may distribute the labour demand more evenly which could help stabilize employment. This implies that OS farming may provide an opportunity to rural masses of sustained gainful farm employment throughout the year.

The quantity and quality of seed influences the crop stand and productivity. The use of sugarcane seed was found to be 2.97 and 3.35 ton/ha for OS and IS crop respectively in study district. On an average, 11.34% less seed was used by OS farmers mainly due to use of 2-bud setts, and use of strip method of planting. Besides reducing the seed requirement, the strip planting facilitates intercropping with sugarcane. The use of organic manures is quite high on OS farms. The OS farmers used about 5 ton/ha more manure than the manure used by IS farmers. This is obvious considering the dependence of OS farmers on organic manures for augmenting and sustaining the soil resources. In addition, about 180 kg/ha of bio-fertilizer was also used by OS farmers.

Table 2: Input Use Pattern on Organic and Inorganic Sugarcane Sample Farms

Sr. No.	Input	Organic Sugarcane (OS)	Inorganic Sugarcane (IS)	% increase over Inorganic
1.	Human Labour (days)	247.80	206.15	20.20
2.	Bullock Labour (pair days)	9.72	8.51	14.22
3.	Tractor (hours)	6.42	5.96	7.72
4.	Seed (ton)	2.97	3.35	-11.34
5.	Organic Manures (ton)	11.40	6.36	79.25
6.	Bio-fertilizers (kg)	178.70	-	-
7.	Chemical Fertilizers (kg)			
	• Nitrogen (N)	-	341.37	-
	• Phosphate (P)	-	110.25	-
	• Potash (K)	-	77.42	-
8.	Insecticide/ Pesticide (kg)	2.03	2.50	-18.80
9.	Number of Irrigations	21.45	26.51	-19.09

Source: Field Survey

As the sugarcane crop produces huge quantity of biomass, its nutrient requirements are also very high. It could be found from Table 2 that IS farmers used 341.37 kg N, 110.25 kg P, and 77.42 kg K per ha for their sugarcane crop. This is quite high when compared with the levels of 110.10 kg N, 44.70 kg P and 30.10 kg K per hectare for irrigated sugarcane crop in the country (GOI, 2000). The IS farmers also augmented their soil resources by complementing chemical fertilizers with organic manures. In terms of the average use of bio-pesticides for OS crop and chemical pesticides for IS crop, IS farmers used 18.80% more quantity compared to OS farmers. This is mainly because, along with bio-pesticides, OS farmers also used other practices such as crop rotation and intercropping for management of pests and diseases. The average number of irrigations given to OS crop were 19.09% less than the IS crop. We will return to this issue in the next section.

Another notable aspect reported by most of the OS farmers which is important from the point of view of present study is that they did not purchased inputs from the market, rather they used self-produced inputs such as seeds, manures, green-manuring, vermi-compost, bio-fertilizers, Amrutpani, Jivamrut, bio-pesticides, etc. This reduced their dependence on external costly inputs and consequently enhanced their self-reliance in crop production. The OS farmers also expressed their satisfaction on being saved from the risk of getting sub-standard inputs. The water use for sugarcane irrigation is discussed in next section.

4.2 Impact on Cost of Cultivation

This sub-section explores the relative impact of organic farming on operation-wise cost of cultivation of sugarcane in the study districts.[5] This analysis shows that average cost of cultivation of OS crop was Rs. 36,573.74/ ha as against Rs. 42,861.84/ ha for IS crop, reflecting 14.67% lower cost on OS farms than the IS farms (Table 3). The lower cost of cultivation observed on OS farms is not surprising. This is because, first, the highest cost reduction observed on OS farms is on account of non-use of chemical fertilizers. The OS farmers spent Rs. 9,822.65/ha on manures and manuring, mostly produced by themselves, which is 59.65% higher than IS farmers. In addition, Rs. 1,651.15/ha were spent on bio-fertilizers, etc., by the OS farmers. These 2 together cost Rs. 11,473.80/ha which is quite less than the cost of Rs. 15,842.32/ha incurred by IS farmers on chemical fertilizers and manures. Thus, OS farmers saved 27.58% expenditure on account of soil nutrient supplements alone.

Table 3: Cost of Cultivation of Organic and Inorganic Sugarcane (Rs./ha)

Sr. No.	Operations	Organic (OS) Sugarcane (OS)	Inorganic Sugarcane (IS)	Per cent over Inorganic
1.	Land Preparation	5834.73 (15.95) [a]	4995.48 (11.65)	16.80
2.	Seed and Planting	5524.27 (15.10)	6834.95 (15.95)	-19.18
3.	Manure and Manuring	9822.65 (26.86)	6152.77 (14.35)	59.65
4.	Bio-fertilizers	1651.15 (4.51)	-	-
5.	Chemical Fertilizers	-	9689.55 (22.61)	-
6.	Weeding and Interculture	5168.24 (14.13)	4951.19 (11.55)	4.38
7.	Irrigation	5899.56 (16.13)	7378.67 (17.22)	-20.05
8.	Plant Protection	862.35 (2.36)	1193.42 (2.78)	-27.74
9.	Others	1810.79 (4.95)	1665.81 (3.89)	8.70
	Total Cost (GCC) [b]	36573.74 (100.00)	42861.84 (100.00)	-14.67

Note: a : Figures in parentheses are percentage of total cost.
b : This does not include the cost of harvesting, transport and marketing.

Secondly, the irrigation cost was found to be 20.05% less on OS farms. Thirdly, OS farmers spent about Rs. 1,310/ha less on seed and planting as compared to IS farmers. Fourthly, the average per ha cost on plant protection was lower on OS farms as most of this material was prepared by OS farmers themselves and they also used other methods. Besides this, the OS cultivation was also found to be more cost efficient than IS cultivation as the per ton cost of production of OS cane was 9.03% lower on OS farms (Table 4).

The increased cost of cultivation due to increased input prices has also increased the requirement of credit for agriculture. However, several studies have concluded that the inability to payback the credit is one of the important reasons for creating distress among farmers (Mishra, 2006; TISS, 2005). The foregoing results indicate that OS farming reduces the cost of cultivation of a crop implying reduced requirement of credit for crop production.

4.3 Impact on Yield

The capacity of organic farming in achieving the yield levels obtained under the conventional inorganic farming is under doubt (Bhattacharyya and Chakraborty, 2005; Das and Biswas, 2002). Some studies have also noted that the change from conventional intensive farming to organic farming reduces the yield, at least during the initial years (IFAD, 2005; Rajendran et al., 2000). This study also found that the average yield of OS crop was 95.16 ton/ha as against 101.45 ton/ha of IS crop showing that OS farmers realised 6.2% lower yield than IS farmers (Table 4). However, the OS farmers were confident and it has also been reported by some scholars that in subsequent years, the OS farming is able to reduce this yield gap (Rajendran et al., 2000) and some times have also given higher yields than conventional methods (Thakur and Sharma, 2005).

Table 4: Yield, Value of Production and Profits from Organic and Inorganic Sugarcane

Sr. No.	Particulars	Organic Sugarcane	Inorganic Sugarcane	% over Inorganic
1.	Sugarcane Yield (ton/ha)	95.16	101.45	-6.20
2.	CV of Sugarcane Yield (%)	29.84	44.38	-14.54
3.	Cost of Production (Rs./ton)	384.34	422.49	-9.03
4.	Gross Value of Production (Rs./ha)	114,017.85	109,784.25	3.86
5.	Gross Profit (Rs./ha)	774,44.11	66,922.41	15.72
6.	CV of Gross Profit (%)	41.63	49.81	-8.18
7.	GVP/GCC	3.12	2.56	21.71

A stable yield is an important feature of sustainability. The yield stability measured by coefficient of variation (CV) indicates that the CV of yields was substantially lower at 29.84% in OS crop as against the 44.38% in IS crop suggesting that yields were more stable under OS farming than the IS farming (Table 4). It is also to be noted here that lower yields on OS farms were more than compensated by the price premium fetched by organic sugarcane and the sugarcane yield stability observed on OS farms.

4.4 Impact on gross value of production and profits

The increase in price of inputs in conventional agriculture had inflated the cost of cultivation and had reduced the profitability (Sen and Bhatia, 2004). Therefore, the issue of profitability is intimately related to economic well-being and livelihood security of the farmers. In this context, the examination of Table 4 shows that the gross value of production (GVP) and profits were higher on OS farms than the IS farms. For example, the GVP from OS farm amounted to Rs. 114,017.85/ha as against Rs. 109,784.25/ha from IS farm. This has resulted in higher profits by 15.72% from OS crop than the IS crop thereby enhancing farmers' income. This is mainly due to lower cost of cultivation on OS farms and relatively higher price fetched by organic sugarcane. Moreover, the CV of gross profits was also lower on OS farms than IS farms denoting greater stability of profits on OS farms. Thus, OS farming not only enhances the farmers' income but also provides greater stability to farm income.

Higher output-input (GVP/GCC) ratio is another feature of OS farming. The ratio was found to be 3.12 on OS farm as compared to 2.56 on IS farm. This indicates that after investing a rupee in the cultivation of OS crop, GVP was 21.71% higher than IS crop. In fact, the higher GVP/GCC ratio on OS farms is the reflection of higher input use efficiency observed on OS farms. In summary, these features of OS farming are critical for ensuring not only the economic well-being and livelihood security of the farmers but also for the sustainable cultivation of sugarcane crop in the state.

5. IMPACT OF OS FARMING ON WATER USE EFFICIENCY (WUE)

In Maharashtra, the coverage of irrigation for sugarcane crop is 100% (GoI, 2005)[a]. Therefore, water is essential not only for cultivation of sugarcane crop but also for increasing its productivity. However, water is the most limiting resource for sugarcane production in Maharashtra. About 80% of the water is utilized for agriculture in Maharashtra (World Bank, 2003) and more than 60% of it is utilized for sugarcane crop alone. Sugarcane crop produces huge quantity of biomass and it also consumes large quantity of water. The water requirement of sugarcane crop varies from 200 cm to 300 cm depending upon the type of soil and agro climatic conditions. It may be recalled that the main source of irrigation water for sugarcane crop was observed to be wells in the study district. Farmers are virtually mining water from deep aquifers for sugarcane crop. This is a cause of great concern and demands its conservation and judicious use as it has endangered the stability and sustainability of agriculture. However, the concern shown by individual farmers is rather circumscribed. This is mainly because the individual farmers are only interested in their own gains and costs and paying no attention at all to the social costs of over exploitation of groundwater resource (Vaidyanathan, 1996).

To study the comparative use of water under OS and IS farming, one may need actual measured data on use of water on both OS and IS farms. However, we concede that we do not have such a irrigation water measured data for sample farms. In absence of actual measured data, other indicators such as irrigation cost, number of irrigations given, productivity per irrigation, and returns per irrigation can be used to assess the WUE in the cultivation of OS and IS crop. The survey data is used to work out the various WUE indicators. The results of this analysis are presented in Table 5.

The results from preceding section revealed that irrigation cost is the second highest cost in the cultivation of sugarcane crop. However, it was considerably lower on OS farms as compared to IS farms. The average per hectare expenditure incurred on irrigation was found to be Rs. 5899.56 on OS farms as compared to Rs. 7378.67 on IS farms. In other words, OS farmers spent Rs. 1479.11/ha less on account of irrigation as compared to IS farmers. Another aspect to be noted from Table 5 is the lower irrigation cost per unit of cane production on OS farm. The average irrigation cost per ton of cane production on OS farm was Rs. 62 while it was Rs. 72.73 on IS farm, meaning 14.75% less irrigation cost per tonne of cane production on OS farm. In other words, it indicates higher sugarcane productivity per unit of irrigation expenditure on OS farms in

Table 5: Water Use Efficiency in Organic and Inorganic Sugarcane Farming

Sr. No.	Indicator of Water Use Efficiency	Organic Sugarcane	Inorganic Sugarcane	% over Inorganic
1.	Irrigation cost (Rs./ha)	5899.56	7378.67	-20.05
2.	Irrigation cost (Rs./ton)	62.00	72.73	-14.75
3.	Number of irrigations applied	21.45	26.51	-19.09
4.	Productivity per irrigation (ton/ha)	4.44	3.83	15.93
5.	GVP per irrigation (Rs./ha)	5315.52	4141.24	28.36
6.	Profits per irrigation (Rs./ha)	3610.45	2524.42	43.02

comparison with IS farms. It follows from this analysis that the irrigation costs incurred on per unit of area as well as per unit of cane production were lower on OS farms implying less use of water, saving of groundwater by OS farmers for cultivation of sugarcane crop.

Another result that comes out very clearly from Table 4 is the number of irrigations given to OS crop were quite less than the IS crop. The OS crop was given 21.45 irrigations while the IS crop was given 26.51 irrigations by the selected sample farmers. This indicates that OS needs 19.09% less number of irrigations than the IS crop. The water use efficiency expressed as the productivity of sugarcane per irrigation was found to be higher at 4.44 ton/ha on OS farm as compared to 3.83 ton/ha on IS farm suggesting 15.93% higher WUE on OS farm. Furthermore, the GVP per irrigation was 28.36% higher on OS farm. Yet another measure, the profits per irrigation was also substantially higher at 43.02% on OS farm than the IS farm.

The foregoing results revealed that various water use indicators performed better under OS farming as compared to IS farming. This suggests that OS farming is very effective and superior in saving water as compared to conventional IS farming. This may be mainly attributed to the fact that incorporation of organic matter to soil improves its structure and enhances its micro-porosity leading to improved infiltration of rain water and increased soil moisture retention capacity (Kumar and Tripathi, 1990; Sarkar et al, 2003). Rahudkar and Phate (1992) also observed that irrigation requirement of OS crop reduced by 45% than the conventional production method. Thus, OS farming has substantial potential in enhancing the sugarcane productivity and profit per unit of water use and saving the scarce groundwater thereby providing an opportunity for its conservation and sustainable use. No doubt, this is crucial for a relatively water scarce state like Maharashtra.

6. EMERGING ISSUES AND FUTURE POLICIES

The preceding results from this study indicate that organic farming is quite successful in the study area. Some of the key factors that are important for the success of OS farming, and not discussed so far, are related to conversion to organic farming, certified organic inputs, low yields and certification. These and few other issues are discussed in this section.

6.1 Conversion to organic farming

The sample farmers reported that the period involved in conversion from conventional farming to organic farming is the most difficult one. This is mainly because (a) lack of knowledge about the principles of organic farming, (b) shift to organic farming brings in several significant changes in agricultural practices, (c) at least it takes three years to complete the conversion successfully, (d) decrease in sugarcane yield with the beginning of the conversion period, (e) no premium prices, (f) due to (d) and (e) there is reduction in farmers income during the conversion period, and (g) non-cooperation from neighbouring farmers who practice conventional agriculture. These factors form the major hurdle in the adoption and spread of organic farming. Therefore, it is recommended that the beginners should receive not only the training but also the support in organic production methods, certification and marketing during this period. If feasible, the beginners should shift to organic in stages rather than trying to convert all their landholding at once. It is also suggested that the beginners themselves should prepare for the transition period in terms of time required, crops to be taken, inputs management, financial provision, etc., to pass the period of transition rather smoothly. Moreover, all the farmers having contiguous fields should be encouraged to shift to organic methods to avoid problems related to leaching and or contamination of chemical fertilizers and pesticides.

6.2 Certified Organic Inputs

The use of organic inputs such as organic manures, bio-fertilizers, vermi-compost, bio-pesticides, etc., was found to be higher on OS farms compared to IS farms as organic farmers substituted chemical fertilizers and pesticides with these organic inputs. The demand for these inputs is likely to increase with the expansion of area under organic farming. Therefore, it is most essential to ensure the smooth flow of these inputs so that they do not form the hurdle in the progress of organic farming in the state. In this context, the involvement of self-help groups (SHGs) of landless households for production of certified inputs would be most useful. Therefore, it is recommended that specific schemes may be developed for involvement of SHGs in production of certified inputs required for OS farming. The transfer of technology for production of certified organic inputs along with training, financial assistance, facilities for distribution and marketing should form the major components of such schemes for the SHGs. This may help in smooth supply of quality organic inputs at a reasonable price to organic farmers. At the same time it may also help in providing gainful employment opportunities to the landless rural people in their own area.

6.3 Low Yields

The sugarcane yield on OS farms was observed to be 6.20% lower than the IS farms. It is thus necessary to resolve the yield limiting issues in OS farming on priority basis. A fairly well developed infrastructure for agricultural research, training, and education exists in Maharashtra. The use of this infrastructure can be made effectively to resurrect the productivity by developing and spreading package of practices for water and soil nutrient management, as well as biotic and abiotic stress management in OS farming. Involvement of farmers by the researchers, where possible, should prove beneficial for developing and transferring the new technologies within the shortest possible time.

6.4 Certification

The certification of organic products is essential to distinguish it from those produced by conventional methods and to get an appropriate price in the market. The OS sample farmers operated certified farms. Even the study district has the largest number of certified OS farmers in the state. The credit for this goes to farmers associations. The association facilitated the certification of organic produce through an internationally recognised certification agency under the group certification programme. Thus, the association made organic certification easy, less costly and beneficial for its member farmers. This emphasizes the need of such associations which play an important role in not only helping the farmers in organic certification but also during the difficult period of conversion and post harvest operations. Such associations can also play an important role in stimulating the rapid adoption and spread of organic farming. Therefore, public and private agencies and NGOs may encourage farmers to form their own associations.

6.5 Other issues

Water is one of the most important resources essential in the cultivation of sugarcane crop in Maharashtra. Therefore, further research is necessary to critically assess the actual water requirements of organic vis-à-vis inorganic sugarcane crop in the state. In this context, the researchers may accurately measure the quantities of water applied to OS and IS crop with different water saving technologies and soil types. It is also necessary to study the impact of OS farming on the quality of groundwater resources in the state of Maharashtra. This kind of studies may help in making the specific recommendations for the use of irrigation water in the cultivation of OS crop in Maharashtra.

Some OS sample farmers complained of being deceived by traders by selling them spurious organic inputs. This resulted in heavy losses to victimized farmers. Therefore, efforts may be made to enhance the awareness among the organic farmers and strict vigilance by the quality control and regulatory authorities to prevent such malpractices involving pseudo-organic inputs.

The foregoing results of this study clearly indicated that the benefit of OS farming is not in enhancing the yield but in other crucial benefits. Therefore, it is essential for extension agencies to project these crucial benefits such as superiority of OS farming in saving water, low cost farming, higher farm employment, higher profit, farmers' increased self-reliance and reduced risk in right perspective for its rapid adoption in the state. The growing of crops by following organic practices in conformity with certain standards is a process beginning from land preparation to finally reaching the produce in the hands of consumers. Therefore, it is essential to impart scientific training not only to farmers but also to other stakeholders to make them knowledgeable, skilled and efficient in production, processing and marketing of organic products

The organic farming does have social benefits in terms of saving water, conservation of soil resources and benefits to human health and environment. Therefore, it is suggested that the social benefits as well as the social costs of OS farming may be properly measured and quantified to get an idea about the extent of incentives that could be justified for promotion of OS farming in the state.

In summary, it is essential to resolve these emerging issues in order to realize its full potential for ensuring sustainability of sugarcane cultivation and for enhancing the economic well-being and livelihood security of the farmers in the State.

7. CONCLUSIONS

The study finds that farmers practicing OS farming are relatively younger and more educated having larger landholding and better resources. The OS farming was found to be superior than IS farming on account of increased human labour employment, lower cost of cultivation, higher profits, better input use efficiency and reduced risk leading to increased income, enhanced self-reliance and livelihood security of the farmers. Moreover, OS farming had positive impact on water use efficiency demonstrating substantial potential for conservation and sustenance of water resources in a water scarce state like Maharashtra. Thus, OS farming has greater potential in achieving the goal of sustainable cultivation of sugarcane crop and ensuring economic well-being of the farmers. Besides addressing the emerging issues from this study, it is crucial to formulate policies and strategies to promote OS farming in order to realize its full potential in selected regions of Maharashtra.

Notes

1 The sugarcane productivity in Maharashtra attained a high level of 95.15 ton/ha in TE 1982-83 from just 70.95 ton/ha a decade earlier (TE 1972-73). After that the productivity declined to 80.98 ton/ha in TE 1992-93 and further dwindled to 78.33 ton/ha in TE 2002-03.

2 The area under irrigation was only 18.10% of gross cropped area of the state as compared to 40.20% at the national level in 2002-03. Thus, Maharashtra is on one of the water deficient states of the country. Despite this, the coverage of irrigation for sugarcane crop is 100% in the state. Sugarcane being a relatively long durational water intensive crop producing huge quantity of biomass, it requires enormous quantity of water for its cultivation.

3 The top ten organic countries in the world are Australia, Argentina, China, USA, Italy, Brazil, Spain, Germany, Uruguay, and UK. The area under organic farming in these countries varies between 620,000 ha in U K to 11,800,000 ha in Australia. These ten countries cover more than 77% of total area under organic farming in the world (Willer and Yussefi 2007).

4 In fact, we have not came across a single comprehensive study that is based on farm level data looking at the impact of organic farming on input use, costs, yields, returns and WUE in the cultivation of sugarcane crop in Maharashtra.

5 The cost of cultivation is referred to cost A_2 plus family labour which includes all actual expenses in cash and kind incurred in production by owner plus rent paid for leased-in land plus imputed value of family labour as defined by the Commission for Agricultural Costs and Prices (CACP), Government of India (2005)[b]. The gross profit is calculated as gross value of production minus the cost of cultivation.

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ECONOMICS OF WATER PRODUCTIVITY AND INSTITUTIONAL CHANGES IN MAJOR IRRIGATION PROJECTS - CHALLENGES AND OPPORTUNITIES: A CONCEPTUAL FRAMEWORK

G. G. Koppa[1]

Abstract

The paper focuses on understanding the dynamics of water management, challenges and opportunities for increasing water productivity and economic efficiency at the system level by focusing on on-farm water management in major irrigation projects. In the context of the ongoing irrigation management transfer to water users' association, the discussion tries to look at ways to achieve water savings in existing uses through increases in water use efficiency and water productivity in agriculture. This is perceived as the path to meeting future water demands while satisfying current needs. Understanding the concept of water productivity at various scales of the system helps to know the capacity and willingness of the small farmers to pay the increased water fees under new institutional arrangements.

The study looks at the institutional strategies with a focus on command area development authority, which is responsible for on farm development (OFD) which can increase the water use efficiency. The paper tries to identify problems and constraints in achieving OFD and the future role of recently formed water users' associations. There is a need to examine the interface between the apparently divergent processes of agriculture development and irrigation in the command and its implication on land use and water management practices both at farm and system level. The paper proposes the transaction cost approach as a conceptual framework for understanding the role of water institutions and stage based perspective to provide insights into the internal dynamics of ongoing water institutional change. This study proposes a conceptual framework to identify practically relevant principles for reform design and implementation.

1. INTRODUCTION

All forms of life on earth are threatened unless water of the right quality and quantity is available for their use. These are threats to the health and life of humans and other life forms in the ecosystem and translate into day-to-day threats to the security of individuals and nations in the form of diseases, food shortages, and chronic health problems. At the extreme end, they translate into hunger, conflicts and wars. Statistics on water from the World Resources Institute, the World Bank, IWMI, and IFPRI all lead to the same conclusion that water is getting scarcer due to excessive unsustainable use and water quality is deteriorating largely due to unsanitary human practices, intensive agriculture, or simply ignorance about proper water use at the farm, household, community and institutional levels.

Whenever there is a reference to water use, naturally the attention goes to agriculture, as agriculture sector is the largest consumer of water accounting at 72% of the total water worldwide and 87% in developing countries. With growing demand for water for non-agricultural uses (domestic, municipal, industrial and environmental), the share of agriculture is projected to decline to 62% worldwide and 73% in developing countries. In developing countries, the growth in water demand for industrial and municipal uses, in absolute terms is expected to exceed the growth in water demand for agriculture between 1995 and 2020 (Rosé grant, Ringler and Gerpacio, 1997).

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Water for agriculture covers a wide range of consumptive and non-consumptive water uses in all the agricultural sub-sectors and significant social, economic and environmental issues. It is a fact that agriculture produces the necessary food for the world's population under both rain-fed and irrigated conditions (Appelgren and Klohn, 2001). Agriculture is thus not only the main consumer of water but also a critical factor shaping important terrestrial and freshwater biomes that form part of necessary life-supporting eco-system services. Agriculture has also become a source of water pollution that has upset the nutrition cycle in the watercourses and soil-water systems and rendered the water unsuitable or less valuable for other water uses.

Water use in agriculture is economically far less efficient than in other sectors (Barker, et al., 2003; Xie et al., 1993). Growing physical shortage of water on the one hand, and scarcity of economically accessible water owing to increasing cost of production and supply of the resource on the other, has preoccupied researchers with the fundamental question of increasing productivity of water use in agriculture in order to get maximum production or value from every unit of water used (Kijne, et al., 2003). Raising water productivity is the cornerstone of any demand management strategy (Molden, et al., 2001).

With high economic and environment cost of developing new water resources, improvements in the water use efficiency and productivity through better management strategies are crucial to mitigate the envisaged water crisis and meet both current and future demands.(Ximing Cai, et al., 2001; Molden and Fishermen, 2001; Seckler, 2003; Asian Productivity Organization, 2004). Sometimes, it is conceded that current efficiency is so low especially in major irrigation projects that most of the future water needs could be met by increased efficiency alone without development of new sources for supply of water (Seckler, et al., 2003). Thus, irrigated agriculture sector especially the farmers are increasingly feeling the pressure to both demonstrate and improve irrigation performance (Burt, et al., 1997).

Improving irrigation performance from the farmers point of view means raising crop yields per unit of water consumed, though with declining crop yield growth globally, the attention has shifted to potential offered by improved management of water resources (Kijne, et al., 2003 as cited in Dinesh Kumar, et al., 2005). It provides a means both to ease water scarcity and make more water available for other sectors. However, the key to understanding the ways to enhance water productivity is to understand what it means (Kijne, et al., 2003). Many researchers have argued that the scope for improving water productivity through water management, or efficiency improvement, is often over-estimated and reuse of water is underestimated (Seckler, et al., 2003).

Great opportunities exist for enhancing productivity of water use in agriculture in India (Dinesh Kumar, 2005). These include, irrigating the crops at the critical stages of growth, establishing greater control over timing and quantum of water delivery; providing appropriate quantum of other inputs to the crops; and growing certain crops in regions, where the ET requirements are lower and genetic potential of the crop can be realized. When water becomes scarce, the irrigation water allocation must be optimal to get positive marginal productivity. There are 2 major issues confronting water users, particularly farmers. First, amidst increasing water scarcity, there is an increasing competition for agriculture water for non-agriculture uses in major irrigation projects (IWMI, 2006). Second, are the ongoing institutional changes in irrigation sector especially irrigation management transfer to water users' association in major irrigation projects. The supposition is that water is no longer a free good and every user must pay for water to increase efficiency of use. The review tries to look into the literature to understand how improvements in water productivity are possible and what are the institutional level issues and challenges that need to be addressed to improve water productivity.

The objective of this review is to propose a conceptual frame work to understand the concept of water productivity and see how it can be improved in the context of ongoing institutional changes at field level with a focus on the interactions between scales of irrigation system, the trade offs between different uses of water (agriculture, fisheries, forests, livestock and field crops) and linkages between water productivity and farmer income. The conceptual framework can help in reforming design of ongoing institutional changes with prioritization like sequencing and packaging and implementation principles of minimizing transaction cost, creating favorable political environment and exploiting synergies within and outside water institutions.

2. WATER USE EFFICIENCY UNDER IRRIGATION

Water use efficiency in irrigation has various definitions. There are concepts of physical and economic efficiency. Whereas physical efficiency compares the volumes of water delivered and consumed, economic efficiency relates the value of output and the opportunity costs of water used in agricultural production to the value of water applied. Another definition compares the water applied to the biomass or yield output. The relationships between these measures of water use efficiency are not always clear and, although all of these efficiency concepts can be useful for irrigation water management, their perspectives can result in differing policy implications and strategies for investment in water management and irrigation.

2.1 Physical Irrigation Efficiency

In a review of technical and economic efficiency terms, Wichelns (1999) terms physical irrigation efficiency as the fraction of water beneficially used over water withdrawn. Classical irrigation efficiency (IEc) is defined as the ratio of water volume beneficially used by plants to the volume of water delivered through an irrigation system, adjusted for effective rainfall and changes in the water storage in the root zone (Burt et al. 1997):

$$IEc = \frac{\text{Crop - Evapotranspiration - Effective rainfall}}{\text{Volume of water delivered-Change in root zone storage}}$$

Irrigation efficiency at the project level is typically subdivided into distribution efficiency (water distribution in the main canal), conveyance efficiency (water distribution in secondary canals), and field application efficiency (water distribution in the crop fields). Keller and Keller (1995) and Keller et al., (1996) argue that although the classical or local irrigation efficiency concept is appropriate for irrigation system design and management, it could lead to erroneous conclusions and serious mismanagement of scarce water resources if it is used for water accounting at a larger scale. This is because the classical approach ignores the potential reuses of irrigation return flows. To overcome the limitations of the classical irrigation efficiency concept, they proposed a new concept, called effective efficiency (IEe), which takes into account the quantity of the water delivered from and returned to a basin's water supply

$$IEc = \frac{\text{Crop - Evapotranspiration - Effective rainfall}}{\text{Volume of water delivered- Change in root zone storage – Volume of water returned}}$$

2.2 Economic Efficiency

Economic efficiency of irrigation water use refers to the economic benefits and costs of water use in agricultural production. It includes the cost of water delivery, the opportunity cost of irrigation and drainage activities, and potential third-party effects or negative (and positive) externalities (Dinar, 1993). Economic efficiency can be expressed in various forms, for example, as total net benefit, as net benefit per unit of water, or per unit of crop area and its broader approach compared to physical efficiency allows an analysis of private and social costs and benefits. Economic efficiency is a criterion that describes the conditions that must be satisfied to guarantee that resources are being used to generate the largest possible net benefit (Wichelns, 1999).

3. WATER PRODUCTIVITY AND AGRICULTURE

There are two contradictory views on mechanisms to increase water productivity in agriculture. One view is that there is lot of scope to increase water use efficiency and productivity as only one third of available water is being used to produce food. Failure to include the potential for recycling or reuse of water diverted for irrigation in measurement of irrigation efficiency has led to the widely accepted view that public irrigation systems are poorly managed (Jensen, et al., 1990 and Molden, 1990). An opposing view focuses on the potential gains from improving agricultural water use efficiencies which may be minimal. Measured water use efficiencies gains are derived from individual farms or systems rather than from system/basin-wide assessments (Keller and Keller, 1995; Seckler, 1995). Unmeasured downstream recovery of drained water and recharge and extractions of groundwater can result in actual basin-wide efficiencies substantially greater than the nominal values for particular farms or systems. (Keller, 1995). This depends on alternative and previous uses and reuses of the water saved in the irrigation field, water quality, and location of the area within the basin.

Whether water management practices/technologies designed to increase water productivity and economic efficiency at the farm level translate into water productivity and economic efficiency gains at the system or basin level needs to be determined (Randolph Barker et al., 2003). Here, the problem lies in allocating the water among its multiple uses and users by irrigation agencies and the government.

Agriculture water use and management cross many scales like crops, fields, delivery systems, basins, nations and the globe. Water use efficiency is a scale dependent concept due to the recycling of return flows by downstream users (David Molden, et al., 2003). Opportunities to increase water productivity are diverse and occur at multiple scales viz. biological, environmental and management (Kassam, et al., 2007). Hydrology requires that potential productivity gains should be examined at farm, system and basin level. A problem may be observed within at one level but either the causes or its consequences might happen at another level or scales.

Increasing the water productivity is a shared responsibility as farmers and managers of water systems determine the levels of technical and allocative efficiency of the water resource and their decisions are influenced by the policy and regulatory instruments and complementary interventions (Simon Cook, et al., 2006). All these producers and managers have multiple objectives like productivity, profitability, diversity and stability based on which they assess the performance of their production systems (McConnell and Dillon, 1997). The definition of water productivity is found useful by people depending on scale at which they are working (Molden, et al., 2003).

4. ON-FARM WATER MANAGEMENT

On-farm (system) water management in major irrigation projects consists irrigation systems including the engineering and managerial tools, which maximize yields and farm incomes; the drainage system relating to the tools preventing water logging; salinity on the crops; labor and social system dealing with the impacts of irrigation on the welfare of farmers, workers, and the environmental system related to the impacts of the irrigation on environment (ICID, 1997).

Still on-farm irrigation faces an old problem, on the one hand, engineers considered the farm as a matter for the agronomists and farmers, and devoted their attention to off farm systems, on the other hand agronomists paid attention to the plant, the crop, and the crop responses to water stress, limiting their attention to define when to irrigate. The gap between the traditional engineering and agronomist disciplines was left to the farmer (Luis Pereira, ICID, 1997). Even though efforts have been made to fill these gaps, these measures mattered only to large farmers and relatively few developments concern the small farmers.

The studies addressing problems related to efficient use and management of water for irrigation have highlighted 2 critical parameters, namely the absence of scientific land development in irrigation commands and lack of discipline among stakeholders regarding development, distribution and management of water. Agricultural use of water for irrigation is itself contingent on land resources (J. Dillon, FAO, 2004). Given the importance of on-farm development (OFD) and on-farm water management (OFWM) in the efficient performance of irrigation systems, there have been commendable efforts to examine the economics of OFD as well as the dynamics of water management practices in canal commands. It is found that the low progress of OFD and non implementation of land consolidation program by Command Area Development Authority(CADA) have led to low productivity (Reddy, 1991 and Vishwanath, 2001) in major irrigation projects in Karnataka and Kerala respectively

5. ECONOMICS OF WATER USE

With an international consensus (Dublin Statement, 1992), water management is considered in relation to issues of economic efficiency, environmental protection, sustainability and the needs of marginalized and poor people (Kerry Turner, et al., FAO, 2004). Accordingly, the value of water is increasingly seen in terms of economic, social and environmental requirements (Hussain, et al., 2007). The popular productivity indicators based on crop output do not capture the full range of benefits and costs associated with agricultural water use. The value of agricultural water may not be as low as it is generally perceived when all major uses, both direct and indirect, at various levels, are properly accounted for. As of now, water productivity at farm scale leaves out the multiple uses of water but at basin level the water productivity takes into consideration the beneficial depletion for multiple uses of water (Palanisami, et al., 2006). The value of water varies across time and space and scales in the system endorsing the view of Molden, et al., (2003).

For irrigation, on-farm performance is typically a physical case in terms of application efficiency and distribution uniformity (Luis Periera, ICID, 1997). There is a need to further develop and use other innovative approaches to analyse on-farm irrigation performance with regard to economic return of water use, the labour requirements, the welfare provided by improvements in irrigation. There are questions about trade offs between higher water productivity of desired outputs, the agronomic or economic gain of high water productivity, and the cost and efforts of concurrent investments to obtain this productivity (Dirk Zoebl, 2006). Working out water productivity within agriculture, water use by fisheries, forests, livestock and field crops is very important and analyzing each water use independently often leads to false conclusions because of the interactions among these components (Molden, et al., 2003). Considering these dimensions, it may be appropriate to represent on-farm system as composed of irrigation system, the drainage system, the labour and social system and environmental system (ICID, 1997). Empirical work on broad application of economics of small water systems can be a starting point. (Leon Hermons, 2004; Bandopadhyay, 2007)

6. INSTITUTIONAL CHANGE

With regard to water scarcity there are two predominant views, on one hand there are researchers who believe that scarcity of water is due to lack of available water resources, a phenomenon which is aggravated by pollution problems and climate change (Van Koppen, 2003; Madulu, 2003, etc.). On the other hand there are those who argue that the problem of water scarcity is economic in nature, caused by the lack of proper institutional framework and lack of incentives to adequately develop and manage scarce water resources (Dinar, 2000; Tushar Shah, 2005; Denoso and Melo, 2005).

Water productivity improvements in large scale irrigation are possible, but require major programmes of modernization, a combination of institutional change and investment in system improvement (World Bank, 2006). The most significant change in institutional arrangements in recent years has been the participatory irrigation management (PIM) and the development of water users associations (WUAs), which is more of a purposive reform program than the normal process of institutional evolution. The dominant water sector concerns no longer revolve around water development and water quantity but around water allocation and water quality (Saleth and Dinar,1999). This development paradigm enhancing the influence of economic forces and participation of stakeholders in decision making is irreversible.

The underlying rationale for participation in irrigation management is that users have a direct interest in the efficiency and flexibility of water delivery and are more willing to pay for the costs if they have an influence over operations (World Bank, 2006). The success of these water users' institutions (WUAs) will only be possible if the economic productivity of water for irrigated agriculture generates sufficient returns. From an economic perspective, it is tempting to reduce the study to a benefit-cost analysis of water use before and after institutional change, but the analysis requires more (Livingston, 2005).

The opportunity and transaction costs of institutional changes in the water sector are strongly influenced by forces external to the water sector. These water users' associations created to improve the functioning of water economy critically depend on the level of formalization of water economies (Tushar Shah, 2005), which in turn depend upon the overall economic evolution of that country. It is therefore crucial to exploit the political economy and organizational context to gain momentum for accelerated reforms in the water institutions. The institutional change can emerge both from the endogenous structure as well as from the exogenous environment of institutions.

Saleth and Dinar (2004) advocate using the performance and transaction cost impacts of institutional linkages as a framework to interpret the way different factors affect the change process. Like all institutions, water institutions are also subjective[2], path dependent[3] and hierarchically embedded within the cultural, social, economic and political context. This suggests the perception of individuals as a source of change, nature of the change process, the scope for scale economies in transaction costs and the powerful role of contextual factors in institutional change.

The ongoing irrigation management transfer to water users cooperatives in irrigation projects across developing countries including India suppose that irrigation water has to be priced on volumetric basis as decides by the irrigation agencies, and farmers will have to pay for the cost of water supply and related services, by forming water users' associations. When zealously implemented, especially in the informal segments of the water economy with large number of users, water permits and water prices hit poor people in remote rural areas hard (IWMI, 2007).

Gulati, et al., (2005) observe that most water user organizations failed in India because they were focused areas of concern to the government but not necessarily to the farmers. They recommend that user organizations receive the authority to levy water fees, conduct maintenance, and represent farmers' interests to government agencies. This demonstrates potential but successful irrigation management transfer requires much greater policy and institutional changes. Even where formal conditions seem to be in place, as in Andhra Pradesh, there is considerable evidence that there is unwillingness of government organizations to delegate or share power with user organizations (Ratna Reddy and Prudvikar, 2005). This raises a fundamental issue: while governments may be willing to transfer the hard work and expense of local water management to users, they are rarely willing to restructure their bureaucracies or to make the other legal and structural changes needed to achieve a new balance of political power favoring users (Wade 1982).

From an aggregate perspective, if the objectives of the politically prevailing interest group does not coincide with greater economic efficiency, researchers especially economists will have to identify opportunities to change water institutions in a way that could increase economic efficiency integrating every section of the water users including non elites (tail enders, small and marginal farmers, socially, economically and politically backward users). As a guiding principle, the concept economic efficiency is powerful, but limited. While institutional change is likely to increase or decrease the aggregate net beneûts accruing to a society, it will definitely change the distribution of those benefits and costs. Therefore, equity must also be a central element of the evaluation methodology.

There is unanimity that WUAs work better where the irrigation system is central to a dynamic, high-performing agriculture; the average farm size is large enough for a typical farmer to operate. The reform also supposes that supply of water resources is just sufficient to meet the demand requirements in the given command. The farm producers are linked with global input and output markets. The costs of self-managed irrigation are a insignificant part of the gross value of the product of farming (Tushar Shah, 2005a). But command areas in India have a large proportion of small and marginal farmers growing mostly low-value cereal crops. The informal nature of irrigation economy reduces the farmers' stake in improving the public irrigation system. This informality increase the transaction cost of community management. Relatively low value of produce and the fact that reforms often come with higher irrigation fee and greater management responsibilities reduce the potential pay-offs of farmers.

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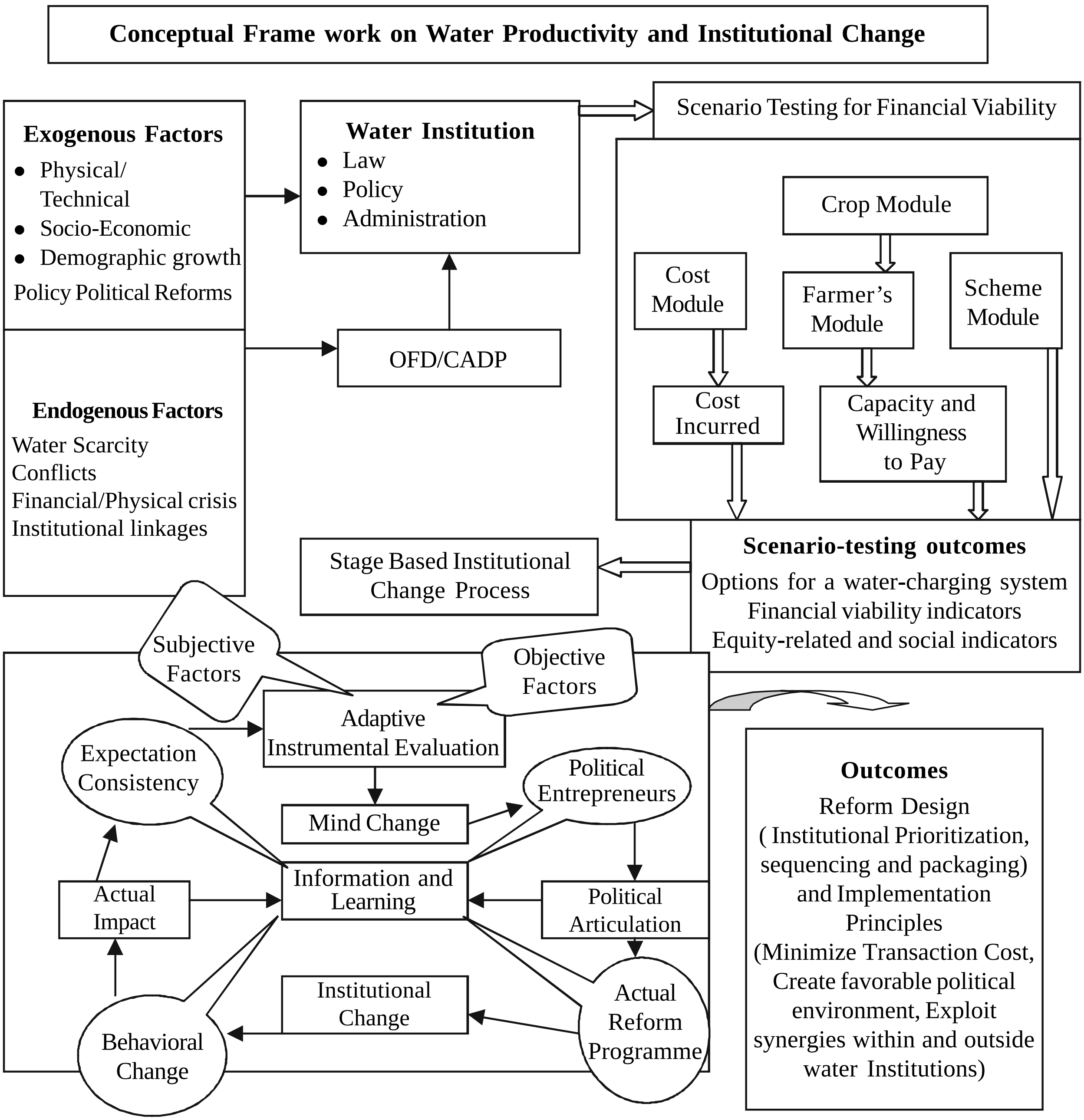
[2] Institutions are subjective in origin and operation but objective in manifestation and impact. Their subjective nature is recognized as the belief system, behavioral habits, or the subjective model of individuals (North, 1990)

[3] Path dependency means that the present status and future direction of institutions cannot be divorced from their earlier course and past history (North, 1990). Here the institutional linkages in temporal sense and hierarchical means institutional linkages in a structure sense.

As evident from the literature reviewed, the ongoing institutional reforms will be able to succeed only if there is an understanding on transaction cost for the institutional changes, scope for increasing water productivity at different levels and constraints in on-farm water management.

7. CONCEPTUAL FRAMEWORK

Consistent with the institutional economics literature (North, 1990; Ostrom,1992), water institutions are conceived in a much broader sense than mere organization. Water institutions set the rules and thereby define the action for both individual and collective decision-making in the realm of water resource development, allocation, use, and management. Since these rules are often formalized in terms of three inter-related aspects, i.e., legal framework, policy environment, and administrative arrangement, water institutions can be conceptualized



as an entity defined interactively by these three concepts. Factors that lead to changes in these three components have diverse origin and varying level of impact. For analytical convenience, these factors can be grouped into endogenous factors that are internal to water sector and exogenous factors that are outside the strict confines of both water institution and water sector. The endogenous factors include water scarcity, water conflicts, financial and physical deterioration of water infrastructure, and operational inefficiency of water institutions. Exogenous factors include general legal system, economic development, demographic growth, technical progress, economic policies, political reforms, international commitments, changing social values and ethos, and natural calamities including floods and droughts. The exogenous factors, define the general environment within which water-institution interaction occurs while the endogenous factors capture the dynamics of such interaction.

Each of the institutional components can also be decomposed further to highlight some of the key institutional aspects. These aspects will be used as an analytical framework for organizing a comparative review of existing structure and ongoing changes in the water institutions vis-à-vis the institutional needs of the reform.

A major feature of the stage-based perspective of institutional change is that the change process is not entirely evolutionary or autonomous. Deliberate and purposive policies can substantially alter or reinforce the course of institutional change. Various policy options and reform strategies are implicit not only in the institutional features but also in the very mechanics of the stage-based process of institutional change itself (Saleth and Dinar, 2004). This framework can be used as a basis for developing strategies and tactics for altering the change process in terms of a few reform design and implementation principle. The focus will be around the following key aspects depending upon context and information availability.

- Review the progress, key issues, and constraints in achieving on-farm development and water-related targets at the project and state levels.
- Review changes, trends, and patterns in the water sector.
- Review key features of existing structure and ongoing changes in the institutional arrangements governing the water sector of select developing countries.
- Assess how conducive or favourable the conditions in water sector and the structure and changes in water institutions are for achieving the water-related targets at the project and regional level.

7.1 Scenario Testing

The analysis of water productivity in the irrigation command where irrigation management has been transferred to WUAs involves scenario-testing for the capacity and willingness of farmers to pay the costs incurred by the scheme and participate in the charging system to be set up. They must also understand the impact of certain measures or decisions, or certain farmers' strategies on the financial viability of the scheme. The approach must include a sustained and multi-disciplinary partnership during scenario development and discussion between farmers and transfer operators (NGOs, irrigation agency). Such an approach has huge potential for information and decision-making support towards transfer operators, for training, and for farmers' participation.

There are costs incurred by supplying water and water-related services to farmers, and hence financial viability must be pursued at scheme level (involving partial or total cost recovery). In the irrigation management transfer context, this means that 1) The management entity (WUA) provides irrigation water and related services to farmers, 2) Such services incur costs (capital, maintenance, operation and personnel-related), 3) The management entity charges the farmers based on the system to be established, and 4) The farmers tap into their monetary resources (generated by irrigated or rain-fed cropping systems, by off-farm income) to pay these water service fees. However, one should understand that smallholders' agricultural and resource-management systems face a quickly changing economic, legal and social environment.

7.1.1 Implementation features

The approach involves 3 phases: 1) Information on the scheme at household level, 2) Information analysis and information-system development, which requires a typology[4] of farmers, and 3) Running the model on a scenario-testing basis, evaluating the impact of certain measures or decisions, or certain farmers' strategies on agricultural and production features, land allocation, costs and cost recovery, and sustainability-related indicators. Different farmers strategies and practices co-exist within a scheme. Grouping irrigation farmers into several types helps representing this reality,

7.1.2 Analysis of the situation

The model's conceptual framework (S. R. Perret, 2002) takes into consideration the economic and financial aspects of scheme's management, and addresses some technical indicators in order to check out whether the scenarios are realistic (example: water resource availability). 5 input modules form the basis of the information system, as interfaces for data capturing by the user.

7.1.2.1 Cost Module

Each cost-generating item is listed in the "cost" module. This module generates output variables that reckon the costs incurred by the scheme and its management (i.e., capital costs, maintenance costs, operation costs, personnel costs). Such information answers the question on how much does it cost to operate the scheme in a sustainable manner, regardless of who is going to pay for it.

7.1.2.2 Crop Module

In the "crop" module, each irrigated crop is listed with its technical and economic features (example: management style, cropping calendar, water demand, yield, production costs). This module generates micro-economic output variables (example: gross and net margins) that allow comparative evaluation of crops in terms of profitability, land productivity, and water productivity.

7.1.2.3 Farmer Module

A "farmer" module captures different types of farmers, with their cropping systems (combination of crops that have been documented in the crop module), average farm size, scheme's size (percentage), willingness to pay for irrigation water services. This module generates type-related output variables (example: aggregated income per type, crop calendar) and scheme-related output variables (example: number of farmers, aggregated water demand) when combined with the "scheme" module.

7.1.2.4 Scheme Module

A "scheme" module lists the scheme's characteristics (example: size, rainfall and resource-availability patterns, tariff structure). This module is combined with the "farmer" and "cost" modules, and generates output variables on water pricing, tariff, cost recovery rate, contribution per type. The capacity and willingness of farmers to pay can be assessed by amalgamating crop and cost module and using them in water charging system and generated output variables on cost recovery rate. This answers question such as who may pay, and how much, for what water services. It also generates some social and equity-related indicators farmers, crop type, area per type, gross margin per type and gross margin per type at scheme level, total water consumed), and resource-related indicators (example: total number of farmers, area per type, number of farmers per type, type net income, scheme total net income, total water consumption, overall weekly water balance).

Additional scenarios may be tested through the capture of non-real/prospective data, especially when the given scheme has not yet been rehabilitated or transferred (example: alternative crops and cropping systems, emerging farmers' types, changes in scheme's management patterns, options for a charging system, new infrastructures, and so on). Based on the scenario testing of the ground realities in the command on going institutional change in the command will be studied by stage based conception of institutional change approach.

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[4] Developing a farmers' typology is a prerequisite, as one can neither address all farmers individually nor consider them all similar.

7.2 Water Institutional Change: A Stage-based Perspective

While the institutional transaction cost approach explains the logic of institutional change, it has an analytical limitation in explaining the process of change, as the interesting dynamics are subsumed within the beneût–cost calculus. There are other theories such as those based on market approach. As water scarcity becomes acute, the social costs of inefficient institutions tend to rise. These costs are relatively high in the early stages of reform, but tend to decline as institutions mature, with the articulation of stronger institutional linkages to facilitate upstream and downstream changes. For instance, with transferable water rights, prospects for conûict resolution and water markets become brighter owing to transaction cost linkages within these aspects. Scale economies in transaction costs are also possible when water reforms become a part of the larger economic and political reforms. Intentional institutional design, induced institutional innovation, rent-seeking and political bargaining also have limitations as they capture only a part but not the entire process of institu-tional change. However, a combination of relevant theories can be logically linked to capture the whole dynamics of the change process.

The stage-based perspective of institutional change proposed by Saleth and Dinar (2004) can be a general framework for linking different theories to provide a simple but relatively more complete description of the change process. This framework depicts the stage-based perspective characterized by four main stages of institutional change. These stages progress as a circular process that is subject to constant subjective and objective feedback, learning and adaptation. In different stages, the change process is mediated by mechanisms such as instrumental (or reference point-based) subjective evaluation, information ûow and learning externalities, political lobbying and bargaining, organizational power and politics, and behavioral changes and performance expectations.

Of the 4 stages, the First stage involving mind change is significant. Mind change and perceptive convergence occur among individuals not only from their adaptive and instru-mental evaluation of subjective and objective factors but also from the information feedback and learning experience they gain from existing institutions and ongoing changes. Since perceptive convergence means an implicit demand for institutional change, political entrepreneurs with an eye on electoral payoffs articulate such demand with their campaigns and lobbying.

In the second stage, political agreement about the need for change does not mean agreement about the details of change. Whether political entrepreneurs take these initiatives (a form of public goods) depends on their ex-ante perception of a tangible political benefit for them or for their political parties (Knight and Sened, 1995 as cited in Saleth and Dinar, 2005). Owing to the potential for divergence in the transaction cost of different social and political groups, there will be an intense debate, bargaining and even, counter-campaigns. The reform program that would emerge from this process is an outcome of the relative bargaining power of different groups.

The third stage is crucial as it is found where institutional supply occurs with reform implementation. However, there is a vast scope for slippage between reform implementation and actual changes in view of many financial, organizational and bureaucratic constraints. Often, imple-mentation proceeds with ceremonial and procedural changes (example: policy declarations and renaming or merging of organizations) and ends up only with euphoria rather than with actual change. But even these cosmetic changes are useful both in realigning political groups and creating a pro-reform atmosphere conducive for undertaking substantive changes (example: legal reforms, devolution, privatization and water rights). Even with substantive institutional changes, reform benefits may not be immediate and perceptible, as the direct outcome of institutional change is only a process of behavioral changes and its outcome depends on the impact of these behavioral changes on actual resource allocation, use and management. While institutional change is a slow and continuous process, it is neither linear nor unidirectional, as the change process can proceed to the next stage, stay in the same stage, or revert to previous ones as dictated by the interplay of factors in different stages. The stage-based perspective can be used as a framework to identify and link relevant theories. The reform implementation principles can be used to decide how and when to initiate and deepen the reform efforts. Although reform design aspects themselves have a major bearing on these decisions, what is more important are the strategic and tactical opportunities for reform imple-mentation provided by the exogenous factors. For instance, the political economy contexts provided by changes in the overall institutional environment (example: fiscal crisis, political reforms, international agreements and donor pressures) can be exploited with appropriate timing, dose and scale of reform implementation. Thus, fiscal crisis provides a favorable context for implementing even a radical program with the least political opposition. Similarly, when the water sector reform forms part of larger political or economic reforms, its implementation becomes easier owing to synergic effects and scale economy benefits from the larger program to stages of the change process.

8. CONCLUSION

Proposed ways in which water is to be owned, distributed and managed imply fundamental changes. An understanding of how the water economy really works is very important in order to intervene in a promising and workable way. Even though the essential elements of effective institutions and policies are applicable in all the locations and at all scales they are contingent, context specific and non-linear and therefore outcomes are uncertain. In India, reforms are implemented without understanding how India's water economy really functions.

Based on this review and in the light of on going irrigation management transfer to water users' associations in most of the irrigation systems; based on past experiences with these reforms; and little or no knowledge of the actual and potential of economics of water use owing to small size of land holdings, the following inference can be made

1. It appears there is lot of scope for farmers to increase water productivity and economic efficiency with the existing cropping system and other water use practices in the system as a whole. However, it is not certain whether increased productivity addresses the issue of equity and poverty.
2. In the context of proposed reforms, if there is increased income from increased water productivity, small farmers will also be willing to pay higher water charges. However, it is not clear how does the size of the production system influence the changes.
3. There is need to understand what water productivity and economic efficiency mean at various levels of field, farm, distributary and system.
4. Even though it clear that there are trade offs in increasing system level water productivity between upstream and down stream use, agriculture and environment (production versus conservation), cropping and livestock/fisheries/forestry, there is no clarity or consensus on how to manage these trade offs.
5. There is a need to understand the form/structure of the local water users' institutions that have been emerging and how they are similar or different from the existing formal and informal institutions.
6. The question that remains unanswered is what are the contextual factors that determine the success of new institutions and how they are influencing the ongoing institutional change process.

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LOCAL PERCEPTION AND USE OF THE MULTIFUNCTIONALITY OF TANKS IN TWO VILLAGES OF TAMIL NADU SOUTH INDIA

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Abstract

Interventions aiming to devolve water management to local populations can be problematic if they overlook socio-cultural aspects, such as local perceptions and uses of water management systems. We used ethnographic and survey data collected in two villages in Tamil Nadu, India, to analyze local perceptions and uses of tanks, a traditional irrigation infrastructure. We found that informants recognize the importance of tanks for irrigation, but also acknowledge other socio-economic uses and ecological functions. Our data also suggest that marginal segements (i.e., Scheduled Castes) use tank resources in more diverse ways than other segements of the population. International organizations working on the revival of tanks aim to transfer water management to farmers for the purpose of irrigation. By recognizing that tanks benefit people other than farmers and in ways other than providing irrigation water, organizations working on tank rejuvenation could achieve a more equitable management of tank resources.

1. INTRODUCTION

Over the last two decades, irrigation researchers, policy-makers, and donor agencies have become increasingly disenchanted with large-scale irrigation systems (Hussain and Hanjra, 2004; Moris and Thom, 1990; Webb, 2006) and have shifted their focus to farmer managed irrigation systems (Watson et al., 1998). The shift has ocurred parallel to a trend to decentralize water management programs from the state to local users (Parker and Tsur, 1997). Research suggests that interventions by outside agencies that aim to devolve water management to local populations can be problematic (Meinzen-Dick and Zwarteveen, 1998; Webb, 2006). Issues such as the appropriateness of technology, forms of social organization (including gender considerations), and patterns of resource rights have significant implications for conventional top-down approaches (Meinzen-Dick and Zwarteveen, 1998; Watson et al., 1998). Social scientists have long argued that if interventions aimed at improving the developmental role of indigenous water management systems are to be effective, planners need to not only reconsider technical, but also socio-cultural factors (Gleick 2000; Pahl-Wostl et al. 2007; Diemer and Huibers 1996). Despite the claim, many development programs still fail to effectively include socio-cultural considerations, often because of the scant research on the topic.

In this article, we analyze local perceptions and uses of a locally-managed irrigation system, the tanks. tanks are an old irrigation infrastructure widespread in the semi-arid areas of southern and central India (Vaidyanathan, 2001). tanks are shallow reservoirs ranging from a few to over a thousand hectares and are formed by constructing earthen embankments that extend across the natural drainage flow and that dam in situ

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rainfall and seasonal runoff. Tanks are mainly found in regions where rainfall is moderate (350–800 mm), inter-annual variability is high, and there are clay soils with low permeability, which reduces seepage into the ground (Agarwal and Narain 1997; Gunnell and Krishnamurthy, 2003). Tanks are mainly meant for irrigation but research shows that they also provide other socio-economic uses and ecological functions that benefit sectors of the society beyond farmers (Gunnell and Krishnamurthy, 2003; Palanisami and Meinzen-Dick, 2001; Shan and Raju, 2002).

Researchers concur that the importance of tanks for irrigation in South India steadily fell during the nineteenth and twentieth centuries (Aubriot 2008; Janakarajan 1993; Palanisami and Meinzen-Dick, 2001). Despite the decreasing importance of tanks for irrigation, researchers claim that tanks can provide a locally managed alternative to groundwater irrigation and to the controversial construction of big infrastructures such as dams (Agarwal and Narain, 1997). For the last two decades, Indian and international organizations (including the European Union, the World Bank, and the ADB) have invested considerable resources in the revival of tanks (ADB, 2006; Sakthivadivel et al., 2004). Two common traits are found in tank rehabilitation projects. First, tank rehabilitation projects mainly focus on irrigation and water storage (ADB, 2006), but neglect most alternative uses of water or other tank resources (except fish cultivation). Second, tank rehabilitation projects promote the participation of land-owners in tank management (Meinzen-Dick and Zwarteveen, 1998), thereby excluding other sectors of the population.

In this study, we used data collected in two villages in Tamil Nadu, South India, to analyze local perceptions and uses of tanks. Differently from previous social research on the topic (Palanisami and Meinzen-Dick, 2001; Shah and Raju, 2002), we analyzed local users perceptions of the benefits provided by tanks. Our emic approach complements the etic understanding of the socio-economic and ecological benefits of tanks provided by previous literature. By analyzing responses from farmers and non-farmers, we assess whether tanks are locally perceived and used for proposed other than irrigation. We propose that a better understanding of local people's perception and uses of tanks might help improve the design and implementation of tank rehabilitation projects.

2. TANKS IN SOUTH INDIA

Originally, tanks were mainly constructed for agricultural purposes. By impounding runoff water from the monsoon rains, tanks support cultivation in the reservoir command area (Jayatilaka, et al., 2003). Research shows that tanks also provide other socio-economic uses and ecological functions (Palanisami and Meinzen-Dick, 2001; Shan and Raju, 2002). Water from tanks provide many economic (example, fisheries) and domestic (example, fresh water) uses. Tanks, as they are not full most part of the year, also provide other resources, such as silt, trees, and grass. Socially, tanks are repositories of symbolic resources and are central elements of villages (Mosse, 1997). Tank management systems have been interpreted as public institutions that express social relations, status, prestige, and honor (Singh, 2006). Tanks, as other common property resources (Freeman III, 1993), provide many environmental services and ecological functions. Tanks provide direct environmental services (such as irrigation water and drinking water) as well as indirect environmental services (such as contributing to flood control and providing habitat for a variety of species (Ratnavel and Gomathinayagam, 2006).

Tank resources and ecological functions benefit different sectors of the society. In theory, access to water for irrigation is available to all farmers in the tank command area. Water is available to the entire population, not only farmers, but also for domestic uses (i.e., washing clothes, bathing). Other benefits from the tank resources (e.g., extraction of silt) also reach the entire population in a village (Palanisami and Meinzen-Dick 2001). More importantly, rights to fish, trees, and grass along the tanks are often auctioned. Funds generated from auctioned tank resources are often expended on village social activities such as temple construction or village festivals (Janakarajan 1993; Meinzen-Dick 1984; Mosse 1997; Prabhakar 2008; Wade 1987).

3. THE SETTING AND THE PEOPLE

There are around 39,000 tanks for about 15,000 villages in Tamil Nadu. The Public Works Department (PWD) of Tamil Nadu has control over 8,903 tanks that have a command area of more than 40 ha. Panchayat Unions have control of the 20,413 tanks that have a command area of 40 ha and less. There are also 9,886 tanks called the Ex-zamin tank. Individual local chiefs called Zamindars once controlled these tanks. Nowadays, the PWD is responsible to undertake repair works in these tanks. Tanks were the main source of surface irrigation in Tamil Nadu until the 1960s (35% of total irrigated area) and they still accounted for about 17% of irrigated area in 2004-2005 (Season and Crop reports of Tamil Nadu, cited in Aubriot 2008).

For the purpose of this research, we selected villages with tanks still in use for agriculture. We conducted research in two villages in the Villupuram District (Tamil Nadu): Attur and Endiyur (Table 1). Both villages are located about 5km away from the nearest city, Tindivanam (about 200,000 people), in a pediplain rocky zone of the Kaluvelli watershed. Agriculture and cattle rearing are the two main economic activities in the studied villages. The main crops grown in irrigated land are paddy, sugarcane, banana, casuarina, and cotton, and the main crops grown in non-irrigated lands are groundnut, black gram, finger millet, cotton, and chili. The two villages experience permanent and seasonal migration.

Table 1 - General characteristics of the two study villages

	Source	Attur	Endiyur
Total Population	Census of India 2002	1508	2683
Population from Scheduled Castes	Census of India 2002	658	0
Landless population (%)	Village Administrative Office	37	17
Wells for irrigation	Well census 2004	274	227
Tanks command area (in ha)	Village Administrative Office	115	62
Rainfed cultivated area (in ha)	Village Administrative Office	256	252

Each village has a large and a small non-system tank (i.e., rainfed tanks not connected to rivers). Irrigation water from tanks is available from October to December-February (according to rains). Tank irrigation is supplemented with groundwater irrigation. At the time of the research, there were 208 electricity lines for agricultural pumps in Endiyur and 55 in Attur, and numerous pumps using diesel engines. The Public Works Department (PWD) is responsible for opening the sluices and maintenance (i.e., repairs and desiltation) of the large tank in each village. The Panchayat Union is responsible for the small tanks. Every year, the PWD and the Panchayat Union alienate the rights to manage the tank resources (i.e., grass, fish) through open auctions. Farmers are responsible for water distribution and irrigation canal maintenance. In Endiyur, there are two Water Users Associations, formed in 2000 with the help of a non-governmental organization working in tank rehabilitation. All farmers in the command area of Endiyur’s tanks, and only these farmers, are included in the Water Users Associations, which has the duty of managing the tanks (i.e., implement rehabilitation work with the assistance of PWD, plan the water rotational system, and remove encroachers). Nevertheless, Water Users Associations seem not to be effective in the study villages, and tanks are actually managed by traditional institutions and the Village Panchayat.

4. METHODS

The study was conducted under the umbrella of the Social Water Management program of the French Institute of Pondicherry. Three researchers collected data with the help of two assistants fluent in English and Tamil.

4.1 Data Collection and Analysis

4.1.1 Participant observation

Three researchers lived in Endiyur for a three-month period (February-April 2007). Since Attur is only about 3 km away from Endiyur, the researchers were able to visit this village regularly. During fieldwork, researchers participated in the regular activities of the villages. Notably, they accompanied people in their festive and work activities. Participant observation allowed the understanding of the different ways in which resources from tanks are used. We also conducted group interviews to get a better understanding of the different perceptions and uses of tanks according to different social groups.

4.1.2 Free listing

We conducted free listing to generate a comprehensive list of reasons why tanks are important for villagers (Weller, 1998). We used a stratified sampling strategy (Bernard, 1995), selecting informants from various groups with expected variation in uses of the tanks such as men, women (Meinzen-Dick and Zwarteveen, 1998), and people from different castes (Tiwary, 2006). We also selected people with different occupations (i.e., farmers, shepherds). The total sample for free listing was 54 respondents from 54 households, which represents 6% of the total number of households in the study villages.

Respondents were asked to generate a list of items in response to the question: "Why do you think tanks are important for the village?" We probed respondents to give as many reasons as they could conceive. Once the list was completed, we asked informants to provide a short description of the reasons that were not clear to us when the informant had listed them. Because our question was general, we do not know if people were referring to a specific tank when answering our question. Although free-listing is widely used in anthropological research (Bernard, 1995), the question used here might have biased the answers as it indirectly conveys that tanks are indeed important. Thus, households that might not place a particular importance on tanks, might have given positive answers because of the framing of the question. Unfortunately we did not collect information on the relative importance of tanks in relation to aspects of livelihoods (such as drinking water or sanitation) to weight the bias introduced by our question.

From responses to free listing, we calculated: 1) the percentage of people who mentioned each reason, 2) the average rank of the order of mention of each reason, and 3) the saliency of each reason (the weighted average of the inverse rank of an item across multiple free lists, where each list is weighted by the number of items on the list) (Bernard, 1995). The saliency index evaluates, with a range from 0 to 1, the overall importance of an item across all of the lists.

Based on the saliency index, we arbitrarily created four categories: High Saliency ($S>0.5$), Medium Saliency ($S<0.5$ & $S>0.1$), Low Saliency ($S<0.1$ & $S>0.01$), and Marginal Saliency ($S<0.01$). We also used informants' explanations to classify items according to their main use or function (ecologic, economic, and socio-cultural). Among economic functions we differentiate between agricultural, non-agricultural, and domestic. As one particular item might have more than one use or function (example, flood prevention has an economic use and an ecologic function), the results from this classification should be taken with caution.

4.1.3 Survey

We conducted a survey to assess household variation in the uses of tanks. To select informants for the survey, we followed the same sampling strategy that was used to select informants for free listing. The sample for the survey included 96 adults (people over 15 years old) from different households. Of the total, 53 informants were from Endiyur and 43 from Attur.

The household survey included socio-economic questions (i.e., caste, land ownership) and questions related to the use of tanks (Table 2). Questions related to the use of tanks were selected from responses to free listings and refer to economic uses. We did not include questions on social uses or ecological functions because the ecological (example, attract biodiversity) and social (example, source of revenue for village festivals) functions that appeared in free listing likely do not vary across households. If participants reported the economic use, we coded the answer as 1 and, otherwise we coded the answer as 0; therefore the total score might vary from 0 to 8 uses.

Table 2: Survey questions on the use of tanks in two rural villages in Tamil Nadu (n=96)

Category of use	Question	% Positive answers
Agricultural	Do you use water from the tank for irrigation?	47.9
	Do you use the tank's silt to fertilize your lands?	34.3
Non-agricultural	Do your cattle drink from the tank?	36.4
	Did you participate in the last auction of a resource from the tank?	18.7
	Have you ever bought wood from the person who won the auction of the trees?	11.4
Domestic	Does the grass on your roof come from the tank?	31.2
	Do you use medicinal plants from the tank?	36.4
	Do you wash clothes in the tank?	59.3

Our survey included questions related to agricultural, non-agricultural, and domestic uses of tanks. For each household, we generated a diversity score for each one of the three economic uses by adding the positive answers in each group. We also generated a total diversity score by adding responses to all of the questions. We used t-test and an ordinary least square regression to analyze differences in diversity of use across households with various socio-economic characteristics.

4.2 Results

4.2.1 Why are tanks locally considered important?

Respondents listed 49 different reasons why tanks are important (Table 3). On average, informants listed 8.01 different reasons (SD=3). The shortest list included only two reasons and the longest included 17.

Table 3: Results from free-listing about the importance of water tanks in two rural villages in Tamil Nadu (n=54)

Reasons listed	Category	% resp	Avg rank	Saliency
High Saliency (S>0.5) (n=1)				
Crop production	Econ-Agri	80	2.093	0.69
Medium saliency (S<0.5 & S>0.1) (n=14)				
Irrigation	Econ-Agri	46	2.84	0.37
Drinking water for cattle	Econ- Non Agri	54	3.75	0.37
Favor presence of fish	Ecol	61	5.51	0.28
Drinking water	Econ-Domestic	43	3.78	0.28
Well recharge	Ecol	37	3.70	0.26
Water storage	Ecol	26	2.92	0.19
Wash clothes	Econ-Domestic	35	6.21	0.17
Grass for roofs	Econ-Domestic	28	4.93	0.17

Reasons listed	Category	% resp	Avg rank	Saliency
Favor presence of trees	Ecol	39	6.00	0.16
Favor presence of grass	Ecol	30	5.50	0.15
Firewood production	Econ-Domestic	30	6.43	0.13
Bathing	Econ-Domestic	28	6.33	0.12
Formation of silt for manure	Econ-Agri	26	6.92	0.11
Fish auction	Econ- Non Agri	28	7.06	0.10
Low saliency (S<0.1 and S>0.01) (n=22)				
Grass auction	Econ- Non Agri	22	6.91	0.09
Favor presence of plants	Ecol	19	6.30	0.08
Employment creation	Econ- Non Agri	19	6.50	0.07
Grass for cattle	Econ- Non Agri	19	6.50	0.07
Trees auction	Econ- Non Agri	15	8.75	0.06
Increase of production	Econ-Agri	7	4.25	0.04
Favor presence of birds	Ecol	9	7.60	0.04
Temperature control	Ecol	9	7.00	0.04
Wash cattle	Econ-Non Agri	7	6.75	0.03
Favor presence of crabs	Econ-Domestic	7	5.00	0.03
Trees for shadow	Ecol	7	8.00	0.03
Silt formation	Econ-Domestic	7	5.00	0.03
Provides livelihood	Econ- Non Agri	7	6.75	0.02
Males toilet	Econ-Domestic	4	5.50	0.02
Trees attract the rain	Ecol	6	11.00	0.01
Saves pumping electricity	Econ- Non Agri	2	2.00	0.01
Recharge fresh water pond	Ecol	2	3.00	0.01
Favor presence of snakes	Ecol	4	6.50	0.01
Favor presence of snails	Econ-Domestic	4	6.50	0.01
Fruit production	Econ-Domestic	4	7.00	0.01
Wash vehicles	Econ-Domestic	2	3.00	0.01
Trees for erosion control	Ecol	4	11.00	0.01
Marginal saliency (S<0.01) (n=12)				
Learn to swim	Socio	2	8.00	0.008
Flood prevention	Ecol	4	15.00	0.007
Favor honey production	Econ-Domestic	2	6.00	0.007
Soil formation	Ecol	2	8.00	0.006
Ornamental function	Socio	2	5.00	0.006
Provides common area	Socio	2	7.00	0.005
Favor presence of frogs	Econ-Domestic	2	8.00	0.002
Leisure space	Socio	2	8.00	0.002
Festival	Socio	2	8.00	0.002
Liquor from trees	Econ-Domestic	2	16.00	0.002
Temple	Socio	2	12.00	0.002
Domestic water	Econ-Domestic	2	14.00	0.001

Notes: Econ= economic uses, Ecol=Ecologic uses, Socio= socio- cultural uses. Agri=agricultural uses, Non-Agri= non-agricultural uses, Domestic=Domestic uses.

Only one of the 49 reasons recorded fall in the category of High Saliency: crop production. Crop production was listed by 80% of people in the sample and, on average, the reason appeared in the second position on the lists (S=0.69).

The Medium Saliency group includes nine economic and five ecological reasons. Among the economic reasons, we found two reasons related to agriculture (irrigation and silt for manure), two reasons not directly related to agriculture (water for cattle and fish auction), and five domestic uses (example,, fresh water, grass for roofs). From the five ecological reasons in the Medium Saliency group, two relate to water for agriculture (well recharge and water storage) and three to other natural resources (example,, favor presence of fish and trees).

The Low Saliency group is the largest group and includes 22 reasons, most of which were mentioned by less than 20% of the informants, typically at the end of their lists. The group includes one economic reason related to agriculture, seven economic reasons not directly related to agriculture, and six domestic reasons. The Low Saliency group also includes ten ecological functions of tanks (example,, favor presence of plants and birds).

Last, 12 of the 49 reasons fall into the Marginal Saliency group. The group includes two ecological functions (i.e., flood prevention and soil formation), four domestic uses (exmaple, favor honey production), and six socio-cultural reasons (example,, provides common area). Socio-cultural reasons appear only in the Marginal Saliency group.

4.2.2 How do villagers use tanks?

Data from the survey suggest that most households in the sample use tanks. The average informant reported 2.76 of the eight uses included in the survey (SD=1.58). Only nine informants reported no economic use of the tank by their household. None of the respondents answered positively to all of the uses and only one answered positively to seven of the eight questions. Forty-one percent of the households in the sample reported no agricultural uses of the tank, 45% reported zero non-agricultural uses of the tank, and 23% did not report any domestic use.

In results from bivariate analysis (not shown) we found that households from Scheduled Castes reported a higher diversity of uses in comparison to households from other castes ($p<0.05$). The difference is due to higher domestic uses (1.7 versus 1.1; $p<0.001$), as we did not find statistically significant differences in agricultural and non-agricultural economic uses of tanks according to caste. Households who owned land reportedly had a higher diversity of uses of tanks than landless households (2.43 versus 1.78, $p<0.05$). Households owning land had a higher number of agricultural (0.42 versus 0.08, $p<0.001$) and non-agricultural (0.72 versus 0.47, $p<0.1$) economic uses than landless households. We did not find differences in the number of domestic uses between the two groups. Cattle owners reported more uses than non-cattle owners (2.64 versus 1.83, $p<0.001$). Cattle owners reported more non-agricultural uses of tanks than households who did not own cattle (0.91 versus 0.32; $p<0.001$), but a similar number of agricultural and domestic uses. Well owners reported a higher diversity of agricultural ($p<0.001$) and non-agricultural ($p=0.07$) uses than households who did not own a well but there was no statistically significant difference between the groups in the number of domestic uses.

Bivariate analysis does not allow us to simultaneously control for several individual level characteristics. In multivariate analysis (Table 4), we ran an ordinary least square regression of our diversity score against the four socio-economic characteristics just analyzed. We found three statistically significant variables. Being from a Scheduled Caste is associated with 0.91 more uses of the tanks ($p=0.06$). Land ownership was associated in a statistically significant and negative way to diversity of uses of tanks. One additional acre of land was associated with 0.11 less uses of tanks ($p=0.054$). Well ownership was associated in a positive way to diversity of uses of tanks ($p=0.02$).

Ordinary least square regression of the score of diversity of uses of tanks against household socio-economic characteristics (n=96).

Explanatory variables	Coef.	RobustStd. Err.	P>|t|
Scheduled Castes	.94	.11	0.07
Number of cows	.16	.04	0.17
Acres of land owned	-.11	.009	0.05
Number of wells	.75	.02	0.02
R2	0.26		

Notes: Regression is an OLS with robust standard errors and clustering by village of residency.

5. DISCUSSION AND CONCLUSION

We organize the discussion around two findings that emerge from our results. First, our data suggests that, without denying the importance of these tanks for agriculture, villagers also acknowledge the multifunctionality of tanks. Second, our data suggest that marginal sectors use tank resources in more diverse ways than other sectors of the population.

The first finding that deserves discussion is the local perception of tanks as multifunctional. In contrast to previous research (Palanisami and Meinzen-Dick 2001), we drew on informants' insights to compile a list of the reasons why tanks are locally appreciated. We found that most, but not all, informants mentioned crop production and irrigation as the most relevant uses of tanks. Thirteen percent of respondents did not mention crop production or irrigation as important reasons for the existence of tanks, which can be interpreted as an indicator that villagers perceive tanks to be important beyond agricultural uses.

Previous ethnographic research on the topic has highlighted the importance of tanks as articulators of social institutions (Mosse 1997; Singh 2006; Wade 1987). Results from our free listing data complement this previous research and suggest that people give more importance to the economic uses of tanks than to the socio-cultural functions. The finding however should be read with caution as the divergence in findings might be due to methodological issues. When asked about the importance of tanks, people might have understood the question as referring mostly to the material importance of tanks. Therefore, our method might not have fully captured the socio-cultural importance of tanks.

The second finding that deserves discussion is the distribution of uses of tanks across the population. Our data suggest that marginal sectors (Scheduled Castes and people with less land) use water resources in more diverse ways than other sectors of the population. Scheduled Castes have historically had less access to land and irrigation than other castes, and they often live far from tanks (Tiwary 2006). In Attur people from Scheduled Castes lived in proximity to tanks, and our data suggest that currently they use tanks in more diverse ways than people from other castes. Much of the difference is due to a higher diversity of domestic uses. Although domestic uses of tanks might be economically less relevant than agricultural uses, these uses might have high value in terms of household consumption, nutrition, and health, especially for the poorer.

Future research needs to tackle the validity of this finding paying especial attention to an important omitted variable in our analysis: income. Poor people might be more dependant on tanks for their livelihoods than rich people. Since people from Scheduled Castes are typically among the poorest, our finding might just point at the importance of income, rather than cast, as a relevant explanatory variable to understand the importance of tanks in rural livelihoods. Future research should decouple the relative role of cast and income in their association with diversity of uses of tanks.

We conclude by hightlighting some policy issues that emerge from our analysis. Our findings suggest that local population seems to benefit from the multiplicity of uses and functions of tanks, irrespective of whether they use tanks for irrigation. These findings pose at least three issues that need to be addresed by policies on tank management. First, which of the uses and services generated by tanks are exclusive? What are the potential trade-offs between different uses and services? Second, if there are trade-offs between uses and services, which ones should be maintained? Our research gernerated a ranked list of the uses and services provided by tanks to the local population. Future research should analyze the size of those uses and services for different sectors of the population. Third, should beneficiaries of relativelly less salient uses and services participate in tank management? If not, how can users other than farmers have a voice to ensure than "non-irrigation" uses and services are maintained? We suggest that in addressing those complex policy issues, organizations working on tank rehabilitation can achieve a more equitable and socially sustainable management of tank resources if they recognize that tanks benefit people other than farmers and in ways other than providing water for irrigation.

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A TURNING POINT? WATER SAVING TECHNOLOGIES IN NORTH GUJARAT'S GROUNDWATER SOCIO-ECOLOGY

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Abstract

Micro-irrigation systems help saves water, energy, labour, pesticides and fertilizer and there is less scope for waste. If chosen properly and used correctly, this technology increases crop production. The North Gujarat Initiative project of the International Water Management Institute initiated interventions using Water Saving Technologies (WST) in Banaskantha district five years ago. The project also introduced vermi-culture and horticulture along with WST. This three-way intervention has brought about a 'synergic' effect in the farm economy of Banaskantha district. Bith the farm economy and non-farm economy has changed significantly in the region. A large increase in the farm income has brought about a new dimension in the life-style of the farmers who adopted this technology. The introduction of micro irrigation has turned into a movement and is perhaps playing a significant role in pushing agriculture to a significantly higher level of resource-productivity.

1. INTRODUCTION

Technology enhances the socio-economic development in a society. This is a worldwide phenomenon. Rosenberg (1982) in his book 'Inside the Black Box' writes that "technical progress is inseparable from the history of civilisation itself, dealing as it does with human efforts to raise productivity under an extremely diverse range of environmental conditions". Technical progress, the diffusion of new technology and finally the 'spin-off" in a typical technology has an impact upon productivity and growth. From telephone to television, automobile to mobile phone, information technology, and hybrid seed to dry land farming and flood irrigation to micro irrigation – all have brought development and changes in the socio-economic conditions in a country. However, the degrees of change depends upon the internalization of technologies and their intensive and extensive uses in the society. For example, extensive and intensive use of technologies in medicine, communications and computers are changing the world scenario in a different dimension. The term 'technology' has been described or defined in many different ways and in many related things[3] .

The process of development of a particular technology gives rise to parallel development in some other technologies in order to provide alternative, competitive and appropriate solutions for different economic, geographical and social environment needs. Technological development also becomes necessary to mitigate the adverse effects of a particular technology, for example, the changes in plastic technology to mitigating the harmful effects of its pollutants. It is seen that technological development encompasses and influences a very large segment of the society and the 'spin-offs' of technological development, in general, are beneficial to the society at large. Overall, technological development is a continuous, inevitable process. It benefits society largely, provided appropriate checks and balances are applied to ensure that the adverse effects are avoided to the extent possible. It is also to be insured that technology is reaching to the last person of society so that society gets its benefit, whether it is mobile phone or micro-irrigation.

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[1] Centre for Action, Research and Education in Water, A Division of INREM Foundation, Anand, Gujarat

[2] North Gujarat Initiative, IWMI-Tata Water Policy Programme, Palanpur, Gujarat

[3] In the Longman – Dictionary of Contemporary English, "Technology" defined as – (1) knowledge about scientific or industrial methods or the use of these methods; (2) machinery and equipment used or developed as a result of this knowledge (p. 1481; 3rd edition, 1995).

Where water is available in plenty, people go for conventional flood and furrow method of irrigation. In this method, plant gets water more than it needs. There is loss of water due to evaporation, transportation (conveyence loss) and there is water-logging between the rows and between the plants.

In water stressed areas, people traditionally applied water using earthen pots with tiny holes at the root zone of the plant. The same principle has been developed into a durable, portable, and affordable technology, during the last five decades. The entire amalgamation of such technologies are today together known as water saving technology (WST). Especially after the second world war, with the creation of inexpensive, weather-resistant plastic (Postel et al., 2001), development of drip or sprinkler irrigation system became easy although commercial perfection and large scale use took place in Isreal before 40 years. This irrigation system, also known as micro-irrigation, is practised where availability of irrigation water is scarce.

Compared to the conventional flood and furrow irrigation, the micro-irrigation system saves water, by reducing the loss of water due to transportation (conveyence loss) and evaporation between the plants. Since most types of weeds grow very less or not at all, weeding operation is almost nil, thus saving labour. Fertilizers and pesticides are used through pipes mixed with water flow therefore no extra labour is required for its application. Using this technology, the yield of crops incresed by about 100% to 200% from the same unit of area (Sivanappan, 1994 and GGRC, 2008). The two major environmental problems associated with flood irrigation - soil salinity and water logging - are also completely absent under Drip Method of Irrigation (Narayanamoorthy, 2004).

About eight different micro-irrigation systems are in practice now namely, (1) Micro Tube Drip, (2) Mini Sprinkler, (3) Micro Sprinkler, (4) Easy Drip/ KB Drip, (5) Inline Drip, (6) IDE Local Sprinkler, (7) Overhead Sprinkler and (8) Naan Sprinkler. Individually all these apparatus have their specific use, which depends on the soil condition, crop to be grown and water quality. There are many manufactureres in India and world wide. However, in India certain parts of the sprinklers and drips are imported. World's first commercial production started by Netafim; and in India, during 1989, Jain Irrigation started pioneering effective water-management through Drip Irrigation. Before Jain Irrigation, Netafim used to import and assemble the complete system.

Micro-irrigation technologies (drip and sprinkler-based systems), first perfected in Israel during the 1960s, have spread to many other parts of the world, especially the US (Shah and Keller, 2002). During 1970s this technology was introduced in India mostly in the water stressed areas of Maharastra and southern India. Micro-irrigation is especially well adapted for undulating terrain, shallow soils, porous soils, and water scarce areas. Saline/brackish water can also be used since water is applied daily, which keeps the moisture and salt stress stays at a minimum (Sivanappan, 1994).

Narayanamoorthy cited from ICID (International Commission on Irrigation and Drainage) survey that area under micro-irrigation has increased from just 40 ha in 1960 to about 54,600 ha in 1975 and further to about 1.78 mha in 1991 [INCID, 1994]. According to recent estimates, the global area under micro-irrrigation has roughly expanded by 75% since 1991, which could be approximately 2.8 mha (Narayanamoorthy, 2004). However, ICID database shows that India's total irrigated area is 57.19 mha of which the area under sprinkler is 658,500 ha and area under micro-irrigation is 260,000 ha and total total area under sprinkler and micro-irrigation is 918,500 ha, that is, only 1.6% of the total irrigated area (ICID, 2008). As seen from the available data, in India the area under micro-irrigation is a very small proportion of the total irrigated area. There are 35 countries in the world using drip irrigation systems including the US. US alone accounts for over 35% of the world total drip irrigated area (Narayanamoorthy, 2004). People are now beginning to realise that drip irrigation gives 2 times more yield, save water, labour, energy [if metered], increases income if there is good market price, and its many other positive outcomes. However, this technology has not been internalized within the farmers' society despite its scope. While discussing the adoption of drip irrigation technology in north Gujarat in his book, Dinesh Kumar inferred that it is not only that awareness was low among farmers regarding WST, but the necessary economic incentives did not exist (Kumar, 2007). While cost of cultivation had increased due to the increased cost of abstraction of groundwater, people were not attempting to adopt WST or shifting to low water-consuming crops that could help them maintain the net income from every unit of water and land used (Kumar, 2007, 237).

Literatures in the past has attempted to find the benefit-cost ratio of using drip irrigation as compared with conventional flood irrigation. Sivanappan found the incremental benefit – drip cost ratio for various crops ranges from 1.35 to 13.35 excluding water saving and 2.78 to 32.32 including water saving. Drip irrigation is technically feasible and socially acceptable for large, small and marginal farms provided they get tailored or custom-built systems at affordable price. The system is also suitable for hilly and undulated tracts, coastal and sand terrains; and for water scarce areas of South and western India (Sivanappan, 1994). Alfalfa accounts for 13% of the total water for irrigation in Gujarat according to some estimates. An experiment was conducted in North Gujarat and it is found that drip irrigation of alfalfa vs. floor irrigation is economically viable and its B/C ratio is 1.28 to 2.78 when economic value of water is included (Kumar, 2007). This also reduced water application from about 7% to 43% and yield increased from 7.9% to 10.8% (Kumar 2007). Using drip or sprinkler gives higher yield, increases water productivity and help raise farmer's crop income.

North Gujarat has been experiencing a ground water crisis for the last three decades or more. The farmers of North Gujarat largely depend on groundwater for irrigation. Because of overexploitation, the crisis has deepened further. However, the region has responded with great resilience to perpetual water scarcity and variation in hydrology (deep alluvial, shallow alluvial and some hard rock zones) (Indu, 1999). Despite various types of irrigation management structures from individual ownership to group co-operatives, the farmers have found various solutions to the water crises. There was no application of water saving technologies in North Gujarat. However, in the last few decades, introduction of MI systems such as drips and sprinklers have improved crop output for those who have adopted the technology. The North Gujarat Initiative [NGI] was started (in 2002) as an action research project to identify ways to establish local management regimes for addressing north Gujarat's groundwater depletion problems in 30 villages" (Kumar, 2007). They had introduced '(1) high-valued and water-efficient orchard crops replacing conventional crops like wheat, bajra; (2) water-saving micro-irrigation technologies for alfalfa, row crops such as cotton and castor, and orchard crops; and (3) vermi-composting and use of organic manure for all crops, replacing chemical fertilizers to ensure enhanced biomass utilisation efficiencies and improved primary productivity and water-retention of degraded soils' (Kumar, 2007). Many farmers changed their cropping pattern from usual traditional crops such as bajra, wheat and alfalfa to high-return crops like pomegranate, grapes, gooseberry and other fruits. Some of them even cultivated flowers. Farmers producing potato, cotton and groundnut are getting 2-3 times more produce after adopting drip or sprinkler technology.

During nineties, this technology was in a stage of infancy with problems of affordability and acceptability and low rate of adoption and acceptance. There were lots of 'ifs and buts', doubts and prejudices for adoption in the initial stage in 2002. Eventually when farmers saw the results of WST in demonstration plots, they gradually came forward and started adopting the technology. Medium and large farmers were the ones to adopt WST in the beginning. In 2005, government of Gujarat introduced subsidies for micro-irrigation equipments with a new set up of GGRC (Gujarat Green Revolutionary Company) and came up with an easy scheme for disbursing subsidy for the MI. The subsidy of 50% plus 40% loan from bank and 10% down payment by the farmers with a more or less straight forward and transparent procedure (for details please see GGRC website, 2008), encouraged all categories of farmers, small and big, to adopt WSTs. It was initiated in 2002 by NGI and later other NGOs partnered with them to further strengthen the programme. The adoption rate increased to a very soon after the subsidy was introduced. The area has seen so much adoption of the technology that it feels like a movement. However, there are very farmers who have adopted and continuously using the technology for more than 5 years. Therefore it is too early to see and appreciate its full benefits and constraints. It may take some more years to assess the socio-economic impact.

There is literature available on the impact of MI technology on water productivity (Kumar 2007), benefit-cost ratio, increase in farm income (Sivanappan, 1994; Narayanamoorthy, 2004) technical efficiency, developing affordable designs for small plots of smaller farmers, potential market, and its use for poverty alleviation, (Postel; Polak; Gonzales and Keller, 2001). However, very little literature is available on changes in the socio-economic status of farmers using MI technology. There are studies on direct and indirect effects of large irrigation systems in the society (Bhattarai et al., 2007) but no specific studies on MI technology. There is a good discussion on adoption and impacts of MI technology in Maharastra by Namara, Regassa E., et al., 2005. They talk about advantages and disadvantages of technologies, as well as the factors influencing the adoption. They also talked about impact MI technology on women. There is a discussion on poverty and women with respect to MI technology. Introduction of a technology in society brings about changes – direct and indirect – which have many dimensions, namely, social, economical, psychological and cultural. It was found that level of awareness among farmers was low, drip system was least known, sprinklers were popular and perceptions of benefits and disadvantages was not very clear, however, the point of 'water-saving' by using MI system was almost agreed universally (Kumar, 2007). But by the end of 2007, farmers' concept regarding MI systems and WST changed. This study examines: [1] the takers of MI technologies; [2] whether adoption of MI systems improves farmers' socio-economic conditions including income from crop production; and [3] the influence of intervention among adopters and non-adopters by the way of accepting modern agricultural technologies and agronomic practices.

2. OBJECTIVES OF THE STUDY

The objectives of the paper are to: 1] determine the socio-economic profile of adopter farmers; 2] analyze the changes in farming systems of the adopters associated with introduction of MI system; 3] assess the depth or intensiveness of MI system use among the adopter-farmers; and, 4] analyze the socio-economic impact of MI system adoption, comprising assessment of household dynamic and socio-economic status (crop productivity, economics, net income from farming, food security, asset building) of adopters, and village-level dynamic--cropping systems, employment generation, exposure to new farming technology.

3. METHODOLOGY

We started with the following broad research questions: 1. Who are the adopters of MI technology and what are their social and economic backgrounds? 2. Whether adopters accepted or used other allied water saving practices, which extended or deepened the use of the WST or only used drip or sprinkler irrigation? 3. Whether the adopters brought more land under this technology or expanded the area under irrigation after adoption? 4. Do the adopters really achieve higher output and income due to MI adoption? 5. Do the farmers change their cropping pattern towards high-valued crops along with MI adoption? 6. What are the changes in the socio-economic status of the farmers after adoption? 7. Does there impacts of MI introduction extend beyond the adopter families?

The study villages were selected on the basis of the depth and extent of adoption of MI systems in the villages. Quantitative information was collected through a structured questionnaire, answered by selected farmers. In order to realize the specific objectives, the following methodology was employed:

1. Analysis of changes in farming system and socio-economic impacts at the household level through "before-and-after" (longitudinal) comparison of adopters and "with-or-without" (cross sectional) comparison between adopters and non-adopters.
2. Focus group discussion – among adopters and non-adopters separately in intervened and selected villages were selected from the diocese of NGI and other agencies, to gather socio-economic information – cropping system, cropping pattern, agricultural labour scenario etc.

3.1 Sample Design and Sample Size

Two types of villages were selected for the study. First: the villages with extensive adoption of MI systems where almost all the WSTs and water-saving practices are found, with the largest number of adopters. Second: the villages where least number of WSTs and practices and very few adopters. Also, non-adopters from the first category (that with high rate of WST adoption) were also selected to understand their reasons for non-adoption. We collected secondary information regarding adoption from NGI as they made the first intervention for MI system in north Gujarat. We have tried to select sample from the oldest adopters (before 2002). Socio-economic changes cannot be seen with 2 years of income, as the income and consumption gap would be narrow. However, we selected a sample of recent adopters from districts of Patan and Mehsana (which have low adoption rates) also since the surge of adoption was very high from 2005 onwards.

We selected 63 adopters randomly from 5 talukas of Banaskantha district as it is the first district of intervention. The talukas are Amirgadh, Dantiwada, Deesa, Palanpur and Vadgam. 32 non-adopters were randomly selected from the same talukas of Banaskantha district, but a few have been selected from the newly intervened talukas like Siddhpur of Patan district and Unjha of Mehsana district. The 63 adopters and 32 non-adopter farmers are from 35 different villages from three districts.

3.2 Weakness of the Data

First of all, recall data are generally weak. Secondly, we did not find farmers who had been adopters of MI technology for long period of time. About 26% of the households (16 households) were recent adopters--during 2006 and 2007. The recent adopters could not realize the full benefits of the technology due to lack of experience.

3.3 About the Study Area

The total geographical area of Banaskantha is 10400.10 km^2. The total population of the district is 2504244, of which rural population is 2228743, and urban population is 275501. The total number of farmers is 482803 and the total cultivable area is 8.19 lac ha.

4. RESULTS AND DISCUSSION

4.1 Profile of the farmers

The selected adopters are largely (56%) large farmers owning more than 4 ha of land. The total number of family members among the selected adopter households is 496 (51% male). The total number of family members in the non-adopter families is 189 (53% male). Our sample has the largest number of households belonging to the Mali caste (29%), followed by Patels (24%) and Chaudhuries (24%). All these three castes have divergent socio-cultural background, which eventually influences their decision making in cultivation, and therefore in adopting a new technology. In Deesa taluka of Banskantha district, the member of Mali community played a strong role in the economic development. In our sample, Malis are from Deesa and Dantiwada taluka. The Patels and Chaudhuries are mainly from Palanpur and Vadgam talukas and a very few from Deesa. The verbal history says (as we have heard from very elderly persons) that Malis came from Marwar of Rajasthan, Haryana and western part of Uttar Pradesh after the Second World War. Being outsiders, there is possibility of this community being more progressive and enterprising in their farming practices. In contrast, the relatively more localized communities of Jats and Thakors have less orientation towards commercial farming. These reflect on our samples too; in the case of non-adopters 66% households are a mix of Chaudhury, Patels and Thakors. Only two of the non-adopter households belong to *Mali* community.

The total irrigated land of the sample households is 436.54 ha; more than 86% land is irrigated. This is because all sample farmers have own sources of irrigation in their owned land. There are 63 bore wells; among the sample householdsm, there are those having more than two bore wells. The capacity of pumpsets range from 7.5 - 115 HP; and the mean value of the pump capacity is 23 HP.

4.2 Adoption of WST

Micro-irrigation technology offers several products. They are being chosen according to the holding of land, need of the crop, affordability of the farmers, and availability in the market including its after-sales services. This means that the devices are space, price, service and need specific.There are eight types of systems (already discussed). Coupled with one of the eight systems of MI (mentioned earlier), vermiculture and change in cropping pattern towards horticulture, greatly enhance production and income of adopters. Vermiculture and horticulture are discussed in later sections.

Of the eight different MI systems available, five are mainly use by our sample farmers. They are: (1) Micro Tube Drip[4], (2) Mini Sprinkler, (3) Inline/On line Drip, (4) Overhead Sprinkler, and (5) Naan Sprinkler. We have put the year-wise adoption of different systems of MI technology among the adopters in Table 2 (Annexure) and charts. We have shown the adoption of vermiculture and horticulture also. While big farmers are adopting MI technology, marginal and small farmers unable to afford WST may go for vermiculture as they will have a ready market for vermi-compost. Horticulture gives the highest income after adopting WST. Farmers grow vegetables in between the rows of orchards so long as flowering does not take place in the orchard trees. Many a time the farmers could recover more than 50% of their initial investment in WST in the first year itself.

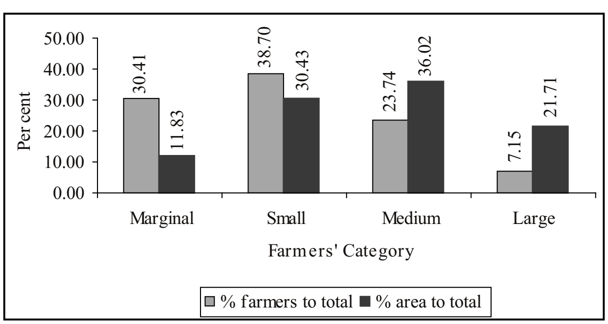
Many villagers do minor repair and maintenance of these systems, however we found that sprinklers are popular among Deesa farmers and drip systems are popular in Palanpur and Vadgam area. *Mali* farmers of Deesa area have very large holdings, they grow groundnut after potatoes and prefer sprinklers; whereas Palanpur and Vadgam area farmers grow cotton after potatoes and they prefer drip irrigation. Many farmers from Palanpur and Vadgam are shifting to sprinkler recently as they found that managing sprinklers is easier than managing drips. They feel that manoeuvring one place to other is easier for sprinkler than drips.

Amongst the adopters, 25% adopted MI only after 2005. Almost 50 - 80% of large farmers adopted MI technology – a higher number in comparison to marginal and small farmers. The number of small and marginal farmers adopting MI technology may grow now, with the introduction of subsidy. We found from that data that out of the total adopters in his list, 7.15% are large farmers, medium farmers (23.74%), marginal (30.41%), small (38.70%) and (Chart – 1), that is about 69% new adopters are from marginal and small farmers' group[5]. This shows the impact of subsidy. Vermiculture that was adopted by 70% of the marginal, small and medium farmers together.

GGRC data also says that after subsidy (2005) the adoption of micro-irrigation technology has risen substantially amongst marginal, small and medium size farmers. Chart 2 and 3 show the situation of Gujarat and in the districts Banaskantha, Mehsana, and Patan respectively for all kinds or micro-irrigation instruments adopted through GGRC. In our selected farmers, few of them adopters after 2005. Some farmers avoid subsidies because of the time and effort spent to obtain them. Others have increased their irrigation area after technology adoption since they could irrigate more area with the same amount of water. Many farmers adopted new equipments after the subsidy.

Our selected adopters have had MI technology for 3 to 5 years only; only a few of them have had it for 5-12 years. It is difficult to find the impact of adoption so early. However, we have observed the extent of adoption among users. Many of them changed from overhead sprinkler (1991, 1996) to inline drip system (2005) or to Naan sprinkler (2002) and brought larger area of land under MI technology systems. The older

Chart 1: Farmers and their area under sprinkler
(Data from a dealer of Deesa after subsidy)



[4] Despite increase in MI technology, there is a decline in adoption of Micro-tube drip and overhead sprinkler systems. The system was adopted in 1991 but lost is popularity after 1996, because farmers found it inconvenient because of clogging. There was some more adoption in 2000, but no adoption after 2005 among the sample farmers.

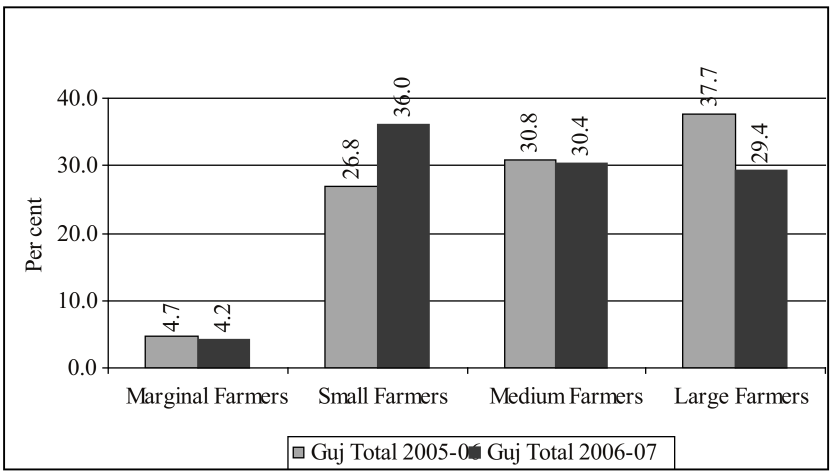
[5] Data obtained from one year of the sale of a MI System dealer in Deesa.

adopters do not like to give much importance to subsidy. This has been reflected in the ranking for 'reasons for adopting' given by the adopter farmers for adopting the technology, which we have discussed in later section. Subsidy has boosted the adoption but adoption it was initiated and accepted because of the benefits it gave.

4.3 Changes in Cropping Pattern

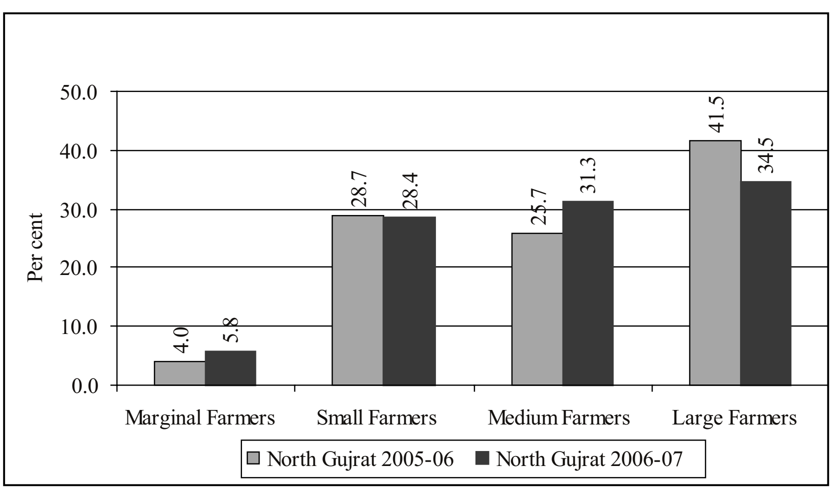
There is a shift in the cropping pattern among the selected adopter farmers shown in Chart 4. The adopter farmers opted for high return crops immediately after technology adoption. Although scarcity of water is a driver in adoption of WSTs, higher incomes is also a motivating factor. Bajra crop reduced by 79% over the surveyed areas and cotton, fennel, potato and groundnut increased by about 117%, 20%, 14% and 32% respectively. The reduction in the area of vegetable probably does not reflect in the chart. We have not captured the area in between the rows of orchards of different fruit crops; plenty of vegetables are grown in these rows during the gestation period of the first fruit harvest. Horticulturists sometimes recover half of their investments of the drip or sprinkler within one or two seasons of vegetables growing. The sum total of those areas is quite large, which may show much increase in vegetable adoption, particularly among orchard farmers.

Chart 2: Area under Micro-Irrigation in Gujarat 2005-06 and 2006-07



Source: GGRC

Chart 3: Area under Micro-Irrigation in north Gujarat 2005-06 and 2006-07



Source - GGRC

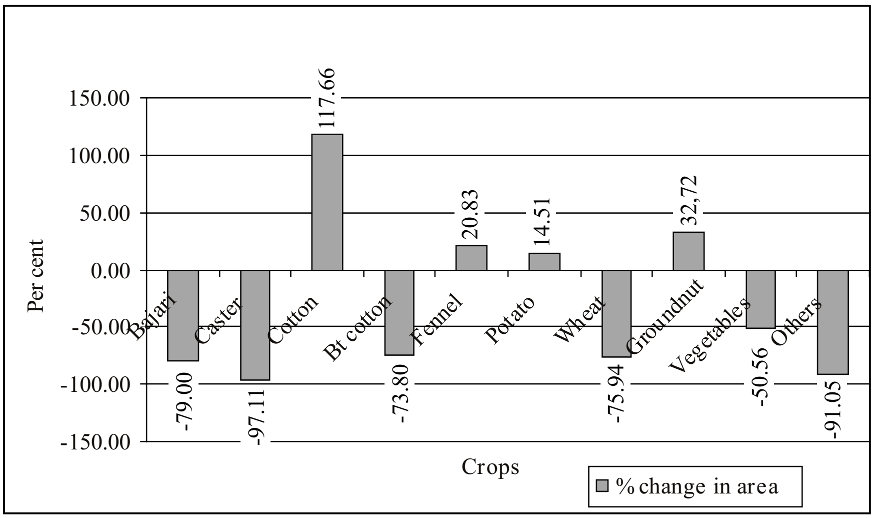
4.4 Changes in crop income and production after adoption

If the technology helps raising the farmers' income, then farmers would agree to adopt that technology. We have analysed the percentage increase in net income per hectare of irrigated crops after the adoption of WST.

The landholding category-wise analysis shows an increase in net income by more than 300% from unit hectare of the crop (Table 1). The marginal farmers received the same income increment as large farmers. The marginal farmers are usually more efficient in using their inputs and hence secure higher returns. Increases in income could be owing to different factors such as: 1) more intensive use of land; 2) increased crop yields; 3) higher market value of the produce; and, 4) shift towards higher yielding varieties.

Results of crop-wise analysis of the impact of the technology on yield and net income are presented in Table 2. It shows that the following: the yield of potato was only slightly higher for plots under WSTs in 2007.

Chart 4: Changes in Cropping Pattern before and after Adoption



Source: Field Data

However, the net return from the crop was higher for the plots irrigated by WST to an extent of 106%. This could perhaps be because the quality of the potato seeds used in the plots under WST was better. The potato produced in WST plots were of the same size, tasted better and looked glossy and hence fetched more price (Rs.5 against Rs. 4 for the crops irrigated under traditional method. Last year potato crop was attacked by a disease particularly in the adopters' plots. Since the technology was new to them, they were not able to use it

Table 1: Percentage increase in net income per ha after adoption of WST over the net income before adoption

Farmer Category	Before adoption		After adoption		% increase in income after adoption
	Area (ha)	Average net income Rs/ha	Area (ha)*	Average net income (Rs/ha)	
Marginal – 1	1.5	14487	1.5	58100	301.05
Small - 2	15.4	10761	10.3	40220	273.76
Medium – 3	79.3	12108	55.6	47340	290.98
Large – 4	492.5	13812	378.5	61947	348.50
	588.6	12792	446.0	51902	305.73

Source: Field Data; *Note: Some plots were not under WST properly and did not get the desired yield. Highest positve impact of WST on yield and net return was seen in the case of castor. In contrast to what was seen in the case of other crops, in the case of wheat, a reduction in yield was seen. Most of the farmers used WST for wheat on experimental basis. Hence, probably like in the case of potato, they could not use the technology properly.

Table 2: Percentage Change in Yield and Income Per Hectare after Adoption

Name of Crop	% change in yield after adoption	% change in net retun per ha after adoption
Fennel	2.04	89.67
Potato	5.78	105.82
vegetables	Not Applicable	124.02
Wheat	-0.46	41.90
Bajra (Kharif)	32.48	274.54
Bt cotton	48.36	56.00
Castor	172.39	394.39
Cotton	46.93	153.84
Fennel	100.00	501.72
Groundnut	37.23	97.34
Bajra (Summer)	-11.07	3.79

Source: Field data

4.5 Horticulture

Horticulture (chiku and berries), was practiced in very few places and did not fetch good returns before the WST intervention by NGI-IWMI in north Gujarat. Many expressed their ignorance and expressed happiness on seeing returns from orchards with WSTs. Now adopters are earning Rs. 1.51 lac from papaya, Rs. 1.96 lac from mango, and Rs. 2.30 lac from pomegranate from a hectare of land. The production of fruits takes more time than one season, depending on the fruit chosen, papaya takes 6 to 8 months, mango takes about 3 years and pomegranate about 18 months. During this gestation period farmers grow vegetables or any short-duration crop in between the plant rows. An orchard grower, thus, has two sources of income. The area under horticulture fruits, total net income and net income per hectare is is shown in Table 3.

4.6 Vermiculture

The vermiculture produces vermicompost. Using this as the manure results in the soil becoming more porous facilitating aeration. The moisture retention capacity of the soil also imporves. Selected farmers, particularly marginal and small farmers, seeing the great market, have adopted vermiculture to produce vermicompost as one of their enterprises. Eventually this has become a good source of income for them. Vermiculture has become an ancillary activity for WST users in this area. This requires little investment and gives very high return within a short period. In 2002, it was Rs. 500 kg, but after rapid adoption and replication of this activity across the region it has come down to Rs. 100 kg. It usually starts with 1 kg. worms and 20 kg Farm Yard Manure (FYM). The worms double and prepare approx 10 kg compost within 50-60 days. One kg worms can become 70 kg and produce 600 kg of compost in a year. (Source: NGI, Palanpur). In general the sale price ranges form Rs 1.80 to

Table 3: Area under Horticultural Crops and Income

Name of Crop	Area (ha)	Total Net Income (Rs)	Net Income (Rs/ha)
Chickoo	1.5	16100	11000
Grapes	1.4	171200	122000
Lemon	8.0	180000	23000
Mango	0.6	117500	196000
Papaya	0.1	15100	151000
Pomegranate	8.5	1954139	230000
Total Horticulture	20.1	2454039	122000

Source: Field Data

Rs. 2/- per kg. Among our selected households the earliest adopter was in the year 2002. In our sample, 12 farmers are practicing this venture; of these eight households (66%) are from smaller category of farmers. We found that return from a rupee of investment is Rs. 6, considering the total production of 5 years from 2002 to 2006. The average gross income per year per household is about Rs.8000 against the investment about Rs. 1300. Women generally look after vermiculture. *Ajba ben* saved Rs 72000 from her vermi-culture income and invested in overhead sprinklers and low cost drum kit for her small piece of land. One more example is *Heeraben*, for her it has become a livelihood.

4.7 Women's Outlook about Systems Micro Irrigation System in Agriculture

Adoption of WST has brought about an improvement in the quality of life of women by reducing their number of work hours[3]. According to one of the women farmers, before adoption of MI system, they were often not able to recover their cost of cultivation. About 77% women of the sample households felt that farm has become neat and tidy after the WST adoption. According to them, it increases production and saves water, power and labour. Now with electricity supply becoming timely, women can schedule their daily work conveniently.

Within a few years of WST adoption, women are now well experienced in running the system and can do minor maintenance like clogging of the system and fittings themselves. After installation of WST, their hard labor has reduced. Weeding work is now almost nil and applying fertilizer has become easy. The labour involved in sowing, and bundling and packing of dry straw has reduced. Plucking vegetables and fruits and making them ready for sale in the market are the additional responsibilities. Since many farmers changed their cropping pattern towards vegetables (chilly, brinjal) and orchards, the work pattern has changed (source: personal communication, Anuben) with disappearance of one type of wage labour and emergence of another. Women from landless households are deprived of wage labour in weeding operation. However, new farming operations such as vegetable picking, packing and marketing of the harvest are now generated, and can be taken up by landless women.

Some WST adopters have increased their livestock holding because of an increase in their incomes and availability of more spare time. Some others have chosen to reduce their livestock holding. One reason may be that the return on investment in livestock is lesser than that in land irrigated by WST. Another reason, which came out from group discussions, is that MI system has introduced precision farming, whereas managing livestock is still messy[6]. The farmers understand that by using WST system, they would get higher income.

4.8 Changes in Income among Adopters

There is reluctance amongst farmers to disclose their income from farming. We estimated the net farm income from cultivation data gathered during the survey. WST adopters have earned more than 108% from their farm during the year and 101% from all sources after adoption. Highest increase in farm income (more than 324%) was found among small farmers, as they also earned income from vericulture.

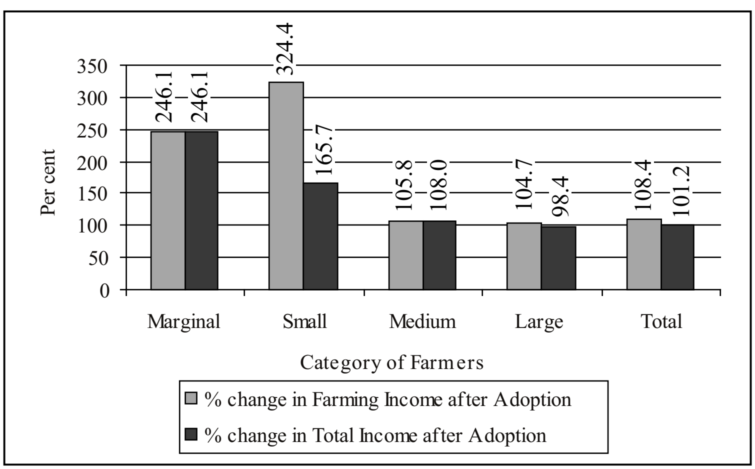
After adoption of WST, the total farm income of all adopters increased from Rs.1.17 crore to nearly Rs. 2.5 crore; and the total income including all both farming and non-farm activities increased from Rs. 1.25 crore to Rs. 2.6 crore. That means that the average household income of an adopter has gone up by Rs. 2 lac due to adoption. But, in the case of non-adopter, the average household income from all sources is only Rs. 54,766 and farm income is only Rs. 45,188.

4.9 Changes in Lifestyle of Adopters

There is a sharp change in the investments by farmers post WST adoption. The gross irrigated land has increased by more than 200%[7] (Chart 6). Farmers have taken land on lease and have irrigated them using micro-irrigation system, as they could irrigate more land by same available water and power supply. People who earlier took 2 crops can now grow 3 crops and also do inter cropping with horticulture. There is also an increase in purchase and use of agri-equipments. The increase is 22% for tractor, 27% for thresher 27.8%, 66.7% for planter, 128.6% for digger and 51% for others such as plough, harrow and cultivator. The sum total of asset of agri-equipments would be about Rs. 58.1 lac.

Holding of live stock has significantly reduced after adoption; bullocks by 37.6%, buffaloes by 7.5% and cows by 28.2%. Reduction in bullock is because of mechanisation of cultivation. The reduction in holding of buffaloes and cows is probably due to the differential income between crop cultivation and dairying. This has

Chart 6: Percentage Change in Farm and Total Income after Adoption



Source: Field Data

[6] One interesting question was asked, at this point of discussion to all the women mentioned above that if they were given 5 livestock or 5 bighas of land (without MI system) what they would like to keep? They agreed for livestock. But, when asked the next alternative that if the same size of land be given with MI system what they would prefer? They quickly agreed for land with WST.

[7] In flood irrigation 2 ha can be irrigated in 8 hr x 7 days i.e. 56 hrs in a week (not in horticulture). But, WST can irrigate 1 ha in 2-3 hours, so irrigated area increased among adopter farmers.

been more obvious when we discussed with the women members of the sample families. If farmers get more yield and income from the same area of land by using micro irrigation system, they refrain from holding more livestock, particularly when marginal income is less from livestock. About 32% people have taken new life insurance policies after having experienced significant increase in their farm income; the premium amount has increased by 61%. The total amount of premium went up to Rs. 17.5 lac from Rs. 11 lac after the adoption. This shows an increase in saving among WST adopters. The farmers do have other postal savings and investment in gold and silver, but we did not inquire about those details.

An interesting pattern is found in investment in consumer durables. There is reduction in investment on radio (-4.2%), but an increase in the investment in TVs both colour and black and white; 38 households have colour TVs. Before adoption only 17 households were using cycle, scooter, motorbike and cars and after adoption there are 52 households using any one of these vehicles. There is sharp rise of 206% investments in this. Many of them have more than two motorbikes and scooter in their homes. There is a negative investment of 42% in sewing machines since people can afford to go to a tailor.

The women members of WST adopter households expressed their interest in sending their children away from the village to get better and higher education since they are now able to afford higher tuition fee and expenses for boarding and lodging. Some families have sent their children for higher studies to Ahmedabad, Surat, Vallabh Vidyanagar and Anand. There is a sharp rise in incidence of private tuition also; with 77% of the sample families reportedly spending on private tuition. The expense towards this increased from Rs 7 lac to about Rs 23 lac, more than 3-fold increase. The number of households paying for private tuition increased from 11 to 47.

4.9.1 Other Positive Changes

Introducing the WST in this area has not only brought about significant changes in the lives of the farming community, but it also has impacted other sectors. A new business opportunity in the form of dealership of micro irrigation equipments is now created. In 2002, there was no dealer for micro-irrigation equipments in Palanpur town. The staff of NGI used to travel more than 150 km visiting Ahmedabad and Gandhinagar to purchase different components of MI systems such as lateral pipes, drippers and to manage assemblers. Within a year, in 2003, they could arrange three dealerships in Palanpur, two from IDE and one from Netafim, the largest manufacturer of drips and sprinklers internationally. Today, there are 91 dealers of MI equipments in North Gujarat, of which 72 are in Banaskantha, 11 in Mehsana and 8 in Patan.

Many potato farmers have now become cold storage owners, either individually or in groups. We met several potato growers who cherish the dream of opening a cold storage in Deesa taluka. The first cold storage of Banaskantha was established in 1985. In 2002, there were only 18 cold storages including two government managed ones. Now there are 62 cold storages functioning in Deesa and Palanpur talukas of Banaskatha. In Banaskantha there are 482803 cultivators and only about 4987 cultivators (1.03%) have adopted MI technology till January 2008; cultivable area of Banskantha is 819000 ha and only 9495 ha (1.16%) is under micro irrigation. What could be the impact when at least 25% of the cultivators and 25% of the cultivable land would have MI technology?

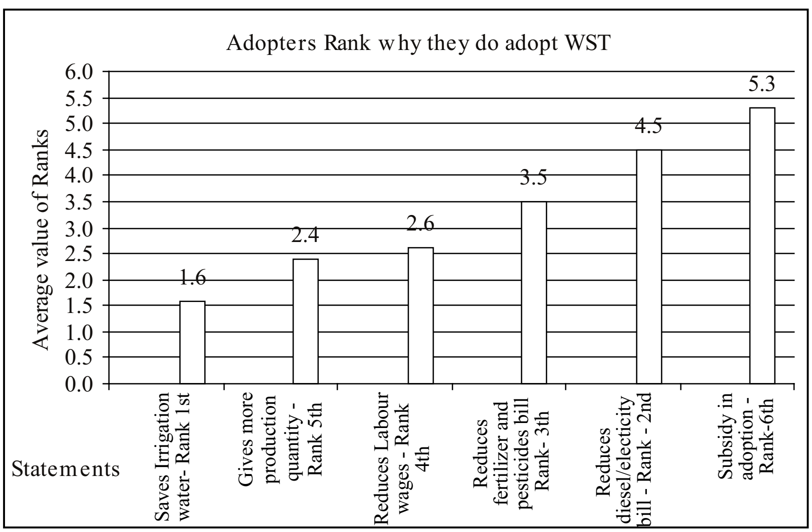
We found that among our sample adopters, farmers who have made good savings out of farming , particularly during the last few years, are interested in investing in non-farm sector. Owing to WST adoption, they have now got that extra time which they are using for obtaining good educating for their children. They also put their children in non-farm work such as vegetable selling, running whole-sale shops and provision store, running dealership of MI equipments (Netafim and Jain Irrigation). Some of them, who have greater savings, invest in cold storages. Large horticulturists (pomegranate) are considering setting up food processing units.

WST adoption also saves labour. There is a widespread misperception that WST will lead to unemployment. In reality, a new generation of high wage and high skill labour for farms with MI equipments, has emerged due to its intensive and extensive adoption for many crops. The labour rate for potato seed cutter is now Rs. 175 a day or even more, which was just Rs. 80 an year ago.

4.10 Reason for Adoption and Non-Adoption

As shown in chart 6, WST adopters reported "saving in irrigation water" most important, and "provision of subsidy" as the least important reason for technology adoption. The primary reason for not adopting WST was paucity of fund (Chart 7). The non-adopters are slowly beginning to realise the benefits of WST. However, there are several reasons for non adoption, other than finance. Use of MI equipments calls for meeting certain basic requirements such as: a) independent source of water in the farm; b) regular and timely supply of power unless the farmer uses drum kit which depends on gravitational flow[8]. If land is divided into many small parcels, it is difficult to derive sufficient incremental income benefit from WST adoption that offsets the additional costs associated with it. If many farmers share an irrigation well, equitable distribution of water becomes difficult, when MI equipment is used. Further, all the shareholders of the well may not be interested in the same technology. This was the case in Siddhpur area, where extension work has recently started[9]. Owing to three consecutive good monsoons, many farmers do not feel the pressure for using MI systems. The farmers also feel that getting loan from banks is quite challenging and time consuming. Some farmers had debts incurred during drought years, which were still not repaid, and hence could not take more risk for installing MI system. Priority to other social responsibilities is another hurdle in MI adoption. Above all, there is ignorance of the benefit of the MI systems and less severity of the crisis of irrigation water being felt by the farmers. In areas with sharp decline in groundwater table, government does not give permission for new electricity connections for bore wells. Many farmers rely on rain fed agriculture. Such constraints keep the farmers away from MI systems, even though many of them realize the benefit.

Chart 6: Reason for Adoption: Ranking



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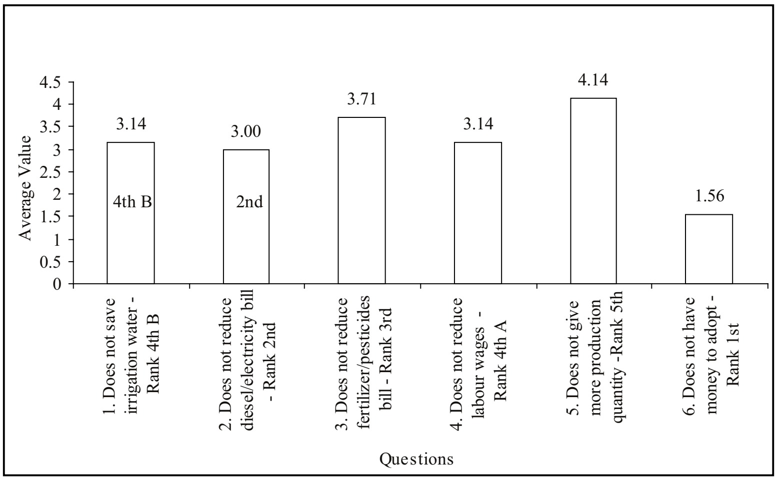
[8] The drum kit is useful for small land holdings.

[9] In Siddhpur area individually owned borewells are not many. In Jagnathpura village of Unjha taluka we talked to one farmer. He said that there were 35 bore wells in his village, of which only 4 bore wells are individually owned. Another 31 have 7 to 15 partners on each. Under such situation, it becomes difficult to convince all partners to adopt drip systems. In this area, poor quality groundwater is also a problem as it results in clogging for MI system. Recent availability of canal water in Samoda village and availability of water in plenty in Saraswati river also discourage the farmers from going for MI systems. The groundwater is available at a depth of 1000 to 1200 feet. Therefore the construction cost of well is also very high, about Rs 12 to 15 lac. In Kahoda village of Siddhpur taluka there are 75 to 80 bore wells, in which 4-5 bore wells are individually owned. Some bore wells have 70-75 partners. These farmers are small land holders (owing 4-5 vighas of land). So, they feel that WST is not economically viable for them.

5. FINDINGS AND CONCLUSIONS

The water saving technology for minor irrigation not only saves water, energy, and labour inputs but also increases farm income through higher production per unit of land. Though labour is saved for some agricultural operations which can create unemployment, a new generation of skilled labour has emerged - like potato seed-cutters who are earning Rs. 175 day, who were earning Rs. 70 day a few years ago. The technology was adopted because of shortage of perennial supply of labour, as the adoption does not require much labour for several agricultural operations. Introducing this technology opens up new opportunities in the form of large numbers of cold storage for potatoes and dealerships of MI equipments.

Chart 7: Reasons for Non-Adoption-Ranking



The study shown that Vermiculture can get very good results generating employment, increased incomes and improving soil productivity. This activity is often undertaken by women farmers, improving their economic conditions.

Micro Irrigation brought about a revolutionary increase in horticulture in north Gujarat. The unique three-way intervention made by NGI, i.e., growing vegetables between the rows of orchards during the gestation period of the fruit greatly increased cultivation and income. With two seasons of growing vegetables in the rows of orchards, farmers were able to recover 50% of their investment on MI.

WST has given a more than 100% increase in farm incomes. This gives a solid base to the farmers to go for non-farm investment, which can lead to greater economic development in the form of farm income for non-farm investment. A ‘synergic’ effect of spatial growth is already found in Deesa area. In this area there is growth of large number of cold storages, increasing number of WST dealerships, and newly trained workmanship for WST maintenances, buildings, markets and private businesses. Investing the extra income in education, particularly higher education will add a new dimension to the economic development of the region in the future.

Rinally, subsidy has made a boosted WST adoption. However, there are some complaints that the quality of the equipments is deteriorating because of low vigilance on quality control. This issue should be carefully handled to check and avoid the downfall in WST adoption.

WST adoption seems to be poor in dominantly canal-irrigated areas, areas with multiple ownership of wells and those where groundwater is highly saline.

Note: Kahoda village of Siddhpur taluka has 75-80 bore wells. Of these, 4-5 are of single owners. Some bore wells have 70-75 partners. Farmers are small land holders (average 4-5 vighas), so they feel WST is not economically viable for them.

Finally, it appears that there is huge potential for WST in the region. At present only 1% of the cultivable land is under micro irrigation. If such a small scale of adoption has brought about such significant positive changes, a higher scale of adoption can bring about dramatic changes in the region's agriculture and rural livelihoods.

5. ACKNOWLEDGEMENTS

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FEASIBILITY OF DRIP IRRIGATION IN THE ORCHARDS OF NORTH EASTERN HILLY STATES

Mayuri Hazarika[1]

Abstract

The state of Arunachal Pradesh is reported to have very high potential for growing a large number of horticultural crops due to the remarkable variations in topography and agro climate within a small geographical area. However, the productivity status of various crops is still low as compared to all India level. The purpose of the paper is to examine the physical and economic feasibility of drip irrigation in kiwi crop in hilly tracks of Arunachal Pradesh. First, the paper examines the effect of erratic rainfall on the yield and quality of kiwi fruit. Secondly, it examines the physical feasibility of drip irrigation under the undulating topography and high rainfall. Thirdly, it evaluates the economic viability of drip irrigation in cultivation of kiwi crop.

Dip irrigation can increase yield and quality of kiwi crop under undulating topography and heavy rainfall conditions. Kiwi is an exotic crop, which needs water during its critical stages of growth for obtaining better price in the market. Erratic rainfall causes loss of yield and quality of kiwi frit, which can be corrected with the help of drip irrigation. The cop can be irrigated by drip in a cost effective manner in Arunachal Pradesh because difference in elevation minimizes fuel cost for water supply. However, the cost of drip is insignificant in comparison to total cost of cultivation.

Drip irrigation system is economically viable in kiwi crop in Arunachal Pradesh. The net present value of drip irrigation in kiwi is Rs.87673 and benefit cost ratio (B:C) is 1: 1.18. The pay back period of the system is 6 years. In between farmers can gain some return by intercropping of some annual crops. Lack of proper marketing system is a major draw back among the kiwi growers in the state. Intervention of government agencies and private parties is essential for developing proper marketing channels for the movement of the produce.

1. INTRODUCTION

The northeastern region of India with eight states namely Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim lies between 21^{o}57' and 29^{o}28' north latitude and 89^{o}40' to 97^{o}50' east longitude. The total geographical area of the region is 2.55 lakh km^2, which is about 8% of the country's total area. The region is divided into three divisions, viz., the northeastern hills, the Brahmaputra valley and Meghalayan Plateau. The NE hills alone accounts for 65% of the total land area while the Brahmaputra valley and the Meghalaya Plateau cover 22% and 13% of the area, respectively.

The region has distinct precipitation and drainage patterns due to its unique location and orography. Empirical Orthogonal Function (EOF) analysis of southwesterly monsoon rainfall over India shows that seasonal rainfall patterns over the northeastern region is different from the rest of the country. In general, north east region is perceived as a higher rainfall area. On an average, the region receives 2070 mm rainfall annually, which is almost double the national average. Nearly 20% of this rainfall comes from thunderstorms that occur during March and May. During the months of June to September, southwesterly monsoons supply 70% of the annual precipitation. Another 8% of rainfall between October and November is associated with northeasterly monsoons. During the southwesterly monsoon season, frequent floods, responsible for both human casualties and property damage, occur as the powerful Brahmaputra River flows are constricted through the narrow Assam valley, which is fed by torrential rains and snowmelt from Himalayan ranges. The rainfall is laden with silt from actively eroding steep headwater slopes.

[1] Independent Consultant

The present overall land-man ratio of the region is 0.66ha, more than double the ratio in India as a whole (0.32 ha). In 1991, the ratios were 0.81 and 0.39 for the North-East and all India average respectively. Total cropped area in the region is 5.3 mha and its population is 39 million. The region's total cultivable area is only 25% of its geographical area, compared to the national average of 59%, and its cultivable area utilized is only 59%, compared to the national average of 73%.

The region offers scope for cultivation of a wide variety of horticultural crops such as fruits, vegetables, flowers, tuber and rhizomatous crops and spices because of its diversity in topography, altitude and climatic conditions. A range of fruit crops varying from highly temperate types like walnut and apple to subtropical and tropical grow well in this region. Similarly wide and diverse types of vegetables including indigenous ones are cultivated in the region.

Despite the favorable factors and the scope for cultivation of horticultural crops, the development of horticulture has not picked the desired momentum. The productivity of the horticultural crops is very low in the region because of erratic rainfall. During the summer months, the most needed moisture is not available to the crops. There is also an absence of irrigation infrastructure suitable for hill slopes. The availability of sufficient water for irrigation is also an issue, especially during the summer months.

The scope of any type of technology or device is judged based mainly on three things – first the actual demand of the element facilitated by the device, second the physical feasibility of the technology under prevailing condition and third is the reliability for economic gain.

The purpose of the paper is to examine the physical and economic feasibility of drip irrigation in kiwi crop in hilly track of Northeastern India. First, the paper examines the effect of the erratic nature of rainfall on the yield and quality of kiwi fruit. Secondly, it examines the physical feasibility of drip irrigation under the undulating topography and high rainfall. Thirdly, it evaluates the economic viability of drip irrigation in cultivation of crop kiwi.

2. DRIP IRRIGATION FOR KIWI ORCHARDS IN ARUNACHAL PRADESH

Arunachal Pradesh is the largest hilly state in the northern hill region, located between 26^{o} 39' N latitude and 91^{o}35' to 97^{o}27' East longitude with elevation ranging from 250-7090 m a.m.s.1. The state has a high potential for horticultural development since topographically and agro climatically there are wide range of variations suitable for growing a large number of horticultural crops. Further, the grain farming is proving un remunerative in comparison to growing of horticultural crops in this hilly undulating area which are devoid of irrigation facilities. The state is as such very rich in biodiversity and biomass. Biodiversity is profuse and generous, catering to the needs of the rural tribal habitants of the state. The dietary components such as herbs and indigenous fruits and vegetable offer self-sufficiency to the people of the state. The total area of fruits during 2000-01 was estimated as 44128 ha with a total production of 93084 metric ton and 9260 ha under spices with 30,017 metric ton production. However, the productivity of various crops is still low in comparison to all India levels.

Kiwi is considered as an exotic fruit in the basket of nutrition. At the global level, production of kiwi is estimated at 908777 metric ton covering an area of 49,322 ha. The countries, which grow kiwi include Italy, New Zealand, Greece, France, Japan and parts of USA. In India kiwi is grown in Himachal Pradesh, Arunachal Pradesh and some part of Nagaland covering around 400 ha of land. The productivity of kiwi in India was 1.2 metric ton/ha during early nineties but it has increased now. The maximum productivity of this crop is 21.5 metric ton/ha, obtained in New Zealand. A ripe fruit has a refreshing delicate flavor with pleasing aroma. Almost all parts of the plant are used in China. The seeds are used in making pastries, fragrant flowers in producing perfumes and leaves as pig feed. Roots can be processed into an effective insecticide against tea caterpillars, aphids and rice borer. In addition, mucilage is used in construction materials for paving roads and wall covering and in preparing wax paper and printing ink and dye.

Farmers in West Kameng district of Arunachal Pradesh started growing this crop during the later part of 19^{th} century. Government of Arunachal Pradesh attempted large-scale cultivation of this crop to promote horticulture in the state. Irrigation of kiwi orchard was introduced in 2001 under the schemes of technology mission for horticultural crop. Under this mission, the government fully subsidized the drip systems to the kiwi farmers under the projects of the northeast council. The harvesting of fruits from orchards that are under drip systems started in 2004. Drip irrigation of kiwi orchard picked up a little momentum in terms of acreage and production. Presently there is more than 100 ha of kiwi cultivation in this state.

2.1 Objectives of the Study

The primary objective of the study is to assess the viability of drip irrigation for Kiwi orchards in the hilly states of Northeast India having higher rainfall history. The specific objectives are: 1] to assess the need of drip irrigation to compensate for moisture stress experienced by Kiwi crop due to seasonal variation of rainfall in the orchard of hilly state of Arunachal Pradesh; 2] to analyze the impact of drip irrigation on the yield of kiwi crop under the prevailing situation; and 3] to carry out economic evaluation of drip irrigation devices

2.2. Location, Methods and Materials of the Study

Study was conducted in the kiwi orchards of Dirang, Rupa and Bomdila of West Kameng district of Arunachal Pradesh. Kiwi is an emerging crop in Northeastern hilly region. 15 farmers having irrigation system were interviewed during the study. Their crops are in different stages of growth.

Hypothesis was formulated at the beginning of the study that the drip irrigation technology can be a best fit in undulating topography and can increase the yield and quality of horticultural crop kiwi and hence enables high income generation for farmers growing horticultural crop in the hilly areas.

To support and justify the hypothesis, the following are discussed: erratic nature of rain fall in the region and its affect on yield and quality of the crops, the physical feasibility of MI in terms of conditions prevailed in the region and the calculation and comparison of incremental return from using Micro irrigation and other irrigation system in the region.

The following approach was used to test the hypothesis: field visits to capture, comments and opinions of the farmers growing the crops both under irrigated and rain fed conditions; study of physical attributes, relationship of crop physiology and data on existing physical conditions like weather, rainfall etc., from research stations and review of literature (papers and research documents).

An outsider's perception of the region is that it is a water-surplus region with higher annual rainfall and high range of topographical variation. The mechanization of farming and infrastructural amenities is also not at par with the more developed states of the country. The use of ground water in agriculture is also very low as compared to rest of the country, except the valley portion of Assam and Tripura, which are using ground water to some extent to irrigate some of their crops. The farming community of the region is always skeptical about the use of modern, precision irrigation devices like drips. The concept of productivity of water is still new to the people of the region, whereas productivity of land use is a common concept. The traditional practice of agriculture like Jhum still prevails in a substantial acreage among the tribal people in the hilly states.

This study is tying to address the issue of improving the productivity of the available water in fruit production through efficient use with the help of drip irrigation. In this study, efforts are made to assess whether crops like kiwi and orange actually need irrigation for better performance in high rainfall conditions. Arunachal Pradesh is perceived as a higher rainfall zone but the distribution of the precipitation is erratic with low precipitation during the winter months of December, January and February.

2.3. Water Requirement of Kiwi and Rainfall Pattern of the Region

Inadequate soil moisture during dry season adversely affects the fruit size, yield and crop return as the water requirement of this fruit is very high because of vigorous vegetative growth and larger leaf area. Irrigation of matured vine is essential when the average annual rainfall is below 1000mm and water holding capacity of soil is low. Fully grown vines require 80-100 lt of water for total daily transpiration from 16-17m^2 canopy area during summer.

- Moisture deficiency results in foliage dropping of the vines during the early stages of growth (first 2-3 years).

- If plants suffer from moisture stress during the period of rapid growth, it will wilt and leaves turn brown. (Chauhan, Chandel, Negi).
- Water stress during the flowering and bearing stage results in lesser yield in terms of number of fruit per vine and size of the fruit.
- Poor management of the vines along with water stress during the dormant stage of the crop results in lesser bearing in the next season.

Young trees should be irrigated at an interval of 2-3 days, while fruit-bearing trees need irrigation at an interval of 5-7 days, with 20% depletion of soil moisture from field capacity during summer to get better size of fruits. It is very important to meet the water requirement of the vines during the first two years after plantation for successful production of kiwi orchard (Awasthi and Badyal, 2005).

Kiwi fruit requires a well distributed rainfall and high humidity. Application of drip is recommended, which should be operated for two hours everyday.

According to Chandel et al., (2004), the vines irrigated at 100% ETc with drip method registered 39 and 43% increase in shoot growth and trunk girth, respectively, over traditional basin method of irrigation. Water use efficiency was found to be highest (2.91 q/ha-cm) with drip irrigation at 100% ETc and lowest (1.84 q/ha-cm) with basin irrigation at 15 days interval. Besides saving 22% of irrigation water, drip irrigation at 100% ETc yielded 19.4% more fruits compared with basin irrigation, and also produced fruits of better size and quality.

Irrigation in different stages of growth in crucial for kiwi, as the crop has large canopy and vigorous growth. The physiology of the crop reveals that there are a few critical stages in the life cycle of kiwi crop where providing sufficient water to the roots is very important for a good crop harvest and sometimes even for the survival of crop itself. These stages coincide with the dry spell of the region.

The critical stages of bearing plants of kiwi are bud formation from the month of February to March; flowering from the month of April to June; fruit growing stage from September to October; and, fruit maturity stage from November to December. Besides these, the young plants need water for entire year to attain vigorous canopy growth. The first 2 years of growth are important for better bearing of the plant. The water requirement in this period of time is high and subsequently foliage covering the entire area acts as mulch and reduces the frequency of irrigation.

2.4 Fuel-free Drip Irrigation in Kiwi Vineyards of Arunachal Pradesh

Commercial cultivation of fruits like apple and kiwi and vegetable like tomato and flower like orchid has started in the state very recently. The drip irrigation systems used in kiwi vineyards in the study area are gravity operated.

There are plenty of surface streams in undulating slopes in the state, which are a primary source of water in the area. They are mainly perennial and flow from very high altitudes thereby providing elevation difference. Government departments like public health engineering department and department of horticulture construct community tanks at the foothills, collect the water and send to supply tanks constructed in the valley. The high pressure gradient of the streams because of the steepness and difference in altitude provides the required pressure for drips. Water is distributes water with the help of hosepipes. Government departments maintain the community tanks. Farmers may sometimes govern the tanks made for agricultural activities.

The study area has a very large stream, which supplies water to the population within 20 km range under the range of elevation difference of 700 ft to 1500 ft. The farmers have to pay a minimal monthly charge and some deposit to PHE department against the water supply to their residences and fields. In some of the fields, the farmers have constructed storage tanks in the field for operating drip systems. Farmers do not use pump set. Since most of the orchards are on the location of the hill, water flowing from the tank over the hill does not require additional pressure. However, many times the pressure become higher than required. In such cases, farmers use additional check valves and other ways to bypass the additional water and control the water pressure. Farmers thus enjoy fuel or power free drip irrigation systems.

2.5. Impact of Irrigation on the Yield of Kiwi

To understand the economic viability of the system in terms of certain parameters like yield and quality impact and comparing the incremental income from the crops under drip irrigated and rain fed cultivation we conducted a primary survey of villages using drip irrigation for cultivation. In Arunachal Pradesh, the kiwi growers of West Kameng district responded positively towards water requirement of the crop. The 100% of the farmers interviewed during the study responded that drip irrigation increases the yield of the crop.

First, 5 factors were identified as affecting the yield of kiwi in the region. They are: altitude of the vineyard, management practices, air temperature and type of soil, and variety of crop. The farmers were them asked to rank the factors affecting the yield and quality of kiwi production, in the order of importance, majority of the farmers ranked irrigation as top followed by management practices and variety.

2.6 Impact of Drip Irrigation in the Production of Kiwi and Fruit Quality

The determinants of better quality fruit for obtaining better price in the market are size of the fruit, juice content, flavor and some oregano type of taste like sweetness. The size of a best quality fruit ranges from 100-130gm. Weight of medium quality fruit size ranges from 60-100gm and weight below that constitutes average quality.

In the study area the average size of the fruits are not uniform. The average size of the fruit under irrigated condition is 60gm per fruit and fruit grown under rain fed condition is 40gm. Table 1 shows the criteria for fruit quality and how it changes depending on water source. As a part of post harvesting activities, the fruits are sorted according to the size. Farmers in study area reported that irrigated farms harvested better quality fruits/plant as compared to rain fed farms. Subsequently, irrigated farms got a better price realization from the crops.

Table 1: Change in Fruit Quality due to Irrigation

Fruit Quality Criteria	Irrigated Kiwi	Rain fed
Average (less than 40gm)	10%	40%
Better (40-70gm)	60%	50%
Best (more than 70gm)	30%	10%

Yield impact: Farmers of study area responded that there is more gain in fruits per pant of kiwi under irrigated condition irrespective of variety as compared to rain fed cultivation. Kiwi is a very high yielding crop under favorable growth conditions. A matured kiwi crop can yield up to 800 fruit/bearing. In study area, the average number of fruits per plant is not very high ranging from 50-700 during different years of production. The bearing of fruit also depends on the variety of fruit. Table 2 shows the yield impact of rain fed farming vs.

Table 2 : Yield Impact of Rain fed Farming vs. Irrigated Farming.

Variety wise Yield	Number of fruit per plant under irrigated condition			Number of fruits per plant under Non irrigated		
	Allison	Haward	Monty	Allison	Haward	Monty
4th year	100-150	90-200	100-150	60-100	50-80	65-90
5th year	250-450	200-400	200-400	150-200	100-250	100-200
6th year	500-600	500-700	450-550	300-500	200- 450	300-400

The Haward variety under irrigated condition bears highest number of fruits during the sixth year of growth. Farmers are expecting more yields in the coming year.

2.7 Economic Benefit in terms of Labor Saving

Weed is a major constraint in cultivation of most of the crops grown in the region because of vigorous vegetation growth. Weeding is a cost intensive operation for widely spaced crop like kiwi. Drip irrigation restricts weed growth because of less availability of soil moisture for their growth. So, man days required for weeding are reduced. The cost of weeding is higher in hilly areas because of higher labor charge at the cost of Rs.70/man day. According to farmers in the study area, in drip irrigated plots the weed growth is less compared to rain fed plots.

2.8 Checking of Soil Erosion

The top soil is always susceptible to erosion when the land is sloppy. Drip irrigation checks the vulnerability of the soil towards erosion because of moisture availability in the root zone of the plants. The fruits being perennial, help in checking soil erosion and provide high density green cover to the soil.

3. ECONOMIC BENEFITS FROM DRIP IRRIGATED KIWI

3.1 Net Present Worth of Return from Drip Irrigation in Kiwi Crop

Drip irrigation system is an investment, which is able to give returns over time and the cash flows can also change in due course of time. Since this system involves fixed capital, it is necessary to take into account the income streams for the whole life span of drip investment. The economic feasibility of drip is determined by calculating the B: C ratio as well as the NPV over a period of 6 years. In kiwi crop, the initial investment is high. The operational cost of drip is low because of fuel free irrigation (due to gravity flow caused by difference in elevation). The operational cost occurs in terms of man days for weeding as well as some physical maintenance of the system.

Table 3: Benefit Cost Analysis of micro irrigation.

Year	Investment Cost (Rs)	O & M Cost (Rs)	Total Cost (Rs)	Benefit (Rs)	Net benefit (Rs)		Discount Coefficient	Net present Worth (Rs)	
					- ve	+ ve	12%	-ve	+ve
1	5,00,000	20,000	52,0000		5,2,0000		0.8929	4,64,308	
2		20,000	20,000	6,000	14,000		0.7972	11,161	
3		20,000	20,000	6,000	14,000		0.7118	9,965	
4		20,000	20,000	6,000	14,000		0.6355	8,897	
5		20,000	20,000	2,50,000		3,40,000	0.5674		1,92,916
6		20,000	20,000	6,40,000		7,68,000	0.5066		3,89,088
							49,4331	5,82,004	

The benefit cost ratio (B-C ratio) is 1:1.18. The NPV of the returns from drip irrigated Kiwi orchard is Rs. 87673 (Rs. 582004-Rs. 494331). The pay back period is 6 years. The NPV is satisfactory and the B:C ratio is greater than unity. This implies that drip irrigation in kiwi crop is economically viable.

3.2 Findings

Dip irrigation can increase yield and quality of kiwi crop under undulating topography in heavy rainfall zones. Kiwi is an exotic crop, which needs water during its critical stages of growth for obtaining better price in the market. The erratic nature of rainfall causes loss to the yield and quality of kiwi frit which can be corrected with the help of drip irrigation. The cop can be irrigated by drip in a cost effective manner because of fuel free water supply in the state due to difference in elevation. The cost of drip is insignificant in comparison to total cost of cultivation.

Drip irrigation system is economically viable in kiwi crop in Arunachal Pradesh. The net present value of drip irrigation in kiwi is Rs.87673 and benefit cost ratio is 1: 1.18. The pay back period of the system is 6 years. In between farmers can gain some return by intercropping some annual crops. Thus, investment on drip irrigation is sound and economically viable. Therefore, the cultivators are advised to make use of drip sets.
The stream water is plenty in the state now and is used extensively in all type of activities, which may lead to severe depletion during the course of time with increasing population. Deforestation is causing depletion of rainfall, which adversely affects the availability of water in the streams. Proper practices for conserving streams should be launched for sustainability of agriculture in the state.

4. CONSTRAINTS FOR KIWI CULTIVATION IN ARUNACHAL PRADESH

4.1 Non-Availability of Quality Planting Materials

Good quality material is key to the success of any fruit crop. Fruit crops are generally perennial in nature and bad effect of inferior planting materials is only visible after several years of efforts made by growers and when the trees have come to the stage of bearing fruits. The cost of planting material in case of kiwi is high. The grafted panting material is about Rs. 85 in study area, which is a major item in calculating cost of production of the crop.

4.2 Lack of Marketing Facilities

Major issue facing kiwi growers is the marketing of the fruit. There is strong need for an organized marketing system for kiwi in Arunachal Pradesh. Intervention of government agencies and private parties is essential in developing proper marketing channels for the movement of the produce. The cost of marketing is very high because of higher transportation cost. At present farmers are marketing their products through middle men, and often sell it in the local market. Recently APEDA (Agricultural Processed Fruit Export Development Authority) purchased a few tons of kiwi, but was not able to buy the whole lot, which was produced. Horticultural crops being perishable require proper handling and distribution within a limited period. But, due to lack of marketing infrastructure, farmers are forced to sell their produce at a very low price. To achieve better realization to the growers, therefore, there is need to establish marketing systems with forward and backward linkages. By this, farmers can get remunerative price for their produce and would further generate employment opportunities for the people of the state.

4.3 Lack of Processing Industry

There is no processing industry that can utilize the excess produce and protect the growers' interest. Better quality juice, jam, jelly and canned slices of fruit can be made from kiwi, which have very much remuneration in metros and cities. Processing units, which are in the proximity of the fruit-growing area, can be more efficient because of the poor transport facilities available in the state. Until today, there are hardly any cold storage facilities available in the state. A few processing units exist but are not functioning to the desired capacity.

Table 4: Costs of production of kiwi fruit crop grown under rain fed and drip irrigation system

Sr. No.	Attributes	Under Drip Irrigation	Under Rainfed Condition
1.	Average size of land under cultivation (ha)	1.2	1.5
2.	Average annual cost of cultivation (Rs) of Kiwi	500000	4,40000
3.	Operational Cost	20000	25000
4.	Average Yield	260	175
5.	Annual Gross Returns	15,60000	7,00,000

Table 5: Break up of cost of production of kiwi in Arunachal Pradesh (Rs. / ha)

Sr. No.	Activity	Under drip irrigation	Under rainfed
1.	Planting Material	14,000	14,000
2.	Cleaning Forests	10,500	10,500
3.	Digging	7,000	7000
4.	Cost of T bar	3,20,000	3,20,000
5.	Fertilizer	5,000	5,000
6.	Land preparation	7,000	7,000
7.	Fencing	50,000	50,000
8.	Irrigation	30,000	Nil
9.	Harvesting	20,000	10,000
10.	Marketing	30,000	15,000
11.	Total	4,93,500	4,38,500
12.	Operational Cost	20,000	25,000

The operational cost includes cost of man days for weeding and the maintenance of drip system. Till date, no pest and disease are reported by farmers in kiwi cultivation. This reduces the input cost.

Table 6: Area and Prodcution of Various Fruits (2004-05)

Name of Crop	Area (ha)	Production ('00 ton)
Apple	8403	9474
Citrus	23360	27251
Banana	4914	14817
Pineapple	7913	36310
Kiwi	190	62
Walnut	3516	58
Others	5916	15262
Total fruits	54213	103234
Large cardamom	4142	572
Black Pepper	1612	133
Ginger	7618	36666
Total spices	13372	37371
Grand Total	67584	140605

Source: Annual Report 2004-05, Dept. of Horticulture, Govt. of Arunachal Pradesh

Table 7: Minimum Annual Rainfall in Arunachal Pradesh & Assam (2004-05)

Station	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	MAR	Driest Month
Bomdila	20	20	15	73	118	243	239	159	116	103	29	8	1143	Dec
Dening	73	132	250	460	589	1461	1017	871	588	204	67	46	5758	Dec
Gerukamukh	35	151	89	465	130	270	580	58	55	51	51	8	1942	Nov
Kimin	34	37	54	232	396	513	961	542	590	143	51	27	3579	Dec
Pasighat	47	97	140	248	407	890	1053	751	574	222	31	26	4484	Dec
Sunpura	38	76	145	255	308	449	488	325	337	133	37	25	2616	Dec
Yazali	18	27	57	102	156	313	194	136	125	58	24	15	1224	Dec
Ziro	39	59	78	152	194	239	253	177	153	69	50	47	1510	Dec
Assam														
Gohpur	40	33	58	141	336	444	432	372	236	133	34	19	2277	Dec

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PROMOTING DRIP IRRIGATION*
WHERE AND WHY?

D. Suresh Kumar[1]

Abstract

This paper tries to look at the changes which drip irrigation brings to the farming system and the factors which limit or motivate drip irrigation. The study revealed that adoption of drip irrigation technology increased the net sown area, net irrigated area and there by helped in achieving higher cropping intensity and irrigation intensity. Discussion with the farmers revealed that huge initial investment and small size of holding are the major constraints limiting the adoption of drip technology. Other reasons are unsuitable cropping pattern, lack of access to subsidy and no technical support for follow up action. As cropping pattern decides the adoption and suitability of drip irrigation, widespread adoption of micro irrigation could be promoted in the regions where there is a shift towards crops like coconut, banana, grapes etc. Further, drip irrigation is suitable in areas where there is a scarcity of water and labour.

1. INTRODUCTION

Water is becoming an increasingly scarce resource and limiting agricultural development in many developing and developed economies across the world. Developing infrastructure for water resources and their management have been the common policy agenda in many developing economies particularly in arid and semi-arid tropical countries. Physical and economic scarcity of water across regions has forced water resources economists and scientist to critically analyze different options for managing water. A study by the International Water Management Institute (IWMI) shows that around 50% of the increase in demand for water by the year 2025 can be met by increasing the effectiveness of irrigation. Most of this gain in irrigation efficiency can come in countries which grow high percentage of irrigated rice.

The capacity of large countries like India to efficiently develop and manage water resources is likely to be a key determinant of global food security in the 21st century (Seckler et al., 1998). In India, almost all the easily possible and economically viable irrigation water potential has already been developed. However, the demand for water for different sectors has been growing continuously (Saleth, 1996; Vaidyanathan, 1999). Moreover, the water use efficiency in the agricultural sector, which still consumes over 80% of water, is only in the range of 30-40% in India, indicating that there is considerable scope for improving the water use efficiency.

A lot has been discussed on the ever-increasing demand for water resources for multiple uses which has led to overexploitation of groundwater. It is argued that low electricity pricing policies and shifting of electricity tariff from pro-rata to flat rate have reduced the marginal costs of water to zero. As a result, farmers use both groundwater and electricity inefficiently. The effect of such cheaper electricity has resulted in various negative externalities such as over pumping, changes in crop pattern towards more water intensive crops, well deepening, drilling new bore wells, increase in well investments, pumping costs, well failure and abandonment and out migration which are increasing at a much faster rate (Narayanamoorthy, 1997; Palanisami and Suresh Kumar, 2003).

The review of past studies shows that the solution to the problem of growing groundwater scarcity and persistent groundwater resource degradation across regions are two fold: Firstly, the supply side management

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practices like watershed development, water resources development through major, medium and minor irrigation projects. The second is thorough the demand management by efficient use of the available water both in the short and long run. This includes drip irrigation and other improved water management practices.

Recognizing the importance of sustainable water use efficiency in agriculture, a number of demand management strategies (like water pricing, water users association, turnover system) have been introduced since the late seventies to increase the water use efficiency especially in the use of surface irrigation water. While various strategies introduced for improving the water use efficiency have been continuing, the net impact of these strategies in increasing water use efficiency is not very impressive (Narayanamoorthy, 2003).

One of the demand management mechanisms is the adoption of micro irrigation such as drip and sprinkler method of irrigation. Evidences show that the water use efficiency increases up to 100% in a properly designed and managed drip irrigation system (INCID, 1994; Sivanappan, 1994). Drip method of irrigation helps to reduce the over exploitation of groundwater that partly occurs because of inefficient use of water under surface method of irrigation. Environmental problems associated with the surface irrigation like water logging and salinity are also completely absent under drip method of irrigation (Narayanamoorhty, 1997). In addition, drip method helps in achieving saving in irrigation water, increased water use efficiency, decreased tillage requirement, higher quality products, increased crop yields and higher fertilizer use efficiency (Qureshi et al, 2001; Sivanappan, 2002; Namara et al., 2005). In addition to the private benefits, the drip irrigation generate substantial social impacts in the form of enhanced food security, women participation in agriculture (http://www.ide-india.org/ide/socialimpact.shtml) and social status (Shah et al.,).

Though the potential benefits generated by the drip irrigation methods are apparent, the adoption of drip irrigation is yet to be widely promoted across regions and states. Though there are many studies attempted to identify factors limiting the adoption of drip irrigation, still, it is not clear where we should promote micro irrigation. The issue of promoting micro irrigation forms one of key policy agendas in many developing countries including India. Keeping these issues in view, the present paper addresses three important issues: (i.) what changes the drip irrigation brings to the farming system?, (ii) whether the adoption of drip irrigation is motivated by the cropping pattern or the cropping pattern is followed by the drip adoption? and (iii) what factors limit or motivate drip adoption?.

2. METHODOLOGY

The present study aims to analyze the adoption and impact of drip irrigation. To identify the factors driving adoption of drip irrigation and assess the associated positive and negative externalities, one control region where there is no drip adoption was selected.

The study was conducted in Coimbatore district of Tamil Nadu state where groundwater resource degradation is alarming. Two blocks each representing water scarcity were selected and studied. From the selected block, two revenue villages were selected purposely where the adoption of drip irrigation is widespread. Farm households in the selected villages constituted the sample units. To examine the adoption and impact of drip irrigation on resource use, agricultural production and farm income, 25 drip adopting farmers were selected in each village and correspondingly 25 non-drip adopters were selected in control villages. In additon to drawing sample farmers in the control village, farmers who did not adopt from the drip village were also studied. A sample of 10 non-drip adopters in the same village was studied. Thus, we studied two set of control farmers. One set of control farmers with in the drip village and another set of farmers from the control village. Total samples of 120 farmers were studied.

2.1 Source of data

For the purpose of the study, both secondary and primary information were collected from different sources. The secondary information included rainfall trends, growth in number of wells, wells functioning, number of defunct wells, cropping pattern, crop yields, occupational structure, area irrigated and socio-economic conditions like migration, employment. The general particulars of the area were collected from the assistant director of statistics, and assistant director of agriculture of the respective regions. Interview schedules were formulated and pretested. The needed information were gathered by personal interview of the respondents. The primary information collected from the farm households include details on well investment, groundwater use, extraction and management, crop production including input use and output realized, farm income, adoption of drip irrigation, and investment on drip irrigation. This also includes asset position, education, consumption and other socio-economic conditions.

2.2 Factors influencing adoption of drip irrigation

A key concern of policy makers is to make farm households adopt micro irrigation technologies in order to manage the growing groundwater scarcity. Thus, an important research question is what factors influence farm households' decision to adopt drip irrigation. For the purpose, area covered under drip irrigation is considered as the dependent variable.

The dependent variable for adoption of drip irrigation would be zero for those households who do not adopt drip irrigation. If the dependent variable is censored, values in a certain range may all be recorded as single value. Given that dependent variable is censored at zero, a Tobit estimation rather than OLS is appropriate (Madalla, 1989; Tobin, 1958). In such a case, Tobit estimators may be used. Thus, the functional form of the model specified in the present study with a Tobit model, with an error term (Ui) which is independently, normally distributed with zero mean and constant covariance, is

$$T^*_i = X_i b + U_i$$
$$T_i = T^*_i = 0 \qquad \text{if, } X_i b + U_i > 0$$
$$\text{if } X_i b + U_i <= 0$$
$$i = 1....n \qquad \text{……………(1)}$$

where,

T_i = Area covered under drip irrigation in hectares
X_i = Vector of independent variables
b = Vector of unknown coefficients
n = Number of observations

In the above functional relationship, the Ti is the endogenous variable which is expected to be influenced by other exogenous variables viz., age of the farmer in years (AGE), educational level of the farmer in years of schooling (EDUCATION), farm size in hectares (FSIZE), proportion of wider spaced crop (WIDERCROP), participation in off-farm and non-farm income activities (OFFFARM) and percentage of area irrigated by wells (AWELLS).

Economic implications can be drawn by using the results of the empirical model. Following a Tobit decomposition framework suggested by Mc Donald and Moffitt (1980), the effects of the changes in the explanatory variables on the elasticity of adoption of drip irrigation and intensity of adoption could be obtained.

The basic relationship between the expected value of all observations, E(T), the expected value conditional upon being above the limit, E(T*), and the probability of being above the limit, F(z), is

$$E(T) = E(T^*).F(z) \qquad \text{……..…(2)}$$

The effect of a given change in the level of the explanatory variables on the dependent variables can be obtained by decomposing the equation (2) is,

$$\frac{\partial E(T)}{\partial X_i} = F(z)\left(\frac{\partial E(T^*)}{\partial X_i}\right) + E(HC^*)\left(\frac{\partial F(z)}{\partial X_i}\right) \qquad \text{………..(3)}$$

Thus, the total elasticity of change in the level of the explanatory variable consists of two effects: (i) change in T of those above the limit (i.e. elasticity of intensity of adoption, for those households who already are adopter) and (ii) the change in the probability of being above the limit (i.e. probability of adoption).

To assess the physical, and socio-economic impact of adoption of drip irrigation, the impacts on different domains were compared between the regions of high degree of adoption with the region of no drip adoption (control region). Both, with and without and before and after approaches were employed to assess the impact of drip irrigation technologies.

The adoption of micro irrigation is expected to have impacts on resource use (water, labour, fertilizers in agricultural crop production), area irrigated, cropping pattern, cropping intensity, water potential of the wells, crop yield, farm household income, asset position, consumption, education, livestock possession and labour absorption etc. It will also have bearing on the wage rate, prices of cereals, migration and mobility of labour. In addition, the additional employment created through development of allied industries. Inter-temporal comparison was also made to study the impact of drip irrigation.

2.3 Social impacts

The adoption of drip irrigation has significant bearing on the society as a whole and generates various positive and negative externalities (Dhawan, 2000). The positive externalities may include reduction in well failure rate, reduction in deepening of existing wells or cost of drilling new wells, and increased availability of irrigation water. Similarly, the adoption of drip irrigation also generates negative externalities such as reduction in human labour employment due to cropping pattern changes i.e. labour intensive annual cereal crop production to less labour intensive trees, and additional consumption expenditure incurred by the local villagers because of increased local price of cereals due to reduced local production. Generally, externalities arise when certain actions of producers or consumers have unintended external (indirect) effects on other producers or consumers. Externalities exist when not all costs or benefits are taken into consideration by consumers and producers while conducting their consumption and production activities (Markandya et al., 2002). Externalities may be positive or negative. Positive externalities arise when an action by an individual or a group confers benefits to others. Negative externalities arise when an action by an individual or group of producers gives harmful effects to others. In an activity generating positive externality, social benefit is higher than private benefit and in an activity generating negative externality, social cost is higher than private cost.

2.4 Quantification of benefits and double difference methodology

Farm level data was collected for both drip adopters and non-adopters before and after drip irrigation technology. This enables the use of the double difference method to quantify the impacts due to adoption of drip irrigation. The framework was adapted from the program evaluation literature (Maluccio and Flores, 2005).

Table.1: Double Difference Method of Quantifying Impacts Due to Drip Technology

Particulars	Drip adopters	Non-drip adopters	Difference across groups
After drip	D1	C1	D1-C1
Baseline/Before drip	D0	C0	D0-C0
Difference across time	D1-D0	C1-C0	Double difference (D1-C1)-(D0-C0)

The columns distinguish between the groups between drip adopters and non-drip adopters and the rows distinguish between before and after the drip adoption. This is best explained in the Figure.1.

In order to quantify various positive and negative externalities caused by the drip irrigation technology, it is essential to enumerate and differentiate between the private and social cost and benefits. Since the social cost is the sum of private cost and external cost and the social benefit is the sum of private benefit and external benefit, it is crucial to enumerate these costs and benefits (Markandya et al., 2002).

Figure.1: Illustration of impact of drip adoption by double difference method

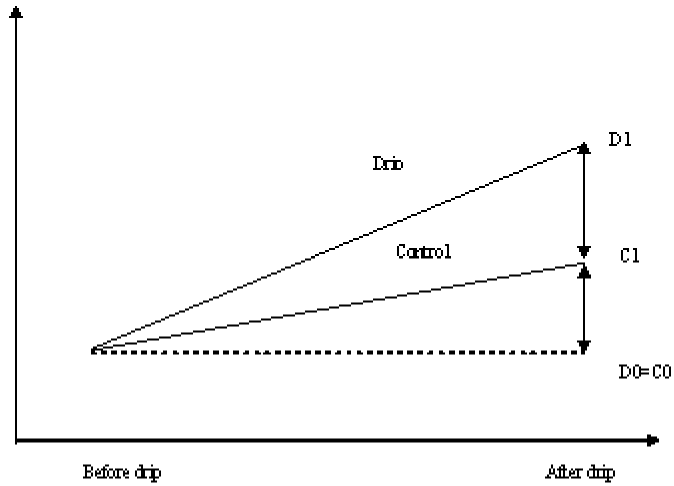


Table.2: Cost and Benefits Associated with Drip Adoption

Cost		Benefit	
Private	External	Private	External
Capital cost (investment cost)	Reduction in labour absorption per ha of traditionally irrigated crop replaced by drip system	Value of saved water	Increased water availability for irrigation purposes
Maintenance cost	Reduction in food security due to replacement of traditional cereals by high valued vegetables, cash crops and fruits	Value of labour saved	Reduced power energy consumption in agriculture
Depreciation on drip equipments	Additional cost incurred towards purchase of cereals because of drip adoption	Increase in value of outputs (due to increased yield)	Reduction in cost of well deepening
Interest on fixed capital	-	Expansion in cropped area	Reduction in cost of drilling new bore wells / wells Reduction in well failure

It is apparent that the adoption of drip irrigation generates various positive externalities. They include increase in water availability for irrigation, reduction in cost of electricity, reduction in cost of well deepening, reduction in cost of drilling new wells/bore wells and reduction in well failure.

3. STUDY AREA

The study area comprises Coimbatore district of western zone of Tamil Nadu state. The average annual rainfall of this district is 647.2 mm from winter, hot weather, southwest monsoons and northeast monsoons.

There are six different soil types viz., red calcareous soil, black soil, red non-calcareous soil, alluvial and colluvial soil, brown soil and forest soil. The chief source of irrigation in the district is through wells, which play a significant role in the irrigation of the district followed by surface water structures. The district also receives water through tanks. There are 66 irrigation tanks in the district.

A wide range of high-grade metamorphic rocks of the peninsular gneissic complex covers the district. These rocks are extensively weathered and overlain by recent valley fills and alluviam at places. The major rock types present in the district are charnockites, granites, complex gneisses mainly hornblende biotite and sillimanite gneiss with basic and ultra basic intrusives, crystalline limestone, syenite, pegmatite and quartz veins.

3.1 Groundwater potential

The importance and need of water, particularly, for agriculture and its role in augmenting food production needs no emphasis since water is the basic input. Prudential planning for systematic and scientific development of groundwater resources by means of various types of groundwater abstraction structures requires balanced estimation of groundwater potential.

The groundwater potential as on January 2003 indicates that the total groundwater recharge is 880.97 million cubic meter (MCM). Net groundwater availability (90% of total groundwater recharge) is 792.87 MCM. Domestic and industrial draft is 40.57 MCM and irrigation draft is 779.13 MCM. Balance available for future development is 0 MCM and the stage of development is 103%. The level of groundwater development exceeds 100% of the utilisable groundwater recharge in eleven blocks, between 90-100% in four blocks and between 70-90% in four blocks. The groundwater potential, net draft, balance potential available and stages of groundwater development are furnished in Table.3. The stages of groundwater development is 169% in Thondamuthur block and 173% in Annur block. Well failure is found to be about 20% - 60%. This led farmers to adopt various demand side coping strategies like adoption of drip irrigation, shifting agricultural crops to trees, etc.

Table.3: Groundwater potential, utilization and balance potential in the study area (as on 2003)

Name of the Blocks	Total Annual groundwater recharge (MCM)	Natural recharge during non monsoon (MCM)	Net GW availability (MCM)	Irrigation draft as on 2003 (MCM)	Net groundwater availability for future irrigation development (MCM)	Stage of groundwater development as on 1998	Stages of groundwater development As on 2003
Thondamuthur	37.92	3.79	28.21	46.47	0.00	167	169
Annur	38.77	3.88	34.13	56.84	0.00	170	173
Coimbatore district	880.98	88.09	792.87	779.13	112.34	-	-

3.2 Source wise area irrigated

The area irrigated by different sources has significant bearing on the adoption of micro irrigation. Heavy dependence on groundwater necessitates the farmers to go for wide adoption of micro irrigation to cope with growing groundwater scarcity. The trend in source wise area irrigated shows a significant decline in tank irrigation. This is augmented by groundwater as evidenced by increasing area under both open well and bore well irrigation. The groundwater irrigation is to some extent reliable as the co-efficient of variation is small (14.63% in open well). Farmers in this district rely heavily on groundwater for irrigation.

3.3 Groundwater irrigation in selected blocks

Dependence on groundwater for irrigation is a common phenomenon in both the study blocks. The source wise area irrigated indicates that groundwater accounts 88.7% and 52% to the total area irrigated respectively in Thondamuthur and Annur blocks. This confirms the importance of groundwater for agricultural crop production. The area irrigated by different abstraction structures is much more than that of surface water sources. The irrigation system often suffers due to inadequate supply of surface water and depends upon groundwater sources to supplement surface water to stabilize irrigation.

Figure 2: Sourcewise Area Irrigated in Coimbatore District

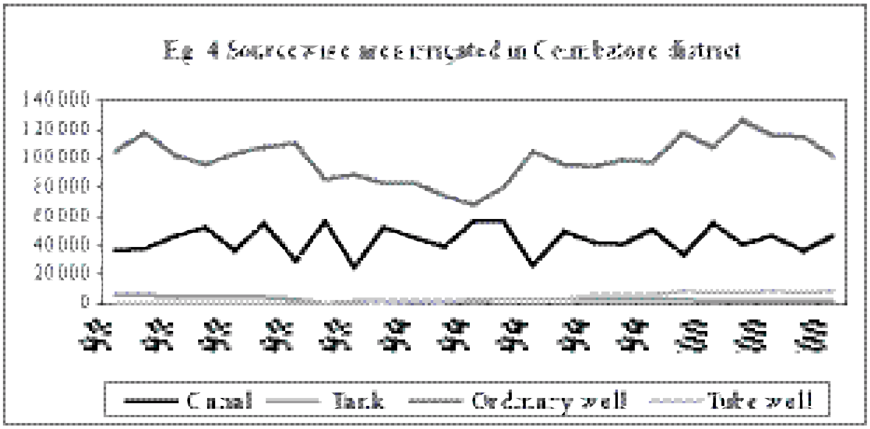
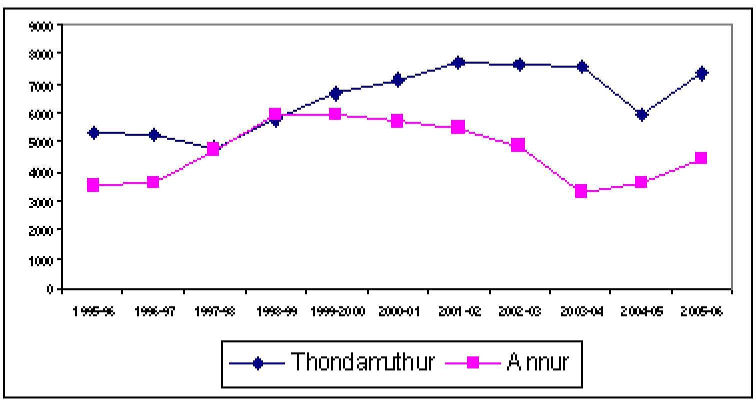


Figure 3: Groundwater Irrigation in Selected Blocks



4. RESULTS FROM FIELD STUDIES

Development of micro irrigation helps the agricultural sector in many ways. Evidence shows that drip irrigation achieves resource saving, enhances yield of various crops and generates various positive externalities. This section examines the spatial and temporal changes in farming system as a result of adoption of micro irrigation.

4.1 What changes the drip method brought in to the farming system?

Key indicators about the impact of drip irrigation across regions over a period were analyzed. Here our aim is to observe any significant changes in land holdings, cropped area, irrigated area due to the introduction of drip irrigation. For the purpose, the drip adopters are compared with two types of control households. It is seen from the Table.4 that the size of holding is worked out to 5.69 hectares for drip adopters and 2.14 hectares for non-drip adopters and 2.3 hectares in control village. It can be seen that the average size of holding among the drip adopters is significantly large when compared to non-adopters both in the same village and in control village. Since drip method of irrigation involves huge initial investment, large farmers adopt widely when compared to small and marginal farmers.

It is argued that drip irrigation increases cropped area and area under irrigation as it is a viable water saving technology. Our study confirms the earlier findings that the drip irrigation technology increased the net sown area, net irrigated area and there by helps in achieving higher cropping intensity and irrigation intensity. For instance, in the drip village, the net sown area increased from 4.63 ha to 5.39 ha where as the gross cropped area increased from 4.88 ha to 6.44 ha. Similar trend was observed in net irrigated area and gross irrigated area. During the survey, we found that drip irrigation technology resulted in significant impacts. It led to 40-50% water saving and helped double the irrigated area and cropped area.

Table.4: Drip irrigation and its impact on farming

Crops	Drip village				Control village	
	Drip adopters		Non-adopters			
	Before	After	Before	After	Before	After
Number of farm households	50		20		50	
Number of workers in the household	2.7	2.7	2.1	2.1	2.3	2.3
Farm size (ha)	5.69	5.69	2.14	2.14	2.48	2.48
Net sown area (ha)	4.63	5.39	1.95	2.05	2.12	2.08
Gross cropped area (ha)	4.88	6.44	2.06	2.11	2.30	2.13
Cropping intensity (%)[a]	105.37	124.84	102.44	102.26	108.49	108.87
Net irrigated area (ha)	3.65	4.97	1.46	1.78	1.80	1.75
Gross irrigated area (ha)	3.84	6.26	1.53	1.85	2.03	1.84
Irrigation intensity (%)[b]	104.88	130.16	117.0	116.83	112.78	109.97
% of area irrigated by wells to the total cropped area	80.21	96.73	91.77	88.92	88.26	86.38
% of area irrigated under drip to gross cropped area	66.35	..	..			
% of area irrigated under drip to gross irrigated area	68.57	..	..			

Source : Field survey during 2007-08

Notes:

a : Cropping intensity is defined as the ratio of gross cropped area to net sown area and expressed as percentage

b : irrigation intensity is the ratio of gross irrigated area to net irrigated area and expressed as percentage

It is interesting to note that drip irrigation not only resulted in private benefits to the drip adopters, but also generate positive externalities. Debate is going on among the hydrologists, water resource managers and agronomists whether drip technology helped in water saving at meso level i.e at village level or watershed level or basin level. Though it is not based on experiments like pumping test, our discussion with the farmers revealed that water level in the wells adjacent to the drip adopters field were raised in many cases or maintained at the same level. It is evidenced that the net irrigated area among non-adopters in the drip village increased from 1.46 ha to 1.78 ha where as the gross irrigated area increased from 1.53 ha to 1.85 ha. Growing groundwater scarcity is a common phenomenon in the entire state of Tamil Nadu and declining groundwater table is alarming. In spite of frequent failure of monsoon coupled with growing groundwater scarcity, the net irrigated area has increased slightly over the years. This increase might be due to several reasons like rise in water table due to rainfall, reduction in groundwater extraction due to shift from agricultural to non-agricultural use of land, water saving technologies such as drip irrigation and so on. However, it is not immediately apparent that the increase in irrigated area among non-adopters is due to wider adoption of drip irrigation, one cannot ignore that it is also due to drip irrigation. The net irrigated area has declined from 1.80 ha to 1.75 ha over the years in the control village.

The percentage of area irrigated by wells to the total cropped area has increased significantly among drip adopters in drip village. It is evidenced that the percentage of area irrigated by wells to gross cropped area has increased from 80.21% to 96.73% due to the drip intervention. From the analysis, it is clear that drip has two effects: (i) it saves water both at farm level and at meso level if there is limited/or no scope for further expansion i.e. when land is limited and (ii) it helps in expansion of cropped area when there is unlimited land resource. In this case, drip method may not be a water saving technology at meso level.

Whether drip irrigation had followed a certain new cropping system or the crops had followed drip technology which is a response to growing water scarcity?.

Changes in cropping pattern due to drip adoption are analyzed and discussed here. The cropping pattern i.e. proportion of area under different crops is a good indicator of resources development and agricultural production. It is expected that drip method of irrigation helps in developing water resource potential and thereby helps the farmers to get more crop and income per drop of water.

Table.5: Drip irrigation and cropping pattern (Percentage)

Crops	Drip village				Control village	
	Drip adopters		Non-adopters			
	Before	After	Before	After	Before	After
Banana	15.00	15.97	23.12	29.72		
Turmeric		6.99		10.56		
Sorghum	14.70		14.61		8.70	17.39
Ragi	4.17		7.41		13.04	21.74
Maize	8.75	8.84	6.72	8.88		
Cotton	3.15					
Sugarcane					26.09	8.70
Coconut	4.92	22.48	6.09	7.48	17.39	34.78
Grapes	18.82	24.01	3.89	9.58		
Vegetables including tomato	30.47	21.69	38.05	33.77	34.78	17.39

The longitudinal analysis of cropping pattern across farm households and villages revealed that the adoption of drip irrigation is motivated by many factors. The two major constraints limiting agricultural production are human labour and water scarcity. These made the farmers alter their cropping pattern towards less labour and water intensive crops. Resource poor farmers go in for rain-fed crops like sorghum and maize. However, the big farmers who have adequate access to capital adopt various coping strategies. One such strategy is adoption of drip irrigation. In regions where there is severe water and labour scarcity, first there is a shift from labour and water intensive crops such as vegetables, sugarcane, cotton, paddy to less labor intensive crops such as coconut and the next is drip adoption. As drip irrigation saves human labor substantially, by reduction in irrigation labor and weeding labor, water intensive crops such as banana and grapes are planted.

Experiences from the survey revealed that there is a significant shift towards crops such as coconut and grapes in the drip villages. Similarly, there is a reduction in vegetable crops. The percentage of area under vegetables declined from 22% - 30% among drip adopters. In the control village, there is a reduction in vegetable, sugarcane and increase in coconut, and rain fed cereals. It is thus clear that micro irrigation can be promoted in regions with high water and labour scarcity. As cropping pattern decides the adoption and suitability of drip irrigation, widespread adoption of micro irrigation can be promoted in the regions where shift towards crops like coconut, banana, grapes etc. are common.

4.2 What influences adoption of drip irrigation?

Estimation of the factors that determine adoption of drip irrigation is presented in Table.6. The sample includes 70 farmers both the drip adopters and non-adopters in the drip village. Given the significance of the coefficients obtained for the different variables hypothesized to determine adoption of drip method of irrigation, we have greater confidence in our results.

It could be seen that the variables of age, education, family size, widercrop, and off-farm are found to be significant determinants of adoption of drip irrigation on the expected positive line. Age of head of the household influences the adoption of drip irrigation positively. The age, which reflects the experience in farming has significant bearing on adoption of various agricultural crop production technologies. Our results confirm that the experience in farming significantly influences the drip adoption. The educational level of the head of the household has a positive and significant impact on adoption of drip method of irrigation. Education improves awareness about the positive externalities generated by drip irrigation and motivates farmers to initiate action. The size of the farm reflects the wealth status of the farmers, which is expected to influence drip irrigation positively as drip involves huge initial investment.

Table.6: Factors influencing adoption of drip irrigation

Variables	Regression Coefficient	Elasticity of Intensity of Adoption	Elasticity of Adoption
CONSTANT	- 8.025 (-4.515)	..	..
AGE	0.0219 * (1.904)	0.3762	0.4407
EDUCATION	0.3251 *** (4.968)	1.0190	1.1937
FISIZE	0.6187 *** (7.383)	0.9359	1.0963
WIDERCROP	0.0172 *** (2.814)	0.6092	0.7136
OFFFARM	1.0145 *** (2.870)	0.3238	0.3793
AWELLS	0.0199 (1.202)	0.1780	0.2085
Log-likelihood function	- 80.7137		
Number of observations	70		
Dependent variable	DAREA		
Model	TOBIT		

Source: Field Survey 2007-2008

Note: *** significance at 1 % level; ** significance at 5 % level; * significance at 10 % level

Figures in parentheses indicate estimated ‘t’ ratios

We found that size of the farm exerts a significant and positive influence on adoption of drip irrigation. However, few small and marginal farmers also show inclination towards adoption of drip irrigation. However, for want of initial investment all low income farmers do not opt for drip irrigation.

Cropping pattern in any region has significant bearing on the adoption of drip technology. It is known that drip technology is more suitable when the cropping pattern is dominated by wider spaced crops such as banana, coconut, grapes, sugarcane and so on. It is clear from the analysis that the proportion of wider spaced crop significantly influences drip adoption. In our study area, the farmers prefer to grow crops like coconut, grapes and banana. This change in cropping pattern again motivates the farm households to adopt drip technology.

One can expect that participation in off-farm and non-farm income activities enabled the households to generate additional income to manage both their households and make adequate investments on farm development. It is evident that the variable off-farm is found to significantly and positively influence drip adoption. Participation in off-farm and non-farm activities is more when the number of workers is more in the household.

It is evidenced that the variable education has the highest impact on both probability of adoption and intensity of adoption followed by fsize and widercrop. The total elasticity for the variable fsize is estimated to be 2.0322 which is divided into 1.0963 for probability of adoption and 0.9359 for intensity of adoption. This suggests that a 10% increase in farm size is expected to result in about 20% increase in adoption of drip technology and extent of drip irrigation. Similarly, the other factors viz., educational level of the head of the household and area under wider spaced crops have significant influence on drip adoption and extent of adoption.

Enough efforts have also been made to know the impact of drip irrigation on agricultural crop production and farming system. Almost 100% of the farmers reported that drip irrigation helps in resource saving, expansion in irrigated area, reduction in cultivation cost, increase in groundwater table, labour saving and reduction in pumping hours. Nearly, 32% of the farmers reported that there is increase in yield of crops.

Table.7: Opinion of farmers about drip irrigation and their like impact

Particulars	% of farmers
Resource saving	100.00
Expansion in area irrigated	100.00
Increase in crop yield	32.00
Increase in cropping intensity	85.65
Reduction in cost of cultivation	100.00
Increase in groundwater table	100.00
Reduction in pumping hours	100.00
Labour saving	100.00
Altered cropping pattern	76.54

Discussion with the farmers also revealed that huge initial investment and small size of holding are the major constraints limiting the adoption of drip technology. Other reasons are unsuitable cropping pattern, lack of access to subsidy and no technical support for follow up action.

5. CONCLUSION

The present paper aimed to study the adoption and impact of drip irrigation both spatially and temporally. The study revealed that adoption of drip irrigation technology increased the net sown area, net irrigated area and there by helped in achieving higher cropping intensity and irrigation intensity. As cropping pattern decides the adoption and suitability of drip irrigation, widespread adoption of micro irrigation could be promoted in the regions where there is a shift towards crops like coconut, banana, grapes etc. The analysis of factors influencing drip adoption revealed that the age of the farmer, educational level, farm size, area under wider spaced crops and participation in off-farm and non-farm activities found to significantly influence adoption of drip technology. Thus, our policy focus may be tilted towards promotion of drip irrigation in regions where water and labour scarcities are predominant and regions where shift towards wider spaced crops has taken place.

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TECHNOLOGICAL AND INSTITUTIONAL APPROACH FOR ENHANCING WATER (LOGGED) PRODUCTIVITY IN AGRICULTURE: A CASE STUDY OF GANGA BASIN IN ALLAHABAD

Firdaus Fatima Rizvi*

Abstract

This paper deals with the case study of Allahabad that is rich in water resources and is one of the most fertile plains of the Ganges. Since the coming up of Sharda Sahayak Canal in the area, there has been a problem of waterlogging in the area for the past fourteen years. Surplus water from canal, rainwater, absence of effective drainage system and low capacity of river Varuna all add up to create high level of waterlogging in the fields. Land area of about 600 hectares in Phulpur block is waterlogged. The high water table has engulfed vast areas significantly affecting agricultural production.

This paper throws light on water availability in agriculture, extent, height and duration of waterlogging in crop fields and extent of crop loss because of waterlogging. It also includes landuse pattern of agricultural households and calculation of loss of production expected. It predicts future benefits in terms of agriculture production with certain estimated investments into the region. The paper lastly deals with technological and institutional approach for enhancing water productivity in agriculture. The study helps in the promotion of self-generating income activities on one hand and solving water related problems on the other at the village level.

1. INTRODUCTION

The progress of the economy in developing countries, largely depends on the performance of agriculture sector. Among the determinants for agricultural growth, the provision of irrigation is very important because rainfall is not evenly distributed over the year and is uncertain. The assured supply of irrigation water can increase crop yields even without any increase in inputs, and reduce the uncertainty of crop production (Reddy, 1997).

The failure to take the groundwater into account and inadequate attention to drainage and soil condition in the canal irrigation have led to emergence of conditions of waterlogging and salinity in many areas, resulting in valuable agricultural land going out of use (Dhawan, 1988). At times, waterlogging in agricultural fields forced farmers to go for single crop whereas other farmers go for multiple crops. The farmers have to wait for the water to subside before they can resume work.

Irrigation facility ensures security to agriculture crops during low rainfall but the rigidity in irrigation timings proves to be fatal (Hill and Dracup, 1975). The water distribution among the farmers is highly uneven, depending upon the location of the farm, resourcefulness of the farmer and on the water delivery system that is supply driven. The farmers who get water easily misuse it, thereby leading to very low irrigation efficiency. This has caused inadequate and unreliable water supply, and created a wide gap between created and utilised irrigation potential, temporal imbalance of water demands and supplies, excessive seepage and operational losses leading to waterlogging and soil salination (Paul and Sharma, 2001).

In irrigated agriculture, water supply is sufficient in upstream fields as compared to tail end fields. The demand for water by the tail end farmers is justified though this demand of water creates waterlogging situation in upstream farms because of their interdependence (Bromley, 1982). Each farmer must also be able to cut off supply when there is no need of water. Any excess water that has come into the fields has to be drained away (Singh, 1984).

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2. CONCEPT OF WATERLOGGING

In agricultural terms, the soil should be considered as waterlogged when the water table is within such a distance from the surface of the ground that it reduces the crop production below its normal yield that would be expected from the soil type of that area (Department of Irrigation, Uttar Pradesh). In physical context, an area is said to be waterlogged when the water table rises to an extent that the soil pore in the root zone of a crop become saturated, resulting in restriction of the normal circulation of air and decline in the level of oxygen that further increases the level of carbon dioxide. The actual depth of water table, which is considered to be harmful, would depend upon the type of crop, the type of soil and the quality of water and the period for which the water table remains high. The actual depth of water table when it starts affecting the yield of the crop adversity may vary over wide range from zero for the paddy to about 1.5 m for the other crops. The crops, which otherwise, would have grown in the wheat season cannot be grown then due to high water table.

The yield of the following crops suffered when the water table depth is equal to or less than the depth indicated against each crop below (Department of Irrigation, Uttar Pradesh, 2001) -

1. Rice 0.6 m
2. Wheat 0.9 - 1.2 m
3. Sugarcane 0.9 m
4. Fodder 1 - 1.2 m
5. Cotton 1.5 - 1.8 m

Water is more valuable for a particular crop at crucial time called as "critical water" clearly mentioned in Table 1 depicting water requirement by various crops. If the water is not available at a specific time, then it becomes impossible to implant the crop. This usually happens when the rain fails to arrive on time and the canal water too is not available. Once the crop is planted, the marginal value of water decreases gradually and at certain time, it becomes zero, i.e., at the time of harvest. Thus, a situation occurs when plant require optimum water for its growth.

Table 1: Water Requirements by Various Crops

Crop	Growing Period (days)	Applied Water	Water per 100 days (cm)
Rice98	104	106	
Sunflower	110	87	79
Sugarcane	360	237	58
Cotton	200	105	53
Maize	100	44	44
Wheat	88	37	42
Linseed	88	32	36
Soyabean	110	37	34

3. STUDY AREA AND METHODOLOGY

Allahabad has a very good natural resource and is one of the most fertile plains of the Ganges, but villages selected for study in Phulpur block face severe problem of waterlogging. The study area is substantially rich in water resources and is one of the most fertile plains of the Ganges. But since the coming up of Sharda Sahayak Canal in the region, waterlogging has emerged as a problem for the past fourteen years. The surplus water from canal, rainwater during monsoon, the absence of effective drainage system and low capacity of river Varuna has all added up to contribute high level of waterlogging in the agricultural fields.

To find out the nature of the crisis, different blocks were visited and information collected on various aspects of water management. In Phulpur block, it was communicated by officials that certain villages in the block were in the grip of crisis not on account of scarcity of water but waterlogging. To make the study comprehensive and more effective, stratified random sampling technique was used to collect the primary data from the households.

In the initial stage, Phulpur block from Phulpur Tehsil was purposely selected for the case study. Three Nyaya Panchayats were selected from Phulpur block, and from each Nyaya Panchayat one-Gram Panchayat was selected. Then all revenue villages from each Gram Panchayats were selected to collect the required information with the help of a structured questionnaire. The cross sectional data was collected from all the revenue villages. The number of households were selected in proportion to the total number of households present in that particular revenue village, constituting more than 10% of the total households.

Further, secondary data was collected from district economics and statistical office, Department of Minor Irrigation, Department. of Sharda Sahayak canal system, soil conservation and soil profile office, block development office, DRDA and various officials working to facilitate the water supply in the area. The estimated investment cost of draining the river Varuna (projected by the engineers of Sharda Sahayak Khand, Phupur) was taken from the DRDA office. This study gives a technological approach in the form of the Benefit-Cost Analysis estimated on the basis of agriculture produce on one hand and investment cost of draining the river Varuna on the other. Apart from this, the study also provides an institutional approach in enhancing water productivity in agriculture. The study also suggests some self-generating activities for sustainance of livelihood.

4. PHULPUR BLOCK UNDER DIFFERENT DRAINAGE CLASS

Out of the total area 22794.3 ha, about 685.4 ha (3.0%) has been identified as the area under poorly drained class which remains submerged during monsoon period, 16993.5 ha (74.6%) area has been recognized as imperfectly drained and need proper drainage system for sustained cultivation. About 765.5 ha (3.4%) was moderately well drained and the remaining 2171.7 ha (9.5%) falls under well drained class and the rest 5% under miscellaneous use (Table 2).

Table 2: Area under different Drainage Classes

(Figures in bracket denote percentage)

Drainage Class	Area (in ha)
Poorly drained (D1)	685.4 (3.0)
Imperfectly drained (D2)	16,993.5 (74.6)
Moderately well drained (D4)	765.5 (3.4)
Well drained (D5)	2,171.7 (9.5)
Total	20,616.1 (90.5)
Miscellaneous	2,178.2 (9.5)
Grand Total	22,794.3 (100.0)

Source: Soil Survey Office, Allahabad, 2001

5. SOURCES OF IRRIGATION

The net irrigated area of district Allahabad and Phulpur block have increased with time (Table 3). Approximately 85% of the total area was net irrigated area in Phulpur block whereas, the district showed 71.31% net irrigated area for the year 2000-01.

Table 3: Irrigated Area by different Sources in Phulpur Block and Allahabad District

Sources	Phulpur Block			District Allahabad		
	1980-81	1990-91	2000-01	1980-81	1990-91	2000-01
Net irrigated area	67.06	75.14	84.86	42.83	57.47	71.31
Canal	6.56	41.19	7.26	37.96	48.70	54.93
Tubewells	80.28	53.25	85.79	52.15	45.73	42.69
Other wells	3.51	0.17	3.70	6.66	3.48	0.77
Tanks, lakes and ponds	9.65	5.36	3.26	2.44	1.07	0.87
Other sources	-	0.02	-	0.79	1.02	0.73
Total	(100.00)	(100.00)	(100.00)	(100.00)	(100.00)	(100.00)

Source: District Statistical Reports, Allahabad

The source wise analysis of irrigation in Phulpur block showed that during 1980-81, only 6.56% area was irrigated by canal and 80.28% was irrigated by tubewells. Subsequently, with the coming up of Sharda Sahayak Canal, the canal irrigated area drastically increased to 41.19% of the total net irrigated area. During the same phase, waterlogging phenomenon has reached epic proportions, threatening the agricultural productivity. It is clear from Table 3 that farmers switched to an alternate source of irrigation practices in the year 2000-01 so the canal-irrigated area further decreased to 7.26% of the total net irrigated area in Phulpur block, 86% area was irrigated by tubewells and the rest of the irrigation was carried out by lifting water from lakes, ponds and rivers.

6. SHARDA SAHAYAK CANAL IRRIGATION

Sharda Sahayak Irrigation Project provides for the diversion of water from the river Ghagra and Sharda to 14 districts in Uttar Pradesh. Phulpur block has also been covered under this project. This canal was taken off from the river Sharda at Banbasa near the foothills to command the area between the rivers Ganga and Ghagra. Sharda Sahayak Canal passed through Phulpur block in the 1990s. The unlined canal has been constructed without considering the geography and watershed of the region and without taking into account the capacity of River Varuna where the canal ends.

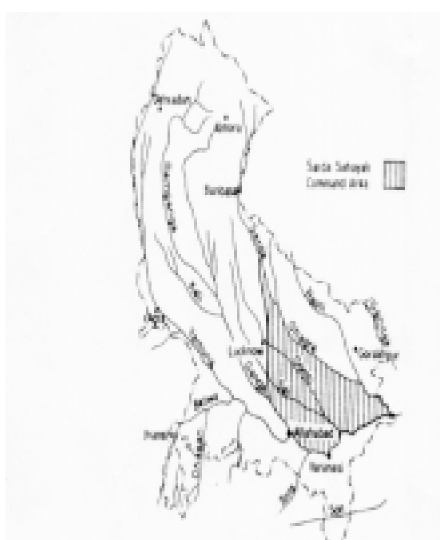

Figure 1: Sharda Sahayak Canal Command Area

The review work by Sharda Sahayak Khand 39 focuses on the major reasons behind vast water logging - Insufficient provision for drainage in the project estimate. No stress was given on construction of drains during the initial period. Drains were not dug to proper levels. Outfalls for drains were not available in Sharda Sahayak command area. No importance was given to drainage system. The drainage should have been completed from downstream to upstream. After the pressure on land increased the railway and bridges were constructed, that led to impeded drainage. Weed growth was very common in drains and needed to be eradicated from its roots. Because of continued rostering, no respite was available to crops through out Rabi from the water table rise.

7. LANDHOLDING PATTERN OF AGRICULTURAL HOUSEHOLDS

The landholding pattern also reflects the social and economic status of the society. Due to population pressure on land, average sizes of holdings have declined (Singh, 2001). Out of the total 150 households, 111 households were agricultural households. The land distribution pattern in the study area shows that approximately 29% of the agriculture households had less than 0.5 ha of land and 40% households had landholdings between 0.5 - 1.0 ha of land. This shows that around 69% landowners were marginal farmers. The small and semi-medium farmers consisted 21% and 10% respectively. The study also shows that there were no households where landholdings could be termed as large.

8. NATURE OF LAND USE IN AGRICULTURE HOUSEHOLDS

Out of the total land area (Table 4), inequitable distribution of irrigation had made almost 37% of the total agriculture fields waterlogged, getting water more than its optimum share (that includes 13% of the agriculture households which got completely submerged in water) and 2.65% was fallow land. Whereas 57.31% agricultural land was irrigated and receives optimum water for irrigation while only 3.18% land was unirrigated. The net operational area (both irrigated and non-irrigated land excluding waterlogged and fallow land accounted for 60% of the total cultivable land of the total agricultural households.

9. OCCURRENCE OF WATERLOGGING: ITS DURATION AND HEIGHT IN AGRICULTURAL FIELDS

The waterlogging in the sample area starts with the advent of the rainy season in the month of June and July. Of the total households, 80% agriculture households stated that waterlogging occurred in the month of August and September when there was high precipitation. Nevertheless, when the rostering of canal water takes place during this season for paddy cultivation, then the situation becomes worse.

The extent of waterlogging was quite high in agricultural fields where 13% agricultural households have crop fields' completely submerged in water. As far as the duration of waterlogging was concerned, 36% of the respondent opined that water remained there for 4 - 5 months a year, and an equal number of households had problem of waterlogging for 6 - 7 months in continuation, whereas 10% had fields waterlogged for 8 - 11 months and about 2% had waterlogging for the whole year. Only 5.41% agricultural households had fields where no water accumulated

The height of water in the agricultural fields reflects the intensity of crop loss due to waterlogging and its impact on productivity of the land. Out of the total land, more than 44% and 32% agricultural households had crop fields where water stagnated to a height of 6 - 7ft and 4 - 5ft respectively. Only 1% faced waterlogging of 8ft. However, about 17% of the total households had agricultural lands with low waterlogging of 0 - 3ft above the ground and 5% households did not report waterlogging in their fields.

The canal and rainwater together spoil paddy crops, which grow up to a certain height. The water remained in the field for 5 - 6 months from July-August to December- January till the critical period for sowing of wheat crop also passes (see water requirements by various crops mentioned in Table 1). Thus, there was a proportionate change in loss for both the crops.

10. ESTIMATED LOSS OF AGRICULTURAL PRODUCE

In the study villages, according to field discussions and perceptions of the farmers and household respondents, there were namely 3 types of lands- good quality (Type A), medium (Type B) and low quality lands (Type C). The average yield of wheat was 6 qtl/bigah by taking an average of each quality of land (Type A: 7.5 qtl, Type B: 6 qtl, Type C: 4.5 qtl). The average yield of paddy was 8.83 qtl/bigah (Type A: 11 qtl, Type B: 9 qtl, Type C: 6.5 qtl).

The wheat and paddy production was assigned value of Rs. 623 /qtl and 616 /qtl respectively as per the prevailing market prices for the year 2001-02 (District Statistical Handbook, Allahabad, 2002). According to the data available from the block development office Phulpur, the total waterlogged area in the Phulpur Tehsil was 2400 bigah (600 ha). The expected crop loss for wheat was Rs. 8971200 (Rs. 89.71 lac) at an average yield of 6 qtl/bigah in the total waterlogged area.

The expected crop loss for paddy crop was calculated to be Rs. 13059200 (Rs. 130.59 lac) at an average yield of 8.83 qtl/bigah in the waterlogged area. It makes upto an annual loss of Rs. 22030400 (Rs. 220.30 lac) for both wheat and paddy crops excluding the loss of other cash crops that would have been sown had there been no incidence of waterlogging.

11. TECHNOLOGICAL APPROACH: DRAINING OF RIVER VARUNA

To make the study area free from waterlogging, it becomes utmost necessary to clean river Varuna so that has a larger carrying capacity till it reaches the Ganges in Varanasi. The draining of the Mahlahan lake and other adjourning small lakes should also be carried out simultaneously. According to Table 5, the total estimated investment cost (PVCt) 'With the Project' for the draining of the river Varuna 2001-02 was worked out to be Rs. 200.98 lac, projected by the engineers of Sharda Sahayak Khand, Phulpur (Source: Project economist, District Rural Development Office, Allahabad). The investment cost includes the cost of material as well as labour in mandays.

The agricultural study has been analysed for the year 2001-02 (within the waterlogged condition) which estimated the loss of agricultural production for paddy and wheat crops that represent the case of 'Without Project'. In the framework of social benefit cost analysis, the sample villages would be considered as a project area if the draining of river Varuna would be done in future, then would represent the case of 'With the Project'. The agricultural loss, which has been estimated earlier, would then turn into incoming future benefit. Thus, it can be said that if the government would spend Rs. 200.98 lac (PVCt -estimated investment cost) on draining of the river Varuna, the benefit will accrue in terms of crop production (Rabi and Kharif), a value that is estimated to be around Rs. 220.30 lac. So the Net Present Value of Benefit (NPVBt) (for the current year of analysis) will be-

NPVBt = NPVBt of paddy + NPVBt of wheat - PVCt

= Rs. 130.59 lac + Rs. 89.71 lac – Rs. 200.98 lac

= Rs. 220.30 lac – Rs. 200.98 lac

= Rs. 19.32 lac

The present value of benefit would be Rs. 19.32 lac just for paddy and wheat crops for the current year excluding all other crops that can be sown. It is also expected that the average agricultural yield in the defined area would also increase in future in addition with increase in quantity of livestock when the area is made free from waterlogging. The future benefit will also include all the intangible social and environmental benefits

Further, if draining of the river will not be required for the next 10 years as suggested by Sharda Sahayak engineers, then agriculture production of wheat and paddy including leguminous plants, oilseeds, cash and vegetable crops that are supposed to be sown in waterlogged area will turn into future benefit for the coming 10 years.

The intangible social costs like continuous reduction of fertility of land, the health cost, transportation and shelter problem, loss of livestock, migration, and other cost suffered would subsequently turn into intangible benefits in future. The environmental cost from declining productivity of natural resources like land, water, grassland (in the form of soil degradation, water pollution and other land resources linked with water, forest etc.) and actual cost for treatment of soil erosion, salinity and alkalinity etc., would also change into intangible future benefits (Reddy and Ratna, 2003).

12. INSTITUTIONAL APPROACH TO WATER RESOURCE MANAGEMENT

Recognition of the importance of ecological water demand is relatively recent. It has been highlighted at the Dublin Conference in 1992 (a preparatory meeting for UNCED, Rio 1992), which unanimously accepted that ‘since water sustains all life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems (WMO, 1992).

The dimensions and components of a socially and ecologically responsible ways of governing water resources require a comprehensive elaboration. It is a necessity of using an integrated method for water resource management that takes the interaction among different sectors into consideration viz., the links among environment and food sectors, water and land interest, agriculture and non-agriculture sectors, upstream and downstream sectors and the like. Integrated Water Resource Management (IWRM) is a process that endorses the coordinated development of water, land and related resources.

One of the main issues is of designing the management of water among various uses and various users i.e the allocation of water among different sectors, and the allocation of water between different users of the same sector. The balance among different uses and users can be best addressed and dealt with under a political decision making mechanism that promotes participation, accountability and transparency (Adaman and Madra, 2003).

The issue of water governance should be addressed in an institutional set up and the corresponding legislation and enforcement mechanism are needed for an effective and sustainable policy (see Model- Institutional Approach in Water Resource Management). Thus, the participatory decision-making procedures and process, socially and environmentally embedded governance of water management should be enacted. The participatory approach for sustainable water management requires coordination among the governmental institutions and community institutions.

To ensure effectiveness, institutions are designed to support other existing institutions, human capabilities and available technologies. Innovation can create stronger institutions because of differences at local levels-differences ranging from social norms to environment and geography. Institutional reform is not just the preserve of a national government but also of the individual and communities, local entrepreneur, and multilateral organizations that can build institutions often in partnership with each other (WDR, 2002).

Coordination among institutions like block development functionaries, panchayati raj institutions, irrigation departments, agriculture development office, and district rural development agencies with the community Institutions is a necessity for rural development and water management. Government needs to involve user representatives in a system management and reduce its role in field level management by delegating a substantial part of the responsibility to user groups and creating incentives to induce them to assume this responsibility.

13. GOVERNMENT INSTITUTIONS AND THEIR ROLE IN WATER MANAGEMENT

13.1 Panchayati Raj Institution

According to the 73rd and 74th Constitutional Amendment Act, the panchayats, as a local self-government have been given full autonomy in deciding their priorities and also determining allocation to different programs (India Panchayati Raj Report, 2001). Gram panchayats have been assigned the responsibility to act as state tubewell and hand-pump functionaries. The gram panchayat and the kshetra panchayat have 6 subject committees, which include water management committee to execute all works. Item listed under the Eleventh

Schedule are minor irrigation, water management, watershed development, drinking water and sanitation. PRIs should utilise the fund in village-level development or make arrangements for water-related matters, which come under 6 subject committee.

Rural areas should be provided with a well developed, properly planned sewerage system, which should take care of both domestic and agricultural waste. It is proposed that a comprehensive sewerage and drainage programs be undertaken on an area wise basis after detailed study of the socio-economic conditions of the consumers site, existing land-use pattern and other incidental parameters

13.2 Agriculture and Irrigation Department

There should be water management committees at the district, block and panchayat levels involving district agriculture officer, block development officer, tehsildar, irrigation field functionaries, agriculture engineers, economists and farmers representatives. The committees will take decision on (a) Timing of canal closure for annual repair and maintenance (b) designing of suitable cropping pattern for each block within the irrigation command (c) delineating the waterlogged and high water table areas for rice and fish farming (d) avoiding mismatch between timing of water delivery and crop needs in canal command areas, and (e) laying out field channels and drains and making suitable provisions for their maintenance at the gram panchayat level.

13.2.1 Assessment of improvement in Agricultural Production as a measure of Irrigation Efficiency

The primary objective of irrigation system is to enhance agricultural production to a specified degree. However, the performance evaluation of a system is done only in terms of the area irrigated with no emphasis on quality of irrigation and its productivity. It is therefore necessary that besides the gross irrigated area, the quality of irrigation and productivity of the area is also recorded and used in the evaluation of the performance of irrigation systems.

The BDOs, agriculture department and related functionaries should be assigned the task to promote agricultural education through “Farmer Field School”. Farmers should be mobilised through these schools by transferring new agricultural technologies and providing help through documentation’s and field experiences. Promotion of “farmers interest groups” such as SHGs at the village level with a participatory approach would help in solving the water-related problems. New concept and technologies related to aquaculture, pisciculture, etc., and tolerant varieties of crops should be introduced in waterlogged areas. Irrigation projects should ensure better, timely and more equitable supply and economic use of water. Within area of operation, water users association or farmers organisation should be given powers that have so far been vested with the state irrigation departments so that the institutional base of village level associations can be strengthened.

All state irrigation acts needs to be amended to incorporate new provisions as per the formation of farmers’ bodies. Farmers must be encouraged to take responsibility for system operations, maintenance and water distribution. The District Planning Commission (DPCs) and the local governments, as required by provision of Constitution of India to plan for local areas, should work out the location specific watershed programs.

The agriculture department should install tube-wells in a waterlogged area to lower the water table and pass the pumped water to other non-waterlogged areas. Construction of private as well as state wells/tube-wells and cutting of canal supply and providing irrigation from groundwater pumped from well and tube-wells should also be undertaken further. The farmers should to be encouraged to grow water friendly plants such as water berry, sugarcane, bamboo, mushroom and eucalyptus in their fields. Cultivation of cash crops should also be encouraged.

The farm level has to be properly developed for irrigation through command area development. Open drains should be maintained and the slope of the field should be so formed, as to make the water gush quickly into the neighboring fields, and to other areas in between the fields. Small check dams and ponds should be constructed to collect excess water from the fields. The panchayats should also be made responsible to maintain the structures for water storage at village level.

Appropriate surface drainage technology needs to be evolved in integrating preventive and curative measures. Adequate research backup with appropriate cost-benefit assessment is required for the development of efficient drainage systems. These wet lands are part of our environment and suitable technological packages should be developed keeping the socio-economic condition in view.

13.3 Sharda Sahayak Canal Irrigation Department

Maintenance of irrigation systems requires periodic inspection of the facility to identify any deterioration (such as leakage in embankments, erosion, silting of canal beds, growth of weeds, malfunction of sluices etc) and execute the necessary repairs. Besides, the organisation also needs to be able to identifying major malfunctions as they rise and should have the capacity to correct them promptly.

The rostering of canal water should be done at times of need. The Sharda Sahayak Canal System should keep the records correctly pertaining to the time of sowing. When there is sufficient rainwater then supply of canal water should be stopped. Canal water needs not be supplied at the time of monsoons when the water is already available. A system should be developed to stop water so that unwanted water may be retained in the main canal itself.

Irrigation management is essentially a multi-disciplinary activity and requires multi dimensional attention. Effective and sustained linkages should be developed amongst the canal management authorities, command development authorities, agriculture extension services and the farmers. Unless there is active participation of farmers, no planning and implementation of on-farm development works would be successful. Before implementing any project, many predictions of soil behaviour under irrigation can be made. Among them more important are- Extent and location of areas suitable for irrigation; levelling of land in the command area according to geography and local topography so that each piece of land gets required water; adequate numbers of regulatory and controls structures including water measuring devices and canal escapes; crops that may be grown and yields that may be expected; uprooting of weeds as important measure for drainage improvement; addressing problems in drainage, addressing salinity and alkalinity that may arise; need for land reclamation; water delivery requirement under alternative cropping pattern and soil and water management.

Modernisation of the existing irrigation projects with selective lining in the canal distribution system and field channels should be undertaken to stop water seepage. It will also help in reducing the leakage of canal water due to which a high percentage of water is lost. The canal branches have abrupt open ends, which does not meet any natural drains. The canal escapes should be linked with big rivers and small check dams can be made in between the main branch of the canal and small branches to manipulate water according to need.

Waterlogging can be corrected by pumping and constructing adequate drainage in command area. 2 types of drains are required in the command are-

1. Open Drains- One to two meter deep open drains, which are useful in lowering the water table and in reducing sloughing of the side. These are the hollow fillings with mud.
2. Special underground drains are also useful for lowering the water table. They consist of field drains laid under the ground and are being extensively used in Egypt. These are expensive but highly efficient. Wherever the drains are constructed, the harvest gets nearly doubled (Rao, 1979).

Conjunctive use of two or more sources of irrigation in an area particularly those tapping surface and groundwater has often been recommended as a policy. This will not only augment water supply but will also lower water table. The complementary use of both surface and groundwater tends to offset each other, minimizing ecological externalities like waterlogging.

The technique of remote sensing should also be utilised as a remedial measure against waterlogging. If waterlogging is noticed at frequent intervals, it will alert irrigation and agriculture officers in charge of the project, to take suitable remedial actions in time or in advance. Thus, further deterioration due to waterlogging can be avoided or can be reduced. If the ground water wells are at shallow depth, then larger irrigation under well water should be planned.

In the canal system, for instance, it should be possible to construct small reservoirs in the command area to which water is supplied and the control over quantity and timing of water release to the users be left at the local level (Bharadwaj, 1990). The nodal centre at the Panchayat level should also have a link with the Sharda Sahayak Khand authorities so that the problem is tackled at village level.

14. WATER USER'S AGENCY THROUGH TRAINING AND APPROPRIATE LEGAL ACTS

Performance of the irrigation sector in increasing agricultural productivity in India is observed to be sub-optimal, inefficient and inequitable. It has been emphasized that the water users within a canal command at the tertiary level like minor/subminor should organise themselves and form Water Users Association (WUA), which should be formally registered. It is contemplated to delegate some responsibility to these WUAs, which include distribution of canal water among water users, operation and maintenance of the canal and collection of water rates. In accordance with the spirit of the National Water Policy (1987) of GoI, farmers should be made partners in management and distribution of water. This can be done by organising and registering farmers into "Water User Association".

The concept of system turnover to water users is grounded in laudable ideologies like democratisation, decentralisation. The farmers who are the end-users of irrigation water should participate in its management starting from planning, design and construction to operation and maintenance of the system. Farmers have sufficient knowledge about their local resources like land and water. Existing social capital, which includes local knowledge, skill, community network and kinship ties should be utilised in the management of irrigation systems. As the irrigation service is meant for the farmers and farm production, their views should be given due importance in the management of irrigation. The work responsibility ultimately goes to WUAs as it is difficult for irrigation agency to look after the individual problems of numerous farmers catering to their specific needs.

The benefit will accrue to the farmers and irrigation agencies by WUAs formation. It will lead to farmers' flexibility in the use of water and choice of the crops, optimal use of water in agriculture, ensuring equity in water allocation, resolving disputes in water distribution and more economic use of water and less wastage. On the other hand, irrigation efficiency will also increase, it will improve the relations with client farmers, the irrigation agency will face less obstructions and maintenance problems of outlets, better collection of water rates and saving on maintenance costs.

15. COMMUNITY INSTITUTIONS AND ITS ROLE IN WATER MANAGEMENT

It is said that if the common pool resources are smaller and more defined boundaries, the chance of success increases. Better the knowledge of sustainable yields, greater the chances of success. Secondly, smaller the numbers of users better the chance of success. If the users are bound by certain obligations and if the committee is homogeneous then there is greater chance of success (Wade, 1987).

State intervention and cooperative action are 2 ways of coordinating economic activity. Social cooperation plays a crucial role in process of development, by helping to translate economic prosperity into social opportunity as community activity helps in maintaining irrigation structures or civic initiatives (Dreze and Sen, ibid, 56). If environmental degradation is pervasive, the best solution is to leave the management of environmental resources to the local communities.

16. COLLECTIVE ACTIONS IN WATER MANAGEMENT

Collective action is action taken by more than one person and is directed towards the achievement of a common goal or the satisfaction of a common interest that is a goal or interest that cannot be obtained by an individual acting on his own. If the common goal or common interest is characterised by infinite benefits and non-exclusion, the achievement of that common goal or interest means that a collective good has been provided. Thus the collective action might be the formulation of a rule of restrained access to a common pool resource and observance of that rule.

Another strong movement is "Raising Voice" by the local users. Democracy should have a vital role if changes are to occur in India's environmental management, Through public discussions only the precariousness of the environmental situation can be recognized more fully. This could influence behavioral pattern and values in individuals and groups, government and local authorities. The instrumental role of democracy can determine the official policy at different levels of governance that can be influential in turning environmental concerns into an electoral issues and giving them a political significance (Dreze and Sen, 2002).

17. SELF-GENERATING ACTIVITIES FOR LIVELIHOOD SUSTENANCE

17.1 Rice Fish Farming

There is a good prospect of pisciculture and aquaculture activities in certain villages where vast land remains perennially waterlogged and village ponds are available. Training could be imparted to farmers for pisciculture and aquacultural activities. The rice-fish farming system could generate year round employment in the farm and ensure high productivity and profitability besides assuring conservation of the ecosystem. This needs to be improved through an integrated use of crop (staple rice) and fish culture technology.

17.2 Makhana-Fish Cultivation

Makhana (*Euryale Ferox Salisbury*) is known as “Gorgon Nut” or “Fox Nut” of the oldest aquatic cash crop of Muthilanchal (north Bihar). It is said that this crop has a greater potential to survive the waterlogging conditions, and also has a high nutritional value. It is easily and cheaply cultivated in suitable standing pools. The minimum level of water required is at least 2.5 - 2 m high during October-November and 0.6 - 1m during May-June for makhana cultivation. The time of sowing Makhana is usually November-December (Reddy, 2002). Air breathing fish like clarius batrachus (magur), chana punctatus (murrels), and anabus testrodinus (koi) could be combined for makhana fish cultivation for better monetary prospects.

17.3 Tree Cultivation

Remedial measures usually employed to remove waterlogging are canal lining and provision of subsoil drainage by construction of subsoil and surface drains. However, these are expensive measures. A more dynamic way of reclaiming such areas is to utilize the surplus water through afforestation by planting suitable tree samplings. If the area is planted by the trees then it is quite feasible and possible that the planted samplings would absorb the water, utilize part of it for their growth and transpire the rest in atmosphere. The trees adapted to the soil condition if planted in sufficient numbers are capable of minimising seepage in the end.

18. CREDIT MANAGEMENT FOR SELF GENERATING ACTIVITIES

The aforementioned self-generating activities in agriculture and other related fields as well as water-related problems require funds for development. This fund should be generated by the local self-governments, local institutions and users and need proper credit management. The funds generated can provide credit to the users for self generating activities like agriculture, pisciculture, aquaculture, etc on one hand and in solving water related problems on the other hand.

Strict rules and regulations should be framed to help in management decisions and monitoring use to ensure that individual users adhere to these rules. Credit provided to the users must have a legalized rate of interest and a specific time for returning the money fixed by the committee.

19. CONCLUSION

The state and local governments, irrigation and agriculture departments in coordination with the farmers and users association and self-help groups can come forward to tackle the problem of waterlogging, increase productivity and remove poverty from the region. Agriculture being the primary source of livelihood in these areas, the worst victims of this phenomenon is the landowners belonging to different categories and sharecroppers.

The cumulative population of such areas forms a good part of the total percentage. Therefore, innovative technologies to nullify the effect of waterlogging and salinity and other concomitant factors would be of significance in increasing the productivity of agriculture and contributing to decrease the effect that leads to poverty.

Private innovations, its practices and success eventually led the government to change the laws. Private innovation supported by formal institutional change may altogether strengthen institutions by directly supporting experiments, by allowing them to proceed and if tested successfully, by encouraging their growth. Openness in information sharing provides impetus to adopt and expand successful experiments. Policy makers can replicate successful innovation at other areas (WDR, 2002).

Water resource development leaders, planners and managers should be accountable to the people by working through transparent and consultative process. Water resource planning and development should be a multidisciplinary task rather than an engineering driven exercise. Successful response to water related disaster must be an activity of regular planning supported by accurate and timely information. Public debates, public hearings and water tribunals should be used to influence policies at different levels and to ensure the public accountability. Mass media and collective action should be used as a vehicle to get political commitment for integrated water resource management.

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Table 4: Distribution of Agriculture Landholdings to Total Area (in Bigah)

Villages	Waterlogged Land (1)	Fallow Land (2)	Irrigated land (3)	Unirrigated Land (4)	Net operated area (5=3+4)	Total Area (1+2+5)
Rajepur	3.50 (5.19)	3.0 (4.44)	55.0 (81.48)	6.0 (8.89)	61.0 (90.37)	67.5 (100.0)
Rajepur Sarain Arjani	13.50 (27.55)	6.50 (13.27)	29.0 (59.18)	0.0 (0.0)	29.0 (59.18)	49.0 (100.0)
Mahlahan	31.05 (41.34)	0.00 (0.00)	44.05 (58.66)	0.05 (0.07)	44.10 (58.72)	75.1 (100.0)
Rasoolpur	2.0 (20.73)	0.0 (0.0)	7.35 (76.17)	0.30 (3.11)	7.65 (79.27)	9.65 (100.0)
Chitaha	19.0 (48.72)	0.0 (0.0)	19.50 (50.0)	0.50 (1.28)	20.0 (51.28)	39.0 (100.0)
Balkaranpur	23.40 (68.02)	0.0 (0.0)	9.50 (27.62)	1.50 (4.36)	11.0 (31.98)	34.4 (100.0)
Jalaalpur	21.0 (57.53)	0.40 (1.10)	15.10 (41.37)	0.0 (0.0)	15.10 (41.37)	36.5 (100.0)
Bahmai	24.10 (38.87)	0.0 (0.0)	34.35 (55.40)	3.50 (5.65)	37.85 (61.05)	62.0 (100.0)
Total	137.55 (36.86)	9.9 (2.65)	213.85 (57.31)	11.85 (3.17)	225.70 (60.49)	373.15 (100.0)

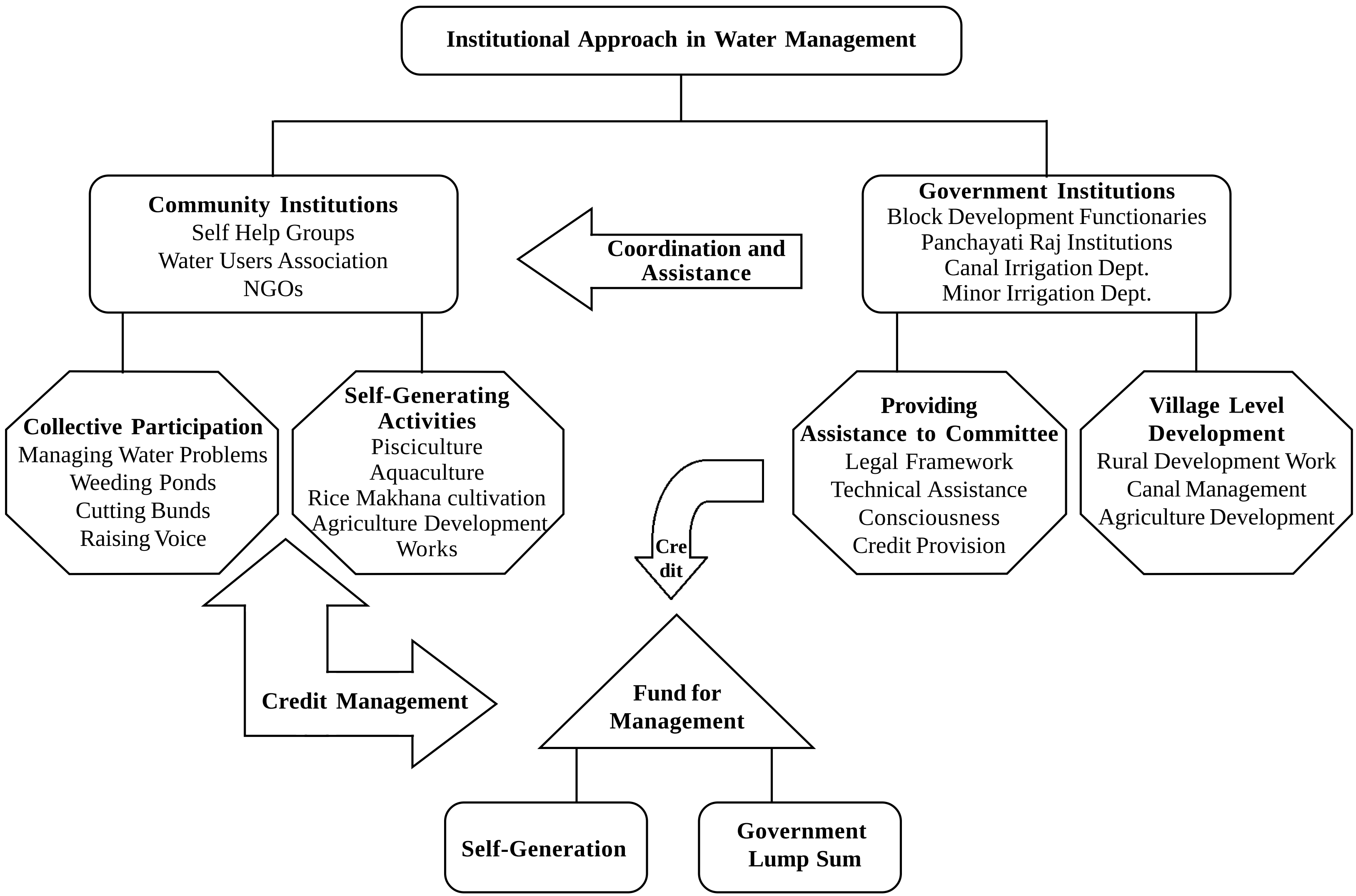
Source: Field Survey (Figures in bracket denote percentage)

Note: 1ha = 4 Bigah
Net Operated Area = Total Area - Waterlogged Land - Fallow Land

Table 5: Estimated Investment Cost of Draining River Varuna for the year 2001-02

Total Length of the River	Work for Removing Silt		Masonry Work			Ratio of Material and Labour	Total Estimated Cost (in lac)	Total Estimated Mandays (in number)	Demand of Money for Year 2000-01 (in lac)
	length (in km)	Cost (in lac)	Cost of Material (in lac)	Labour Cost (in lac)	Total (in lac)				
196.0 to 189.0	7.0	22.61	1.60	0.710	2.31	10:90	24.92	16,500	24.92
189.0 to 178.0	11.0	24.24	0.48	0.26	0.74	40:60	24.98	20,000	24.88
178.0 to 169.0	9.0	22.73	0.65	0.45	1.1	40:60	23.83	20,000	23.83
169.0 to 165.0	4.0	20.34	-	-	-	40:60	20.34	1500	20.34
165.0 to 162.0	3.0	19.20	-	-	-	40:60	19.20	1400	19.20
162.0 to 160.50	1.50	13.60	-	-	-	40:60	13.60	1000	13.60
160.50 to 158.0	2.50	24.60	-	-	-	40:60	24.60	1700	19.49
158.0 to 155.50	2.50	24.78	-	-	-	40:60	24.78	1800	24.78
155.50 to 153.0	2.50	24.73	-	-	-	40:60	24.73	1750	24.73
196.0 to 153.0	43	196.83	2.73	1.42	4.15		200.98	65,650	195.77

Source: District Rural Development Office, Allahabad



Model- Institutional Approach in Water Resource Management

WATER PRODUCTIVITY IN AGRICULTURE- A REVIEW OF EMPIRICAL EVIDENCE FOR SELECTED ASIAN COUNTRIES AND INDIA

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Abstract

In the context of the growing demand for water and the emerging water crisis, this paper examines the prospects for improving water use efficiency in agriculture that will help water savings and also increase crop yields per unit of water input. Evidences from experimental or farmer participatory trials in a cross section of regions, countries, sites in Asia and the Indo-Gangetic plains suggest that alternate agronomic and crop management practices such as zero-tillage, bed planting, non-puddled rice culture and laser leveling can result in water savings and also improve rice and wheat yields per unit of water input.

1. INTRODUCTION

Although water seems to be the most abundant resource available on the earth, it is paradoxical that governments, international organizations and policy makers are talking of an emerging water crisis. This paradox can partly be explained by the fact that although water is seemingly so plentiful, of the world's water resources about 97.5% is salty and hence unfit for human consumption and crop production (Saleth and Dinar, 2004). Of the remaining water resources which constitutes fresh water resources most of it, i.e., an estimated 35 km^3 per year, cannot be fully accessed since most of it is locked either in the ice cover of the Artic or Antarctic regions, or in deep underground aquifers (Saleth and Dinar, 2004). The physically accessible freshwater potential of the world is estimated at only 90,000 km^3 per year or just 0.26% of global freshwater resources (Saleth and Dinar, 2004). However, even of the physically accessible freshwater resources only about 12,500 m^3 can be accessed under present economic and technical conditions (FAO; 1996, Saleth and Dinar, 2004). In relative terms, however, water resources or water availability or water withdrawals show wide variations across countries, regions and sites. For instance, the per capita annual water withdrawals during 2003 ranged from 10 m^3/person in Congo D.R. to 1607 m^3/person in Canada (www.wri.org, 2005). For Asian countries these figures ranged between 60 m^3/person for Cambodia to 1451 m^3/person in Nepal (www.wri.org, 2005). Owing to increasing population, incomes, and economic growth, extension and intensification of agriculture, rapid urbanization and industrialization, demand for water is expanding fast putting great strain on the available water resources and on global, regional, national and local economies. Added to that climatic-induced variations in the level and spatial pattern of global temperature and precipitation are going to further affect utilization of the accessible freshwater resources (Saleth and Dinar, 2004). In fact, water is turning out to be the most important constraint for sustaining human life and economic activity, and in the days to come the water crisis, as it is popularly referred to, is going to be the most important factor impeding and sustaining economic growth.

What is more disturbing is that it is the developing countries especially in Africa and Asia struggling to increase their living standards that are going to be hit the hardest by the emerging water crisis. By the year 2025 it is estimated that about 2 billion people will live in countries or regions with absolute water scarcity. Most countries in the Middle East and North Africa are presently classified as having absolute water scarcity (www.iwmi.org, 2005). By 2025 these countries will be joined by Pakistan, South Africa and large parts of India and China (www.iwmi.org, 2005). It is reported that many countries especially in the Middle East are

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nearing or exceeding their renewable water supply limit (Gleick, 1993; Saleth and Dinar, 2004). Fifty-five countries in Africa and Asia are unable to meet the basic water needs of their growing population. It is noted that about 2.2 billion people in the world especially in developing countries do not have access to clean water and about 2.7 billion people do not have access to sanitation services (Gleick, 1998; Saleth and Dinar, 2004). Poor access to safe water and sanitation also leads to high health and economic costs due to water borne diseases such as diarrhea, typhoid, gastro-enteritis, malaria, and water pollution.

Against the background of the global water scenario, this study seeks to assess the prospects and constraints for sustainable use and management of water resources. This study, therefore, seeks to focus attention on an important aspect i.e. water productivity which has a bearing on sustainable use and management of water resources.

2. OBJECTIVES

The specific objective of this paper is to analyse water productivity in agriculture across countries, regions or sites and crops in selected Asian countries and India.

3. DATA AND APPROACH

The study is based on secondary data and sources of information drawn from official publications, research reports and journal articles. The data analysed here are drawn from experimental trials or farmer participatory trials conducted in a cross section of countries and regions in Asia and India between 1998-2002. Dose-response method or with and without treatment approach have been used to assess the impact of different treatments, technologies or crop practices on water productivity of crops, and water savings. The analysis covers rice and wheat, which are the two important staples in Asia and the Indian sub-continent and account for a major share of irrigation water use. In fact more than 80% of the developed freshwater resources in Asia are used for irrigation purposes, and about half of the total irrigation water is used for rice production alone (Bhuiyan, 1992; Guerra et al., 1998). However, while comparing the estimates of crop water productivity across regions and countries in Asia and India, one must not lose sight of the fact that rice and wheat are grown under diverse agro-climate situations and environments in Asia and India.

4. WATER PRODUCTIVITY

Agriculture and especially the irrigation sector accounts for bulk of the water consumption in most regions, and more so in Asia. For instance, agriculture's share in annual freshwater withdrawals for the world as a whole is about 71%, as compared to 9% for domestic and 20% for industrial sectors. In most Asian countries, agriculture's share in annual freshwater withdrawals exceeds 70 – 90%; in fact in most South and Southeast Asian countries agriculture's share exceeds 90%. However, with growing water scarcities and growing competition for available water from the domestic, industrial and environmental sectors as well as the prohibitive costs of future irrigation investments, economizing on water use and improving water use efficiency especially in agriculture, assumes importance. In this context, improving crop yields per unit of water input and reducing water losses need attention.

Rice, which is the staple food for nearly half of the world's population especially in Asia, is a heavily irrigated crop. More than 90% of the world's rice is produced and consumed in Asia (Barker and Herdt, 1985; vide Guerra et al., 1998). In fact, more than 80% of the developed freshwater resources in Asia are used for irrigation purposes and about half of the total irrigation water is used for rice production (Bhuiyan; 1992:vide Guerra et al., 1998). The abundant water environment in which rice grows best differentiates it from other important crops (Guerra et al., 1998). However, with water becoming increasingly scarce and with agriculture's share of water projected to decline faster because of increasing competition for available water from the urban, industrial and environmental sectors, economizing on water use in agricultural production is an important objective. For instance, it is noted that in many Asian countries, per capita availability of freshwater declined by

40-60% between 1955 and 1990 and is expected to decline further by 15-54% over the next 35 years (Gleick, 1993; Bouman and Toung, 2000). Rice being a water intensive crop, it is believed that there is tremendous scope to economise on water use in rice production and thereby improve water use efficiency and water productivity. Consequently, many resources are being invested on research to find ways for improving water use efficiency and water productivity in agriculture especially of water intensive crops like rice.

Before discussing crop water productivity, we briefly deal with the issue of irrigation efficiency in general. Irrigation efficiency is generally defined as the ratio of the amount of water that is required for an intended purpose divided by the total amount of water diverted to a spatial domain of interest (Guerra et al., 1998). The domain may refer to a farm, system or basin level. Overall irrigation efficiency of an irrigation system is defined as the ratio of water used by the crop to water released at the headworks. It can be sub-divided into conveyance efficiency, field channel efficiency and field application efficiency. Water losses could occur at different levels, i.e, at the farm, irrigation system or basin level. Reducing water losses at each stage and overall water loss is an important goal for saving water and improving water use efficiency. Table 1 gives an idea of the overall irrigation efficiency of selected irrigation systems in some Asian countries. It is interesting to note that the overall irrigation efficiency of the irrigation systems in four countries under review show large variations. These range from around 30-38% in India to 40-65% in Indonesia. In Thailand for the irrigation system under review the irrigation efficiency for wet season was 37-46% and between 40-62% for dry season. If these figures could be taken as indicative of the level of water use efficiency of irrigation systems in Asia it suggests that there is tremendous scope to cut down water losses and improve water use efficiency in irrigated agriculture.

Table 1: Overall Irrigation Efficiency of Selected Irrigation System in Some Asian Countries

Country/Irrigation System	Overall Irrigation Efficiency%	Remark	Source
Indonesia	40-65		Hutasoit, 1991
Malaysia - Kerian Irrigation System	35-45	Command area = 23,560 ha	
Thailand - Northern, Maeklong Chao Phraya, >12800 ha	37-46 40-62	Irrigable area >12,800 ha Wet season Dry season	Khao-Uppatun, 1992
India - Canal system, north India - Tungabhadra Irrigation System, Karnataka State	38 30		Ali, 1983 Bos and Wolters, 1991

Source: Guerra et al., 1998

Note: Overall Irrigation Efficiency of an irrigation system is defined as the ratio of water used by the crop to water released at the headworks. It can be subdivided into conveyance efficiency, field channel efficiency and field application efficiency.

Rice, as mentioned earlier, is a heavily irrigated crop. Rice grown under traditional practices in medium to heavy textured soils in the Asian tropics and subtropics requires between 700 to 1500 mm of water (Bhuiyan, 1992; Guerra et al., 1998). This consists of: (1) land preparation requirement of 150 to 250 mm, (2) water requirement of about 50 mm for growing rice seedlings in the nursery or seedbed before transplanting, and (3) water need of between 500 to 1200 mm (5-12 mm per day for 100 days) to meet the evapotranspiration (ET) demand and unavoidable seepage and percolation in maintaining a saturated root zone during the crop growth period (Guerra et al., 1998). The actual amount of water used by farmers for land preparation is often several times higher than the typical requirement of 150-250 mm. For instance, in the Ganges-Kobadak irrigation project in Bangladesh it is reported that farmers used as high as 1500 mm for land preparation (Ghani et al., 1989; Guerra et al., 1998). This may be due to the need for land soaking to maintain a wet soil condition to facilitate plowing, harrowing, puddling, and land leveling so that rice seedlings can be easily transplanted (Guerra et al., 1998). In evaluating water productivity one needs to take care of the following. Crops require water to satisfy their evapotranspiration (ET) needs. Further during crop growth, the amount of water applied to the field is often much more than the actual field requirement. This leads to high surface runoffs. In fact, Seepage and Percolation (S&P) losses are considerable, and according to one estimate, S&P accounts for 50-80% of the total water input in the field (Sharma, 1989; Guerra et al., 1998). Reducing the amount of S&P losses would help in improving farm water efficiency. It may, however, be noted that water lost at the farm level may seep downstream and be recovered for crop use and hence doesn’t constitute a loss for the irrigation system. Similarly, water loss at the irrigation system level may not contribute to losses at the water basin level. These need to be taken note of while discussing about improving water use efficiency and reducing water losses. Further one also needs to take note of the fact that policies for improving water use efficiency and water productivity cannot be considered in isolation from other factors that contribute to crop yield improvements such as better crop varieties and agronomic practices, crop duration etc. The concept of water productivity, therefore, needs to be clearly specified. For instance, there are number of water productivity concepts such as irrigation water productivity, basin water productivity, transpiration water productivity, etc. (cited in Bessembinder et al., 2005). However, a simple definition is to consider the amount of food or crop yield produced per unit volume of water used. Here it is also important to specify the water use components taken into account while assessing water productivity such as evapotranspiration, seepage and percolation, drainage during land preparation and crop growth period, as noted earlier.

Keeping in view the above points, we may examine Table 2 which presents the on farm water productivity of rice for three Asian Countries when different components of water inputs are taken into account. These water components are Evapotranspiration (ET), Seepage and Percolation (S&P), and Land Preparation Requirement (LPR). The table shows that rice yields per unit ET varies from 1.61 kg/m^3 of water use in Philippines to around 0.88-0.89 kg/m^3 in Malaysia and India. When other water components (i.e., S&P and LPR) are taken into account, the rice productivity declines from 1.61 to 0.39 kg/m^3 of water used in Philippines; similarly from 0.88 to 0.33 kg/m^3 of water used in Malaysia. The water use efficiency, i.e., the ratio of ET to water input, shows wide variations for the countries under review. For instance, if the water components ET, S&P and LPR are taken into account, the water use efficiency ratios for rice range from 0.22-0.24 in Philippines to 0.35-0.61 in Malaysia. This shows that the on farm water productivity of rice varies considerably across the three Asian countries under review. However, in making such inter country comparisons and drawing possible policy inferences one should not lose sight of the fact that local level conditions under which rice is grown in the different countries vary. For instance, East Asian systems including in China have a much higher degree of management and control than those in South and Southeast Asia, and rice cultivation practices are markedly different even within the same region (Guerra et al., 1998).

Bouman and Toung (2000) report the results of experimental trials in two contrasting rice growing areas, one in the sub tropics of Central Northern India and the other in the tropics of the Philippines. The data set pertains to the period 1966 to 1997, and covers a wide range of experimental conditions in terms of

Table 2: On-Farm Water Productivity of Rice in kg. per m^3 of Water used when different components of water inputs are taken into account

Location	Rice Description	Water Productivity of Rice with respect to			Source
		ET	ET+S&P	ET+S&P+LPR	
Philippines	West seeded Rice	1.61	0.68 (0.42)	0.39 (0.24)	Bhuiyan et.al., 1995
Philippines	Transplanted Rice	1.39	0.48 (0.35)	0.29 (0.22)	Bhuiyan et.al., 1995
India	-	1.10	0.45 (0.41)	-	Sandhu et al., 1980
Malaysia	Dry season	0.95	0.66 (0.69)	0.58 (0.61)	Kitamura., 1990
Malaysia	Wet season	0.88	0.48 (0.50)	0.33 (0.35)	Kitamura., 1990
India	Continuous flooding	0.89	0.34 (0.36)	-	Mishra et al., 1990
India	Alternate wet and dry	0.89	0.37 (0.42)	-	Mishra et al., 1990

Source: Guerra et al, 1998

Notes: 1. ET – Evapotranspiration; S&P – Seepage and Percolation; LPR – Land Preparation Requirement.

2. Figures in parenthesis are water use efficiency ratios, i.e., ratio of ET to water input.

environment (from pots in greenhouses to on-farm fields), rice variety, soil type, hydrology and climatic conditions. The experiments and treatments had two components, one to study the drought effects on rice and the other on the water saving effects on rice yields. Most of the experiments used transplanted rice, while some used direct seeded rice and others both transplanted and direct seeded rice. The water saving experiments included treatments with just saturated soil either continuously or during part of the growing season and alternate wetting/drying treatments. The latter were treatments where irrigation was given only for certain number of days after ponded water had infiltrated into the soil or after a certain level of soil water potential in the root zone was reached, or after symptoms of soil cracking at appeared. The relationship between water savings and yield reductions were quantified using data of all experiments reporting water input and yield. Since the experiments spanned a wide range of conditions, yield levels and water inputs were not comparable and hence the study used relative yields and relative water scarcities that were calculated by normalizing the yields/ water inputs obtained in the drought or water saving treatments to the yield/water inputs obtained in the reference treatment (in percentage). The reference treatment consisted of continuously ponded water of 5-10 cm depth, which is generally considered as the optimum depth for rice growth. While yield was assessed in terms of rough grain yield, water input was assessed as the sum of effective rainfall and irrigation applications from transplanting to harvest, or from sowing to harvest in the case of direct seeding. The vegetative stage of growth was defined as the period from sowing to panicle initiation, and the reproduction stage from panicle initiation to harvest. The study notes that in 93% of the cases water input reduced compared with the continuous 5-10 cm ponded water treatments. The study notes that water productivity i.e. grain yield over water input increased with water savings from the standard practice of continuous 5-10 cm ponded water. Water saving irrigation treatments that continuously kept the soil just at saturation, or allowed for only one day soil drying before re-applying a shallow layer of water were effective in reducing water input while maintaining high yield levels of 33 treatments, the mean water savings were 23% whereas yield reduction was only 6%. The study notes that typically water productivity was 0.2-0.4 g. grain per kg water in India and 0.3-1.1 g. grain per kg water in the Philippines. The relatively higher water productivities in the Philippines as compared to that in India is attributed to the higher yield levels and lower S&P rates of the soils. The study also examined the water productivity water input relationship from all experiments. The study notes that the Indian field data reported the highest water inputs, roughly 500-3000 mm, with the lowest water productivities of 0.1-0.6 g. grain per kg water whereas for the Philippines field experiments water inputs were comparatively lower 300-1500 mm and water productivities higher at 0.3-1.4 g. grain per kg water. There were, of course, exceptions with high water productivities of 1.6-1.9 g. grain per kg water with low water input. The study notes that reducing water input from continuous ponded water levels increases water productivity, up to a maximum of 1.9 g. grain per kg water. However, when ponded water depths drop to zero or when soil water potentials in the root zone become negative, yields (i.e., land productivity) get reduced. The overall conclusion of the study is that the most promising option to save water and increase water productivity without decreasing land productivity too much is by reducing the ponded water depth from 5-10 cm to the level of soil saturation. Water savings were on average 23% (+ or – 14%) whereas yield reductions were only 6% (+ or – 6%). The adoption of such techniques will have implications for irrigation systems because water delivery to the field needs to be very accurate and timely. Farmers operating pumps would likely benefit most from this water-saving irrigation technique. However, most Asian farmers in public irrigation systems have little incentive to reduce water input to their fields since irrigation water is mostly charged on area basis. Volumetric based charging of irrigation may induce farmers to economise and optimize on water use. Although water savings may reduce yields, the water so saved could be used to irrigate more area, which can help increase total rice output.

Alternate agronomic and crop management practices such as zero-tillage, bed planting, non-puddled rice culture and laser leveling are advocated to reduce costs and water use in crop farming and as well as improves productivity (Gupta et al., 2002; Hobbs and Gupta; 2002). For instance, in the Indo-Gangetic Plains where rice-wheat cropping system is predominant, wheat is usually sown after rice. Traditional land preparation practices for wheat after rice in this region involve as many as 12 tractor passes. But, under zero-tillage system farmer sow wheat in a single tractor operation after the rice harvest, planting the seed directly in the rice stubble (CIMMYT, 2002). The practice reportedly saves 75% of more fuel, obtains better yields, uses about half the herbicide, and requires at least 10% less water (CIMMYT, 2002). Because zero-tillage takes immediate advantage of residual moisture from the previous rice crop, as well as cuts down on subsequent irrigation requirements, it results in considerable water savings. An estimate suggests that changing to a zero-tillage system on one ha of land, besides saving 60 lt of diesel, saves approximately one million lt of irrigation water (CIMMYT, 2002). This also has significant environmental benefits by reducing carbon dioxide (CO_2) missions. For instance, using a conversion factor of 2.6 kg of carbon dioxide per liter of diesel burned, this represents about a quarter ton less emissions of carbon dioxide per ha which is the major contributor to global warming (CIMMYT, 2002). If zero-tillage system is widely adopted in the rice-wheat system of the Indo-Gangetic Plains, it is estimated that if just 5 out of the 12 million ha adopts zero-tillage, it will result in annual diesel savings of nearly 0.3 billion lt equivalent to a reduction of nearly 800,000 tons in CO_2 emissions each year as well as increase water availability and efficiency in the rice-wheat cropping system in the Indo-Gangetic Plains. Farmers adopting zero-tillage save around USD 65/ha in production costs (CIMMYT, 2002). The area under zero-tillage wheat in India and Pakistan which was estimated at around 3000 ha in 1998-99 is expected to increase to 0.3 million ha by 2001-02 (CIMMYT, 2002). Bed planting is another technique promoted to raise crop productivity and reduce farming costs and inputs. Bed planting is becoming popular in wheat cultivation in India and Pakistan, and being tried in rice cultivation as well. It is reported that planting wheat on raised beds improves yields, increases fertilizer use efficiency, reduces costs and inputs such as herbicides, seeds and water (average 30% water savings) and reduces production costs by 25-35% (CIMMYT, 2002). All the above resource conserving technologies like bed planting, zero tillage, non-puddled rice culture etc., when combined with leveled fields help improve water use efficiency (Hobbs and Gupta, 2002).

These technologies are being tried in the Indo-Gangetic Plains spread across five countries i.e., India, Pakistan, Nepal and Bangladesh in South Asia, by a consortium, which includes CIMMYT, IRRI and other national research organizations. The predominant cropping system in the Indo-Gangetic Plains is rice and wheat, as stated earlier. However, the cropping practices vary across this wide expanse. For instance, while in the northwest region rice is mostly irrigated, in eastern India rice is mostly raised as a rain fed crop. The two crops have contrasting requirements. The total water requirement for wheat varies from 238 mm to 400 mm and for rice from 1144 mm to 1560 mm across different locations in the Indo-Gangetic Plains (Gupta et al., 2002). While rice is commonly transplanted into puddled soils and gets the benefit of continued submergence, wheat is grown in upland well drained soils having good tilth (Gupta et al., 2002). Transplanting rice seedlings into puddled soils is an age old practice and helps to reduce water percolation and control weeds (Gupta et al., 2002). However, puddling degrades the soil and affects the soil conditions for the establishment of the next crop, which is usually wheat in this region. With a view to get a better wheat crop, farmers in the region generally do 6-8 preparatory plowings in rice drying soils to achieve good seed bed (Gupta et al., 2002). However, excessive tillage results in late planting and reduced yields of wheat. Since rice is the major water user, saving water use in rice cultivation is a major goal. Non-puddled rice cultivation is therefore, advocated. Evidences from India suggest that a 3 day drainage period in rice cultivation can effect a minimum of 40% saving in water with marginal decline in rice yields. Table 3, which presents the relevant data shows that water savings across different states in the Indo-Gangetic Plains in India varied from 40 - 54%. In Ludhiana, Punjab, the irrigation requirement after a 5 day drainage period was around 96 cm , as against 190 cm per ha under continuous submergence scenario. The corresponding rice yields were 5.2 and 5.5 ton/ha respectively. Although there is some reduction in rice yields, the water so saved could be diverted to bring more area under cultivation, which will help increase total rice (or agricultural) output. This can improve food security and meet the expanding food needs due to increasing population and incomes. Zero-tillage also helps in water savings, as stated earlier. Zero-tillage is possible after harvesting rice where the residual moisture is available for wheat germination. In many instances, where wheat planting is delayed after harvesting rice, farmers have to pre-irrigate their fields before planting. Zero-tillage saves this irrigation. Further, water advances quicker in untilled soil than in tilled soil, which helps save water (Gupta et al., 2002). Because zero-till wheat takes immediate advantage of the residual moisture from the previous rice crop, as well as cuts down on subsequent irrigation, water use reduced by about 10 cm per ha or approximately 1 mil lt per ha (Gupta et al., 2002). Further, there is less risk of water logging and yellowing of the wheat plants after the first irrigation, which is common on normal ploughed land (Gupta et al., 2002).

Table 3: Effect of Intermittent Irrigation on Rice Yield and Irrigation Water Requirement at Various Locations in the Indo-Gangetic Plains

Location	Soil Type	Yield (t/ha)				Saving in Irrigation Water ***
		Continuous Submergence	Irrigation after Drainage Period*			
			1 day	3 day	5 day	
Pusa (Bihar)	Sandy loam	3.6 (81)	3.5 (60)	3.3 (46)	2.9 (35)	43
Madhepura (Bihar)**	Sandy loam	4.0 (35)	-	4.0 (16)	4.0 (11)	54
Faizabad (UP)	Silt loam	3.8 (65)	2.9 (42)	-	-	-
Pantnagar (UP)	Silt loam	8.1 (121)	7.6 (112)	7.4 (90)	6.9 (60)	44
Ludhiana (Punjab)	Sandy loam	5.5 (190)	5.4 (145)	5.1 (113)	5.2 (96)	40
Hissar (Haryana)	Sandy loam	5.7 (220)	5.2 (196)	4.7 (126)	-	43
Kota (Rajasthan)	Clay loam	5.4 (145)	5.3 (86)	5.1 (68)	-	53

Source: Chaudhary, 1997 vide, Gupta et.al., 2002

Note: * - Drainage period in days after disappearance of ponded water

** - High water table condition

*** - With 3 day drainage vs.continuous submergence

Figures in parenthesis show irrigation water requirement (cm)

Table 4 presents data on wheat yields under zero-till technologies in farmer participatory trials in India. As evident, the water savings realized range between 26% to over 35% for zero-tilled wheat as compared to conventionally tilled wheat. The wheat yields are also conspicuously higher in zero-tilled wheat ranging between 5780 to 6500 kg/ha as compared to 5190 kg/ha in the case of conventionally tilled wheat.

Table 4: Wheat Yield with Zero-Till Technologies in Farmer Participatory Trials

Item	Paired Planting*	Controlled Traffic**	ZT	FP-CT
Water Saving (%)	26.2	30.8	35.4	@
Yield (kg/ha)	6500	5800	5780	5190

Source: Gupta et.al., 2002

Notes: * - Spacing between set rows (14 cm); and between paired sets (25 cm)
** - One row behind each tractor tyre not sown
@ - Compared with conventional tilled wheat planted a week later

Information about the effects of crop residues on zero-tilled wheat yields and savings in irrigation time in farmer participatory trials in Ghaziabad and Meerut districts in Uttar Pradesh State in India are presented in Table 5.

Table 5: Effects of Crop Residues on Yield of Zero-Till (ZT) planted Wheat and Saving in Irrigation Time in Farmer Participatory Trials in Ghaziabad and Meerut districts in Uttar Pradesh, India

Treatment	No. of Plants/m^2	No. of Weeds/m^2	Total Irrigation Time (hrs)	Grain Yield kgs/ha
Manually harvested Rice followed by ZT wheat	133	30	43.4(31.8)	5650
Partial Residue burning followed by ZT wheat	132	30	46.2 (27.4)	5780
ZT planted wheat in combine harvested rice, mulched with shrub master	129	21	40.3 (36.7)	6000
Farmer Field Practices Convental Tilled	117	54	63.6	52.0

Source: Gupta et.al., 2002

Note: Figures in parenthesis are percent saving in water in terms of irrigation time in relation to farmers practices

As evident, not only there is considerable saving in irrigation time for zero-tilled wheat compared to conventionally tilled wheat, but also wheat yields under zero-till situation are conspicuously higher (5650 to 6000 kg/ha) as compared to wheat yields under conventionally tilled situation (5200 kg/ha). A comparison of zero-tilled and conventionally tilled (farmers' practice) wheat yields after rice crop in Pakistan Punjab at different locations, where the planting dates for the two methods differ, indicates that on average wheat yields under zero-till at 3677 kg/ha are conspicuously higher than under farmers' practice at 2598 kg/ha (see Table 6).

Table 6: Wheat Yields after Rice in Zero-Tillage and Farmers' Practice Situations in Punjab, Pakistan at locations where the planting dates for the two methods differ

Locations	Wheat Yield (kg/ha)		Days Difference
	Zero-Tillage	Farmers' Practice	
Daska, Site 2	3143	3209	10
Daska, Site 2	3842	2735	13
Ahmed Nagar	4308	3526	20
Maujianwala	2689	2198	22
Mundir Sharif	4245	2660	33
Daska, Site 3	3838	3420	44
Average	3677	2598	24

Source: Aslam et.al., 1993 vide Hobbs and Gupta, 2002

Table 7 also presents evidence on the effect of different tillage options such as direct seeded rice on beds, transplanted rice on beds, zero-tilled rice on flat, conventionally tilled rice fields etc., on rice grain yields. The table shows that in general other tillage options result in water savings and better rice grain yields as compared to conventionally tilled rice. Bed planting is another resource conserving technology that is being tried. Evidences from India suggest that farmers report 30-45% water savings during the wheat season and still higher during the rice growing season (Gupta et al., 2002, Hobbs and Gupta, 2002). Farmers indicated that it is easier to irrigate with bed planting. When beds are kept submerged for the first few weeks and irrigation supply

Table 7 : Effect of Tillage options on total irrigation time, yield attruibutes and grain yields of rice.

Tillage option	Total Experi-mental Area in ha	No. of plants m^2	Tillage/ Plant	Total Irrigation Time Hrs/ha	Produc-tion Tillers/ Plant	Spike Length cm	Grains/ Panicle	Grain Yield Mg per ha
Directed seeded Rice on beds+	14(22)*	34	24	152.5 (39.0)	15	22.6	165	50.2+
Transplanted Rice on beds	12(20)*	35	24	146.0 (41.5)	19	23.4	173	56.2
Zero-Tilled Rice on Flat	12(10)	56	16	205.0 (17.8)	13	21.9	163	56.9
Reduced Tilled Transplanted Rice on Flats	1.6(7)	32	13	216.3 (13.3)	13	22.6	169	51.9
Conventional Tillage	14(35)	27	16	249.5	12	21.5	163	52.9

Source: Gupta et.al., 2002

Notes:
1. * Figures in parenthesis in Column 2 (i.e., Total experimental area) are the number of farmers participating in the trials.
2. Figures in parenthesis in Column 5 (i.e, Total irrigation time) are the percent saving in water in terms of irrigation time in relation to farmers practices.
3. + - Reduced yields due to severe iron chlorosis in initial crop growth stages and 8 missing beds per ha due to farmer experience

frequency is reduced later, the farmers were able to save around 30% water as well as overcome weed and iron chlorosis problems associated with bed planting systems (Gupta et al., 2002). Another study notes that raised bed planting system gives rise to other problems such as the stability of bed slopes getting eroded due to rainfall and irrigation, transplanting on raised beds being disadvantageous as it requires higher man-days than flat lands, uneven beds leading to non-uniform plants along the bed, and weed problem (especially grass), since the bed is often under aerobic conditions (Cabangon et al., 2002).

Another study analysed the effect of different sowing methods i.e., laser leveling, zero tillage and bed planting as compared to normal planting on water savings, wheat yields and water productivity in Mona Project in Pakistan (Table 8). All sowing options leads to considerable water savings, higher wheat yields (4.1 - 4.8 ton/ ha as against 4 ton/ha in the case of normal planting) and water productivity (i.e. 1.4 - 1.8 kg/m^3 as against just 1.1kg/m^3 in the case of normal planting). The average water saved with laser leveling, zero tillage and bed

Table 8: Wheat Yields and Irrigation Water Productivity under Alternative Resource Conserving Technologies in Mona Project, Pakistan

Item	Laser Levelling	Zero Tillage	Bed Planting	Normal Planting
Water applied (m^3/ha)	2849	2933	2281	3610
Yield (t/ha)	4764	4188	4134	3968
Water Productivity (kg/m^3)	1.67	1.43	1.81	1.10

Source: Gill et.al., 2000 vide Hobbs and Gupta, 2002

planting over the traditional method was 715, 689 and 1329 m^3 per ha valued at Rs 522, 503 and 907per ha based on a water rate of Rs. 900/acre-foot for private tubewells for the year 1999-2000 (Hobbs and Gupta, 2002). Timely planting of rice also benefits the succeeding wheat crop by improving yields and water efficiency. Evidences from Eastern India, for instance, show that timely planting of rice improves wheat yields. Rice wheat system productivity in farmer participatory trials was nearly 12-13 ton/ha when rice was transplanted before June 28; this was reduced by more than 40% to 6-7ton/ha when fields were planted after August 15 (Hobbs and Gupta, 2002).

While the above discussion focuses on ways of improving water use efficiency and productivity in irrigated agriculture, problems of rainfed agriculture and less endowed or fragile regions cannot be overlooked. With prospects for bringing more area under irrigation being limited and the prohibitive costs of future irrigation investment, attention also needs to be focused on improving crop yields and water use efficiency and productivity in arid, semi arid and fragile regions. Managing water in agriculture should not exclusively focus on improving the productivity of the 2500 km^2 of water diverted to irrigation, but must also include improving the productivity of the 16,000 km^2 used in rainfed agriculture (IWMI, 2003). Rainfed agriculture contributes to about 60% of cereal production on 70% of the global cereal area (IWMI, 2003). For these areas, research needs to be focused on evolving crop varieties and technologies that can tolerate droughts and moisture stress as well as thrive on low-quality water (IWMI, 2003). Reducing land degradation, supplemental irrigation combined with on-farm water harvesting practices such as mulching or bunding can reduce vulnerability to drought and help farmers to get the most out of the scarce resources. Mitigating the effects of short term drought is a key step in achieving higher yields and water productivity in rainfed areas (IWMI, 2003). In fact, deficit irrigation a strategy, which maximizes the productivity of water by allowing crops to sustain some degree of water deficit and yield reduction is being advocated for water stressed areas (IWMI, 2003). Various forms of precision irrigation such as sprinkler, drip irrigation systems and dead-level basins can increase yields over good but ordinary irrigation systems by 20-70%, depending on the crop and other conditions (IWMI, 2003). The use of drip irrigation for sugar cultivation is picking up in Maharashtra. The potential of drip irrigation for rice (especially ratoon rice or upland rice) and wheat cultivation in economizing water use as well as increasing incomes needs to be probed. Water reuse or recycling is also becoming an integral part of water management in water scarce areas. For instance, in the Indo-Gangetic plains many farmers employ shallow tubewells to recycle the water that percolates through the soil layer, thereby effectively capturing and using water before it flows out of the basin (IWMI, 2003).

5. CONCLUSIONS

In the context of the growing demand for water and the emerging water crisis, attention is focused on finding appropriate strategies and mechanism to promote sustainable use and management of water resources. Since the prospects for supply augmentation are limited due to prohibitive cost of future irrigation investments and water infrastructure projects, focus is on demand management. Through proper pricing and institutional reforms in the water sector, it is hoped that people and governments will be able to meet the increasing demand for water in various sectors. Reducing water wastages and improving water efficiency and productivity is an important goal. In this context, efforts are underway to improve water productivity in agriculture, and the water so saved may be diverted for bringing more area under agriculture to boost food output, and meet the water needs of other sectors. Evidences from experimental or farmer participatory trials in a cross section of regions, countries, or sites in Asia and the Indo-Gangetic plains suggest that alternate agronomic or crop management practices such as zero-tillage, bed planting, non-puddled rice culture and laser leveling can result in water savings and improve rice and wheat yields per unit of water input. The water so saved can be used to bring more area under irrigation and thereby increase food production to meet the food needs of the growing population. While the benefits of drip irrigation in the case of dry and plantation crops, and more recently sugarcane, are well known. Its potential in economising water use and improving incomes in the context of rice (especially ratoon rice or upland rice) and wheat cultivation needs to be probed. Recycling waste water, rediscovering traditional water harvesting practices are receiving considerable attention in recent years with a view to economise water use and meet the increased demand for water.

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AEROBIC RICE: WATER SAVING RICE PRODUCTION TECHNOLOGY

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Abstract

Field experiments were conducted at Central Farm, Coimbatore to develop a technology package for aerobic rice cultivation from 2004 to 2007. Among 12 rice varieties evaluated, PMK 3 proved to be the best variety in terms of production. The study of plant population in aerobic rice revealed that 100 hills/m2 (20 x 5 cm) was comparable with 50 hills/m2 (20 x 10 cm) in terms of grain yield. Irrigation at IW/ CPE of 1.2 (with water requirement of 618 mm) registered a grain yield of 4.9 ton/ha and was comparable with the grain yield of 4.8 ton/ha in irrigation at IW/CPE of 1.0 (with water requirement of 556mm). Among the N levels, N at 175 kg/ha produced the highest grain yield of 4183 kg/ha and it was comparable with N at 150 kg/ha (4030 kg/ha). To find out the suitability of aerobic rice in Cauvery delta region, a field experiment was initiated in PAJANCOA & RI, Karaikal to screen suitable rice varieties (ADT 36, ADT 43, ADT 48, PMK 3, MDU3 and ADS 18) for aerobic cultivation in comparison with other rice production systems. The grain yield of rice is higher in transplanting and wet seeding when compared to aerobic rice system. However, the most salient feature of this study is that about 92, 42 and 40.6% of water (including rainfall) was used for evapo-transpiration or consumptive purpose while remaining 8.0, 58.0 and 59.4% of water would have left the root zone as seepage and deep percolation, respectively.

1. INTRODUCTION

"International year of rice-2004 AD" had the slogan "*Rice is life*" as its broad meaning encompasses the entire scope of rice as way of life, the source of livelihood. Irrigated lowland rice is consequently the most important agricultural ecosystem in Asia. The present and future food security of most of its population depends on it. However, there are signs that declining water availability is threatening the sustainability of this system. In view of these demands and constraints, the question is – does rice need standing water for optimum production? Flooding in rice is used as management tool, not a specific requirement. Rice is unique in the sense that transplanted paddy requires lot of water for land preparation. Can we go for an alternative that reduces this component? As a result, the concept of aerobic rice was first developed in China (Bouman and Tuong, 2001). The term "Aerobic rice" was coined recently by International Rice Research Institute (Bouman *et al.*, 2002). Aerobic cultivation entails the growing of rice in aerobic soil, with the use of external inputs such as supplementary irrigation and fertilizers, and aiming for high yields. Growing rice aerobically saves water by eliminating continuous seepage and percolation, reducing evaporation and eliminating wetland preparation. To make aerobic rice successful, suitable package of practices should be developed. Hence, research has started at Tamil Nadu Agricultural University, to develop technology package for aerobic rice cultivation. The technology for growing aerobic rice includes the following land preparation and sowing methods:

- ❖ Dry ploughing - after the harvest of the previous crop
- ❖ Ensure that fields are well harrowed and leveled
- ❖ The field should be thoroughly prepared by using disc plough, cultivator and rotavator.
- ❖ Sowing either by using manual seeding or drum seeder
- ❖ Seed rate of 40-45 kg/ha with the spacing of 20x10cm (50 hills/m2)

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2. RICE VARIETIES FOR AEROBIC CULTIVATION

A field experiment was conducted in Central Farm wetlands, Coimbatore to screen suitable rice varieties for aerobic rice cultivation. The field was clay loam in texture. The soil was neutral in pH (7.1) and the EC was 3.9 dS/m1. The soil was low in available N (219 kg/ha), medium in available P (17 kg/ha) and medium in available K (396 kg/ha). Twelve rice varieties *viz*., ADT 38, ADT 39, ADT 43, ADT 46, CO 43, CO 45, CO 46, CO 47, White Ponni, PMK 3, MDU 3 and ADS 16 were evaluated in randomized block design with three replications. The field was prepared under dry conditions. Sprouted seeds were line sown with a spacing of 20 x 5 cm. Pre emergence herbicide pendimethalin at 0.75 kg a.i./ha was applied at 3 days after sowing (DAS). Hand weeding was done at 20 and 45 DAS. Need based plant protection was given. Irrigation was given with 2.5 cm depth of water during the first 30 days and 3.0 cm depth of water later by using Parshall Flume.

Among 12 rice varieties evaluated, the variety PMK-3 produced higher root length and dry matter, higher panicle per unit area and filled grains resulting in the highest grain yield of 3684 kg/ha during *rabi* season of 2004 - 05 (Table1). This was followed by the variety ASD 16 with a grain yield of 3138 kg/ha. The water productivity varied among the varieties depending upon their field duration. The variety PMK 3 with a duration of 137 days registered the highest water productivity of 7.06 kg/ha mm of water. White Ponni recorded the lowest water productivity of 1.5 kg/ha mm of water. The second best variety was ASD 16 which registered 5.79 Kg/ha mm of water.

Table 1: Screening of Rice Varieties for Aerobic Rice Production

Treatments	Panicles m^{-2}	Grain yield (kg/ha)	Irrigation Water used (mm)	Rainfall(mm)	Total water used (mm)	Water productivity in rice (kg/ha mm)
ADT 38	193	1389	503.4	116.4	619.8	2.24
ADT39	255	1753	488.2	116.4	604.6	2.90
ADT 43	294	1248	432.4	89.7	522.1	2.39
ADT 46	262	1321	467.9	116.4	584.3	2.26
CO 43	306	2805	526.4	127.4	653.8	4.29
CO 45	265	2418	488.2	116.4	604.6	4.00
CO 46	283	2755	467.9	116.4	584.3	4.72
CO 47	256	2316	467.9	116.4	584.3	3.96
W. PONNI	186	984	526.4	127.4	653.8	1.51
PMK 3	346	3684	432.4	89.7	522.1	7.06
MDU 3	309	2943	447.7	93.9	541.6	5.43
ASD 16	315	3138	447.7	93.9	541.6	5.79
CD(P=0.05)	17	317				

3. OPTIMIZATION OF PLANT POPULATION FOR AEROBIC RICE

The experiment was laid out in a factorial randomized design with three replications. The treatments included six rice varieties *viz*., PMK 3, ASD 16, MDU 3, MDU 5, CO 47 and RM 96 019 and three plant populations *viz*.,100 hills/m^2 (20 x5cm), 50 hills/m^2 (20x 10 cm) and 33 hills/m^2 (20 x 15 cm). Of the six rice varieties tested with three plant spacing, the variety PMK-3 recorded the highest grain yield of 4517 kg/ha (Table 2). The plant spacing of 20x 5 cm (100 hills/m^2) registered the highest grain yield of 3099 kg/ha. However, this was comparable with a plant spacing of 20x10 cm which recorded a grain yield of 2834 kg/ha

Table 2: Effect of varieties and plant populations on grain yield and water productivity in rice

Treatments	Grain yield (kg/ha)					
	100 Hills	50 Hills	33 Hills	Mean	Total water used (mm)	Water productivity in rice (kg / ha mm)
PMK 3	4787	4647	4117	4517	526	8.6
ASD 16	3410	3083	2557	3017	554	5.4
MDU 3	3053	2833	2690	2859	526	5.4
MDU 5	2580	2227	2217	2341	554	4.2
CO 47	1607	1407	1347	1453	554	2.6
RM 96019	3160	2807	2247	2738	506	5.4
Mean	3099	2834	2529			

	SEd	CD(P=0.05)
Variety (V)	237	500
Spacing (S)	205	433
VXS	0.18	119

4. IRRIGATION AND NITROGEN MANAGEMENT FOR AEROBIC RICE

The experiment was laid out in a strip plot design with three replications. The treatments included four irrigation regimes *viz.*, IW/CPE 0.8, IW/CPE 1.0, IW/CPE 1.2 and 200 % PE (microsprinkler) and four N levels *viz.*, 100, 125,150 and 175 kg/ha. The variety PMK-3 was used for the study. A common fertilizer dose of 50: 50 kg P, K/ha was adopted. The entire dose of P was applied as a basal dose. N and K fertilizers were applied in four equal split doses at 15 DAS, tillering, panicle initiation and heading stages.

Study on irrigation and nitrogen management in aerobic rice reveled that the irrigation at IW/ CPE of 1.2 was the best with a grain yield of 4884 kg/ha (Table 3). This was comparable with the irrigation at IW/CPE of 1.0 which produced a grain yield of 4771 kg/ha. The irrigation water requirement under IW/ CPE ratio of 1.0 and 1.2 were 442, 504 mm, respectively. Among the N levels, N at 175 kg/ha produced higher grain yield of 4183 kg/ ha and it was on par with N at 150 kg/ha (4030 kg/ha).

Table 3: Influence of Irrigation and Nitrogen Management on Aerobic Rice

Treatments	Yield (kg/ha)					Irrigation Water used (mm)	Total water used (mm)	Water productivity in rice (kg/ ha mm)
	100 kg	125 kg	150 kg	175 kg	Mean			
IW/CPE - 0.8	3810	4263	4457	4567	4274	384	498	8.6
IW/CPE - 1.0	4450	4757	4883	4993	4771	442	556	8.6
IW/CPE - 1.2	4727	4763	4950	5097	4884	504	618	7.9
Microsprinkler	1783	1680	1830	2077	1843	545	659	2.8
Mean	3693	3866	4030	4183				

5. WEED MANAGEMENT

Transforming crop establishment technique from transplanting to direct seeding has resulted in dramatic changes in the type and degree of weed infestation. Weed management is one of the most critical factors for successful production of direct seeded rice as the soil conditions favour simultaneous germination of weed seeds along with paddy seeds (Subramanian and James Martin, 2006). Though the conventional method of manual weeding is widely practiced, it is difficult to differentiate and remove the grassy weeds especially *Echinochloa colonum* and *E. crus-galli* due to phenotypical similarities between weeds and rice seedlings in the early stages. The only effective method to control weeds in the early stage is pre-emergence application of herbicides.

- ❖ Application of pre-emergence herbicide pendimethalin at 1.0 kg a.i/ha on 3 DAS
- ❖ Followed by mechanical or hand weeding twice at 25 and 50 days after sowing

To find out the suitability of aerobic rice in Cauvery delta region, a field experiment was initiated at PAJANCOA & RI, Karaikal during *Kharif* season, 2007 to screen suitable rice varieties for aerobic rice cultivation. Seven rice varieties *viz*., ADT 36, ADT 43, ADT 45, ADT 48, PMK 3, MDU 3 and ADS 18 were evaluated in randomized block design with three replications under three systems of rice cultivation (Transplanting, Wet seeding and Aerobic rice). The grain yield of rice was higher in transplanting, and wet seeding methods when compared to aerobic method.

The most salient feature of aerobic rice in the study was the extremely low water input: the total of rainfall and irrigation water input from sowing to harvest varied from 470 to 650 mm, compared to 1200-1300 mm in transplanting and wet seeding. Compared to lowland rice, water consumption in aerobic rice was lower than 50%; water productivity was 60% higher with yield reduction of 25%. This attempt gave much novel ideas of crop-water relationships in aerobic rice (Table 4). Further research is being continued at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal to screen varieties and management technologies for aerobic rice cultivation.

Table 4: Consumptive Use of Water Under Different Systems of Rice Establishment

Particulars	Aerobic rice	Wet seeded rice	Transplanted rice
Land preparation (mm)	-	175	250
Water used for crop growth including rainfall *(mm)	560	1025	1050
Total water used (mm)	560	1200	1300
Evapotranspiration (mm)*	515	504	528
Yield (kg/ha)*	3021	3401	3842

* Mean of seven varieties tested

6. CONCLUSION

The yield of aerobic rice varied from 3.5 to 4.8 t/ha, which is about double the amount obtained from traditional upland varieties and about 20-25% lower than that of lowland varieties grown under flooded conditions. However, the irrigation water use from sowing to harvest in aerobic rice varied from 470 to 650 mm compared to 1200-1300 mm in transplanting which was about 60% less than that of lowland rice.The total water productivity was 1.6 to 1.9 times higher than that of low land rice. In terms of water saving for aerobic, wet seeding and transplanted rice, about 92, 42 and 40.6% of water (including rainfall) was used for evapotranspiration or consumptive purpose while remaining 8.0, 58.0 and 59.4% of water left the root zone as seepage and deep percolation flows, respectively. Because of its low water use with reasonable higher yield, aerobic rice has greater scope in areas where water availability is limited. However, special high-yielding aerobic rice varieties need to be bred and a lot of research is still needed to develop sustainable and viable aerobic rice systems.

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MANAGEMENT OF WETLANDS OF NON-PROMINENCE FROM THE PERSPECTIVE OF BENEFIT-DEGRADATION RELATION

Tuhin K. Das*

Abstract

Wetlands of non-prominence discussed here are some water bodies in the lower-gangetic floodplains of India. People surrounding these wetlands earn their livelihood and derive many direct and indirect benefits from them. To acquire benefits, often stakeholders subject them to environmental degradation. This study tries to identify the socio-economic activities in and around these wetlands to estimate the value of the benefits derived out of these activities, to measure the degradation of physical component of the wetlands, and to estimate the benefit-degradation relations for these wetlands. For the purpose of this study, ten wetlands in Bardhaman district in West Bengal, India were surveyed. The benefit and degradation were measured, and then the benefit-degradation relations have been estimated using regression models. From the benefit-degradation relations some alternatives for uses of wetlands have been worked out in an eco-friendly manner to find the conflicts that might emerge among the stakeholders.

1. INTRODUCTION

Wetlands play a pivotal role for ecology. But apart from the ecological value, wetlands have significant contribution to the economic development both at the micro and macro levels. The interaction of wetlands with the surrounding population generates multifarious benefits through its different functions, uses and attributes (James, 1991). The ecological services provided by this ecosystem are considered as its functions (Table 1). Important wetland functions are ground water recharge and discharge, flood mitigation and wildlife habitat (Adamus et al., 1991). The well-known function of wetlands is as a provider of year-round dwelling place, breeding ground, refuge and wintering sites for migratory birds and a wide range of vertebrates and invertebrates. Various uses of wetland ecosystems are agriculture, aquaculture, forestry and water withdrawal for irrigation. The use value of wetlands also includes benefits like recreation, tourism, education and transport corridor that are being prioritised in recent times. A range of valuation techniques exist for assessing the economic value of the wetland ecosystem (Table 2). But estimation of the aggregate value of a wetland is complex since the component parts of the ecosystem are contingent on the existence and continued proper functioning of the whole (Turner et al., 2000). The value of wetland as a natural resource is embodied in its attributes. These values are largely aesthetic. Nowadays these values are also gaining greater attention worldwide (IPCC, 1995). The attribute incorporates its biological diversity, historic value, cultural value and aesthetic value. Thus the significant role of wetlands is well understood, but in many cases they are under serious threat. In some countries legal measures have been announced in recent years to tackle the problem of wetland degradation. However, this recognition is aimed to safeguard only the prominent wetlands (The Environment Protection Act in India, 1986).

Apart from these prominent wetlands there are a large number of isolated wetlands, which play a significant role in the wellbeing of the surrounding community. The existence of these wetlands is not so important ecologically and their relevance becomes insignificant with reference to the macro-level discussion in an economy. But with respect to the micro-context, their contribution is irrefutable because the population surrounding these wetlands earns their livelihood and derives various benefits from them. The socio-economic

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Table 1: The main functions, products and attributes associated with wetlands

Benefits	Wetlands associated
Functions	
Groundwater recharge	Marshes, Swamps, Lakes
Groundwater discharge	All
Flood Control	Most of the wetlands
Nutrient retention	All
Water Transport	Estuaries, Mangroves, Lakes
Recreation and tourism	All
Products	
Forest resources	Mangrove, Swamps
Fisheries	Most of the wetlands
Forage resources	Estuaries, Mangroves, Marshes
Agricultural resources	Waterlogged, Marshes
Water supply	Lakes, Ponds
Attributes	
Biological diversity	All
Uniqueness to Culture/Heritage	All

life is closely associated with the existence of these ecosystems. However, among all the benefits derived from these wetlands, some activities are not eco-friendly. For example, drawing water for irrigation lowers the water table of these wetlands and hampers the smooth functioning of its ecology. The agricultural activity in seasonally drained wetlands is another activity, which disrupts the ecological balance of wetlands. Such utilisation enhances the benefit from the wetlands but subsequently degrades the ecosystem. It is essential to identify and then quantify their degree of influence. Such quantification can help policy makers and planners to enforce legal measure on unrestricted utilization of the wetlands (Adger, 2000).

Table 2: Wetland values and valuation methods

Values	Valuation methods
Direct use value	Market analysis, productivity loss, hedonic pricing, travel cost, replacement and restoration costs, contingent valuation
Indirect use value	Damage costs, production functions, hedonic pricing, relocation, replacement and restoration costs, contingent valuation
Nonuse value	Contingent valuation

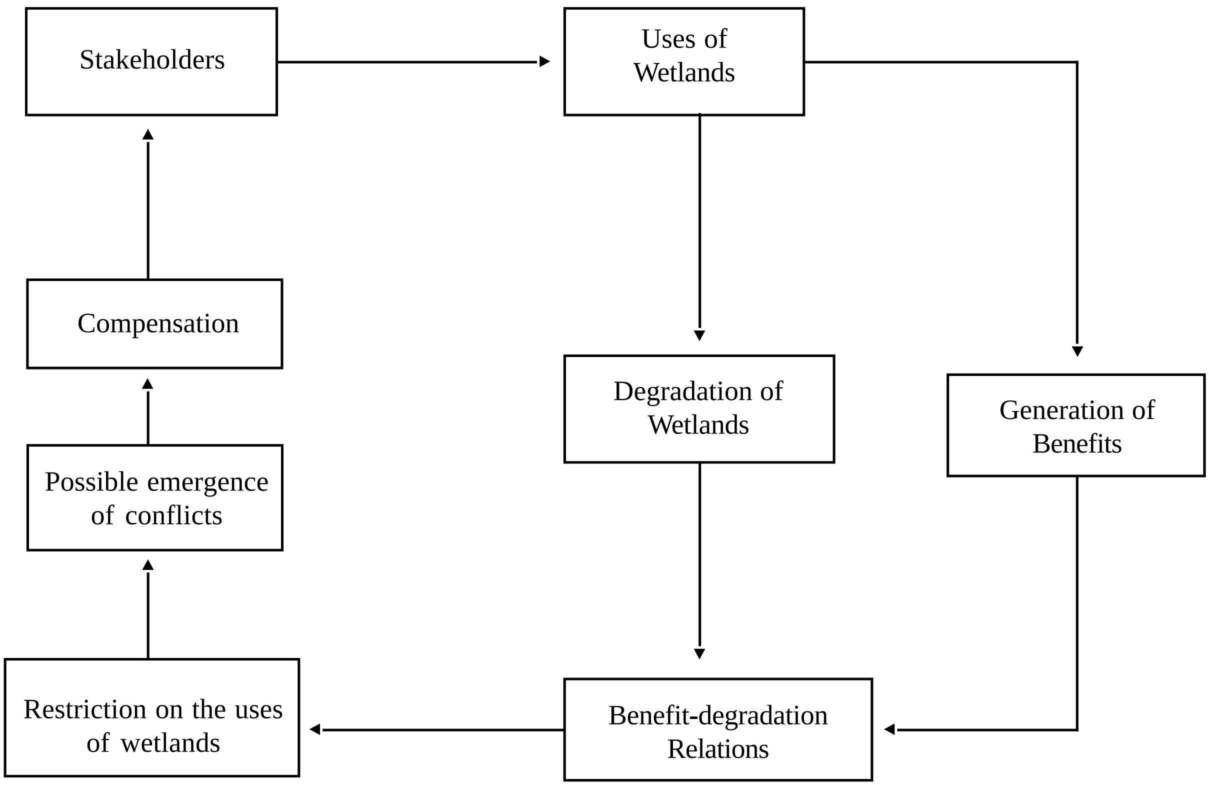
In the Indian context, a number of studies have captured the relevant impacts on wetland ecosystem under different management options (Verma et al., 2001; Singh, 2001). This study estimates the mathematical relationship between economic interaction of wetlands (through its various uses) and the subsequent environmental impact so that appropriate management strategies can be formulated to conserve them. In general, to conserve any natural resources, it is always beneficial to reduce human pressure on them. However, limited admittance to a natural resource like wetland will invariably mean financially displacing some stakeholders, which may lead to conflicts among beneficiaries[1]. This study also looks at the kind of conflicts, which may emerge of if unrestricted utilization of wetlands is no more permitted.

[1] These types of conflicts have been captured through "social cost " by Coase (1960). Coase pointed out that if legal action were taken, there would be loss to someone. Under such circumstances the negotiating parties would interact among themselves to minimise the loss, provided such negotiation is costless.

2. PLAN OF THE WORK

Some isolated wetlands in rural region were selected, and the utilization pattern of these wetlands by the surrounding community was identified. Where possible, the benefits generated and the degradation caused from these wetlands were quantified. Then we tried to established a functional relation between these economic benefits derived and their resultant degradation to arrive at the positive or negative influence of such usage its ecology. To evaluate the economic conflict between various stakeholders if unrestricted utilisation of the wetlands is no more permitted, a pay-off matrix for alternative uses of wetlands was prepared. A schematic diagram of the plan is presented in figure 1.

Figure 1: Schematic plan of the present study



3. METHODOLOGY

To work out the tasks as shown in the schematic diagram of figure 1 the following methodologies have been adopted at various steps.

3.1 Selection of wetlands

This study is confined to the lower-gangetic floodplains, which lie in West Bengal[2]. These wetlands play a very important role in the rural and urban life of the beneficiaries. Most of these wetlands are under increasing pressure for conversion to other forms and vulnerable to degradation as they are not adequately protected. They receive the least consideration or value in conservation plans. In spite of this, a number of wetlands still exist but they are exploited potential without regard to the consequences of such exploitation. They are undergoing steady deterioration due to overutilisation, pollution and lack of scientific conservation effort.

[2] West Bengal has the largest number of wetlands in India

The number of wetlands in West Bengal is largest in Bardhaman district. This district is important in terms of agricultural yield with substantial development in the application of high input-high output technology in agriculture like high yielding variety (HYV) seeds, chemical fertilizers and pesticides. However, the high input modern technology cannot yield fruitful return if controlled irrigation facility is not available in form of ground water irrigation in summer. About 63% of the total sown area in this district is covered by canal irrigation, which is considered to be inadequate (Economic Review, 1999-2000). Farmers extensively use ground water for cultivation during the dry season. The presence of wetlands is vital for maintaining ground water.

The total area under wetlands in Bardhaman district is 6441.77 hectare out of which lakes and oxbow lakes, waterlogged (seasonal) and swamps and marshes occupy 3415.94 hectare (Raha, et al., 1997). The rest are reservoirs, tanks and abandoned quarries. Since the former group of water bodies occupies a significant position in the total water bodies present in the district, they have been chosen for study.[3] Altogether ten wetlands, which are water logged seasonally, swamps and marshes covering an area of 680 hectare (20% of the area) were selected for the study. These wetlands have been selected from similar agro-climatic zone in the same area to avoid significant variation in biodiversity and benefits. While selecting the wetlands for survey, special emphasis was given to those wetlands, which have substantial interaction with the surrounding economy. These wetlands are used for net fishing and withdrawal of water for irrigation. The huge economic benefits obtained from net fishing have caused part of these wetlands to be converted to aquaculture ponds (Das et al., 2001). All the wetlands are used for storage of water, which are accumulated either from runoff or from drenched water of nearby rivers. This water is used for irrigation in periods of water scarcity.

Table 3: Wetland Profile

Sr. no.	Name of wetland	Area of wetland (hectare)	Average depth of water (meter)	
			Pre-monsoon	Post-monsoon
1.	Haruabhanga	10	4.12	6.86
2.	Kalobaur	40	3.36	8.39
3.	Lakshmipur	15	1.07	5.34
4.	Chakkobla	60	1.07	4.12
5.	Barokobla	25	6.86	9.91
6.	Bara Beel	56	1.07	2.74
7.	Jalanga	75	1.67	3.81
8.	Srikhanda	80	0.38	6.86
9.	Bater Beel	275	0.46	2.14
10.	Padma Beel	20	0.23	2.14

Among ten selected wetlands, seven wetlands are perennial and three are seasonal. These seasonal wetlands are converted temporarily in the post monsoon season by draining water to derive fertile agricultural land for harvesting food crops especially, rice. These wetlands are filled up again and return to their original state in monsoon. Some of these wetlands are also being used for jute retting.[4] Thus the major economic benefits from the selected wetlands derived by the surrounding population are fishery, irrigation, jute retting, and drained off fertile farmland for cultivation (Table 4). These specified wetlands are used for various domestic

[3] Among various definitions of wetlands given by different institutions, the most accepted definition was put forward in Ramsar Convention held in Iran (1971) which define wetlands as “areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters.” (Raha et al., 1997). In this study, the selected wetlands under survey are in accordance with the Convention, and these are mainly lakes, and oxbow lakes while some are seasonally waterlogged wetlands (Table 3).

purposes like bathing, washing clothes and utensils and rearing ducks. By grazing cattle in the wetlands, herders save 15-35% of total annual cost of cattle feed. However, due to lack of relevant information and presence of non-quantifiable variables these uses of wetlands are not included in the analysis of benefits derived from wetlands. Instead we just mention these advantages available to the surrounding households due to the presence of these wetlands.

Table 4. Number of households deriving benefits across different wetlands

Sr. No.	Name of wetland	Fishing		Irrigation		Jute retting		Agriculture	
		Population	Sample	Population	Sample	Population	Sample	Population	Sample
1.	Haruabhanga	125	10	125	10	0	50	0	0
2.	Kalobaur	200	25	100	10	60	0	0	0
3.	Lakshmipur	90	10	20	3	0	0	0	0
4.	Chakkobla	20	3	200	15	0	0	0	0
5.	Barokobla	60	5	50	3	0	0	0	0
6.	Bara Beel	400	35	800	75	0	0	0	0
7.	Jalanga	100	10	300	32	0	0	0	0
8.	Srikhanda*	200	22	0	0	200	25	1000	100
9.	Bater Beel*	150	15	0	0	100	12	600	55
10.	Padma Beel*	75	5	0	0	20	4	75	10

*Seasonally drained

4. SELECTION OF SAMPLE OF STAKEHOLDERS

Initially the list of beneficiaries was collected from the office of the Gram Panchayat (village council) and fishermen's co-operative society. Among the total beneficiaries of each category about 12% were selected by random sampling. These beneficiaries were surveyed through personal interviews. Questions were asked questions related to their socio-economic profile - family structure, income level, education and occupation. Information regarding their interaction with the wetlands was captured by asking questions like conversion of the surveyed wetlands, benefits generated, annual income accrued, operational land holding, amount of land cultivated within the wetland, land area generated, area of land irrigated by water from the surveyed wetland, descriptions of biotic abundance found in and around the wetland at present and fifteen years back. The interviewees were also asked to put suggestions regarding any desirable conversion of the wetlands.

About eight percent of the selected households, i.e., approximately ten percent of the total beneficiaries, responded by giving answers to the preformatted questionnaire.

4.1 Estimation of Benefits

The wetlands are often altered to satisfy economic needs with no consideration to the values associated with them in their unaltered state. They represent a resource of high value and their role in the economy should be considered with due care. In the absence of a proper valuation technique, misallocation of wetland resources will occur which might have long-term consequences.

[4] In the process of jute retting, the stems of matured jute plants are collected and bunched together. These bunches are dipped into the wetlands and they are kept drowned completely into water by putting heavy mass on them for a period of about one month. After required interval of time, the fibers are taken out of the stem while the jute stick remains. These fibers are then thrashed and rinsed thoroughly to get pure jute.

Fishing benefit is derived from the entire surveyed area. The value of average annual fish catch from these wetlands has been estimated by market price method, as reliable market prices are available for the fish caught from these wetlands (Winpenny, 1991). We have measured the fishing benefit in two ways:

(i) Fishing benefit per household as FS_{hh} by the formula

$$FS_{hh} = \left(\sum_{i=1}^{n_f} \text{Value of fish catch by ith household}\right) / n_f \quad (1a)$$

(ii) Fishing benefit per hectare as FS_{ha} by the formula:

$$FS_{ha} = (FS_{hh} \ X \ N_f) / A \quad (1b)$$

Where, n_f is the number of surveyed households engaged in fish catching, N_f is the total number of households engaged in fish catching around that wetland and A is the area of the wetland in hectare.

The water from the wetland is being used for irrigation in the surrounding agricultural fields. Seven surveyed wetlands render this benefit. The value of water used for irrigation cannot be estimated by the market price method because this wetland product is not sold in the market or no acceptable price is available for this benefit. But some cost is incurred to get this benefit through uses of pump-sets for lifting water from wetland to the farmland which has been observed to be less than that incurred for lifting water from alternative sources. Here the net benefit method is used for its estimation.[5] However, a true value of water could be obtained through the Household production function (HPF) approach. The underlying assumption in most HPF models is that a household allocates some of its available labour time, and possibly its income, i.e., the household combines its labour and other goods to "produce" a good or service, only for its own consumption and welfare (i.e., household utility). But here we stick to the cost based method, in spite of the superiority of the HPF over the former, mainly due to insufficient data. In the same way as fishing benefit, the benefits from irrigation has been measured in two ways,

(i) Irrigation benefit per household as IRR_{hh} by the formula:

$$IRR_{hh} = \left(\sum_{i=1}^{n_i} \text{Saving from irrigation by the ith household}\right) / n_i \quad (2a)$$

(ii) Irrigation benefit per hectare as IRR_{ha} by the formula:

$$IRR_{ha} = (IRR_{hh} \ X \ N_i) / A \quad (2b)$$

Where, n_i is the number of surveyed households deriving the irrigation benefit, N_i is the total number of households procuring the same benefit around that wetland and A is the area of the wetland in hectare.

The surrounding households are deriving the benefit of jute retting from four of the surveyed wetlands. Ponds can be hired on rental basis for jute retting. But if wetlands are used for this purpose no such rent is charged. Substitute price is used for this use value of the wetlands and the rental charges of the ponds hired for jute retting has been considered here as the value of jute retting benefit. As before, the benefit of jute retting has been calculated in two ways:

[5] If groundwater is extracted instead by privately owned shallow tube-wells or submersibles, it costs higher for the farmer due to the fact that volume of water extracted per hour from the surface of a wetland is much more than that of a non-wetland source like ground water (using a pump-set of the same horse-power). The difference between these two costs of water required for irrigation of one acre of land is being considered to be the value of this wetland use.

(i) Jute retting benefit per household as JR_{hh} by the formula:

$$JR_{hh} = \left(\sum_{i=1}^{n_j} \text{Jute retting benefit derived by the ith household}\right) / n_j \quad (3a)$$

(ii) Jute retting benefit per hectare area as JR_{ha} by the formula:

$$JR_{ha} = (JR_{hh} \times N_j) / A \quad (3b)$$

Where, n_j is the number of surveyed households deriving the jute retting benefit, N_j is the total number of households obtaining the same benefit around that entire wetland and A is the area of the wetland in hectare.

The seasonally drained off wetlands generate productive land for cultivation of food crops, especially rice. (Obviously, this agricultural benefit by draining off wetland is received at the cost of other benefits, viz. fishing, irrigation, etc. Therefore, the agricultural outcome may be regarded as cost and should be deducted form the total benefit. But one of the objectives of this paper is to find the "individual benefit" (i. e., use) – degradation relation (Table 5), so we term it as "benefit" instead of "cost".) The agricultural benefits obtained from three wetlands have been quantified by the monetary value of their production through household survey. The net average annual benefit from cultivation has been estimated per hectare. On this basis the agricultural benefits have been computed from three wetlands. So here, the same market price method has been employed for the value estimation. The two measurements of agricultural benefit are,

(i) Agricultural benefit per household as AG_{hh} by the formula:

$$AG_{hh} = \left(\sum_{i=1}^{n_a} \text{Monetary value of the agricultur al output produced by the ith household}\right) / n_a \quad (4a)$$

(ii) Agricultural benefit per hectare area as AG_{ha} by the formula:

$$AG_{ha} = (AG_{hh} \times N_a) / A \quad (4b)$$

Where, n_a is the number of surveyed households deriving the agricultural benefit, N_a is the total number of households obtaining the same benefit around that entire wetland and A is the area of the wetland in hectare.

5. ASSESSMENT OF DEGRADATION

The degradation of wetlands can be assessed by looking at the deterioration in their biotic and abiotic parameters (IWMED, 1999). Biotic parameters include bio-geographical zone of the wetland, its habitat type and nature of distribution of the aquatic flora and fauna. The abiotic parameters are site area, topographic configuration, water regime and water quality. Degradation in biotic parameters may result in reduced biotic diversity (Dugan, 1993), eutrophication (Jana et al., 2002) and infestation of exotic species (Murty et al., 1998 and Muraleedharan et al., 1997). The degradation of the abiotic parameters may result in loss of wetland area (IPCC, 1995), encroachment (Dogra, 1993), drainage (The CEERA team, 1999), reclamation for agriculture, siltation (Sridhar et al., 2002), reduction in dissolved oxygen content and pollution (De et al., 2002). To assess the degradation of wetland resources in the surveyed area each of the biotic and abiotic parameters were selected.

The wetlands nurture a wide range of flora and fauna. The conversion and other human activities around the wetlands lead to decline in abundance of several flora and fauna. The surrounding population of the surveyed wetlands reported that both varieties and number of fish and other aquatic animals have reduced severely in the last 15 years due to excessive withdrawal of water for irrigation and net fishing. According to them, reduction in biotic abundance is highest for seasonal wetlands (where water is drained out). Also, the bird population is dwindling every year mainly due to (i) unsustainable fish catch distorting the food chain, and (ii) noise of diesel pump-sets (used for lifting water from the wetlands to adjacent agricultural lands) disturbing the serenity of the area. In order to measure the decline in biotic abundance, data have been collected from fisherman community and surrounding farmers, related to the numbers and types of fish, aquatic animals and birds that have disappeared from the wetland. For this study, the reported reduction in biotic abundance is one of the biotic indicators to estimate the degradation of wetlands. Non-sighted or non-available species in the survey area may not be endangered elsewhere but are not longer found in the surveyed wetland areas and may be viewed as local depletion. The reduction in biotic abundance (denoted by $BA_{reduction/ha}$) has been calculated per hectare area of each wetland in the following way:

$$BA_{reduction/ha} = \frac{\text{Total reduction in biotic abundance in a particular wetland}}{\text{Area of the wetland}} \quad (5)$$

The decline in biotic abundance is taken per unit area because a wide range of observations were found to justify that the number of species traced in an area increases with the size of that area (Groombridge, 1992). This increase follows an anticipated pattern known as the Arrhenius relationship.

One key measure of water quality is dissolved oxygen level in it and this is one of the important habitat factors for the aquatic abundance within the wetland. Usually the level of dissolved oxygen stands at 8 mg/l in fresh water at 25°C (Ramachandra and Murty, 2002). Since the highest level of dissolved oxygen level among the surveyed wetlands is close to 7 mg/l and all these surveyed wetlands have extensive interaction with the surrounding population, 7 mg/l is taken as the standard level of dissolved oxygen. The deviation of the actual value of dissolved oxygen of the surveyed wetlands from the assumed standard level of 7 mg/l, denoted by DO_{dev} is considered as the degradation of wetlands in the analysis. Hence,

$$DO_{dev} = 7 - \text{the actual value of the dissolved oxygen} \quad (6)$$

6. ESTIMATION OF BENEFIT - DEGRADATION RELATION

Every economic action can have some effects on the environment and every environmental change can have some impacts on the economy. There exists a relationship between the benefits derived from the wetlands through various economic activities and the degradation of the wetlands. After the estimation of benefits and degradation through the aforesaid indicators the following linear regression model has been framed to identify these benefit-degradation relations:

$$BA_{reduction/ha} = a_0 + a_1 FS_{ha} + a_2 IRR_{ha} + a_3 JR_{ha} + a_4 AG_{ha} \quad (7)$$

and

$$DO_{dev} = b_0 + b_1 FS_{ha} + b_2 IRR_{ha} + b_3 JR_{ha} + b_4 AG_{ha} \quad (8)$$

Where a_0 and b_0 can be interpreted as the degradation of the wetland when it is left aside, and a_i and b_i, (i= 1, 2, 3, 4) are the parameters associated with the explanatory variables. Here the structural factors, which exert explanatory power to the relationship between benefits and degradation, include specific benefits derived per unit area of wetlands. Since there is wide variation in the total commanding area under the surveyed wetlands, it will be commensurate to take into account the value of benefits derived from these wetlands in terms of benefits per unit area.

7. IDENTIFICATION OF THE CONFLICT

Assuming the existence of a close association between benefits derived and resultant degradation, a reduction of benefits might occur while conserving the wetlands. This may have a negative effect on the stakeholders, as some of the beneficiaries would lose in the course of preservation of these fragile ecosystems. As a result a conflict will spurt up, which has been portrayed through a pay off matrix (Frank, 1997). In this pay off matrix method, the possible outcomes of different strategies employed for preservation have been are. From all these feasible outcomes, choosing the socially optimal one would be justified (Coase, 1960).

6. RESULTS AND DISCUSSION

The numbers of households deriving various yields from the surveyed wetlands are presented in Table 4. This table reveals that the average number of households deriving agricultural benefit is highest. Average number of households getting fishing benefit is less than the average number of households receiving irrigation benefit. The average number of households receiving the benefit of jute retting is even smaller because only four out of ten surveyed wetlands render this benefit.

Table 5. Average benefits derived from the surveyed wetlands (in rupees) per annum

Item	Statistics	Fishing	Irrigation	Jute retting	Agriculture
Average benefits derived per household of the stakeholders per annum	Sample mean	2643	823	206	1258
	Standard deviation	2876	969	302	2437
	Coefficient of variation	108.81	117.73	146.60	193.72
Average benefits derived per household of the stakeholders per annum	Sample mean	3280	6313	3770	213
	Standard deviation	3884	5647	5191	292
	Coefficient of variation	118.41	89.45	137.69	137.08

The resulting benefits per household and benefits per hectare separately for each wetland are computed using the formulae (1) - (4). Table 5 shows that the average income per household from fish catch is highest, as all the surveyed wetlands render this service to the neighbouring population. Moreover, this fishing benefit has a lower coefficient of variation than irrigation, jute retting or agriculture benefit. This implies that fishing income per household among the surveyed sample is more consistent than income from other benefits. More or less the same trend has also been observed in case of benefits per hectare.

It is apparent from the descriptive statistics in Table 6 that the average number of fish variety that were not found in abundance, is highest and its variability is least among all the species. In other words, fish are the more threatened species in these wetland ecosystems as compared to aquatic animals and birds. It is also observed from the table that DO levels of the wetlands varied considerably. Except for a few water bodies like

Table 6. Average reduction in abundance of number of species and average water quality

Statistics	Average reduction in abundance of #			Total reduction in biotic abundanceper hectare	Average dissolved oxygen (mg/l)
	Fish	Aquatic animal	Bird		
Mean	1.60	0.90	0.80	0.09	2.62
Standard deviation	1.17	0.74	0.92	0.08	1.87
Coefficient of variation	73.36	81.98	114.87	91.63	71.48

Reduction in abundance means reported numbers of types of fish, aquatic animals and birds that were not being sighted during the reference year in the particular wetland.

Bater Beel, Chakkobla Beel and Jalanga, the DO levels were above 2 mg/l. Its highest was observed at Barokobla (about 6.94 mg/l).

In the first approach of identifying the benefit-degradation relation, degradation has been considered from an ecological point of view i.e., using relation (7). Results of the Multiple Regression analysis in Table 7 show that all the anthropogenic activities derived per unit area though enhance benefits from the wetlands, aggravate the problem of reduction in biotic abundance (Table 7, Model 1a). Human interference is responsible for almost 50% of the total reduction in biotic abundance. However, Stepwise Backward Regression shows that among all the activities performed in and around the wetlands, irrigation and agriculture are most harmful for sustenance of the wetland ecology. They are responsible for 40% of the total reduction in biotic abundance (Table 7, Model 1b).

In the second approach, the water quality is used to indicate the degradation of wetlands i.e., using relation (8). Model 2a of Table 7 shows that the water quality has deteriorated by 85%. Irrigation and agricultural activities cause the deterioration by reducing the dissolved oxygen level in the water whereas fishing and jute retting improve water quality. The Backward Stepwise Regression with the same set of variables in Model 2b of Table 7 shows that fishing and irrigation activities alone exert comparatively strong illustrative power to this relationship with 68% explanation. In the absence of these activities, the deviations from standard DO level would be substantial as is evident from the constant, b_o, of Model 2a and 2b. This would aggravate the situation

Table 7. Multiple Regression Results

Model	Dependent Veriable	Parameters associated with the Explanatory variable					
		Intercept	Fishing benefit per ha	Irrigation benefit per ha	Jute retting benefit per ha	Agriculture benefit per ha	R^2
1a. Linear Multiple Regression	Reduction in biotic abundance per ha abundance per ha	- 0.02508	0.0003616 (0.862)	0.0003381 (0.829)	0.004606 (0.632)	0.0002490 (0.918)	0.496
1b. Backward Stepwise Regression	Reduction in biotic abundance per ha abundance per ha	0.02019	-	0.0005477 (2.058)	-	0.0002930 (1.617)	0.402
2a. Linear Multiple Regression	DO_{dev}	6.346	- 0.02469 (- 4.840)	0.02010 (4.051)	- 0.214 (- 2.413)	0.005762 (1.747)	0.858
2b. Backward Stepwise Regression	DO_{dev}	5.693	- 0.02238 (- 3.931)	0.02007 (3.241)	-	-	0.689

Note: Figure in the parenthesis indicates the t-value.

as observed in many cast aside wetlands. So comprehensive management techniques along with appropriate utilisation should be adopted for better maintenance of these precious ecosystems.

Finally, pay-off matrices were constructed for both perennial and seasonal wetlands for their different uses. Alternative strategies were assumed for preservation and better maintenance of the existing non-converted wetlands. The various optional strategies along with their resultant outcomes in case of Bater Beel - a seasonally drained wetland are shown in Table 8. It is observed that from seasonal conversion the agricultural farmers in Bater Beel can retrieve a 256-hectare of land from which they can procure an amount of rupees 42,17,650 approximately.[6] They also incur an input cost of rupees 35,71,900 approximately, which includes labour, irrigation and fertilizer cost for the recovered land. So the net gain to the farmers is about 6,45,750 rupees. This earning

[6] Total return from agriculture = IRR_{hh} x N, where N is the total number of beneficiaries deriving the agricultural benefit.

is of immense importance to their survival and would not accrue to them had such conversion not taken place. This earning is secured in six months before the beginning of monsoon. On the other hand, during the harvest period if the water would not be drained out fishermen could earn an amount of nearly 1,78,400 rupees in total.[7] But due to conversion they have to stop fishing in the wetland during the six months harvest period. The pay-off matrix for the fishermen and the agricultural farmers are summarized in Case 1 of Table 8. It is assumed that farmers are not liable legally or socially.

Table 8. Outcome and pay-off summary (seasonal wetland)

Case	Legal/social/political regime	Outcome	Net benefit (rupees)		
			Fishermen	Farmer	Total
1.	Agricultural farmers not Liable	Agricultural farmers convert and fishermen stop earning. Ecosystem is disturbed	0	6,45,750	6,45,750
2.	Agricultural farmer liable	Agricultural farmers convert and employ fishermen as agricultural labourer Ecosystem is disturbed.	4,65,750	6,45,750	11,11,500
3	Seasonal draining	Fishermen's income from fishing increases and agricultural farmers stop earning. Lesser disturbance in biotic diversity is stopped	>1,78,400	0	>1,78,400

If the agricultural farmers had to pay compensation for six months to the fisherman it would have been at least 1,78,400 rupees. This is the amount the fishermen could earn from the perennial wetland if the process of conversion were not permitted for the said six months. But in this case, the fishermen are reimbursed through employment as agricultural labourer in the cultivation process. They earn rupees 69 per day per person in the harvest season. They can find employment for 45 days, thereby earning on average an amount of rupees 4,65,750 in total during the entire season. Since their fishing income is far less than their wage receipts, they have no objection to the seasonal conversion of this wetland. So from societal point of view the net benefit is highest when farmer compensates the losers by providing alternative employment opportunities to them (Case 2 in Table 8). This is probably the most efficient pay-off outcome if the impact of environmental degradation for the process of draining is not taken into account.

However, to preserve the wetland ecosystem, seasonal draining should no more be allowed. This would augment the fishermen income and enable biotic diversity to flourish. Agricultural farmers will be displaced, face financial hardship and a conflict would arise. The question arises whether fishermen can be made liable to compensate agricultural farmers. Since, fishermen's income is lower compared to that of agricultural farmers, it is not possible to impose such burden on them. The option then is to rehabilitate the displaced agricultural farmers elsewhere. Such strategy is discussed in Case 3 of Table 8. Through this strategy, not only can we maintain biodiversity but recharge water table in the adjacent upland areas from the resultant perennial wetland.

Alternative strategies along with resultant outcomes in case of the perennial Bara Beel wetland are presented in Table 9. There is a conflict between interests of fishing and irrigation. Due to withdrawal of water from the wetland the agricultural farmers gain and fishermen lose.[8] On the gainers side, agricultural farmers use

[7] Total return from fishery = FS_{hh} x N, where N is the total number of beneficiaries deriving the fishing benefit.

[8] The beneficiaries from this wetland include 800 agricultural farmers who draw irrigation benefit and 400 fishermen drawing fishing benefit (Table1). Among them 200 households are common benefit holders. While calculating the gain of farmers and loss of fishermen these common beneficiaries have been excluded from our analysis to counterbalance because they are gainers on one side and losers on the other.

this water for irrigation in their fields and avoid the cost of ground water lifting by submersible pump sets or tube-wells. This reduction in input cost is their indirect gain. The total value of this indirect benefit to the farmer community was estimated at rupees 2,79,300 per annum. On the other hand, withdrawal of water for irrigation

Table 9. Outcome and pay-off summary (perennial wetland)

Case	Legal/social/political regime	Outcome	Net benefit (rupees)		
			Farmer	Fishermen	Total
1.	Agricultural farmers liable	Agricultural farmers draw water and compensate the fishermen	69,300	2,10,000	2,79,300
2.	Agricultural farmer not liable	Agricultural farmers draw water but not compensate the fishermen and fishermen's income reduces	2,79,300	0	2,79,300
3	Restricted withdrawal of water from the wetland by agricultural farmers	Fishermen's income augments and farmers benefit decreases. The wetland ecosystem sustains	>0	>2,10,000	>2,10,000

lowers the volume of water in this wetland and reduces potential fish catch. The immediate sufferers are the fishermen who suffer a loss of about 2,10,000 rupees per annum due to the water withdrawn for irrigation.[9]

Now if the farmers are liable for withdrawal of water from this wetland, they have to compensate the fishermen for their loss. Thus the compensation for the fishermen ought to be as much as 2,10,000 rupees, so that their losses are outweighed (Case 1 of Table 9). If the farmers repay this amount from their indirect benefit of input cost reduction, the farmers' net benefit will reduce by the amount they have to reimburse to the fishermen i.e., 2,10,000 rupees. Their net gain would turn out to be 69,300 rupees in total. The net benefit to the society is thus 2,79,300 rupees. But if the agricultural farmers are not accountable for extraction of water (which is currently happening), they will not reconcile with the fishermen to compensate their losses. In that case the farmer would draw water, thereby gaining through reduction in their input cost and fishermen's income would be curtailed. However, the net benefit to the society would be the same as in the previous case (Case 2 in Table 9).

In the above two cases, it is assumed that the two negotiating parties interact to pursue their own interest in deriving the best from the wetland resource. But unrestricted withdrawal for a prolonged period will augment agricultural income on one hand and degrade wetland resource on the other. In the long run the species abundance will be severely reduced. This will invariably take a heavy toll on the fishermen community and they have to be compensated for this damage. It would be wise, under such circumstances, to allow the agricultural farmers to draw water up to a certain extent beyond which they must opt for alternative sources of irrigation, if needed. The fishermen's income would augmented by at least 2,10,000 rupees, and farmers incur an additional establishment cost for drawing water from alternative sources if required. The net benefit might be less than the first two alternatives, but would be the best option from ecological point of view as environmental damage is least as is figured in Case 3 of Table 9. Moreover, curbing of environmental damage implies enhancement of the

[9] On an average, the fishing benefit per household from all the ten selected wetlands under study stands at 2,650 rupees per annum, while that from this particular water body is at a lower value of 1,600 rupees per annum. The loss of the fishermen has been estimated assuming this average amount of 2,650 rupees to be the minimal possible earning.

potential income of the fishermen as restriction on withdrawal keeps the habitat place intact and biotic abundance to flourish in and around the wetland.

7. CONCLUSION

The wetlands under study are mainly lakes and oxbow lakes with some being seasonally waterlogged. They contribute greatly to the surrounding population by way of the various values they provide. Their utilization generates benefits in the form of fish catch, irrigation water, jute retting and derived agricultural land. But the utilization pattern is not environmentally benign in many cases and consequently the wetlands degrade. The extent of damage in some cases is beyond sustainable limits. Anthropogenic activities are somehow responsible for this degradation with varying degrees. But the policy makers are not aware of the degradation of wetlands of this type. For example, the government has emphasized in West Bengal Town and Country Planning and Development Act, 1979, (Kundu et al., 1997), that no permission for filling of tanks, ponds, water body, marshy land etc. will be given if it is considered necessary for being used as (a) public water body, (b) maintaining drainage facility, (c) fire fighting purposes, (d) environmental and ecological reasons, and (e) pisiculture. However, these policies either overlook or ignore the degradation of existing wetlands due to anthropogenic activities, which cause deterioration of water quality and reduction of biotic abundance.

A comprehensive policy should be framed for preservation and better maintenance of existing non-converted wetlands. If all the anthropogenic activities cannot be curbed due to economic pressure, only those activities should be encouraged which cause the least damage. But these activities should also be allowed within permissible limits. For example, overfishing in wetlands should be stopped, water lifting for irrigation purposes should be restricted to a predetermined level for the sustenance of existing species habitat, and seasonal draining should not be encouraged, as is supported by the regression results in Table 7.[10] However such restriction on resource utilization will adversely affect some beneficiaries and a conflict may arise.

In case of seasonally drained wetlands the optimal solution would be one where the monetary benefit is apparently the most. This is presented in case 2 of Table 8 when the agricultural farmer converts the wetland to cultivable field by draining the water in the post-monsoon season and employs the displaced fishermen as agricultural labourer. Again in case of the perennial wetland the optimal solution would come forth when the agricultural farmers draw water and compensates the fishermen adequately for lower value of their fish catch. Thus, in both perennial and seasonally drained wetlands, the socially optimal situation is the case where income is highest and consequently the environmental damage is the most. Now, any environmental measure obviously implies conflict among different beneficiary groups as the short-term total net benefit decreases significantly in the micro-economy. But the emerging conflict could be mitigated if they are compensated properly. One such way is to provide alternative employment opportunities to the losers. But these alternative employment opportunities should be planned in such a way that the villagers would get no more incentives from the wetland utilization after being employed elsewhere. Otherwise, the process of wetland preservation would go in vein. Thus, policy makers must have a two-fold strategy to reduce environmental degradation: (i) to find the critical level for sustainable uses of wetlands, and (ii) to find alternative employment opportunities to the losers to reduce pressure on these fragile ecosystems.

[10] The problem of overfishing arises due to the open accessibility of wetland resources. Anyone can harvest from wetland resources because these are common property. The extent of overfishing can be estimated with the help of Maximum Sustainable Yield (MSY), which refers to the stock corresponding to the maximum harvest, or yield that can be sustained indefinitely (Fisher, 1981). Generally, MSY can be estimated using a method involving catch-effort data, the aspect of which has not been incorporated in our field survey (Clark, 1976).

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ESTIMATION OF ECOSYSTEM SERVICES OF REJUVENATED IRRIGATION TANKS: A CASE STUDY IN MID GODAVARI BASIN

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Abstract

Adoption of certain tank management practices was a part of the culture in semi-arid regions to ensure tank's sustainability. However, gradual neglect has led to a decline in its role in local economy and ecology and therefore caused consequent hardships to all stakeholders concerned. With aid of external agencies, community has removed 74,000m^2 of silt from 12 tanks in Warangal district, mid Godavari basin of Andhra Pradesh. Its impacts were monitored before and after intervention in kharif and rabi seasons. Estimated benefits both tangible and intangible, suggest that tank rejuvenation makes economic sense and must be adopted on a larger scale.

1. INTRODUCTION

The management of natural resources requires high degree of participation by those who benefit directly and indirectly from that resource. Proper management of natural resources is the most essential step towards sustainable development. Environmental degradation is one of the first indications of unsustainable social and economic systems. Various studies have indicated that renewable resources are under immense stress and as a result their productivity is on the decline. Competing demands exceed supply in many parts of the world, constraining development and laying the foundation for social revolts and conflict. Consequently, humans use the common pool resources for individual benefit with no regard to long term sustainability, which leads to the depletion and degredation of resources. Further, institutions for promoting participatory development of natural resources are not crafted, individual initiatives did not sustain and finally, the agencies created by the government for the management of these resources were highly centralised and bureaucratic (Hooja and Joshi, 2000).

The tanks of South India suffered a similar fate. A study by Sharma and Selvaraj (1999) on Vallakulam cascade of tanks has addressed governance issues and challenges. The study concluded that the lateral spread of authority across many formal and informal institutions, lack of alignment between roles performed, responsibilities, absence of operational synergy and partnerships and no direct mechanisms to ensure accountability of the governance structures to the system users are responsible for the present state of tanks. Suggestions have been made for integrating the mechanisms or authorities to manage the entire cascade of tanks and lands irrigated under one administrative unit and creating direct accountability for performance. Shah (2003), in her study has used the design of tanks as a way to examine the social and political implications of technology that emerged and were managed in a society that was ridden with class, caste and gender inequalities. It supports the widespread view that the crisis in natural resource management, including the management of tanks, was because of state interference and communities should have been left to manage the resources by themselves.

Sreenivasan et.al., (1999) have highlighted the need for location specific studies to understand the situation to make right interventions. Issues like encroachment of tanks have been obvious due to interventions by people, government or nature. It is imperative that organizations should be formed to protect the tanks and

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strengthen the process of management (Manikandan et.al., 2000). A paper by Kumar (2004) has discussed key issues and specific experiences in the various districts of Karnataka. Mismanagement of water and bad cropping practice have led to negative impacts of water scarcity and ground water depletion due to excessive drilling of borewells. A study by Kanniappam et.al., (2000) highlights the dependency of livestock on tanks and the ill-effects of its negligence. Use of chemical fertilizers and decline in organic manure has contaminated the food chain, and affected the fertility of the soil. Common areas set apart for pasture has been virtually wiped out increasing costs of purchasing fodder. Near most of the tanks, common grazing lands do not exist making it very difficult for the livestock (Ramakrishnan, 2000). Poor and marginal farmers depend on livestock for additional income apart from their various uses like ploughing, land preparation and sowing seeds (Elangovan, 2000).

Proper management of irrigation tanks may be a good solution to addressing the current water crises. Several studies have indicated community participation as the key for rejuvenation. For example, study on rehabilitation of tanks (Dhan Foundation, 2001) for providing drinking water in drought prone Ramanathapuram District of Tamil Nadu, has highlighted the need for community involvement with contribution to resolve their problem and made recommendations for improving the Tank Development and Management Programmes under the 10th Plan based on its experiences and has specifically laid emphasis on involvement of local management in the tank systems.

1.1 Importance of Tanks – An Overview

Tank based water management system is an integrated watershed system with tank as its central point. Historically, India, particularly in the southern states, have been following traditional methods of water management by harnessing runoff from uncertain monsoon through a large network of water holding bodies in the form of tanks. According to the Minor Irrigation Census conducted in 1986-87, the country had over 750,000 minor irrigation structures using surface water. Approximately, 700,000 of the structures were found to be in use. In terms of numbers, a large majority of them consisted of small-scale local diversion of water or lifting from streams and rivers. Tanks, which were relatively small, shallow storages, constituted about a third of all minor works in use. In terms of area irrigated, however, they were far more important, accounting for nearly 80% of the net area irrigated by all minor surface water resources. Country has an estimated 208,000 tanks irrigating 3.5 million ha. Andhra Pradesh, Karnataka and Tamil Nadu account for 60% of tank irrigation in the country. Together, they have nearly 120,000 tanks irrigating 1.8 million ha. In eight districts of Andhra Pradesh and Tamil Nadu, over a fifth of the sown area depends on tank irrigation (Vaidyanathan, 2001). In addition, as source of irrigation, tanks play a significant role in supporting the livelihoods of the marginalised groups and activities like making bricks, pots, baskets, ropes, fisheries etc, in the rural areas apart from numerous other ecological services. In simple words, the entire village economy is linked to the tank directly or indirectly.

Apart from the above-mentioned factors, tanks are eco-friendly and proper management ensure protection and preservation of the micro ecosystem and it provides services like, recycling of nutrients, purification of water, recharge of groundwater, augmenting and maintenance of stream flow and habitat provision for a wide variety of flora and fauna in addition to aesthetic values. It is home for a wide variety of medicinal plant species, which were, used by the rural masses to treat several health disorders. Thus, the tank occupied central part in ecological, economical, social and cultural benefits to its immediate environment. Further, it served as flood moderators during heavy rains and served as water points during drought conditions. Tank irrigation was superior in distributing water, economical in terms of energy utilization compared to the groundwater system or even the major irrigation projects.

But, over time, mismanagement has resulted in decline of tank system, which can be attributed to various factors like interference of the State resulting in disturbing the community institutions. The degree of involvement of farmers itself was reduced as other sources of irrigation like borewells came into existence since the 1980's, further leading to poor resource allocation, encroachments and siltation.

2. THE STUDY

In this context, a study on rejuvenation of tanks and its impacts were taken up in the mid Godavari basin[3]. These tanks are a part of the mid Godavari basin and were built centuries ago. The interlinking channel moved excess water from upstream to downstream tanks. Final surplus flowed into the Godavari river. The system functioned efficiently under the management of village level authorities who contributed to the upkeep of the tank and feeder canals.

Table 1: Some of the Eco-System services of the Irrigation Tanks.

Component	Direct Impact	Indirect
On Groundwater Resources	Recharge of ground water table	Recharge of open wells and bore wells
	Horizontal infiltration of water	Higher level of soil moisture
	Sedimentation of substances	Chelating of chemicals in anioxic sediments
On Land Resource	Moisture content in soil profile	Vegetation growth
Aquatic Flora	Sustenance of submerged, emergent and floating plants	Extension of food chain
Habitat	Diverse and stable habitat with diverse niche for fauna	Extended food web – supporting the natural predators

Inflows into the tanks in this region have decreased due to the expansion of agriculture in the catchment areas. Apart from this, the main links to the tanks have been cut-off with the construction of the Sri Ram Sagar Project Canal. This has given rise to various conflicts concerning rights to water resources. The present status of the system, with the interlinking channels, is mostly in a state of disrepair and the hydrological connections between the tanks have broken down. Extensive deforestation and denudation of the catchments have damaged the catchment's water collecting capacities – resulting in reduced inflows into tanks. Catchment erosion has resulted in rapid silt accumulation on the tank bed and reduced water storage capacity, and decreased groundwater recharge. Unchecked weed growth has further reduced the water storage capacity of tank and the efficiency of the feeder canals. The natural phenomenon of drought was exacerbated by inconsistent agricultural management practices and faulty irrigation norms[4]. In this context, this paper has addressed the valuation of ecosystem services in the context of rejuvenating 'Tanks' in the mid Godavari basin. Various reasons for the decline/degradation of this time-tested system are of the absence of local management, encroachments by public and private with the ultimate result of dilapidated and weak or cut down tank bunds, choked sluices and damaged weirs, sluices with missing shutters, large-scale infestation of weeds, siltation in tank and channels (Raju *et al.*, 2002).

Restoration and rehabilitation of existing irrigational tanks are vital to revive and restore the rural economy. Evolving appropriate methodology on restoration and management can lead to sustainable development. In the current situation, the advantage is that, most of the areas have existing structures and as such do not demand any significant capital investment as compared with other modes of water resource management.

2.1. Tanks of Andhra Pradesh

Andhra Pradesh has 82,500 tanks irrigating more than 48 lac ha of land. At the end of the First Five Year Plan, there were 58,518 tanks in Aandhra Pradesh with an irrigated area of 1.07 million ha, accounting for about two-fifths of the irrigated area of the state. Eight districts of the state were declared drought-prone where tanks were the main source of water supply in these districts for ages. Tanks have been classified into various

[3] Project was funded by WWF- International and desiltation was done by the local NGO - Modern Architects of Rural India (MARI). International Crop Research for the Semi-Arid Tropics (ICRISAT-Hyderabad) conducted the soil analysis and the Institute for Social and Economic Change conducted a study on the socio-economic and ecological impacts of intervention.

[4] This region has also witnessed numerous suicides by farmers for the past few years due to continuous drought because of high debt burden. Maximum number of suicides was reported from Warangal district.

categories for administrative purposes. In Aandhra Pradesh, the Minor Irrigation Department is responsible for its maintenance, repair and water regulation of tanks with ayacuts exceeding 400 ha, and for maintenance and repairs only for tanks with ayacuts between 80 – 400 ha, (40 ha in Telangana), while Panchayatraj institutions maintain the smaller tanks. Similar to other states, the situation with respect to tanks in Andhra Pradesh is also one of negligence. Over the last decade, efforts by various institutions (government, NGOs and collective action efforts) across the country have been striving to revive traditional methods of water management while taking cognizance of modern conditions. Many NGOs have initiated tank restoration and renovation projects, and though they remain minor players, have addressed the immediate issues.

3. STUDY AREA

Warangal district lies between 17^{0} $19^{1}$and 18^{0} 36^{1} north latitude and 78^{0} 49^{1} and 80^{0} 43^{1} east longitude. The elevation ranges from 870 ft to 1700 ft MSL. The geographical area of the district is 12,846 sq. km. About 41% of total area is under cultivation, while 29% is under forest. Current and other fallows account for about 15% and the rest 15% is under miscellaneous category (non-agricultural, barren, grazing land, cultivable waste, etc.). Administratively, the district is divided into four divisions and 51 mandals. The entire area is studded with isolated hills, hill streams, rainfed tanks and large lakes. The soils of the district comprise of sandy loam with patches of shallow black soils, and at places even medium and deep black cotton soil. All the mandals receive about 1,000 mm rainfall mainly through Southwest monsoon. The study was carried in four mandals of the district, which had high percentage of cropped area under irrigation, and irrigated mainly through tanks and open dug/bore wells. The district falls in the catchment of both Krishna and Godavari rivers, two important rivers of Andhra Pradesh. Salivagu micro basin of Godavari river, which has 447 tanks spread over 878.35 sq. km of catchment was selected for the study. Twelve tanks were identified in the Salivagu micro basin for de-silting on pilot basis during 2005-06 (see Annexure I, for the name of the village, tank and the number assigned to the tank and the number is referred in figures). All the tanks were geo-referenced using GPS and a map was prepared using GIS (Fig. 3). The Mid-Godavari Basin (MGB) is endowed with a number of large tanks constructed during the Kakatiya times, which serve as the major source for local irrigation.

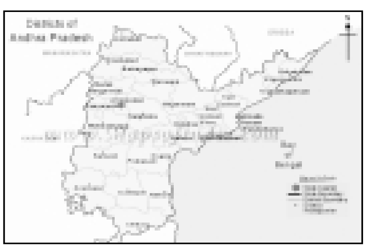


Figure 1: Map of Andhra Pradesh

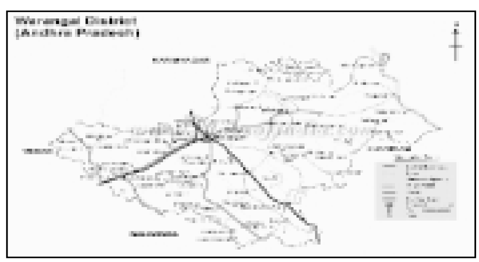


Figure 2: Study Area

Figure 3: Location of Study Tanksanks

The specific objectives of the study included estimating increase in water availability due to desiltation, assessing resultant advantages, both tangible and non-tangible, developing an information gathering process at different levels, which would include data from water users associations, state departments and scientific establishments to establish local institutions for optimum water use; documenting immediate gains versus long-term gains following the restoration process; and preparing a policy document on the valuation of services of the tank– in particular assessing the necessity for their integration in larger irrigation schemes.

The methodology adopted for the study included collection of primary and secondary information. Field studies were conducted at several intervals to note the changes, viz, before and during desiltation, after khariff and rabi crops using indicators to measure impacts and benefits. Informal discussions were held with various groups of people in the village apart from structured interviews and focus group discussions.

3.1 Ecological Impacts of Tank Desiltation

During earlier years, when the village community as a whole used to participate in tank maintenance, desiltation was a primary activity followed by deweeding, strengthening the bunds. The silt from the tanks was applied to the farms to enhance its productivity, as it was rich in nutrients essential for the plant growth. Though desiltation is not the only way to rejuvenate tanks, most efforts involve it, making silt disposal a very important aspect. In the study area, desiltation was carried out by forming various committees within the village and silt thus excavated was lifted by the farmers themselves for field amendments, depending on the nature of silt.

3.1.1 Silt Amendment Benefits

Soil is considered as a pool of nutrients present in both available and reserve forms. Depletion occurs when nutrients do not get replenished from the reserve pool. Depending upon the capacity, the farmers applied 50 – 250 tractor/ha. The tractor has a volume of 2.5 m^3 and when applied it worked to be 1.2cm to 6.0cm depth of soil. 70% of the farmers applied less than 100 tractor loads per ha. 96% of the farmers who applied tank sediment had less than 2 ha of land-holding and 78% of them belonged to backward classes (scheduled caste, scheduled tribe and backward classes). 97% of the farmers applied silt to dry lands. An attempt was made to assess the impact of its application on soil, crop and land use.

3.1.2 Positive Changes in Soil Content

The clay content of the tank sediment ranged from 60%-80% while its application to the field reduced the bulk density of the soil from 1.5 to 1.25 gm/cm^3. Addition of tank sediment at the rate of 50, 100, 150 and 350 tractor loads per ha improved the available water content by 0.002, 0.007, 0.012 and 0.032 gm/gm soil, respectively. All the farmers were in agreement that the moisture retention had gone up by 4 to 7 days, which played an important role during the period of prolonged dry spells. This was confirmed from our studies that the available water content in the root zone had gone up by 1%, i.e., from a normal 6%-7%, which would go a long way in drought-proofing. Farmers did believe that once applied, the impact on crop yield would remain for three years but the invisible aspect was the permanent change in soil physical property. Improved clay and silt content would not only retain higher moisture but would also reduce the losses of nutrients applied through leaching because of improved Cation Exchange Capacity (CEC).

3.1.3 Plant Nutrients from Silt

The quantity of sediment removed from different tanks amounted to 76,393 ton. The total cost incurred in the removal of this sediment amounted to Rs. 1133190. The value of sediment was quantified in terms of fertilizer equivalent costs. The nutrients retrieved from sediment were considered to be the profit (benefit) as against the expenditure (cost) incurred in removing the sediment from the tanks. Additionally, the process of sediment application to farmlands that was rich in organic carbon would result in carbon mineralisation and higher nutrient availability thereby helping plant growth and greater fixation of C through photosynthesis. The benefit-cost ratio ranged from 0.9 to 2.06. The benefit-cost ratio averaged to 1.51 for all the 12 tanks under study.

Average benefits (Table 2) has suggested that desilting operations were not only economically viable but also had additional benefits like environmental protection, increased soil microbial bio-diversity, improved soil quality and increased water storage. If indirect additional environmental benefits were added to the benefits, then there would be even more benefit. Application of sediment back to the agricultural fields formed an improved agricultural management system that enhanced and protected the soil quality resulting in improved production capacity of soil and reversing the process of land degradation.

3.1.4 Increased Yield

Harvest data of Kharif crops have indicated that all the farmers who had applied silt reported increased yield and the details have been given in Annexure 3. As can be seen from the survey results from ten farmers from each of the desilted tank villages, there was increased yield in the crop produce. Highest was observed in groundnut and maize with an average increase of 11.5 qtl / ha and 11.2 qtl/ha respectively in the study area. Lower rates of increase were recorded in case of turmeric with an average of 4.2 qtl/ha. To quantify the economic impact of silt amendment, existing market prices were considered. In all the 12 villages, about 50 ha of land was amended with silt and the resultant economic benefits are presented in Table 2[5].

Table 2: Increased Economic Returns from Enhanced Productivity (in Rs)

Crop	Increased Productivity/ ha in qtl	Market Price / Unit	Economic Benefit / ha	Total Benefits
Cotton	5.75	2,000	11,500	368,0000
Chilly	6	1,500	9,000	108,0000
Maize	11.25	460	5,175	207,000
Groundnut	11.5	1,200	13,800	55,200
Turmeric	4.25	2,600	11,050	33,1500
Total				5,850,500

Source: Survey

3.1.5 Reduced Consumption of Pesticides

With enhanced nutrient availability, vigorous plant growth, higher rate of soil moisture content and microbial population presence (natural predators), the pest incidence was reported less in the silt amended soils thereby reducing the need for repeated application of pesticides. However, the reduction in the pesticide consumption by farmers could also be attributed to the shift to pest resistant types of cotton and climatic conditions. Therefore, though there was significant reduction in pesticide consumption, it was not considered in computing economic benefits (Annexure 3). Summary of the Benefits derived from all the above, silt amendment, increased produce and nutrient recycling has been given in Table 3.

Table 3: Summary of Benefits and Their Economic Equivalents (in Rs.)

Activity	Costs	Benefits
Silt amendment process	1,133,190	
Produce increase		5,850,500
Nutrient recycling		800,018
Total	1,133,190	6,650,519

Source: Survey

[5] Prevailing market prices were considered

3.1.6 Increased Growth of Natural Predators

As a result of reduced use of the agro-chemicals it is, theoretically expected that natural predators of pests would have better chance of survival as pointed by Odum (1992), and this was reported by the farmers who had applied silt. Presence of higher number of natural predators like lady bird beatle (*Epilachna batles*), chysopa, spiders, dragonflies, wasp were observed.

Other positive benefits included increased soil moisture around the tank and enhanced capacity of this wetland ecosystem to provide niche and habitat support to wider species. Here is a brief account of the impact of tank desiltation on the birds. Before this study was undertaken, there was no documentation of the avifauna of these twelve tanks. Though there was evidence of migratory and resident wetland birds, the baseline data did not exist. Based on the orinthological studies and farmers' perceptions it was found that both density and diversity of avian community was better than previous years when drought conditions were prevailing in the study area.

3.2 Socio- Economic Impact

As the tank is central to most of the activities in the village, desiltation activity is bound to have influence on the village life where primary occupation is farm based and very little population is involved in non-farm based occupations, which again is indirectly influenced by farming. The impacts of desiltation in the study area on various activities are as follows.

3.2.1 Increase in the area irrigated before and after Desiltation

The backbone of the economy in the study area is agriculture, which is primarily rain-fed. Some areas exploit the groundwater table, which again is dependent on monsoon. Major crops include rice, cotton, chillies and some horticultural crops. The total command area is 1200 ha. Depending on the water sources, Kharif or Rabi is grown and details of the same are given in Table 4.

Table 4: Total Area Cultivated (Command Area)

Specifics	Before desiltation (BD) 2004-05	After Desiltation (AD) 2005-06
Area Cultivated	Kharif (in ha)	Rabi (in ha)
Wet Kharif	416	1146
Wet Rabi	116	340

Source: Survey

Difference in total area irrigated, before and after the intervention is huge from 416 to 1146 ha in Kharif and 116 to 340 ha in the Rabi[6]. This huge variation is the difference between a drought prone year and best monsoon year. However, for this study, a comparison was made between the area irrigated in the tank command area between two normal years of monsoon when the last time the tank had been filled and after desiltation. The difference is an increase of 58 ha. Table 5 shows the total yield and additional economic value of paddy across villages. However factors like, increased water holding capacity of the tanks due to desiltation, recurring tank filling from Sri Ram Sagar Project (SRSP) in good monsoon and groundwater recharge are equally important. Hence, it cannot be attributed only to desiltation.

Table No 5: Enhanced Production of Paddy

Additional Area Cultivated	Average Yield Per Acre (in bags of 75Kg)	Total Yield	Market Value Per Bag (in Rs)	Total Economic Equivalent (in Rs)
58 hec	34.5	2018	500	1,009,200

Source: Survey

[6]Compared to the year before desilation, the current year has received very good rainfall and thus, the increase in irrigated area can not belinked to the desiltation alone.

Looking at the economic aspect of this extra land where paddy had never before cultivated in Rabi season, would mean that about 58 ha were cultivated this year. The revenue from the extra land that was brought under irrigation in the rabi crop, primarily because of tank desilation resulted in production of paddy, the economic value of which is Rs. 1009200. As opined by the farmers, there was about 25 - 35% profit depending on the number of households engaged in the farming activities.

3.2.2 Reduction in the extraction of groundwater for irrigation

While upland farmers had to depend on the wells for irrigation, command area farmers had the option of making use of open wells (depending on their existence) or tanks for irrigation, depending on the availability of water. A comparison was made on the source of irrigation and number of times irrigation was provided to the major crop, i.e., paddy before and after desiltation. The primary objective was to compare groundwater extraction and number of irrigation during different years. The results given in Table no.6 have shown that after desilting, no farmer in command area of these 12 tanks had used groundwater for irrigation during Kharif crop, as tank water was sufficient, with a result of reduced groundwater use.

Table 6: Number of Irrigations and Source for Paddy

Village	Before Desiltation (BD)			After Desiltation (AD)			
	Kharif		Rabi	Kharif		Rabi	
	Tank	Well		Tank	Well	Tank	Well
1.	8	5	No crop	16	Nil	19	
2.	10	6	No crop	16	Nil	12	
3.	10	6	No crop	15	Nil	13 to 15	
4.	10	6	No crop	17	Nil	14 to 16	
5.	4	7	No crop	15	Nil	6	12
6.	6	10	No crop	16	Nil	16	2
7.	4	12	No crop	4	Nil	10	6
8.	13	5	No crop	16	Nil	18	
9.	7	9	No crop	15	Nil	20	
10.	11	5	No crop	15	Nil	18	4
11.	10	7	No crop	16	Nil	20	
12.	10	6	No crop	15	Nil	16-18	

Source: Survey

As evident form Table 6, though the number of irrigations required remained more or less the same, the source of water, after desiltation continued to be tank unlike the previous year when groundwater was used significantly even for Kharif and no Rabi crop was grown. Only four villages used groundwater to irrigate paddy.

3.2.3 Electric Power saving

The water from the tank flows under gravity and does not require any power in contrast with groundwater, which needs to be lifted using electricity, thus tank water use save electricity. As the State government was not collecting any charges for electricity for irrigation economic savings were not calculated. If one takes the power tariffs into account, for irrigating one ha of paddy it requires 10-15 hrs of pumping of water and money saved would be enormous.

3.2.4 Augmented water flow distance

In addition to the recharging of groundwater, more water in the tank made the water flow longer distances when the sluice gates opened for irrigation thus enabling the lower reach farmers to cultivate. To study the impact of desiltation on the distance of flow of water, comparison was made between the distances of water travelled in the current year with that in previous year. With water flowing longer distances in distributory canal network the fields in the lower reach could also be irrigated as shown in Table 7. Again, this could be attributed to desiltation coupled with good monsoons.

Table 7: Distance of Flow between Head and Tail-end farmers (in kms) (Rabi)

Village	Ideal flow distance Sluice 1	2004-05 BD			2005-06 AD		
		Head Reach	Mid Reach	Tail Reach	Head Reach	Mid Reach	Tail Reach
1	1.0	0.5	Nil	Nil			1.0
2	1.0	0.5	Nil	Nil			1.0
3	1.5	0.5	Nil	Nil		1.0	Nil
4	1.5	1.0	Nil	Nil		1.0	Nil
5	2.0	1.0	Nil	Nil			2.0
6	2	Nil	Nil	Nil		1	Nil
7	3.0	Nil	Nil	Nil		1.0	Nil
8	1.0	Nil	Nil	Nil		2.0	Nil
9	2.5	1.5	Nil	Nil		2.0	Nil
10	1.0	Nil	Nil	Nil	0.5	Nil	Nil
11	2.5	Nil	Nil	Nil	0.25	Nil	Nil
12	2.5	1	Nil	Nil			2.5

Source: Survey

3.2.5 Improved employment opportunities for landless labourers

Around 30% of the villagers were landless labourers. Depending on the demand for labour and its availability, the wages were determined. General daily wages were Rs.50 for men and Rs.25 for women. Due to failure of monsoon in the previous years, there was very little work in the farm sector. However, after desilting and good monsoons, this year there was good demand for labour. Further, with the introduction of National Rural Employment Guarantee Scheme, off-season period also provided significant employment opportunities.

From Table 8, one can see that the number of person-days in the Kharif season itself equaled the employment that was offered during the previous year. However, on account of tank desiltation, an additional area of about 58 ha was cultivated with paddy and without desiltation, this would not have been possible. Cultivation of one hectare of paddy requires about 200 man-days. Thus 58 ha have potential of providing employment in Rabi season. This increase was the result of only 30% desiltation work and would increase if the rate of desiltation were higher.

Table 8: Additional Employment Generated - Agriculture

Additional Hectares Irrigated	Number of Man-days /ha of Paddy	Total Man-days	Daily Wages in Rs.	Economic Equivalent in Rs.
58	200	11,600	45	5,22,000

Source: Survey

3.2.6 Boost in fodder production

A primary factor that influenced the livestock population in the village was the availability of fodder and water. In the previous years, on account of the total failure of the paddy crop, entire villages were forced to buy fodder with the exception of one village, which had three water sources. On the contrary, this year as most of the catchment area was cultivated, there was surplus fodder. Previously, both on account of poor monsoon and less water holding capacity of the tanks, the area cultivated was lesser with the result of perennial shortage of fodder. As can be seen, with significant increase in the area of paddy cultivation this year, there was no fodder problem for the cattle. Looking from an economic point of view, fodder from one ha would be about eight cartloads and would suffice for a pair of cattle for a year and cost about Rs. 5000 in normal demand year.

The fodder from 58 ha in the command area of 12 tanks could support extra 150 pairs of cattle for one year. A pair of cattle in a year produced about two cartloads of organic manure which was very much in demand. The present price for a cartload of cattle manure is about Rs.100. Therefore, the total economic value of manure that would be produced from 150 pairs of cattle would be Rs. 15000. This appears to be a small amount but it has added effects. For instance, with organic manure use, the consumption of synthetic fertilizers would be reduced. Soil biota thrive better without these chemicals and create a better soil ecosystem which helps healthy growth of the plant with less requirement of pesticides. The economic quantification of these impacts is difficult to measure and is a long drawn process and not undertaken in this study[7] .

3.2.7 Enhancement in fish production

Investments and profits derived from fishries before and after desiltation indicate major change as indicated in Table 9. This year, there appears to a net profit of Rs. 167000 in all the tanks together. The reason for the losses in the year even when the tank was filled previously could be attributed to the less duration of water available for the fish growth as there was conflicting interests between the farmers and fisher community, while the former wanted to go for rabi crop and latter opposed. However, being minor stakeholder, the fisher community had to accept the irrigating during the rabi with a result of poor fish harvest.

Table 9: Fish Harvest Before and After Tank Desiltation (in Rs.)

Village	Last time when tank filled		After tank desiltation	
	Investment	Profit	Investment	Total Profits
All 12 villages	584,000	122,000	595,000	762,000

Source: Survey

With the desiltation of tanks, the following changes took place in the tank aquatic ecosystem, viz., increase in the retention of water in the tank as well as the depth which was also a determining factor for the fish growth and secondly, release of micro-nutrients which otherwise were locked in the anixioc sediments of the lake which promoted better plankton growth in the lake. All these changes, contributed to good harvest of fish.

3.2.8 Better benefits to washerman community

Traditionally, washermen depended on tanks for washing clothes. With the tanks being in the proximity of the village and the availability of water would reduce the time required to complete their work and allow them to attend to work on their own lands or as labourers. With the drying up of the tanks in previous years, this community faced inconvenience, both in terms of commuting long distances for washing clothes and missing the limited employment opportunities in the farm based activities. Inconveniences were encountered with the

[7] Another benefit of livestock is that it is used for seeding in the cotton fields. Only animal drag power is used. Mechanized means cannot be used after seeding, but only bullocks can be used. Generally, Rs. 150 was paid to the man with bullocks and in a year, about 150 days, the oxen remain occupied.

onset of summer, beginning from January to April, depending on the strength of monsoon. During lean monsoon years, it was common for them to even walk up to 3 km in some villages in search of bore wells or other water sources. At times, they were forced to request bore well owners for water to wash clothes. Though the prevailing drought conditions during previous years had not made much difference in the employment of washer community, during discussions with them, it was generally opined that with good monsoons, they also engaged in farm activities and required less time to spare and good economic returns.

3.2.9 Decline in migration

The impact of varying water level hits hard, particularly the landless as most of them earned wages on daily basis. During poor monsoon, there was significant amount of out-ward movement of labour from the villages to urban centres seeking employment. In the process, young and old people were left behind in the village. This phenomena, however, appeared to have changed in the study area from this year. Migration to urban centers was highest in summer months and previous year being drought year, there was significant daily and seasonal migration.

However, as desiltation work was carried out in summer, it provided employment opportunity for the labourers, with the result of no migration. With the onset of monsoon, farming activities started requiring all the labour for farm activities resulting in no migration at all. However, some sections of the village, like washerman community and fishing community had reported migration for better employment. Compared to previous years, this year the migration rates had shown a drastic reduction in both short-term and long-term migration.

Table 10: Migration during Crop Season

Specifics	BD	AD
Total families	528	70
Short term	267	45
Long term	98	10
Everyday	300	80

Source: Survey

3.2.10 Reduced drinking water problems

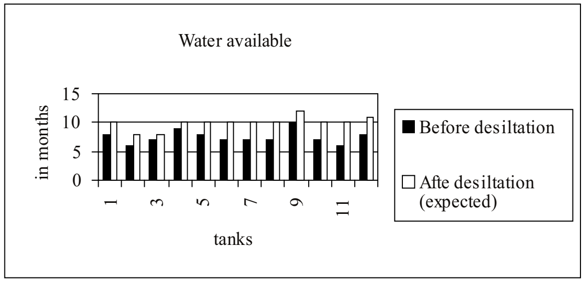
To meet the requirement of water both for domestic and agricultural purposes, the community used open and bore wells to cater to the domestic requirements of the village community and private open and/or bore wells for agricultural demands. The quantum of water available in these sources was primarily dependent on the recharge rate of the groundwater table, which, in turn, was based on monsoon and percolation rates of precipitation with a direct relationship between quantum of water in these sources and water percolation. During previous years, insufficient percolation resulted in drying up of most wells (Figure 5).

From the tables, it is quite clear that there was remarkable groundwater recharge after tank desiltation with the result that many bore and open wells are now active. More than 50% of the wells were functional after tank desiltation and this could be attributed directly to tank desilation partly and good monsoons. The removal of compact silt enhanced the groundwater table recharging and with enhanced water holding capacity, more recharge was possible.

3.2.11 Increased water holding capacity of the Tank

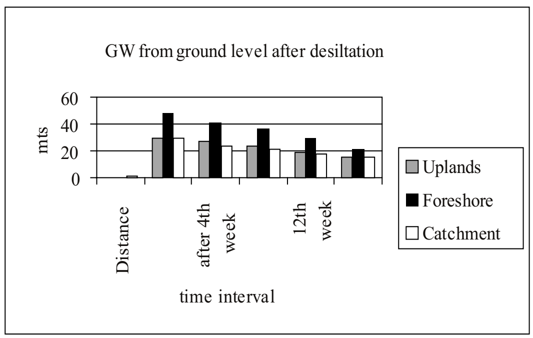
One of the most tangible impacts of any desiliation programme would be the enhanced water holding capacity of the water body. However, the duration of water holding depended on the location of desiltation as it determined whether water would be drained out for various purposes or would remain in the tank. In the study area, desiltation was carried out at places desired by the farming community and location of these places was such that the water would not drain out but would remain in the tank. A comparison has been made regarding water available in the various tanks between the scenario before tank desiltation and present year.

Figure 4: Water Availability



As can be seen from Figure 4. water in all the tanks was available for longer period of time as compared to before desiltation. With the water available and with removal of compacted silt, ground water table got recharged continuously. This was very useful for plant growth as more soil moisture would be available in the root zone. A study was made to understand the impact of desiltation in wells in three regions, viz. foreshore, uplands and command area.

Figure 5: Water Table Fluctuations in Villages



Water retention in the tanks coupled with copious rainfall recharge groundwater. With the groundwater table coming from about 40 ft to as high as 4ft in some villages, it was nothing but natural to assume, that the root zone in the soil profile had high content of moisture. Even after the 16th week after the onset of monsoon, Groundwater table showing this results indicate that even for the coming months, the moisture content remained and promoted both plant growth and detritus cycle in the A, B horizons of soil profile. This faster rate would enable higher recycling of both micro and macronutrients which enhanced the health of the soil profile.

4. INSTITUTIONAL MECHANISMS

The benefits of tank maintenance was well recognized and the same was interwoven into various religio-cultural aspects of the village which made participation of the entire village in tank upkeep a norm over the years. However, with policy shifts only about two centuries back, the prime concern was revenue generation and put a back burner to other systems of water resources management. This alienated the village community from tank upkeep efforts, and subsequent deterioration of tank as an ecological entity. Various stakeholders are dependent on the tank, thus the potential of conflicts are a norm.

Table 11: Conflicting Situations

Situation	Potential Conflict
Lack of water	Between head reach and tail reach farmers
	Between command area farmers and other stakeholders
Surplus water	Between headreach and tail ender regarding the Rabi crop
	Fishries and livestock rearing

All these conflicts used to be resolved within the village with amicable solutions, but with state intervention conflict, resolution entered the domain of formal conflict resolution mechanism, which suited very stakeholders. This resulted in the farming community adopting the energy-subsidized bore wells and marginal stakeholders shifting to other occupations. All these changes had a cascading effect on the tank's health where very few farmers had interest in the tank. For others, tank maintenance lost its significance.

Recent changes to introduce the local management of these micro watersheds, no doubt a good beginning in the decentralization in natural resource management, still isolate a few sections of the community – mostly command area farmers and no role for other stakeholders. For the optimum efficiency of the decentralization efforts, as was attempted in the Andhra Pradesh in the form of Andhra Pradesh Farmer's Management of Irrigation Systems (APFMS) Act, other stakeholders should be provided direct role in the tank management.

5. SUMMARY OF FINDINGS

Thus, to sum up the benefits of silt amendments in the agro ecosystem, survey of 120 farmers across tanks indicate that it is economically and environmentally beneficial. All the benefits and their economic equivalents terms have been given in Table 12 and 13.

Table No: 12: Economic Quantification of Benefits accruing from desiltation of tanks

Activity	Quantum	Economic equivalent	Remarks	Total (Rs)
Tangible				
Paddy Cultivation	Additional area of 58 ha	With yield of 2018 bags	Each bag @Rs. 500	1,009,200
Fisheries	Increased production		Average Rs.25/kg	167,000
Fodder production	1 tractor load / acre	150 tractor loads	Each load @ Rs. 2,000 and can support couple of cattle for one year	300,000
Total benefits				1,476,200
Total Costs				1,133,190

Table 13: Approximate non-tangible benefits

Non-Tangible	Service	Output	Unit value	Total in Rs
Organic manure production	240 cattle can be supported	120 cartloads of OM	Each cartload is @Rs. 100	12,000
Farm Traction	Weeding in cotton field	@Rs. 50 / 150 days		7,500
Milk production	Assuming 2 lt @ Rs. 10 and 50% of cattle are buffalows and milk production is only 6 months	240 lt/day	Rs. 2400 /day	21,600
Silt Amendments	Reduced fertilizers		Each bag is about Rs. 200	24,000
Total Benefits				65,100

Further, the study shows very good rate of return based only on the Kharif and Rabi results of one year. Benefits of the silt amendment are expected to last for 3-4 years, but with slow decrease in impacts.

6. WAY FORWARD

From a hindsight, involvement and active participation of the village community by formation of various committees for tank restoration process would have taken longer time but for the intervention of Community Based Organizations. Influence of the drought conditions prevailing in previous years was also one of the drivers coupled with Collective Action in the study villages. Participation of the community was essential for the optimization of these efforts. Tank desiltation is one part of the management while management of inflow and distributory network, cropping pattern forms the other component. Through Water User Association, a holistic management model needs to be adapted wherein interests of other stakeholders like fishing community also receive consideration. Mobilization of financial resources could be from NREGS and other such schemes. Some farmers were unable to lift silt for the field amendments on account of financial reasons at the time of desiltation and financial institutions may be motivated to extend loan facility for this purpose.

ANNEXURES

Annexure 1: Tanks and Villages Identified and Desilted

Tank Number	Tank name	Village Name
T1	Pedda Cheravu	Koppula
T2	Tummala Cheravu	Relakunta
T3	Yerra Cheravu	Rudragudam
T4	Pedda Cheravu	Chinnakodipaka
T5	Bokki Cheravu	Gorikothapalli
T6	Thimmanakunta	Gangerenigudam
T7	Reddy Cheravu	Nizampalli
T8	Moggulacheravu	Pathipaka
T9	Pedda Cheravu	Dammanapet
T10	Oora Cheravu	Rayaparthi
T11	Oora Cheravu	Repaka
T12	Venkarapalam Cheravu	Muchimpalla

Annexure 2: Economic Valuation of Tank Sediment in Terms of Plant Nutrients Returned to Farm

Name of village and tank	Quantity of sediment (ton)	Amount spent (Rs.)	Nutrients in terms Rupee equivalent					
			N	P	K	Zinc	Boron	Total
Koppula	4478	59700	20903	2711	17931	479	801	42828
Relakunta	7034	93780	55388	9523	34059	4268	1007	104247
Rudragudum	14184	189120	52679	4888	35668	2025	4062	99324
Chinnakodipaka	7853	104700	47423	24358	36152	1028	1405	88445
Gorikothpally	11356	151410	66364	7156	41703	7567	2032	124825
Gangrirenigudum	1355	18060	8087	1100	5918	145	339	15591
Nizampally	7538	100500	34999	1781	20221	1973	1079	60055
Pathipaka	4084	54450	18878	1668	16376	388	731	38044
Dammanapeta	2100	50400	12027	3029	8686	399	375	24518
Rayaparthy	3713	89100	17218	6453	14816	309	531	39329
Repaka	4938	118500	30312	3039	24262	528	1060	59203
Munchupla	7760	103470	65747	5157	29649	1662	1389	103605

Annexure 3: Yield Details from the Silt Amended Fields in Kharif

Name of the village and tank	Quantity of silt (ton)	Amount spent (Rs.)	Market rate and agro produces per quintals in Rs				
			Cotton @Rs.2000	Maize @Rs.460	Chilles @Rs.1500	Ground Nut @ Rs.1200	Turmeric @ Rs. 2600
Koppula	4478	59700	2	5	2	5	1.5
Relakunta	7034	93780	2	4	3	4	2
Rudragudum	14184	189120	2.5	5	3	4	2
Chinnakodepaka	7853	104700	2	5	2	5	1.5
Gorikothpally	11356	151410	2.5	5.5	2	5.5	2
Gangrirenigudum	1355	18060	2	4	3	4	1.5
Nizampally	7538	100500	3	5	2	5	2
Pathipaka	4084	54450	2	4	3	4	1.5
Dammanapeta	2100	50400	2	5	2	4	2
Rayaparthy	3713	89100	3.5	4	2	5	2
Repaka	4938	118500	2	4	3	5	1
Munchupla	7760	103470	2	4	2	5	1.5
Average			2.3	4.5	2.4	4.6	1.7

Annexure 4: Reduced Consumption of Pesticides

Name of village and tank	Quantity of sediment (ton)	Amount spent (Rs.)	Bt Cotton	Chillies
Koppula	4478	59700	6000	5000
Relakunta	7034	93780	5000	4500
Rudragudum	14184	189120	4500	6000
Chinnakodepaka	7853	104700	6500	5500
Gorikothpally	11356	151410	5000	5000
Gangrirenigudum	1355	18060	4000	4500
Nizampally	7538	100500	5000	6000
Pathipaka	4084	54450	4500	5500
Dammanapeta	2100	50400	4500	6000
Rayaparthy	3713	89100	5000	7000
Repaka	4938	118500	4500	4500
Munchupla	7760	103470	3500	5000

Annexure 5: Status of Open Wells in the Study Area

Details	Open wells			Borewells		
	Total	Functional last summer (BD)	Functional present summer	Total	Functional I BD	Functional present summer
Village (GP)	39	13	20	68	66	67
Private	1741	492	1133	149	48	87
Command Area	284	55	154	26	6	24
Upland Area	1468	273	616	240	51	157
Total		833	1923		171	335

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WATER TABLE BEHAVIOUR IN PUNJAB: ISSUES AND POLICY OPTIONS

Karam Singh*

Abstract

Punjab faces a sever problem of declining water tables by as much as 10 – 15m in most parts. The paper focuses on groundwater behavior in various parts (Blocks) of the Punjab in categories of low to high rainfall regions, saline to sweet groundwater zones, scanty to extensive canal water supply areas, the uplands to riverbeds and the cropping pattern in terms of low to high water intensive crops. Any changes in these parameters will affect the recharge and withdrawal of groundwater. In was found that as the area under rice cultivation increased, there was a corresponding decline in ground water recharge. It is often advocated that pricing policy for wheat and rice (Minimum Support Price (MSP) and its effectiveness) and free electricity supply are responsible for the critical ground water situation in Punjab. The paper tires to examine this and look at policy measures needed to address the situation.

1. INTRODUCTION

The groundwater situation in Punjab has been a serious issue for a long time now. The total water requirement for Punjab, with the present cropping pattern and practices and industrial uses, is estimated at 4.33 million ha metres. It varies from 4.30 to 4.40 million ha metres. The total availability of water is estimated at 3.13 million ha metres out of which 1.45 million ha meters is from canals and 1.68 ha meters is from rainfall and seepage. The deficit of almost 1.20 million ha metres is met by ground water withdrawal. The recharge rate is not able to match the rate of withdrawal. This has led to a decline in the water table in Punjab[1]

The annual rainfall in Punjab ranges from over 300 mm in 21 rainy days in the Western part to over 1100 mm in 48 rainy days in the North and North Eastern part. Mean annual rainfall during 1973 to 2005 was 600 mms in 32 rainy days. Almost 80 % of the rainfall comes in the monsoon period with about 57% falling in the months of July and August. Monsoon rain recharges groundwater for use during the remaining period. The heaviest rainfall of 1123 mm was recorded in 1988, when there were floods in the entire state. In 1997, the state received 709 mm rainfall, which was more than the state average.

There are three major perennial rivers - the Ravi, the Beas and the Satluj – in Punjab and their water is stored at Bhakra Dam, Ranjit Sagar Dam and Pong Dam respectively. This water is supplied through a vast canal network of about 14500 kms including distributaries and minor canals to irrigate about 1.6 million hectares (m ha) of land. The canal water supply is more extensive in the South western zone of the State, which receives less rainfall and high salinity in groundwater. This is the cotton-wheat dominant cropping belt and covers about 34 % of the cultivated area of the state.

Out of the total net sown area 96% is irrigated. The entire irrigated area is double cropped every year with a cropping intensity of 187 %. Rice and Wheat cover about 75 % of the total cropped area in the state. There are 11.44 lakh tubewells (8.56 lakh electricity operated) for groundwater abstraction for irrigation.

The paper focuses on groundwater behaviour in various parts (blocks) of the state in categories of low to high rainfall regions, saline to sweet groundwater zones, scanty to extensive canal water supply areas, the

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uplands to riverbeds and the nature of cropping pattern in terms of low to high water intensive (application, actual and tolerance vs requirements) crops. Any changes in these parameters will affect the recharge and withdrawal of groundwater, which is simulated. It is often advocated that pricing policy for wheat and rice (Minimum Support Price (MSP) and its effectiveness) and free electricity supply are responsible for the critical ground water situation in Punjab. The paper tires to examine this and look at policy measures needed to address the situation.

2. DATA AND METHODOLOGY

Hydrologically and agro-climatologically, Punjab is divided into three distinct zones - Foothill, Central and South-Western zones.[2] To study the movement of water table, which is significantly affected by the rivers flowing through the state, it is better demarcated into three regions, which are also culturally and historically called Majha (Between Ravi and Beas rivers – 29 Blocks), Doaba (Between Beas and Satluj rivers – 30 Blocks) and Malwa (South of Satluj river – 73 Blocks). The study is based on the data monitored and collected by the hydrological division of the department of agriculture, Government of Punjab since 1973. To begin with, the Department of Agriculture selected open (observation) wells and started recording the depth of water level in these wells during June (pre-monsoon period) and October (post-monsoon period) between the 10th to 25th of the month. When one observation well dried up, another well in the same village was selected. Later Piezometer wells (PZ meters) were installed. As many as 1842 observation points (wells and/or piezometer tubes) have been set up, though the maximum number of observations at any point of time were only 708. This was because some of the observation wells dried up in between. (This is a preliminary indicator of the enormity of the problem of depleting water table).

Each block carries a number of observation wells but the water table movement does not necessarily follow the block boundaries. Thus grouping of blocks into regions and sub-regions was difficult. Matching was done following the principle of continuity at the same time trying to include every block in every sub region using individual judgment[3].

The impact of rice area on groundwater table was scanned by observing the change in recharge during the monsoon season in those years which received almost similar rainfall. The area was scanned for each region along with the corresponding withdrawal during the rabi season. The recharge required to strike a balance was estimated using regression of recharge on rainfall and rice area.

To correct the water balance measures such as maximizing efficient surface water use, reducing water demand by restructuring incentives (competitive pricing of electricity for irrigation) and improving the water use efficiency are suggested.

3. WATER TABLE BEHAVIOUR IN PUNJAB AND ITS DETERMINANTS

An overview of the water table behaviour (Table 1) shows that although the water table in Punjab has been declining over a large area, there is a belt of 9 blocks in the south west of Malwa Region where the water table has been rising (Map).

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[2] These zones are:

1. Foothill Zone/ Kandi Area: 19 % area; Gurdaspur, Hoshiarpur and Ropar;
   Annual rainfall =950mm, groundwater is sweet but in areas difficult to explore
2. Central Zone: 47 % area, Amritsar, Kapurthala, Jalandhar, Ludhiana, Sangrur and Patiala
   Annual rainfall = 650 mm, groundwater sweet and extensively used; Water table declining
3. South Western Zone: 34 % area; Ferozepur, Faridkot and Bathinda.
   Annual rainfall = 400 mm, groundwater saline, canal water more extensive & precious

[3] The readers may feel that some other sub region or blocks should have been included and not the ones chosen for study.

The riverbed region has 35 blocks with each region (Majha, Doaba and Malwa) having 10 – 14 blocks. It is a rice growing area, though traditionally rice was grown more in the Majha and Doaba regions[4]. The water table in the riverbed blocks has been declining only gradually. The central block consists of 50 blocks out of

Table 1: Preliminary scan of water table situation, region wise, Punjab, 1973 to 2006

Particulars	Majha	Doaba	Malwa	Total
Number of observation point:				
Installed so far	430	464	948	1842
Actual: June 1973	145	141	288	574
Actual: June 2006	159	169	262*	590
Maximum 178	171	359	708	
		Number of Blocks		
Total	29	30	73	132
As river bed	11	14	10	35
Water Table behaviour (No of blocks)				
Rising	0	0	9	9
Static / fluctuating@	7	9	18	34
Declining	22	21	46	89
Rate of decline:				
Gradually	18	11	27	56
Severe: Around 10 metres or more	4	10	19	33
Severest: More than 15 metres	1	2	9	12
Water table level 1973 → 2006 (meters) Up to 5	12 → 1	6 → 1	29 → 11	47 → 13
5 to 10	14 → 12	20 → 7	32 → 17	66 → 36
10 to 15	2 → 11	4 → 7	3 → 21	9 → 39
15 to 20	1 → 1	0 → 10	4 → 17	5 → 31
Above 20	0 → 1	0 → 5	5 → 7	5 → 13
Water table behaviour zones:				
I. Rising	0	0	9	9
II. River bed (Gradual decline)	11	14	10	35
III. Central: Going deep	10	6	13	31
" deeper	1	1	13	16
" deepest	0	0	6	6
IV. Other: Fluctuating, generally static, declining lately	7	9	22$	36

[4] The river beds on both sides of the river taken together makes the Majha and Doaba Central regions look smaller. Rainfall and Rivers in Punjab is given in Annexure 2.

* Relates to 2005

@ Some adjoining blocks with few observations are clubbed and considered as one block

$ There is declining water table since 1999 or so in some of these blocks of which 6 are in the East, 9 in middle south and remaining in the west of Malwa region.

which 8 blocks are in Majha, 10 in Doaba and 32 in Malwa. Rice is intensively cultivated here. The water table here has been declining at varying degrees. The Foothill or Kandhi zone in the North / East side comprises 22 blocks and has a fluctuating water table and though the water is sweet, exploration is difficult. In the blocks in the South West of Malwa region the water table is generally shallow but fluctuating. In some blocks it has been declining since 1999.

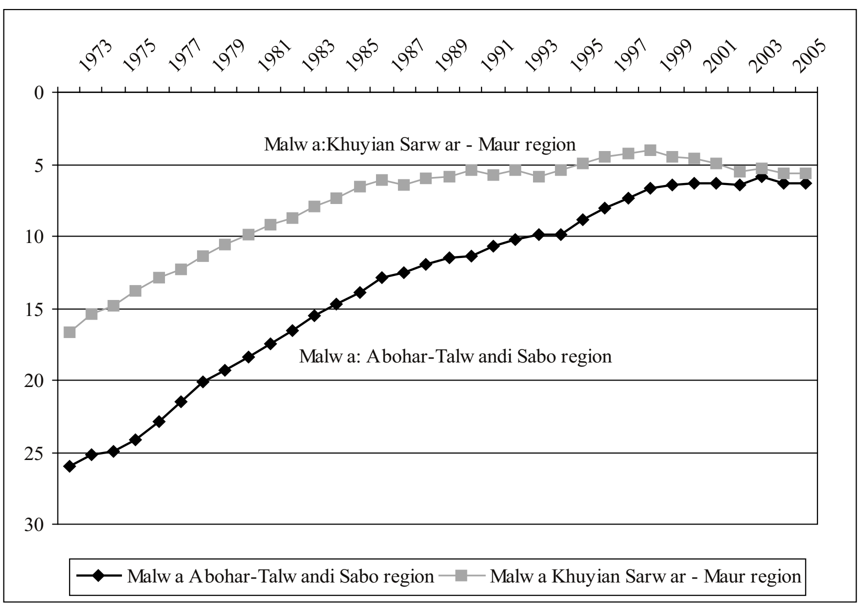
In 1973, there were as many as 113 blocks where water table was less than 10 metres, 9 blocks where water table was 10 to 15 metres and only 10 blocks with water table at more than 15 metres (most of which were in the south west with water unfit for irrigation and these had rising water table). In contrast, in 2005-2006 there were only 44 blocks with water table at more than 15 metres depth, 39 blocks where the water table was 10 to 15 metres and 13 blocks with water level of 5 meters. These 13 blocks like in the Malwa block where water table has been rising.

In Punjab, the water table situation is becoming critical, especially in the Malwa region, which was traditionally not a rice growing area. The situation is less critical but still serious in Doaba and Majha region, where the proportion of the rice cultivation was traditionally higher.

3.1 Rising Water Table Zone

In two sub regions in the Malwa region, the water table has been increasing, which is creating problems of waterlogging. In the 4 blocks of Abohar to Talwandi Sabo sub-region, the water table has gone up from more than 25 meters in 1970s to 5–6 meters in 2003 (Figure 1). Just above these blocks, in the 5 blocks from Khuyian Sarwar to Maur, water table rose from 17 meters in 1970s to 5 metres in 2003 (Figure 1). In both cases, the water table was 5 meters before monsoon. The water is saline and unfit for irrigation. The only solution is draining out the water but it requires huge investment.

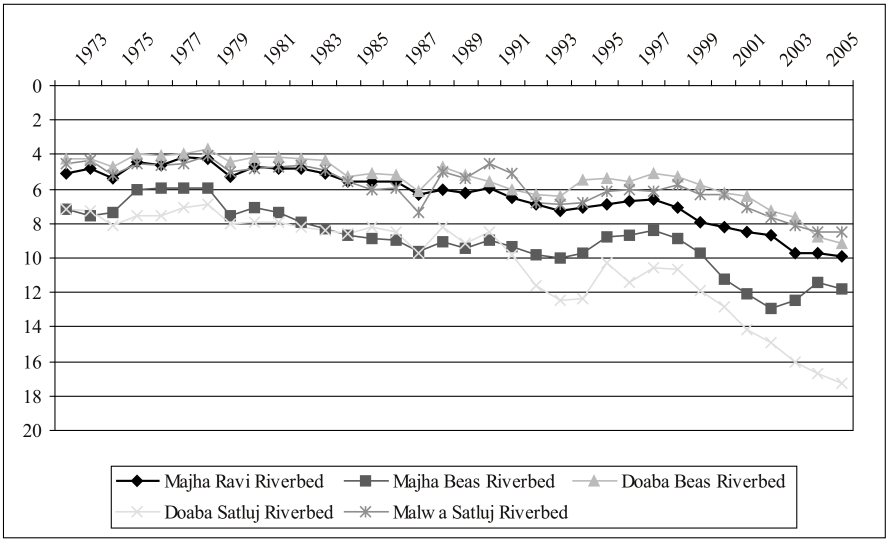
Figure 1. Trend in water table in south-west Malwa sub-region



3.2 River Bed Area

The blocks in the riverbed on the South side of the river (Malwa-Satluj, Doaba –Beas and Majha – Rawi) show a slight decline from 4–5 metres in 1983 to 6-8 metres in 2000 and further to 8–10 metres in 2006. The North side riverbed blocks (Doaba Satluj and Majha – Beas) showed a decline in water table from 8 metres in 1973–75 to 13–15 metres in 2003 though from 1975 to 1979 the water table rose (Figure 2). In Shahkot, Nakodar and Sultanspur blocks in the Western clip of Doaba, the water table declined by more than 10 metres. There were 8 Blocks in all in the Doaba region where water table dropped by more than 10 metres.

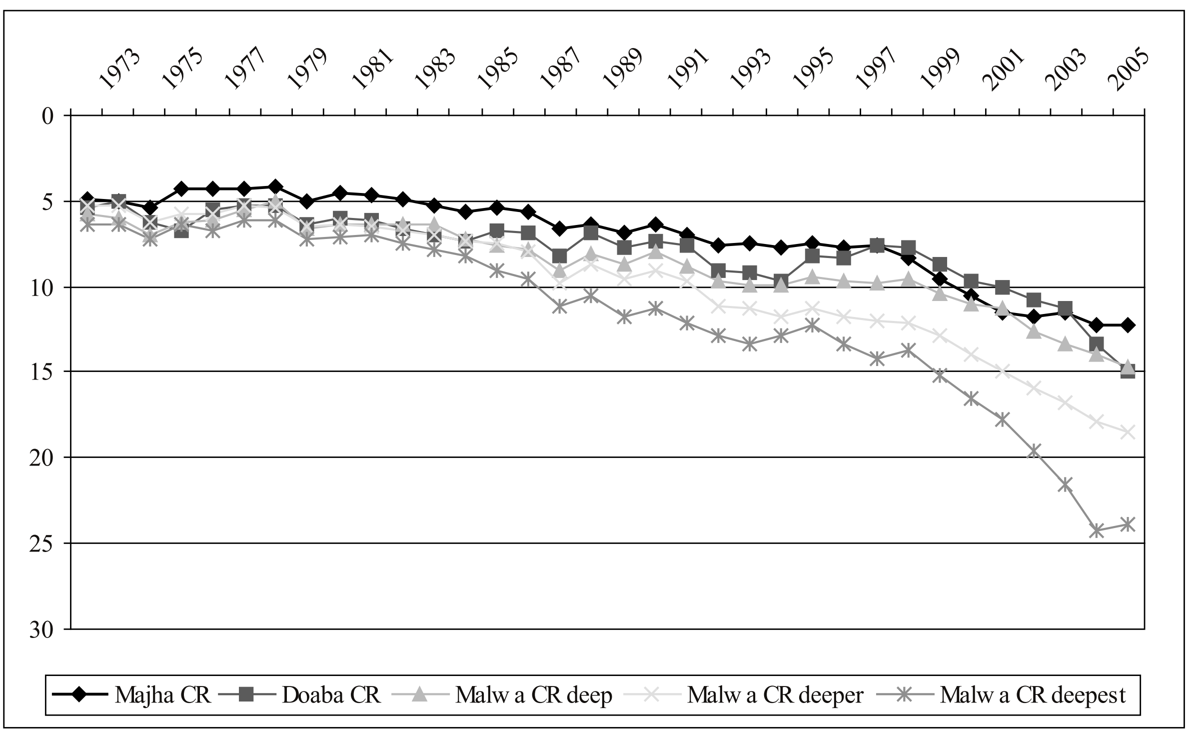
Figure 2. Trend in water table in the riverbed blocks



3.3 Central sub-regions

In all the zones, the central sub-regions are the worst hit. In 1970, the water table in all the central sub-regions was found at 4 to 7 metres. In the Majha Central region (11 Blocks), it has gone down to more than 12 metres and in the Doaba central region (7 Blocks) it has gone down to more than 14 metres. The Malwa Central region is the worst hit where in 13 blocks the water table has gone down to 15 metres, 13 blocks where it has gone down to 20 metres and 6 blocks where it has gone down by more than 24 metres (Figure 3). In 18 blocks of Malwa, the water table has gone down by more than 10 metres, in 9 of these blocks the water table has even gone down by more than 15 metres.

Figure 3. Trend in water table in the Central blocks



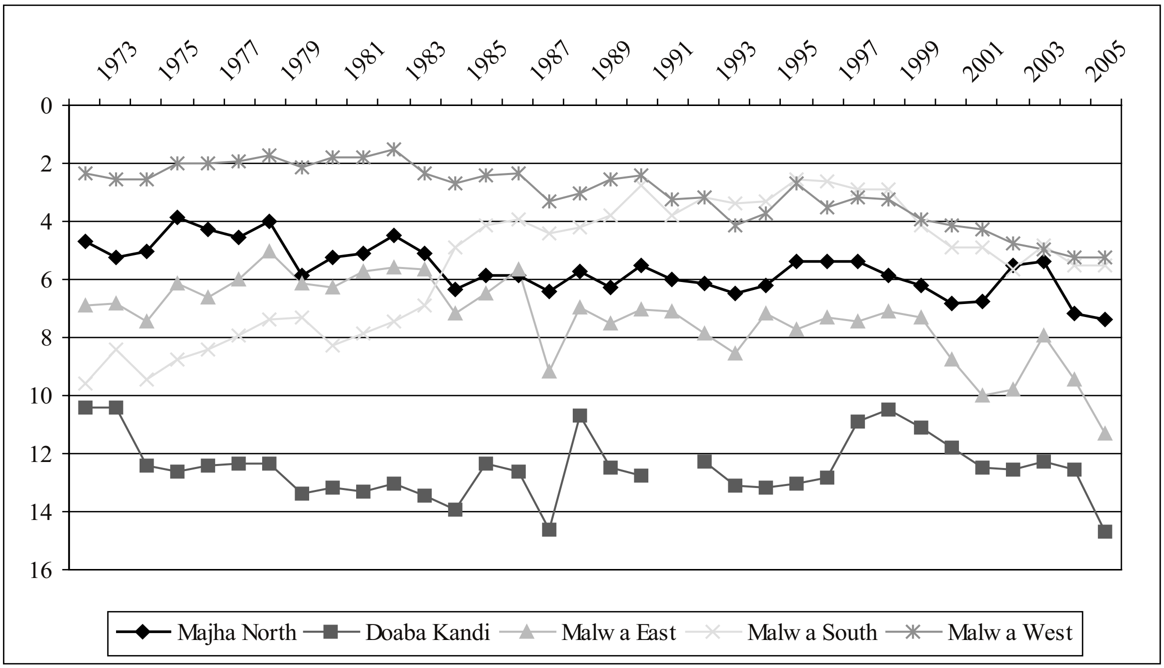
3.4 Static, fluctuating and lately declining water table area

The key observations on water table situations in the other regions are shown in Figure 4.

Majha North	(6 Blocks):	Fluctuating a little but more or less static
Doaba Kandi	(9 Blocks):	Fluctuating but more or less static
Malwa East	(6 Blocks)	Fluctuating widely but more or less static
Middle South	(9 Blocks)	Fluctuating widely with lately declining trend
Western	(7 Blocks)	Shallow, fluctuating and static / some decline

The water table scenario in Punjab is getting worse, more so in the Central Region[5] where there is concentrated rice cultivation. The Malwa central region where rice was not an important crop in early 1970s, is now a dominant rice growing area and worst affected. Malwa region has witnessed major groundwater fluctuations from mild to gradual to serious decline in some places and rising water tables in other places. Some sub regions in Malwa have seen wild fluctuations, more or less static or mildly declining water table.

Figure 4. Trend in water table in the other regions[§]



Grouping the Blocks according to different water level depths in 1975 and 2005, in the categories of up to 5, 5-10, 10-15, 15-20 and above 20 metres shows the up and down of water table more literally (Table 2)[6].

- In 1975, there were almost 90 per cent blocks (27, 25 and 63 out of 29, 30 and 73 blocks in Majha, Doaba and Malwa respectively) where water table was up to 10 metres in June. But in June 2005, there were as many as 16, 20, and 45 blocks in these regions respectively, i.e. more than ½ to 2/3rd where water level was more than 10 metres deep.

- 27, 37 and 21 per cent blocks in Majha, Doaba and Malwa had the same water level in 1975 as well as in 2005

[5] The Central Region of Majha, Doaba and Malwa is different from the Central Punjab

[6] The rise or fall from Table 2 is shifting from one group to another one and is thus an approximation and could give some difference from the actual numbers explained elsewhere

Table 2. No of blocks according to water table depth in 1975 and 2005

1975 (metres	Water table level in 2005 (metres)					
	Upto 5	5-10	10-15	15-20	> 20	Total
MAJHA						
Upto 5	1	5	1		↓↓↓↓	7
5-10		6	10	3	1	20
10-15			1			1
15-20		1				1
> 20	↑↑↑↑					
Total	1	12	12	3	1	29
DOABA						
Upto 5	1	1				2
5-10		8	6	8	1	23
10-15			1		2	3
15-20					1	1
> 20					1	1
Total	1	9	7	8	5	30
MALWA						
Upto 5	6	3	6	3	1	19
5-10	2	8	14	14	6	44
10-15	1	1	1			3
15-20	1	2				3
> 20	1	3				4
Total	11	17	21	17	7	73
TOTAL						
Upto 5	8	9	7	3	1	28
5-10	2	22	30	25	8	87
10-15	1	1	3		2	7
15-20	1	3			1	5
> 20	1	3			1	5
Total	13	38	40	28	13	132

↓↓↓↓ Water table declined from 1975 to 2005

↑↑↑↑ Water level rose from 1975 to 2005

Note: 1. The severity of change is maximum in the bottom left cell and top right cell and declines towards the center

2. The white boxes show no change

- A significant rise in water table was observed in Malwa only in 11 Blocks of which in 3 it came up by more than 20 metres, in 7 it came up by more than 15 metres and in 10 it came up by more than 10 metres
- The decline in water table is observed every where but more prominent in Malwa where in 10 blocks it went down by more than 15 metres, in 30 blocks it went down by more than 10 metres and in other 17 blocks it declined by more than 5 metres
- In Majha and Doaba, the water table declined by more than 10 metres in 5 and 11 blocks respectively

3.4.1 The fluctuations and determinants

The water table was analyzed for each year during 1973 to 2006 in June (pre-monsoon level) and October (post monsoon level). Monsoon is a major determinant of the water table recharge. During this season, the river flow is also high. Area of rice cultivated is the determinant of ground water withdrawal during this season, since rice is a high water consuming crop, especially when transplanted early.

Post monsoon rains are scanty and the normal withdrawal continues during the rabi season too. In 1994 and 2005, there was similar rainfall (around 600 mm) with significant area under rice cultivation. In all three regions, with an increase in the area under cultivation, ground water recharge declined (Table 3).

Table 3: Impact of rice area on withdrawal gauged through change in recharge of water table in years with similar rainfall

Region	Rice area (000 ha)			Recharge during monsoon (m)		
	1994	2005	% increase	1994	2005	% decrease
Majha	488	524	7.4	1.11	0.69	38
Doaba	364	396	8.8	1.41	0.79	24
Malwa	1424	1723	21.0	0.80	0.16	80

The impact was severe in Malwa where a increase in rice cultivation by 21%, caused a decrease in ground water recharge by 80%[7]. Concentration of rice cultivation over time has significantly increased the usage of water during the monsoon season resulting in insufficient recharge in the post monsoon season. Subsequently, there is a decline in water table every year.

The rainfall (positively), the rice area (negatively), and withdrawals in the rabi season affect recharge during the monsoon season and determine the change in water table from year-to-year. The average recharge during 1974 to 2005 was around 1 metre in the rice-zones of Majha and Doaba and little less than 0.5 metres in Malwa. In Majha and Malwa, the average recharge remained almost the same during 1990-2005. It doubled in Doaba from the periods between 1974 - 1987 to 1990- 2005. It could be due to intensive project investments in integrated watershed development in the Kandi area, which started in 1980, which significantly reduced the run-off and flash flow in ten years, i.e., from 1990 onwards. The floods of 1988 had a significant impact on recharge, which were 2.25, 3.58 and 1.86 metres in the rice-zones of Majha, Doaba and Malwa respectively (Table 4).

The average rabi withdrawal has also changed significantly over time. The average rabi withdrawal in Majha zone was 1.03 m during 1974 – 1987 which was more intensively irrigated (and cultivated) even earlier. It increased to 1.18 m during 1990 – 2005, an increase by about 15%. The increase was almost 100% in Malwa (from 0.44 m to 0.85 m and 140% in Doaba (from 0.67 m to 1.60 m). The Doaba region not only has the lowest canal irrigation (2.4 % as compared to 39.3% in Majha and 29.7% in Malwa) but grows highly water intensive crops in the rabi season like sugarcane, potato, sunflower and lately winter maize. The first three crops covered 16.1% of irrigated area in Doaba region compared with 4.5% in Majha and only 1.9% in Malwa (Appendix A)

[7] Although the rainfall zones in Malwa range from 300 to 1100+ mm, the rice zone in Malwa also lies in the rainfall range of 550 – 1000 mm, almost the same as Majha and Doaba

Table 4: Rainfall, recharge, rabi withdrawal and change in water table in the Rice-zones of Majha, Doaba and Malwa, select years and periods, 1974 to 2005

Year /Period	Rainfall (mms)	Average Rechargein monsoon (metres)			Average change in Water table (metres)			Rabi withdrawal (metres)		
		Majha	Doaba	Malwa	Majha	Doaba	Malwa	Majha	Doaba	Malwa
1988	1123	2.25	3.58	1.86	0.40	1.40	0.92	1.86	2.17	0.94
1990	755	1.71	1.99	1.37	0.40	0.24	0.46	1.31	1.74	0.91
1995	794	1.77	2.96	1.38	0.46	1.22	0.55	1.31	1.74	0.84
1997	709	1.35	2.46	0.73	0.14	0.66	-0.14	1.21	1.80	0.87
1999-2005	430	0.53	0.67	-0.10	-0.61	-0.83	-0.87	1.14	1.50	0.77
Av 1974-87	645	0.96	0.58	0.38	-0.07	-0.09	-0.05	1.03	0.67	0.44
Av 1990-05	539	0.89	1.21	0.42	-0.29	-0.39	-0.43	1.18	1.60	0.85
Av 1974-05	603	0.95	0.99	0.44	-0.19	-0.23	-0.26	1.14	1.22	0.70

Note: The years selected here from 1988 to 1997 were high rainfall (700 mm) years. The rainfall during 1999 to 2004 was less than 400 mm in 4 years and less than 500 mm in other two years. In 2005, the rainfall was only 595 mm

Regression analysis was used to determine the effect of rainfall and rice area on recharge during the monsoon period and the final impact on water table and the reduction in rice area required to maintain water balance under different scenarios[8]. Regression was run for each region on recharge and area under rice irrigation. All the regression coefficients were statistically significant and logical (Table 5).

The rainfall coefficient showed a positive impact on water table recharge from 2.8 cms for Malwa, 3.0 cms for Majha and the highest at 4.3 cms for Doaba for each centimeter of rainfall. This is interpreted along with the coefficient of rice area[9], which showed negative impact in each region.

Doaba region received low rainfall but gained because it recharged better. The coefficient of rice area was also the highest (negative) for Doaba. When rice coefficient and coefficient of rainfall were interpreted simultaneously, the ratio was 7 for Doaba, 5 for Majha and 2.5 for Malwa. This means that a relatively smaller cut in rice area and improvement in water use efficiency can restore the equivalent water balance in Doaba and Majha. To achieve the same balance in Malwa, a greater cut in rice area will be required along with water use efficiency.

These coefficients were used to estimate the reduction in rice area that would restore the water balance in each region, which declined at the rate of 38, 58 and 59 cms per year during the last ten years in Majha, Doaba and Malwa respectively. The average rainfall during this period was below normal at 600 mm. In fact, the rainfall during 1990 to 1997 was 640 mm. The rainfall was 760 mm in 1990, 790 mm in 1995 and 710 mm in 1997. Between 1998 to 2005, it was only 440 mm with less than 400mm in 4 years, less than 500 mm in 3 years and 600 mm in 2005. However, area under rice kept on increasing.

At the normal rainfall level of 600 mm, the rice area reduction to restore the water balance in the long run[10] was estimated at 1.2, 1.0 and 6.0 lakh ha in Majha, Doaba and Malwa regions while the current rice area is 5.3, 4.0 and 17.3 lakh ha, respectively. It means about 25% area under rice in Majha and Doaba and about

[8] Regressions were tried for different periods and with different logical variables. As cropping intensity, which is also an important determinant of water use was also increasing along with the rice area, the regressions for the whole period, though mostly had significant coefficients but with lower t-values and low goodness of fit (R^2). The cropping intensity almost reached the saturation by 1990 but the rice area was still increasing through substitution. Thus the regressions, reported here for 1990-2005 were the best of all.

[9] Although the coefficient of rice area was too different for different regions varying from 7.1 to 30.6, but when adjusted with the rice area in each region as per cent of net area sown, the coefficient ranged only from 2.5 to 4.4 only

Table 5: Water table recharge during monsoon (cms) regressed[a] on rainfall (cms) and rice area (lac ha)

Region	Coefficient of[b]			Decline in water table (last ten years) cms/year	Maximum rice area (lac ha) during the period	The rice area to be cut to restore water table balance[d]		
	Rain-fall	R^2	Rice area			With average rainfall (54 cm)	Rainfall at 60 cm	With improved water use efficiency[c]
Majha	2.973 (9.91)	-14.426 (4.26)	0.86	35	525	2.4 (46)	1.2 (23)	0.16 (3)
Doaba	4.337 (5.19)	-30.565 (2.43)	0.63	58	396	1.9 (48)	1.0 (25)	0.34 (9)
Malwa	2.759 (6.24)	-7.059 (4.36)	0.71	59	1726	8.4 (49)	6.0 (35)	4.06 (23)

Note: a. Regressions had intercept at zero as the water recharge is mainly with the rainfall, and even negative in case the rainfall was lower than the withdrawal during the monsoon season.

b. All the coefficients are significant as shown by t-values given in the brackets below

c. Improved water use efficiency was approximated as equivalent to another 5 cm rainfall

d. Figures in brackets are the % of the maximum rice area, i.e. current area in each region

35% area under rice in Malwa needs to be reduced. The improvement in water use efficiency, equivalent to an additional 50 mm of rainfall[11] will almost achieve the same balance in Majha and Doaba. However, in the Malwa region, even with improved water use efficiency, a rice area cut of about 20% would be required to restore the water balance in the long run. The importance of water use efficiency in improving the water balance in the sate is also significant and demands intensive research on the subject.

4. SUMMARY

The water table in the central regions of Majha, Doaba and Malwa has declined alarmingly since 1980. Although in the riverbed-blocks of the three regions, the decline in water table started since 1990s, the situation is alarming in these areas too. Both these sub-regions are the predominant rice growing zones in each region. The Malwa region, where rice cultivation gained prominence only after late 1970s, is the worst hit by decline in water table.

The monsoon rainfall and the rice area are the major determinants (positive and negative respectively) of the extent to which the water table gets recharged during the monsoon season, when about 80% of the yearly rainfall is received. The water is used in the rabi season when there is little rain. The average recharge during 1974 to 2005 was around one metre in the rice-zones of Majha and Doaba but little less than 0.5 m in Malwa. The average recharge in Majha and Malwa remained about the same during 1990-2005 as it was during 1974 - 1987 but it has improved significantly in Doaba where it doubled during 1990- 2005. It could be due to the intensive project investments in integrated watershed development in the Kandi area starting 1980 onwards.

The average rabi withdrawal has increased by 15, 100 and 140% in Majha, Malwa and Doaba regions respectively. The Doaba region not only has the lowest canal irrigation (2.4 % as compared to 39.3 % in Majha and 29.7 % in Malwa) but is also now known for highly water intensive crops in the rabi season like sugarcane,

[10] Perhaps this is the first time that the reduction in rice area to restore water balance is based on detailed simulated analytical exercise. The earlier figures given by various experts, based on expert judgment, had been generally around 10 lakh ha. These estimates did not take any cognizance of the impact of better rainfall or better water use efficiency either.

[11] Various agronomic practices of water use efficiency, as given in the next section, show that the savings in water use vary from 10% to 35%. The farmers are already using some of these measures for some water-intensive crops like sugarcane, etc. Neither all the crops nor all the area would be covered, in practical parlance. A 50 mm rainfall amounts to meeting 10% of the water requirements of about 5000 cubic metres per hectare of most of the normal water-using crops like maize and wheat.

potato, sunflower and lately winter maize. The first 3 crops covered 16.1% of irrigated area in Doaba region compared with 4.5% in Majha and only 1.9% in Malwa.

At the normal rainfall level of 600 mm, the rice area reduction to restore the water balance in the long run was estimated to be about 25% in Majha and Doaba and about 35% in Malwa. The improvement in water use efficiency, approximated, as equivalent to another 50 mm of rainfall will almost achieve the balance in Majha and Doaba. However, in the Malwa region there is no reprieve from cut in rice area. Even with this improved water use efficiency, a cut in rice area to about 20% would be required in the long run. The importance of water use efficiency in improving the water balance in the sate is significant and demands intensive research on the subject.

5. CORRECTING THE WATER BALANCE

The groundwater balance (recharge minus withdrawal) in Punjab has been negative for a long time now, particularly since 1990 as shown by the decline in water table in the previous section. As of April 1, 2002, the net groundwater resources of Punjab state were estimated by the Central Ground Water Board at 16394 MCM, whereas the net draft was estimated at 17189 MCM, a groundwater overdraft of 795 MCM[12]. In-storage fresh groundwater resources of the State are estimated as 907 BCM. The stage of groundwater development for the State is 114% and the State as a whole falls under dark category.

The negative balance between the annual available water supply and the actual use of water needs to be urgently corrected through multi-pronged strategies[13] such as:

· Maximising use of surface water and increasing recharge of groundwater

· Reducing the water demand:

- orienting incentives to encourage substitution of high-water consuming crops with low-water consuming crops
- improving water use efficiency
- redirecting the research on water use efficiency in all-dimensions

Head work	River	Canals
Nangal Head Work	Satluj	1. Bhakhra Main Line 2. Anandpur Hydel Channel
Ropar Head Work	Satluj	1. Sirhind Canal 2. Bist Doab Canal
Shah Nehar Canal System	Beas	1. Mukerian Hydel Channel 2. Kandi Canal
Madhopur Head Work	Ravi	1. UBDC Canal 2. Kashmir Canal
Harike Head Work	Satluj and Beas	1. Rajasthan Feeder 2. Sirhind Feeder
Hussainiwala Head Work	Satluj and Beas	1. Bikaner Canal 2. Eastern Canal

[12] Source: Central Ground Water Board (2004). Water Security through Ground Water Management: Punjab. Central Ground Water Board, North Western region, Chandigarh, July 2004. pp10.

[13] It is also important to aim at "water-democracy", which means, "ensuring that every drop of water is conserved, harvested and shared by the people". It demands massive funding for water projects alongwith the government policies which ensure that the benefits are more equitably shared.

6. MAKING MAXIMUM USE OF SURFACE WATER

Punjab has a fully developed, fully exploited, river water system (Annexure 2) through the canal network of about 14500 kms including distributaries and minors for assured irrigation to about 16 lakh ha as follows.

There is full exploitation of surface water through the above canals and no new canal is under construction. The canal water irrigation policy needs modification as per the prevailing groundwater conditions. It must encourage crop substitutions for low water requiring crops. At present the water allowance is 5.5 cusec per thousand acres in Eastern Canal system and 3.5 cusec per thousand acres in Sirhind Feeder system. Both the systems are water logged at present. While the Bist Doab Canal system has an allowance of 1.95 cusec per thousand acres, and the area is facing depletion in ground water. The canal water allowances in areas, which are waterlogged must be diverted to areas facing severe ground water depletion. However, this is not a substitution for improving water use efficiency. In areas with potential for growing basmati rice, which requires less water but matures late, the canal water supply should be extended towards the maturity season of basmati (October).

7. INCREASING RECHARGE

Harnessing surface run-off for human use and maximizing the recharge should receive priority. Existing dug wells, dug-cum-bore wells, cavity wells, recharge wells in trenches, shaft-cum-recharge wells and excavated ponds effectively recharge the groundwater. Unpolluted stored water in depressions and ponds, used water of swimming pools and accumulated water in low-lying areas should be recycled and used to recharge groundwater[14]. Surplus canal water during monsoon period particularly in good rainfall years should not be wasted.

Major part of Punjab is plain area, which is a natural recharge system it deserves attention. However, the semi-hilly sloping region of the state in the entire eastern belt has tremendous scope for investment in watershed management[15]. The construction of small water harvesting tanks and other integrated water management technologies in the Kandi belt helped in increasing water supplies, reducing run-off and siltation

Table 6: Water requirements of rice and other crops, Punjab.

Crop	Water requirements[a] Cub m per ha	Electric motor hrs[b] Per ha
Paddy	24181	290
Maize	5474	50
G.nut	1123	35
Kh pulses	2355	35
Wheat	5504	60
Barley	4486	35
Gram	2243	30
Rabi puls.	2187	30

a. Source: Department of Soils, Punjab Agricultural University, Ludhiana

b. Source: Cost of cultivation data for 300 farmers. See, Karam Singh and K. K. Jain (2002), Dynamics of Structural Shifts on Costs and Returns in the Farm Economy in Punjab. Report for the Commission for Agricultural Costs and Prices. Agro Economics Research Centre, PAU Ludhiana. March 27, 2002.

14 Note that using 1 ha metre of rain-water harvested in a village pond for one irrigation to 33 ha (or any combination such as 3 irrigations to 11 ha) means equivalent full recharge because the same quantum of groundwater would have been withdrawn. However, in the simple recharge system, quite a significant proportion of water would be lost through evaporation.

15 The impact in Doaba region is already discussed in previous section with Table 3.

16 See: 1. Karam singh, Nirmal singh and Rachhpal Singh (1998). Impact evaluation of Integrated Watershed Development Project (Hills), Punjab. World Bank Project. PAU Ludhiana.

2. Nirmal singh and K K Jain (2004). Long-term Impact Evaluation of Watershed Development Projects in Punjab. *Indian Journal of Agricultural Economics 59 (3) July-Sept. pp. 321 -330*

loads, recharging ground water and decreasing flash floods on a sustainable basis[16]. There is need for more investments on similar initiatives. In many areas, the choes still get flooded and the water flow is still as muddy as it used to be.

The potential of rainfed horticulture is still unexploited though it presents a unique and promising opportunity. Animal grazing though reduced is still not uncommon and the few patches, untreated or inadequately treated, do more harm than good.

8. REDUCING THE DEMAND FOR WATER:

The scope to address the supply side of water, though important, remains limited. Major scope lies in managing demand of water.

The rice crop, though bears greater returns than other kharif crops, is also the most water intensive, using about 24000 cu. metres of water per ha. This is about 6 times more water than maize, almost 20 times more than groundnut and 10 times more than kharif pulses (Table 6).

Rice has benefited the most from its effective Minimum Support Price (MSP), electric power supply (there are 8.56 lakh electric tubewells out of 11.44 lakh) and free electricity supply during 1997-2002. Subsidized (and sometimes even totally free) electricity to the farm sector in Punjab has done more harm than good. Recharging groundwater can be addressed through the following:

- Electricity tariff policy, and
- Minimum Support Price (MSP) of rice (and wheat
- Supporting and encouraging crops other than rice

9. ELECTRICITY TARIFF POLICY

The key question is whether the withdrawal of electricity subsidy would reduce the area under rice or at least reduce the over-irrigation of rice. Rice is the only crop that does not have a negative stage of marginal productivity of water. Nothing is done to restructure subsidies and incentives to improve water use efficiency, especially in case of rice.

It is thus pertinent to work out how much increase in pricing of water will make the other crops compete with rice in terms of area cultivated. Some straight simulations are attempted, which show that with water (electricity) priced at 150 % of the cost of supply, it will make some crops compete with rice. For most of the other crops to compete with rice, the electricity (water) must be priced at 200% of the cost of supply. This is already five times the current cost with subsidy (Table 7).

Table 7: Economic / competitive pricing of water /electricity.

Crop	Yield (Kgs / ha)	Price Factor	With subsidy	No subsidy	Increase in rate	
					150 %	200 %
			Index of profitability relative to rice			
Paddy	6500	1	100 (20000)	100 (75)	100 (60)	100 (47)
Basmati	3000	2.00	100 (100)	125 (94)	145 (87)	178 (84)
Maize	5000	1.00	77 (100)	90 (90)	109 (85)	141 (86)
Groundnut	2250	2.00	48 (100)	61 (95)	74 (93)	97 (95)
Cost / irrigation with electric tubewell Rs/ha			50	250	375	500

Note: 1. The figure in parentheses under paddy with subsidy is the gross margin (Rs / ha) All other figures in brackets are relative to those with subsidy and thus show the decline in profitability of each crop as the electricity supply price is increased

2. The index of profitability is measured with gross margins.

The rate at which Basmati rice can compete when price is relatively favourable. But the area increase reduces the relative margin of price advantage and thus offers limited scope. This simulation of charging water at prices to make crop alternatives compete with rice means reduced income for the farmers. The gross margins from rice with water (electricity) priced at two times the actual cost of supply by the Electricity Board will be only 47% of the current prices with subsidy. If electricity is charged at one and a half times the cost of supply, the farmers' gross margins will decline by 40% of that with subsidy. Charging water for its scarcity value to reduce its use is highly impractical. Hence, the need for some alternative measures where farmers' incomes are not affected.

10. MINIMUM SUPPORT PRICE OF RICE AND WHEAT

The second issue is the procurement policy followed effectively for paddy and wheat. The MSP has been effective in the move towards food security of the country. Wheat is not the a contributor to the groundwater situation in Punjab. Rice is a more stable crop than alternative crops and has remained relatively more profitable even when MSP was almost frozen for 5 years during 2000-2005. Freezing MSP leads to the decline in profitability and farmers' income, and consequent increase in their indebtedness. It also leads to the problem of food security. Freezing MSP caused more problems. Little wonder that for improving food security and farmers' income, increasing the MSP of rice and wheat are on the cards again. However, little care is exercised to price out alternatives (like maize) that give good margins and use less water.

11. SUPPORTING ALTERNATE CROPS TO RICE

The reduction of area under paddy and introduction of alternative crops, particularly in the Malwa region, is required to restore the water balance in the long run. Alternative crops like groundnut, maize, pulses (arhar, moong) and soyabean must be made competitive with paddy. Besides saving water, there are other long-term benefits to the society in terms of improvement in soil fertility and improvement in sanitation and health, improvement of the environment and saving of power. Currently the Punjab government is purchasing high-cost power to irrigate paddy during the critical period. In addition, the government diverts power from the high-return industrial sector to mature paddy crop. If the current acreage and system of paddy cultivation continues, the depleted groundwater will necessitate putting submersible pumps, which will need even more power to irrigate the same acreage.

An average electric motor of 6+ HP (Punjab average), on the average, is used for about 300 hrs / ha for rice and about 40 to 50 hrs / ha for groundnut, soyabean and most other kharif crops[17]. The saving of 250 hrs of such an electric motor, which would consume about 1250 units (KWH), which @ Rs.3.80 per unit works out to a savings of Rs.4,750 / ha of replaced paddy. The income from the use of saved high-cost electric power for high-return industry sector should be invested in the agriculture sector.

Restructuring the electricity subsidy incentives is a bold decision. For example declaring basmati blocks in potential and worst affected areas may be tried by providing yield, price and income insurance for basmati and cutting down farmers' costs (through public nurseries), all equivalent to the cost of the saved electricity is worth the merit. Same strategy should work for maize elsewhere.

Paddy is one crop in Punjab that shone from almost a zero (except some basmati) to hero. It requires more water, occupies a large area and leads to excessive mining of groundwater - leading Punjab towards a stage of hydrological suicide and rice is called the villain. The villain is strong in profitability and stability and neither the farmer nor the rice is willing to leave each other like the proverbial blanket and the wolf story. Strategies are required to achieve a balancing of natural water resources with the maximum possible area of rice. India (read Government of India) wants maximum possible area under rice in Punjab for its food security and it gives a high price and high coverage to rice.

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[17] The cost of cultivation data collected on cost accounting basis for 300 farmers in 30 village clusters by the Department of Economics, PAU Ludhiana. Karam Singh and K. K. Jain (2002), *Dynamics of Structural Shifts on Costs and Returns in the Farm Economy in Punjab.* Report for the Commission for Agricultural Costs and Prices. Agro Economics Research Centre, PAU Ludhiana. March 27, 2002.

Some possibilities do exist for improving water use efficiency in case of rice; the major one is transplanting it towards the end of June so that the groundwater withdrawal in hot summer months is minimized (discussed below in detail). However, there is no incentive for late transplanting; there is no variety that gives better yields when transplanted late except for some premium varieties closer to basmati or of basmati but then the area under these varieties is limited by market demand. Though these varieties have higher price, they give lower yield. The profitability advantage works only at the margin, positive in some years, negative in others, and fluctuating yields add to their uncertainty. The geographical indicators of basmati under WTO and the resultant lower use of electricity (read for drawing out less water) need to be placed in proper incentive perspective

12. IMPROVING THE WATER USE EFFICIENCY

There are so many alternatives such as planting time, irrigation scheduling, mulching, tillage, weed control and land leveling, which improve water use efficiency. Some of these are discussed below:

12.1Time of Planting

The rate of evapo-transpiration of rice, which is the most crucial crop to use or save water decreases with the delay in the date of transplanting. The rice transplanted after June 15th is the most important agronomic practice for saving water, as shown by the data in Table 8

Table 8. Impact of date of rice transplanting on ETR and water table

Date of transplanting	May 1	May 10	May 20	May 30	June 10	June 20	June 30
ETR of rice (cms)	84	80	76	67	60	56	52
Fall/rise in water table	70	60	50	28	10	0	(-) 10

Source: G S Hira, S K Jalota and V K Arora (2004). Efficient Management of Water Resources for Sustainable Cropping in Punjab. Department of Soils, PAU Ludhiana

Rice transplanting after June 15th needs to be promoted even by taking the hard decision like enacting the necessary act for regulating the planting of rice nurseries not before May 10th (The Punjab preservation of Sub Soil Water Act as proposed by the Punjab State Farmers Commission in 2006)

12.2 Water Economizing Irrigation Schedules

Proper scheduling (amount and timing) of irrigation to crops is an important component of water saving technologies. The meteorological approach to schedule irrigation based on the ratio between fixed depth (75 mm) of irrigation water (IW) and net cumulative pan evaporation since previous irrigation (PAN-E minus rainfall) saved 2 irrigations for wheat (IW/PAN-E = 0.9) as compared to 5-6 irrigations at fixed growth satges without any yield loss[18]. Similarly in case of rice, it has been demonstrated that higher yields can be maintained by irrigating crop at 2 d drainage interval after soaking in of previous irrigation (after 2 weeks of continuous ponding following transplanting) This helps in saving as many as 8 irrigations to rice[19]. There should be more research on irrigation scheduling with the objective to save water yet achieve the same (higher) yield levels.

12.3 Irrigation methods:

Water use efficiency in field crops can be increased by using improved irrigation methods. For example, furrow irrigation in wide-row crops like cotton, sunflower and maize. In case of cotton, 33.3% saving of

[18] S S Prihar, et al (1974). Scheduling irrigation to wheat using pan evaporation. Indian Journal of Agricultural Research, New Delhi. Pp. 142.

[19] G S Sandhu et al (1980)Irrigation needs and yield of rice on a sandy loam soil as affected by continuous and intermittent submergence. Indian Journal of Agricultural Science 50 pp 492-496.

irrigation water has been reported by sowing cotton on ridges and application of water in furrows over flat sown crop without any reduction in seed cotton yield[20]. This method is helpful in increasing application efficiency as applied water has less contact area with land surface. The proper orientation of ridges and furrows with respect to solar trajectory will help reduce the net solar radiation reaching the surface of the earth and hence, reducing the net energy available for ET. The north facing side of the East-West oriented ridge had on an average 6.1°C lower temperature and the East face of the North-South oriented ridge 2.6°C higher temperature than flat surface. Therefore, the North face of the east-west oriented ridges would receive less evaporating radiation and hence less water would be lost in evaporation.

Recent innovations of sprinkler and drip irrigation methods apply water without much loss, and can irrigate 1.5 to 3.0 times areas having excessively coarse textured as well as slowly permeable soils, undulating lands having high cost of leveling, and in area of high water table more so with poor quality water. There is need for capital investment subsidy in such irrigation technologies.

12.4 Tillage

Tillage affects water use efficiency by modifying the edaphic environment, which in turn influences root growth and canopy development of crops. Depending upon the changes it causes in soil environment, tillage may enhance or retard the development of root and above ground shoot growth. The rate of canopy development determines the pattern of total water use by the crop, and the proportion of T and E. As the canopy cover increases, the direct soil water evaporation from the cropped field decreases and the ratio of T/ET increases. This affects the WUE favourably. On the other hand, sparse cover resulting from reduced emergence, sub optimal soil temperatures, and high soil bulk density lowers the T/ET ratio by increasing direct water evaporation from soil.

13. CHANGING FROM FLAT TO BED LAYOUTS

Changing from flat to bed layouts alters the hydrology of the system and transport and transformation of nutrients. The water moves horizontally from the furrow into the bed then upwards the bed surface driven by evaporation and capillarity action while downwards driven largely by gravity. The application of irrigation based on IW/CPE (1.0) proves more effective in increasing yield and WUE of wheat sown on beds compared with applying irrigations on fixed crop growth stages[21]. 16.7%, 25% and 33.3% net saving of irrigation water were reported from bed planted for maize, soybean and maize over flat treatment, respectively[22]. Likewise, 25% to 45% higher WUE and about 30% saving of irrigation water were found under planting of one row of maize per bed/trench (furrow) 67.5 cm apart or trench 60 cm apart than flat sowing at 60 cm spacing[23]. The direct seeded rice helps in saving water upto 13% over conventional planted crop[24]. Further direct seeded basmati matures two weeks earlier than transplanted crop, therefore reduction in duration also helps to save water[25]. However, for widespread field application and acceptance by farmers, such water saving technologies need to be researched and established on economics basis.

The ridge transplanting of paddy also saves water by about 30 – 35%, as shown by recent experiments at PAU and the field experiments by the Department of Agriculture. There are more problems of weeds reported

[20] Butter, G S and Aujla, M S (2005) Save water by sowing cotton on ridges. *Progressive Farming*. April 2005 pp 21.
[21] Kaur, M (2003) Studies on seed rate, irrigation, weed control and their interactive effects in bed planted soybean (*Glycine max* L.). Ph.D. Dissertation, PAU Ludhiana.
[21] G S Kalkat, K S Pannu, Karam Singh and P S Rangi (2006). *Agricultural and Rural development of Punjab: Transforming from Crisis to Growth.* The Punjab State Farmers Commission, GOP
[22] Hari, Ram (2006) Micro-environment and productivity of maize-wheat and soybean –wheat sequences in relation to tillage and planting systems. Ph.D. Dissertation, PAU Ludhiana.
[23] Tarundeep, Kaur (2002) Studies on irrigation requirement in relation to methods of planting of maize (*Zea mays* L.). M.Sc. Thesis, PAU Ludhiana.
[24] Mann,R A, Munir, M and Haqqani, A M (2004) Effect of resource conserving techniques on crop productivity in rice-wheat cropping system. *Pakistan Journal of Agricultural Research* 18 (1) : 58.
[25] Gill, M S and Dhingra, K K (2002) Growing of basmati rice by direct seeding method in Punjab. *Indian Farmer's Digest* 13 : 141.

in this sytem, which are being addressed to in further experiments. Nonetheless, as rice is the most water consuming crop, such experiments and recommendations will be very crucial for saving the groundwater.

13.1 Leveling of land

The leveling of land has great significance in irrigation efficiency. A well-leveled field required less time to irrigate same piece of land than unleveled field. In case of cotton, it was reported that only 156 minutes were required to irrigate one hectare under leveled conditions against 187 minutes required under unleveled conditions. Furthermore, lint yield was also higher under leveled conditions due to equal distribution of irrigation water (Table 9).

Table: 9. Effect of land leveling on mean irrigation time

Condition of the land	Irrigation time (min/ha)	Lint yield (kg/ha)
Unleveled	187	2050
Leveled	156	2320

Laser leveling of fields for more uniform and thin/light irrigation is very important. It needs capital investment subsidy. As the investment is very heavy and for use only once in many years it needs to be promoted with the cooperative societies. The agronomic practices for saving water need to be put in to commercial experimentation for testing the economic feasibility.

14. INTENSIFY RESEARCH ON WATER USE EFFICIENCY:

Although the scarcity of water had come to be recognized as the most serious problem of the State in 1985, yet the research, development and investment in water use efficiency did not get the requisite priority in the last 20 years. The research and development programmes on water use efficiency needs to be given the top priority in all-dimensions.

Punjab needs to develop a long-term policy for ground water use and ground water recharge so that water balance is maintained. The government should put in place the necessary investment and policy. Research on water use efficiency needs to be stepped up on the following:

- Evolving varieties of rice, which yield maximum returns when transplanted later than 20th June.
- Experiments on methods of irrigation that save water without reduction in yield
- Experiments on sowing of rice, sugarcane, maize, pulses and soyabean etc. on bunds and beds
- Field experimentation of crop systems, which are more profitable when rice is replaced with incentives to adopt it.

15. TO SUM UP

The water table movement in Punjab is a bad dance with bad rhythms. The beats (table) are rising in the South West for no use, from too deep in 1970s to waterlogged, seriously or nearly, now as groundwater is not fit for use. Still worse, it is falling in major parts of the state, which at many a places is at too alarming a rate. Worse still even the river beds are not immune from this malaise, though it is gradual in major belt. And the fluctuations in some pockets are erratic, which also remain a reason for worry.

The water table has been declining for long time now in 89 blocks of which in 45 blocks it has gone deeper by more than 10 mand in 12 blocks by more than 15 m. The increase in rice area, particularly in the Malwa region has affected adversely the recharge during the monsoon season through more withdrawal of underground water. A 2% increase in Malwa region between 1994 and 2005, which were the similar (normal of 60 cms) rainfall years decreased the recharge level by as much as 80%; in Majha and Doaba, where rice area increased by about 10% the monsoon recharge declined by about 30%.

At the normal rainfall level of 60 cms, the rice area reduction to restore the water balance in the long run was estimated at 1.2, 1.0 and 6.0 lac ha in Majha, Doaba and Malwa regions where it has reached the maximum level of 5.3, 4.0 and 17.3 lac ha, respectively. It means about 25 per cent area under rice in Majha and Doaba and about 35% area under rice in Malwa needs to be reduced. The improvement in water use efficiency, approximated, as equivalent to another 50 mm of rainfall will almost achieve the balance in Majha and Doaba. However, in the Malwa region there is no reprieve from cut in rice area, which even with this improved water use efficiency would be demanding a cut in the long run to about 20% of the rice area.

The freeze in MSP of rice and wheat would lead to reduction in farmers' incomes and thus is not a solution. The electricity tariff at cost of supply will also reduce the farmers' incomes and would still not achieve any significant cut in rice area.

The negative balance between the annual available water supply and the actual use of water needs to be urgently corrected through multi-pronged strategies:

- Making maximum use of the surface water and increasing the recharge
- Addressing the urban sector
- Reducing the water demand:
  - orienting incentives to encourage substitution of low-water consuming crops for high-water consuming crops
  - enacting the nursery act to discipline rice transplanting only after June 10 onwards will reduce significantly the water withdrawal (read losses) from early transplanting of rice
  - improving the water use efficiency through public and private investments in laser leveling, ridge planting, etc
  - redirecting the research on water use efficiency in all-dimensions

Annexure 1

SYL CANAL: POLITICS AND LITIGATION

1960: Indus Water Treaty, signed by India and Pakistan. It reserved waters of the Ravi, Beas and Sutlej exclusively for India
1966: Novemeber 1, 1966. Punjab reorganized. New Haryana state claims share of waters
1976: GOI announced that both the States would receive 3.5 MAF (million acre-feet) of water from the available annual flow of 15 MAF through the construction of the SYL Currently Haryana gets 1.62 MAF of the allotted 3.5 MAF, the balance to be made available through SYL
SYL: Starts from the tailend of Anandpur Hydel canal of Bhakra dam near Nangal and goes up to the Western Yamuna Canal in Haryana
Why the conflict:

- Punjab considers the formation of Haryana under the Punjab Reorganization Act 1966 illegal
- The Punjab Reorganization Act does not mention sharing of the Ravi waters while the 1976 decision of the GoI does
- Dispute over the amount of surplus water actually available based for allocations.
- Distribution based on the utilization in 1960, not on actual use in 1976.
- The political compulsions of the GoI and GoS

The Constitution: It gives full and exclusive powers to the states over water and hydel power. However, when Punjab was bifurcated into Punjab and Haryana, the Punjab Reorganization Act, 1966, gave all powers to the centre ultra vires to the Constitution.
1976: Ministry of Water Resources, GoI unilateral notification:

Estimated surplus river water = 15.85 MAF

Punjab = 3.5 (MAF), Haryana = 3.5, Rajasthan = 8, J & K = 0.65 and Delhi = 0.2

Ground reality: The surplus water available in Punjab was a mere 1.2 MAF
GOP (Giani Zail Singh, CM) asked for a review of the notification
1978: GOP (P S Badal) moved a petition in the Supreme Court challenging the constitutional validity of the notification; GOH also went to SC for implementation of the GOI notification
1981: GOP (Darbara Singh) withdraws the case, signed an agreement with Haryana and Rajasthan for revised allocation of surplus flow of the Ravi and Beas based on 1921-60 flow data estimated at 17.17 MAF as Haryana = 3.5 MAF, Rajasthan = 8.60 MAF and Punjab = 5.07 MAF
The agreement, widely believed to have been signed under pressure, created a furore in Punjab. The Akalis protested and started agitation.
(Haryana completes the first phase of SYL canal by 1982,which it had started in 1976, a 75.5 km long stretch from Ismailpur to Karnal, at a cost of Rs.40 crores)
1985: Punjab Accord: (PM Rajiv Gandhi and Akali leader Harchand Singh Longowal:

- The resentment of the people of Punjab was noted
- A tribunal under the retired Supreme Court Judge (Justice Eradi) was set up
- The Tribunal will conclude on how much water Punjab and Haryana actually used, so that the surplus could be apportioned accordingly
- The SYL canal would be completed by August 15, 1986, allowing Haryana and other downstream states to utilize whatever share of water the Tribunal would eventually allot
- The farmers in Punjab would not have to compromise with lesser water

(There were other clauses of The Punjab Accord to be complied with by 26.1.1986 by GOI, which were backed out)
1987: Justice Eradi concluded that the three states of Punjab, Haryana and Rajasthan use 3.106, 1.620 and 4.985 MAF. Total use = 9.711 MAF, estimated surplus = 6.6 MAF. It awarded 5.00 MAF to Punjab and 3.83 to

Haryana; The arithmetics was wrong – allocating 8.83 against the available 6.6 MAF. The water below the rim stations of the Ravi and Beas, the lowest points at which the data were recorded, was assumed to make up the difference for Punjab. Punjab contested the claim as no dam or barrage could be built along the Pakistan border.

1987: Punjab contested the Eradi Tribunal award – i. It overestimated the available water, and ii. Underestimated the use of water by Punjab farmers

July 1988: Justice Eradi adjourned the tribunal because of violence in the state. It began functioning again in November 1997, after being ordered by the SC to do so. It did not take any clear decision and GoH again approached the SC.

July 1990: Chief engineer, SYL and some labourers killed and all work on SYL canal in Punjab was stopped. Nearly 60 per cent of the 112 km long canal had been constructed till then.

January 15, 2002: SC ordered the Punjab to complete the construction of SYL within 12 months, failing which the GOI would appoint a central agency to complete the work

July 2002: GoH approached the SC to ensure that the GOP kept to the deadline

January 15, 2003: Deadline expires 7th time (December 1983, August 1986, December 1987, March 1988, June 1988, November 1989, January 1991 and January 2003)

January 2003: GoP (Amrinder Singh) files the plea in SC to refer the matter to a larger bench. It also argued that there is no surplus water. The river flow data between 1981 and 2002 show only 14.37 MAF against the 17.17 MAF believed to be available. The transfer would affect 9 lakh acres of irrigated land in Ferozepur, Faridkot, Moga and Mukatsar. The recharge of groundwater in Punjab will be seriously affected.

January 2004: SC rejects the GoP plea to refer the matter to a larger bench

January 15, 2004: GoH petitions the SC about the GoP failure to act on the SC order of January 15, 2002

June 4, 2004: SC directs the GoI to appoint a central agency by June end, which will take up the work of constructing the unfinished part of the SYL by July 15, 2004. GoI directs the central PWD as the agency to take up the work

July 3, 2004: GoP moves the SC to review its June 4 judgement. GoP contended that SC did not have jurisdiction on water dispute under Article 262 of the Constitution, which falls within the exclusive jurisdiction of the Interstate River Waters Dispute Tribunal

August 24, 2004: SC dismissed the GoP petition

GoP threatens to stop releasing water to the neighbouring states

GoR assembly passes a resolution authorizing the GoR to initiate legal and administrative steps to ensure that the state got its full share of water from the Ravi-Beas system as per the 1981 agreement. (In December 2004, Rajasthan CM, Vasundhara Raje met PM to demand water; The Bhakra-Beas Management Board immediately released water as per requisition for the month)

GoP decides to bring a bill to counter the obligation of handing over the SYL project to central agency. The bill was drafted with the help of former solicitor general, Soli Sorabjee with the aim of nullifying the agreement with retrospective effect. It dug up the Northern India Canal and Drainage Act, 1873 for amendment proposing to make it mandatory for any work on a canal – maintenance, repair or construction – that ferried water beyond the borders of Punjab to be sanctioned by the assembly

July 12, 2004: A special session of the Punjab Assembly passes unanimously the Punjab Termination of Agreements Bill, 2004 terminating all agreements relating to sharing of waters of Ravi and Beas with Haryana and Rajasthan. It also abrogated the Yamuna Agreement of May 12, 1994 between Punjab, Haryana, Rajasthan, Delhi and Himachal Pradesh (which allotted 4.6 MAF of Yamuna water to Haryana to be further augmented by SYL) and all other accords for sharing water

The Bill declared the Indus system that existed before Partition had become irrelevant after the event since only three east flowing rivers – Ravi, Beas and Sutlej – out of the six that constitute the Indus River System remained in India. All these rivers flow through Punjab: neither Haryana nor Rajasthan are part of these river basins. The diversion of these waters was contrary to the National Water Policy.

Haryana termed the Act unconstitutional and lawless. Its implementation would lead to the destruction of cooperative federalism and disintegration of the country.
July 15, 2004: GoI filed petition in the SC for fresh directions as a result of the GoP controversial act.
July 20, 2004: GoHP also decides to move the SC against the Punjab Termination of Agreements Act to safeguard its interests
July 22, 2004: President refers the controversial law passed by Punjab Assembly to the SC
August 2, 2004: SC agrees to examine the validity of the Punjab Act and issued notices to the Centre, Punjab, Haryana, Rajasthan, Himachal Pradesh, Jammu and Kashmir and the National Capital Territory of Delhi to file written submissions on facts and the questions of law formulated under the presidential reference under the Article 143 (1) of the Constitution, seeking opinion on:

a. Whether the Punjab Termination of Agreement Act, 2004 and its provisions are constitutionally valid;
b. Whether the Act and the provisions are in accordance with the provisions of the Interstates Water Disputes Act, 1956, Section 78 of the Punjab Reorganization Act, 1966 and the notification dated March 24, 1976 issued thereof; and
c. Whether in view of the provisions of the act, the state of Punjab is discharged from its obligation flowing from the judgement and order dated June 4, 2004 of the Supreme Court.

April 13, 2006: SC admits contempt petition against GoP and GoI for not implementing its January 15, 2002 and June 4, 2004 orders respectively. It is listed for hearing along with the Presidential reference of July 22, 2004.
March 3, 2007: New Punjab CM (P S Badal) announces to scrap the section 5 of PTA Act, 2004, which says that existing use of water to Haryana and Rajasthan will be protected.

March 9, 2007: Haryana moves SC for early hearing of Presidential reference of July 22, 2004. The SC fixes July 29, 2007 for the hearing
March 28, 2007: Punjab states in SC to honour the water pacts. Next hearing is fixed in July 2007
March 30, 2007: CM (Badal) says to challenge the section 78 of the Punjab Reorganization Act, 1966, which says: "….all rights and liabilities of the existing state of Punjab with respect to the Bhakra and Beas projects may be fixed through an agreement by the states after consultation with the central government. If no such agreement is entered into within two years of the appointed day, the central government may, by order, determine the purpose of the projects….." In other words, the central government kept powers with itself to decide the sharing of waters of Punjab and make allocation of the same to other states.This section was "lifted" from the act that was drafted at the time of the organization of the southern states in 1956.

The GoP later filed the civil suit in the SC challenging the legality of Sections 78 and 79 of the Act. GoP also manages to get the SC to stay construction of Hansi-Butana canal by the Haryana Government
October 22, 2007: Delhi High Court admits the GoP petition for furthr hearing a petition challenging the constitutional validity of the reconstitution of the Ravi Beas Water Disputes Tribunal by the union Government, which was reconstituted through a notification dated June 10, 2003 as per the provisions of the Inter-State River Waters Disputes Act, 1956.

Source : Mainly adapted from Indira Khurana (2006). Transboundary Disputes: Politics and Litigation Play
Havoc : Sutlej Yamuna Link Canal. Economic & Political Weekly, February 18. Pp. 608-11. The update is from various newspapers.

Annexure 2

Rainfall and Rivers in Punjab

The annual rainfall in Punjab ranges from 390 mm in 21 rainy days in the Western part to 1100 mm in 48 rainy days in the north and north eastern part. Mean annual rainfall during 1973 to 2005 has been 600 mms in 32 rainy days. July and August are the rainiest months (57 % of annual rainfall). Almost 80 % of the rainfall comes in the monsoon period. The heaviest rainfall was in 1988 (1123 mms), when there were floods all over the state. The last heavy rainfall (more than the normal) was 1997 when it was 709 mms.
There are three major rivers - the Ravi, the Beas and the Satluj.

The Ravi river rises from the Northern face of Rohtang Pass in the Kuku hills in H.P. at an elevation of 4116 m. and enters Punjab at Madhopur where the head works of Upper Bari Doab Canal are constructed. The river flows through Gurdaspur and Amritsar districts forming the international boundary between India and Pakistan and finally enters Pakistan near Kakar Manj, 30 kms from Lahore. The length of the river from its source to the Pakistan border is 725 kms. The catchment area is 5957 sq km. The minimum discharge is 34 cumecs, while the highest flood discharge is 15400 cucecs. The annual mean flow is 7894 million cubic metres. A flood protection embankment on the left side for 150 kms length from Madhopur to Kakar Manj was constructed in 1955. The river is in the share of India and is being extensively utilized through Kashmir canal and Upper Bari Doab Canal.

The Beas river rises close to the source of river Ravi on the southern face of the Rohtang pass ar 4060 m and enters Punjab at the trijunction of Gurdaspur, Hoshiarpur districts of Punjab and the State of Himachal Pradesh and traversing through the Doaba and Majha regions, it finally joins the Satluj river at Harike Pattan. The total length of the river from the source to the confluence with Satluj is 470 kms. The maximum discharge of 17600 cumecs was experienced in 1961. At Pandoh, above Mandi in H. P., a dam has been constructed to divert 257 cumecs of water in to Satluj above the Gobind Sagar lake. At Pong near Talwara a large earthen dam has been constructed to impound water for gradual release into the Rajasthan Canal and Sirhind Feeder taking off from Harike.

The Satluj river rises close to the course of mighty Indus and Brahmaputra rivers near the south-west of the Tibetan lakes of Rakasthal and Mansarovar. The Bhakhra dam, the second highest dam in the world, has been built on this river. This is followed by the Nangal dam 14 kms down to Bhakhra. The river enters the plains of Punjab at Ropar where the headworks of the Sirhind Canal is constructed. About 160 kms below Ropar, the river Beas joins the Satluj at Harike. The river leaves Punjab near Ferozepur and enters Pakistan forming international boundary and finally enters Pakistan at Suleimanki near Fazilka. After the construction of the Bhakhra Dam, the Satluj river has been canalized between Ropar and Harike for a length of 160 km in a width of about 1 km instead of 9-10 kms existing earlier.

There is Ghaggar river, which is defunct Saraswati, emerging from the hills midway between Yamuna and Satluj, flows along the boundary of Punjab and Haryana, and finally disappears itself into the sands of the Rajputana desert. It is more or less a flashy stream, swells with rainfall in the higher catchment and subsides immediately after the rains. Sometimes flash floods in this river cause extensive losses in the Patiala and Sangrur districts.

Note: This section is mainly based on Central ground Water Board, North western Region, Chandigarh. Report on “Water Security through Ground Water Management”. July 2004; and H S Mavi and D S Tiwana (1993). Geography of Punjab. National Book Trust, New Delhi, India

Appendix A: Water-table related characteristics, region-wise, Punjab, 2004-05

Characterestics		Unit	Majha	Doaba	Malwa	Punjab
Blocks		No.	29	30	73	132
Geographical area		000 ha	864	988	3184	5036
Net area sown	1975	000 ha	666	697	2795	4158
	1990	000 ha	736	681	2800	4217
	2004	000 ha	743	668	2789	4200
	2004	% of GA	86	68	88	83
Rainfall		Range (mm)	550 –	600 –	< 300 –	< 300 –
			1100+	1100+	1100+	1100+
Net irrigated area		000 ha	680	616	2739	4035
		% of NAS	92	92	98	96
Canal irrigated area		000 ha	267	21	813	1101
		% of NIA	39.3	3.4	29.7	27.3
Rice area	1975	000 ha	207	97	263	567
	1990	000 ha	450	310	1255	2015
	2004	000 ha	536	358	1753	2647
	1975	% of NAS	31.1	13.9	9.4	13.6
	1990	% of NAS	61.1	45.5	44.8	47.8
	2004	% of NAS	72.1	53.6	62.9	63.0
Area under:	Sugarcane	000 ha	27.0	41.0	18.0	86.0
	Potato	000 ha	3.1	36.4	28.3	67.8
	Sunflower	000 ha	0.7	11.5	5.1	17.3
	Sub-total	000 ha	30.8	98.9	51.4	171.1
		% of NAI	4.5	16.1	1.9	6.5
		% of Rice A	5.7	27.6	2.9	4.2

APPENDIX B.1: MAJHA - Water table level in 1975 and 2005 and monsoon recharging in 1994 and 2005

Region	District	B name	Jun-75	5-Jun	Oct-75	5-Oct	Rechg-94	Rechg-05
A	GDP	NAROT JAIMAL SINGH	3.41	3.61	2.74	3.05	0.98	0.56
A	GDP	GURDAS PUR	5.03	7.21	3.74	6.19	1.86	1.02
A	GDP	DINA NAGAR	5.45	5.64	4.04	4.70	1.84	0.94
A	GDP	KALANAUR	5.92	7.10	3.24	6.10	2.42	0.99
A	GDP	PATHANKOT	6.70	6.07	5.78	5.14	1.84	0.93
A	GDP	KAHNUWAN	12.04	11.77	9.58	10.99	1.05	0.78
B	ASR	AJNALA	4.60	8.93	2.82	8.59	1.67	0.34
B	GDP	DERA BABA NANAK	4.62	7.39	2.49	6.86	2.02	0.54
B	ASR	BHIKHIWIND	5.27	10.39	3.07	9.27	0.61	1.12
B	ASR	CHOGWAN	5.30	11.46	3.12	10.91	2.00	0.55
B	ASR	VALTHOA	6.29	8.95	4.54	8.31	0.31	0.64
B	ASR	GANDIWIND	6.39	11.04	3.42	10.96	0.67	0.09
C	GDP	BATALA	4.00	7.10	1.37	6.31	1.25	0.79
C	GDP	FATEHGARH CHURIAN	4.01	6.83	1.57	5.96	1.82	0.88
C	ASR	MAJITHA	4.12	8.47	1.74	7.60	1.27	0.87
C	ASR	TARSIKKA	4.61	11.52	2.15	10.69	0.60	0.83
C	ASR	VERKA	5.08	22.15	3.13	20.64	0.44	1.51
C	ASR	JANDIALA	5.47	14.17	3.81	13.97	0.27	0.20
C	ASR	HARSA CHHINA	5.77	10.92	3.44	9.54	1.22	1.38
C	ASR	TARN TARAN	6.24	15.39	3.96	15.28	0.55	0.11
C	ASR	NAUSHERA PUNNUAN	6.28	14.93	3.47	14.69	0.39	0.24
C	ASR	PATTI	6.85	14.25	5.22	13.50	0.40	0.75
C	GDP	DHARIWAL	7.26	10.63	4.65	9.50	0.51	1.13
D	ASR	RAYYA	5.55	10.86	2.69	10.57	1.69	0.30
D	GDP	QADIAN	5.78	9.11	3.33	8.25	1.30	0.86
D	ASR	CHOHLA SAHIB	7.14	12.83	5.74	13.02	0.34	-0.19
D	ASR	KHADUR SAHIB	8.73	19.00	6.80	19.00	0.98	0.00
D	GDP	SHRI HAR GOBINDPUR	9.73	12.81	7.68	11.82	2.30	0.99
E	GDP	DHARKALAN	16.80	8.54	10.20	6.32	6.81	2.22

APPENDIX B.2: DOABA - Water table level in 1975 and 2005 and monsoon recharging in 1994 and 2005

Region	District	B name	Jun-75	5-Jun	Oct-75	5-Oct	Rechg-94	Rechg-05
A	HPR	HAZIPUR	8.73	9.80	4.52	8.80	2.20	1.01
A	HPR	TALWARA	9.39	12.03	8.94	10.75	1.40	1.28
B	HPR	HOSHIAR PUR-I	7.09	7.05	5.31	5.83	2.73	1.22
B	HPR	HOSHIAR PUR-II	7.63	15.35	5.66	14.40	2.47	0.95
B	HPR	BHUNGA	7.99	8.12	6.61	7.51	1.93	0.61
C	HPR	MAHIL PUR	11.81	24.98	11.10	24.49	3.05	0.50
C	NWS	BALACHAUR	12.43	12.57	12.29	12.25	0.96	0.32
C	HPR	GARHSHANKAR	15.38	22.35	13.14	21.76	1.01	0.59
C	NWS	SAROYA	28.54	27.13	16.80	26.28	1.76	0.84
D	NWS	AUR	5.92	12.08	4.92	11.99	3.87	0.10
D	JAL	NAKODAR	7.04	23.83	6.06	23.36	0.82	0.47
D	JAL	LOHIAN	7.28	15.27	7.54	12.88	0.00	2.39
D	NWS	NAWAN SHAHAR	7.63	11.11	6.15	11.05	0.63	0.06
D	JAL	RURKA KALAN	8.01	16.00	5.61	17.50	1.18	-1.50
D	JAL	PHILLAUR	9.19	14.72	7.67	14.16	3.04	0.56
D	JAL	NURMAHAL	9.46	16.24	8.45	13.88	0.67	2.36
D	JAL	SHAHKOT	10.32	24.65	9.41	25.39	-0.06	-0.74
E	HPR	MUKERIAN	1.94	3.63	1.47	2.38	1.50	1.25
E	KPT	DHILWAN	3.87	6.67	2.76	5.93	1.32	0.74
E	KPT	NADALA	5.19	8.75	3.04	8.14	1.53	0.60
E	KPT	SULTANPUR	5.20	17.33	3.87	15.31	2.05	2.02
E	HPR	DASUYA	5.99	8.58	5.07	9.31	2.30	-0.73
E	HPR	TANDA	6.13	7.43	4.26	6.91	2.14	0.52
F	JAL	ADAMPUR	5.32	9.42	4.52	8.67	0.78	0.75
F	JAL	BHOGPUR	5.85	7.76	4.26	9.10	0.50	-1.34
F	NWS	BANGA	5.99	11.73	2.10	11.54	2.39	0.19
F	KPT	PHAGWARA	6.15	13.69	3.59	12.82	1.15	0.87
F	KPT	KAPURTHALA	6.15	16.27	4.70	15.36	0.42	0.91
F	JAL	JALANDHAR WEST	7.12	15.97	5.66	13.46	0.89	2.51
F	JAL	JALANDHAR EAST	7.18	18.19	5.89	13.81	0.70	4.37

APPENDIX B.3: MALWA - Water table level in 1975 and 2005 and monsoon recharging in 1994 and 2005

Region	District	B name	Jun-75	5-Jun	Oct-75	5-Oct	Rechg-94	Rechg-05
A	Ropar	Chamkaur Sahib	3.11	7.15	2.01	7.25	1.67	-0.09
A	Ludhiana	Sidhwan Bet	4.72	10.92	3.70	9.84	1.80	1.08
A	Ropar	Nurpur	4.94	10.16	3.81	9.56	2.03	0.60
A	Ropar	Ropar	5.11	9.74	3.83	8.23	2.01	1.51
A	Ludhiana	Mangat	6.35	8.99	5.65	8.58	1.19	0.41
A	Ludhiana	Machhiwara	7.10	4.25	6.74	3.68	1.10	0.57
AB	Ferozepur	Zira	2.78	14.70	1.57	15.37	-0.23	-0.67
AB	Ferozepur	Dharam Kot	3.52	18.90	1.73	19.63	0.37	-0.73
ABC	Ferozepur	Makhu	1.45	10.50	0.39	11.10	-1.11	-0.60
ABC	Ferozepur	Ferozepur	2.77	8.70	1.75	8.55	1.11	0.15
B	Ferozepur	Jalalabad	2.29	1.40	1.15	1.15	0.86	0.25
B	Faridkot	Faridkot	2.55	5.23	1.51	5.08	0.66	0.15
B	Ferozepur	Ghall Khurd	2.68	3.20	1.55	2.00	1.31	1.20
B	Ferozepur	Mamdot	2.81	4.80	1.54	6.00	1.77	-1.20
B	Ferozepur	Guru Harsahai	2.95	4.80	2.05	6.00	0.97	-1.20
B	Muktsar	Muktsar	3.87	2.34	3.55	2.50	0.45	-0.16
B	Ferozepur	Fazilka	4.03	3.30	3.07	3.73	0.15	-0.43
BA	Faridkot	KotKapura	7.06	8.38	6.18	7.75	0.19	0.63
BB	Ferozepur	Khuyian Sarwar	9.26	4.22	8.78	4.60	0.61	-0.38
BC	Bathinda	Talwandi Sabo	23.36	7.16	23.06	6.98	0.23	0.19
BC	Ferozepur	Abohar	24.04	6.18	23.65	6.12	-0.37	0.06
BC	Bathinda	Sangat	25.31	8.07	25.06	8.22	0.07	-0.15
BC	Muktsar	Lambi	27.08	3.86	26.36	3.85	0.27	0.00
C	Muktsar	Malot	14.94	3.20	14.40	2.84	0.39	0.36
C	Bathinda	Bathinda	15.15	7.60	14.92	7.60	0.47	-0.01
C	Muktsar	Kot Bhai	16.46	3.89	16.11	3.40	0.40	0.49
C	Bathinda	Maur	18.08	9.22	18.00	9.19	0.33	0.03
CA	Bathinda	Nathana	9.27	12.19	8.62	12.30	0.77	-0.10
CA	Mansa	Mansa	9.48	5.53	8.88	5.12	0.52	0.42
CA	Mansa	Sardoolgarh	9.61	7.78	8.91	7.52	1.80	0.26
CA	Mansa	jhunir	13.44	5.08	12.65	4.92	0.45	0.17
CD	Mansa	Budhlada	4.02	10.78	3.00	10.96	0.76	-0.18
CD	Mansa	Bhikhi	4.40	11.09	3.07	11.23	0.37	-0.14
CD	Bathinda	Phul	5.22	12.93	4.39	13.51	0.19	-0.58
CD	Bathinda	Rampura	8.30	11.78	8.18	12.33	-0.58	-0.55

APPENDIX B.3: MALWA - Water table level in 1975 and 2005 and monsoon recharging in 1994 and 2005

Region	District	B name	Jun-75	5-Jun	Oct-75	5-Oct	Rechg-94	Rechg-05
D	Patiala	Nabha	4.46	18.55	3.77	18.07	0.93	0.48
D	Sangrur	Sehna	4.47	15.39	3.88	14.78	0.50	0.61
D	Patiala	Samana	4.78	20.75	2.56	21.30	0.93	-0.55
D	Fatehgarh S	Sirhind	5.06	12.03	2.88	12.30	0.67	-0.27
D	Patiala	Patiala	5.27	18.26	3.38	18.21	0.27	0.05
D	Sangrur	Lehragaga-Andana	5.29	12.91	3.97	14.54	2.59	-1.63
D	Sangrur	Mehal Kalan	5.31	15.38	4.45	16.00	-0.08	-0.62
D	Ludhiana	Doraha	5.33	14.90	4.59	14.48	1.35	0.42
D	Sangrur	Bhawanigarh	5.49	19.65	4.28	18.50	0.18	1.15
D	Fatehgarh S	Amloh	5.82	18.50	4.91	17.90	0.44	0.60
D	Sangrur	Barnala	5.83	18.87	5.23	19.55	0.92	-0.68
D	Sangrur	Dhuri-Sherpur	5.83	22.76	5.47	22.93	4.15	-0.17
D	Moga	Moga	5.90	24.08	5.07	24.45	0.70	-0.38
D	Patiala	Sanaur	5.93	15.10	3.74	14.80	0.07	0.30
D	Sangrur	Sangrur	5.97	18.64	5.05	14.87	-2.00	3.77
D	Sangrur	Sunam	6.11	17.43	5.41	18.87	1.52	-1.43
D	Moga	Nihal S Wala	6.32	17.05	5.57	17.90	0.44	-0.85
D	Patiala	Bhunarheri	6.49	22.44	3.91	21.45	1.55	0.99
D	Ludhiana	Dehlon	6.51	12.76	5.54	12.39	1.27	0.37
D	Fatehgarh S	Khamanon	6.62	13.26	6.09	13.00	0.66	0.25
D	Sangrur	Maler Kotla-Amargarh	6.93	16.90	5.83	16.65	0.22	0.25
D	Patiala	Patran	6.98	28.20	5.45	23.90	1.94	4.30
D	Ludhiana	Jagraon	7.46	16.00	6.53	15.97	0.39	0.02
D	Patiala	Rajpura	7.79	13.22	5.33	13.36	2.14	-0.14
D	Ludhiana	Pakhowal	8.39	15.60	7.54	16.55	0.21	-0.95
D	Ludhiana	Khanna	8.57	16.24	7.91	16.22	1.16	0.02
D	Sangrur	Ahmedgarh	8.80	23.85	8.14	23.65	0.60	0.20
D	Ludhiana	Sudhar	8.90	15.01	7.93	14.92	0.76	0.09
D	Fatehgarh S	BassiPathana	9.09	14.60	7.15	15.15	0.53	-0.55
D	Ludhiana	Samrala	9.21	12.53	8.95	11.91	0.92	0.62
D	Ludhiana	Ludhiana	9.45	24.31	8.88	24.44	0.30	-0.13
D	Fatehgarh S	Khera	10.95	14.03	8.55	12.82	1.78	1.21
E	Patiala	Ghanaur	5.89	10.68	3.26	9.63	2.27	1.05
E	Ropar	Kharar	6.17	7.88	3.61	5.99	2.85	1.89
E	Patiala	DeraBassi	7.43	9.44	5.82	8.12	2.68	1.31
E	Ropar	Anandpur	8.12	9.32	6.86	8.65	1.80	0.67
E	Ropar	Morinda	9.68	11.72	9.28	11.14	1.86	0.57
E	Ropar	Majri	9.93	10.84	9.21	9.98	2.18	0.86

WHEN DOES OVEREXPLOITATION REALLY MATTER? A CASE OF GROUNDWATER EXTRACTION IN KARNATAKA, INDIA

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Abstract

The paper analyses the consequences of groundwater overexploitation by using field level data collected from 2 well irrigated districts of Karnataka. The study result shows that the consequences arising out of groundwater overexploitation are severe in high well interference area compared to low well interference area. As a result, the overexploitation of groundwater has differential impact on different categories of the farmers in terms of cost of drilling, area irrigated per well and adoption of conservation measures. The burden of well failure is more or less equally shared by all categories of farmers but small farmers are the worst victims of resource scarcity. The study suggests maintaining inter well distance to prevent 'resource mining' and to educate farmers to cultivate light water crops. Institutional reforms are necessary to restore surface water bodies and facilitate aquifer recharge.

1. INTRODUCTION

Resource scarcity was viewed at best as a major barrier to continued economic development, with the depressing implications which this has for the economies of the developing countries. At the same time it was predicted that overexploitation of natural resources stocks would cause the total collapse of society during the early part of the 21st century (Rees, 1990). It seems clear that technological progress and market forces have not acted to reduce pressures on renewable resources as they have in the stock resource case (Johnson, 1975; Dasgupta, 1982). In the advanced economies higher real consumer incomes have not only increased demands for a better quality of life and a cleaner environment but, coupled with rising levels of personal mobility, have intensified pressures on amenable natural resources such as water, forest and land resources.

Groundwater, as a natural resource, assumes a significant role either as a sole or as a supplementary source of irrigation. Although groundwater is conventionally regarded as a common pool resource, it cannot be treated as a open access resource because its availability is restricted by various socio-economic and hydro-geological factors (Janakarajan, 1997). Moreover, the over-use of groundwater poses a problem of externalities due to cumulative well interference problem. This is because a given aquifer can be shared by many and that creates the problem of competitive extraction (Ibid). This problem is due to lack of efficient legal measures in checking or regulating its use (Singh, 1992) and under pricing of its true value (CVG, 1997). In this context, the paper looks into the consequences of groundwater over exploitation confining to irrigation sector in the central dry zone of Karnataka, India.

We start with an illustration of the natural resource exploitation in the context of developing countries. After describing our study region and methodological issues we report results that are subjected to groundwater irrigation in the central dry zone of Karnataka. In the light of the reported results, the concluding section suggests measures to prevent over exploitation of groundwater resources.

2. NATURAL RESOURCE EXPLOITATION: AN OVERVIEW

Natural resources are important for sustainable development and achieving higher economic growth. Efficient and scientific utilization of these resources ensures the ecological balance of an ecosystem. The contribution of natural resources to local economy is outside the market framework, which are both its strength as well as weakness. Strength in the sense of social justice, that it supports rural families. Weakness lies in

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unsustainable exploitation of these resources, which would result in the tragedy of these resources. Further, unsustainable exploitation leads to scarcity of resources that would then be beyond the reach of the poor.

Barnett and Morse (1979) defined *increasing scarcity as increasing real cost,* which is measured by the amount of labour and capital required to produce a unit of extractive resources. They put forward the following hypothesis:

The real cost of extractive products per unit will increase through time due to limitations in the available quantities and qualities of natural resources. Real cost in this case is measured in terms of labour (man-days, man-hours) or labour plus capital per unit of extractive output (Barnet, 1979).

Barnet and Morse refer to this postulate as the strong hypothesis of increasing economic scarcity. It suggests that increasing resource scarcity will be evident if, over time, an increase in use of labour and capital per unit of extractive output.

The debate on natural resource scarcity brings us to the frontier of externalities. These externalities could be several types depending on the nature of the resources. Externalities related to groundwater resource could be stock related, cost related and strategic in nature (Provencher, 1998). Stock related externalities arise when extraction rates go beyond sustainable yield rates. In such cases, all the available resource stocks are exploited to the extent that there is no further scope for future exploitation (Reddy, 2003). In the case of groundwater, most of the negative externalities arise due to stock related aspects. In broader sense, other externalities viz., cost related, strategic and legislative externalities are associated mainly with stock related externalities. Therefore, loosing the resource base permanently is a risky sign if the non-renewable portions of the stocks are exploited (Ibid).

Most of the natural resources are common pool resources in which rights are limited to use and income deriving. In the case of groundwater aquifer, it can be sold and transferred along with land due to its link with land. Due to absence of property rights in allocating resources such as groundwater, farmers make private investment assuming that they have absolute rights over groundwater aquifer. In the course of these institutional drawbacks, everyone who has the capability to access groundwater remain in the race of exploiting the resources.

3. THE STUDY REGION: CENTRAL DRY ZONE, KARNATAKA, INDIA

The Central Dry Zone consists of 17 taluks with a total geographical area of 20,112.81 sq. km. The rainfall ranges between 455.5 to 717.4 mm in the zone. The elevation of the zone is 800-900 in major areas, in remaining areas 450-800. Table 1 provides details about the characteristics of the zone.

Table 1: Characteristics of Central Dry Zone, Karnataka

Sl. No	Characteristics	Particulars
1.	Rainfall (mm)	Ranges from 455.5 mm to 717.4 mm
2.	Elevation	800-900 in major areas, in remaining areas 450-800
3.	Soil	Red sandy loam in major areas, shallow to deep black soil in remaining areas
4.	Total Geographical area (sq. km)	20,112.81
5.	Gross cropped area (ha)	12,93,011
6.	Net Cropped area (ha)	11,27,500
7.	Total irrigated area (ha)	2,51,270

The population density (ranges between 189 persons / sq. km and 235 persons / sq. km) in the study area is high compared to other zones in the state. Agriculture is the main occupation in the area. In the central dry zone as a whole, about 60% of the working population cultivates land and another 25% is agricultural labour. The literacy rate is average reflecting medium levels of social services and social development in the area.

Because of high population density, the average operational farm holding is considerably small. Farmland in the area is privately owned and a significant portion is farmed by the owners. Sharecropping, lease in and lease out are to the tune of less than 5%. Land fragmentation is a widespread phenomenon.

4. THE METHODOLOGICAL APPROACH

Two taluks reporting high and low well interference problem were selected from central dry zone in Karnataka state[2]. These taluks represent different levels of groundwater situation and reflect the overall situation in the agro-climatic zone. Nine villages have been covered from 2 taluks in order to study the overexploitation problem of groundwater resource[3]. Chosen villages are Adrikatte and Marabaghatta (scarcity villages) and Heggere and Huralihalli (no scarcity villages) in Hosadurga taluk and Garani, Chandragiri and Madenahalli (scarcity villages) D V Halli and Kambadahalli (no scarcity villages) in Madhugiri taluk. Thus, the sample villages range from reasonably good availability of groundwater to acute shortages (including drinking water). Although tanks exist in few study villages, many of them are not filled in since 1992. Therefore, there are no alternative water sources for irrigation as well as drinking purposes.

The data collection has been done at 2 levels. At the first level, Participatory Rural Appraisal (PRA) technique has been used to select respondents in all the villages. At the second level, detailed information regarding various aspects of well irrigation was collected using a detailed questionnaire from households whose wells have been interfered. This study comprises a group of villages where irrigation wells suffer from cumulative well interference (here after HWIA) and another group of villages where interference problem does not lead to high well failure (here after LWIA).

4.1 PRA approach

Understanding the situation of failed wells, due to resource scarcity, from the perspective of farmers is crucial since they are the ultimate decision makers and investors for coping with the well failure problems. The farmers' perception of well failure is different from technical definition of well failure[4]. Therefore, it is necessary to obtain information about failed wells in the study area to reveal the actual situation of the well interference problem. The PRA method was applied to choose the respondents in the sample villages.

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[2]The agro-climatic zone is reported to have serious groundwater problems next to eastern dry zone in the state.

[3]The following criterion was followed in order to choose the taluks with the highest degree of well interference. Interference of irrigation wells per ham of net groundwater availability = (No. of IP sets or wells/utilisable GW for all purposes in ham) for each taluk. Calculation of the ratio involved following steps (Shivakumaraswamy and Chandrakanth 1997). Below are the steps to calculate index of well interference. **Step 1:** In the first step, Irrigation pump sets (IP) are considered as a proxy to irrigation wells and borewells installed. **Step 2:** Net annual groundwater availability is considered to calculate index of cumulative well interference ratio in each taluk. Net annual groundwater availability in hectare meter (ham) will indicate the utilizable quantum of groundwater for all purposes in a particular year for each taluk. The data pertains to 2004-05. **Step 3:** By considering cumulative number of wells and net annual groundwater availability, cumulative well interference index has been calculated, which explains number of wells per hectare meter of utilizable groundwater in each taluk. This can be written as:

Index of Cumulative Well Interference (ICWI) = (No. of IP sets or wells/Utilizable groundwater for all purposes in ham) for each taluk.

Step 4: The taluks are then sorted in descending order of the magnitude of the above index. The taluks are later classified according to agro-climatic zones of the State in order to obtain variability in groundwater use across crop types, soil types and climatic types. Among the Agro-climatic Zones, eastern dry zone topped with respect to ICWI, followed by central dry zone, northern dry zone and southern dry zones, which have the magnitude of ICWI above one. However, we decided to choose the taluk which topped with respect to ICWI in one out of ten agro-climatic zones and which does not have substantial surface irrigation projects. The agro-climatic zone chosen was Central Dry Zone. The selected taluks were Madhugiri and Hosadurga in the Central Dry Zone. The taluks are selected based on highest and lowest magnitude of ICWI respectively.

For the selection of villages in selected taluks in selected Zone, the village-wise availability of groundwater for irrigation was computed by using the ratio. The ratio calculated as below:

(Net Sown area of the village/net sown area for the taluk) x (Utilisable groundwater of the taluk).

Villages are then sorted in descending order of the magnitude of the above ratio. The villages are later selected in order to obtain variability in groundwater use across crop types, soil types and climatic types. The selected villages are representing high and low magnitude of groundwater availability in the respective taluks.

As far as definition of failed well is concerned, various definitions have been emerging out of discussion with farmers in different areas and in different situations. However, we compile them in a holistic manner and we define failed well as:

1. the well that dries because of new well(s) coming in (but not due to lack of rainfall);
2. the well that need deepening because of new well coming in (not because of lack of rainfall); and
3. the large quantity of yield goes off because of new well coming in (but not because of lack of rainfall).

Basic features of the study villages are almost similar in terms of occupational pattern, cropping pattern, infrastructures and social services. In all the villages, small and marginal farmers are in majority. There is high concentration of bore-wells as well as open wells in HWIA compared to LWIA. The area irrigated is less than 25% of the total cultivable land in all the villages except in Heggere, where the area irrigated to total cultivable land is nearly 27%[5].

5. RESULTS AND DISCUSSIONS

5.1 Characteristics of groundwater Irrigation

Groundwater irrigation is characterized by sole ownership rights and control on its access which are quite contrast to traditional community managed or state managed surface irrigation systems. Development of groundwater based irrigation has created a way for intensive multi season agriculture in many parts of India. Since surface irrigation sources and traditionally used tanks have lost the cadence of irrigation potentiality due to various reasons[6], one can see the rapid growth of groundwater irrigation and emergence of groundwater as a crucial productive resource. Further, the status of groundwater irrigation can be understood by analyzing type of wells used, well density, ownership pattern, landholding size and crop pattern.

5.1.1 Type of wells

Prior to green revolution, the major sources of irrigation were traditional tanks, streams and dug wells. With the decline in water levels, depth of dug wells could not be restricted to the weathered zone and had to pierce the underlined fractured zone, the excavation of which was through blasting, rendering the process slow and expensive. Framers, therefore, preferred boring from the bottom of dug wells instead of conventional excavation. Such dug-cum-bore wells allowed the use of centrifugal pump sets installed on dug wells. However, dug-cum-bore wells had limited use because water levels soon declined below the suction limit of centrifugal pump sets, forcing the farmers to switch over to deeper surface bore wells and install submersible pump sets. This commenced in early 1980s and marked an important phase of groundwater development in the state (Rao, 1992). Further, easy access to technology and credit was made available for the growth of bore wells in semi-arid regions of the state. This was coupled with availability of free electricity supply for agriculture. This made multi crops in multi season possible and increased production. All these factors marked a shift of groundwater structures from simply dug-cum-bore wells to deeper surface bore well technology. It is an irony that bore wells constructed as a solution to declining water levels actually hastened the process of water table lowering. The unit draft (withdrawal) of a bore well is more than that of a dug well.

Table 2 provides the listing of different type of groundwater structures in the sample villages. Bore wells seem to be major irrigation structures followed by open wells in the HWIA. However, the contribution from the dug wells to irrigation potential is zero as they all defunct due to either bore well interference problem or decreasing quantum of rainfall in recent decades. In LWIA, nearly 95% of the groundwater structures are bore wells. This implies that the groundwater irrigation through manually lifting devices such as *yetha* was not popular in both LWIA and HWIA and most farmers depend on bore wells.

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[4] The National Bank for Agriculture and Rural Development (NABARD) defines borewells yielding less than 2 liters per second (or 1,582 gph) at the time of installation as failed wells.

[5] The actual area irrigated is higher than the figure mentioned in the official record. Besides, the area irrigated by tanks and other sources was mentioned high in the official record. However, the general picture in the sample villages is far from the reality where groundwater is the only source of irrigation due to drying up of tanks.

[6] Declining irrigation potentiality of surface water bodies are on account of two major factors in the study area– (i) factors related to human intervention and (ii) factors related to nature intervention.

Table 2: Type of Wells in the Sample Villages

Villages	No. of Borewells	No. of Openwells	Total Number of wells
Adrikatte	61 (96.8)	2 (3.2)	63
Heggere	60 (96.8)	2 (3.2)	62
Huralihalli	44 (95.7)	2 (4.3)	46
Marabgatta	55 (90.2)	6 (9.8)	61
LWIA	220 (94.8)	12 (5.2)	232
Chandragiri	89 (69.5)	39 (30.5)	128
D. V. Halli	39 (75.0)	13 (25.0)	52
Garani	70 (66.7)	35 (33.3)	105
Kambadahalli	25 (64.1)	14 (35.9)	39
Madenahalli	49 (69.0)	22 (31.0)	71
HWIA	272 (68.9)	123 (31.1)	395

Source : Primary survey
Note : Figures in parenthesis indicates percentage to the total number of wells.

5.1.2 Type of wells across landholding size

It is important to understand the effect of landholding size on farmers in opting for bore well technology. This aspect is important because of 2 reasons: firstly, landholding size is a decisive factor to understand wealth status of a household as land treated as a productive asset as well as status symbol; secondly, landholding size is a major factor for cultivating variety of crops in different seasons thus, extracting heavy amount of water to sustain the crops.

Table 3 illustrates that as the landholding size increases the preference to have borewell technology increases and *vice versa*. It is clearly visible in the case of LWIA, where the proportion of bore wells is an increasing trend as we move towards larger landholding sizes. However, the ownership of different types of groundwater structures in HWIA reveals a different picture as this is highly affected by well interference problem.

Small farmers in HWIA own the highest number of ground water structures because majority of them are late comers in the resource extraction activity. Therefore, area in which small and marginal farmers install groundwater structures may not strike water as the area is already suffering from acute well interference problem. Even if they are able to mop the capital required for additional well, they bear the risk of not striking (adequate) groundwater. In this situation small farmers tend to have more wells as they are not able to deepen their existing wells because of high equipment cost as well as operation and maintenance cost.

After the dug wells run dry, the farmers biggest priority is to restore well irrigation at any cost. Oblivious to the risk involved, farmers incur heavy expenditure on drilling bore wells, most of them making repeated attempts. Even in case of successful bore wells, many farmers have to incur expenditure on deeper bore wells because the bore wells, which succeeded initially were dry after running for a few years.

5.1.3 Ownership of wells across size class of farmers

In the study area, the ownership rights over borewells and open wells were enjoyed by a single owner and not by joint well owners. Understanding emerging ground water problems and finding potential solutions emerge from this central point. As the bore well owners enjoy ownership rights as well as freedom to extract groundwater as and when required, it increases its rate of extraction.

Table 3: Type of Wells Across Landholding Size in LWIA and HWIA

Landholding size (Ha)	No. of Borewells	No. of Open wells	Total No. of wells
Marginal Farmer (Up to 1) N=10	11(5.0)	0(0.0)	11(4.7)
Small Farmer (1.01 to 3.0) N=37	52(23.6)	3(25.0)	55(23.7)
Medium Farmer (3.01 to 5.0) N=26	58(26.4)	4(33.3)	62(26.7)
Large Farmer (More than 5.0) N=29	99(45.0)	5(41.7)	104(44.8)
LWIA (N=102)	220(100.0)	12(100.0)	232(100.0)
Marginal Farmer (Up to 1) N=15	27(9.9)	19(15.4)	46(11.6)
Small Farmer (1.01 to 3.0) N=73	168(61.8)	74(60.2)	242(61.3)
Medium Farmer (3.01 to 5.0) N=22	49(18.0)	20(16.3)	69(17.5)
Large Farmer (More than 5.0) N=13	28(10.3)	10(8.1)	38(9.6)
HWIA (N=123)	272(100.0)	123(100.0)	395(100.0)

Source : Primary survey
Note : Figures in parenthesis indicate percentages to total

The survey conducted in 9 villages in 2 extreme regions (high well interference and low well interference areas) of Karnataka shows that about one-third of large farmers owned nearly 50% of wells in LWIA (Table 4). Similarly, In HWIA, maximum number of wells were owned by small farmers. It is an indication of high well failure due to well interference problem.

The relevant question is to what extent is it rational to classify the sample well owners according to size of landholding. This is important to get new insights into the characteristics of well owners and their access to groundwater. For instance, a simple fact is that the larger the land area owned greater the possibility of striking groundwater. Further, the scope of sustaining groundwater irrigation is far better for large land owners compared to small holders. But it is imperative to ask for how long will the small (resource poor) farmers sustain the problem of competitive deepening? While the threat of getting eliminated from the race of competitive deepening is seemingly just around the corner for farmers, the resource rich farmers have the capability of sustaining the adverse effects of competitive deepening. Resource rich farmers are not constrained in mobilizing finance for well drilling or well deepening activities as resource poor farmers.

Small farmers in HWIA owns larger number of wells. At the surface it appears as though groundwater irrigation is quite diffused across farming community. The success of the green revolution, greatly attributed to the development of well irrigation. In this setting, the large farmers perhaps entered into groundwater extraction activity much before that of small and marginal farmers. As a result, large farmers have not only exploited groundwater much early, but have done substantial damage by mining the aquifers. Therefore, poor well owning farmers though appear to own large number of wells, are indeed late comers in the race of groundwater extraction.

Sole ownership indicates claim of property rights over groundwater. The law of inheritance perpetuates the problem of ground water extraction. From one generation to the next, the land gets fragmented further. With each fragmentation, additional bore wells are introduced. In their competitiveness to bring more area under irrigation, small and marginal farmers drill more wells even though they may not strike groundwater. If they do strike groundwater, it may be less in quantity.

The area irrigated per well by small and marginal farmers is comparatively low in comparison to medium and large farmers (Table 4). For instance, in both LWIA and HWIA, the area irrigated per well is less than 1 ha in the case of marginal farmers, less than 1.5 ha in the case of small farmers, and more than 2 ha in the case of large farmers. For the same investment in drilling or deepening, small farmers get a lower return because of the smaller size of land holdings in cocmparison to large farmers.

To this there is the increased threat of over exploitation from a common pool – the aquifer. Medium and large farmers continue to enjoy ownership over groundwater as they can compete with declining water tables by deepening wells. But, for small and marginal farmers, the financial burden of drilling and deepening activities is very high with little or no assurance of striking water.

Table 4: Ownership of Wells Across Size Class of Landholding in LWIA and HWIA

Landholding size (Ha)	Number of well owners	Total number of wells owned	Total extent of land irrigated (ha)	Average extent irrigated per well (ha)
Marginal Farmer (Up to 1)	10	11	5.58	0.62
Small Farmer (1.01 to 3.0)	37	55	44.08	1.13
Medium Farmer (3.01 to 5.0)	26	62	51.16	1.42
Large Farmer (More than 5.0)	29	104	106.11	2.12
LWIA	102	232	206.93	1.54
Marginal Farmer (Up to 1)	15	46	6.99	0.64
Small Farmer (1.01 to 3.0)	73	242	73.43	1.41
Medium Farmer (3.01 to 5.0)	22	69	36.54	1.52
Large Farmer (More than 5.0)	13	38	38.05	2.00
HWIA	123	395	155.01	1.46

Source: Primary survey

5.1.4. Well Density[7]

The well density per unit area is 1.2 in HWIA, which is very high as compared to 0.5 of LWIA (Table 5). Higher number of borewells per unit of area in HWIA indicates well failure rates and consequently more investments on bore wells due to high well interference problem. Well density is one of the indicators to measure the sustainability of groundwater resources. In over exploited area, if proper isolation distance and optimum well density in relation to the recharge capacity is not maintained, it is bound to create cumulative well interference problem. As a result, the surrounding wells would dry up. In case of HWIA, the well density is very high reflecting the un-sustainability of the groundwater resource. Though the well density in terms of increased number of wells indicates wider access, the resource needed to own a well and pumps are beyond the reach of small and marginal farmers considering high capital cost. The village-wise analysis indicates that the villages in LWIA are having lower well density compared to HWIA. In HWIA, the well density is high in scarcity villages compared to other villages (Figure 1 and 2). It is not surprising that in villages where well density is high land irrigated per well is low. This leads to the problem of cumulative well interference because small size of land accommodates larger number of wells and water is ebstracted beyond sustainable limits.

Table 5: Well Density in LWIA and HWIA

Villages	Land (ha)	Well density	Area per well
Adrikatte	122.82	0.5	1.9
Heggere	89.87	0.7	1.4
Huralihalli	75.5	0.6	1.6
Marabgatta	147.51	0.4	2.4
LWIA	435.7	0.5	1.9
Chandragiri	46.58	2.7	0.4
D. V. Halli	43.12	1.2	0.8
Garani	117.06	0.9	1.1
Kambadahalli	65.3	0.6	1.7
Madenahalli	53.38	1.3	0.8
HWIA	325.44	1.2	0.8

Source: Primary survey

Figure 1: Well density and area per well in LWIA

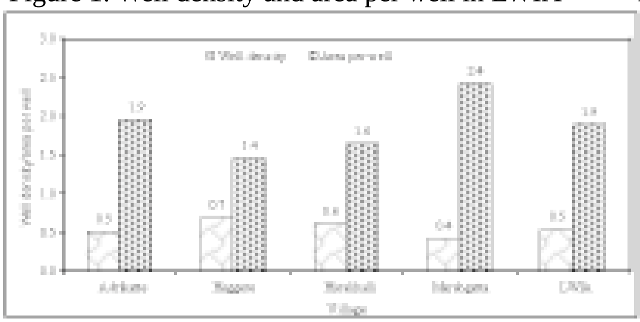
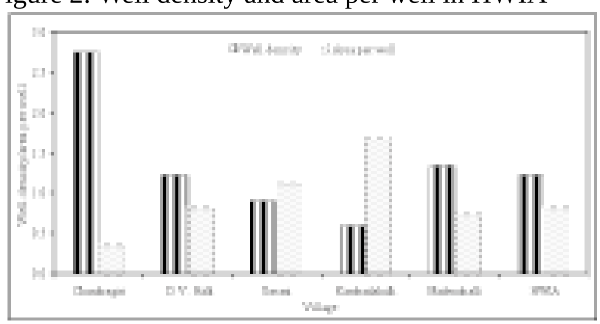


Figure 2: Well density and area per well in HWIA



5.2. Area irrigated, crop pattern and yield

In this section, we present the area irrigated, crop pattern and yield rate of different crops in the study area. It is necessary to mention that HWIA is under severe stress due to over exploitation of the resource compared to LWIA. As a result, cropping pattern is shifting from high water intensive crops to low water intensive tree and plantation crops. Further, the situation in these 2 areas can be comparable to examine the cumulative well interference problem.

5.2.1. Area irrigated

Water yielding characteristics and area irrigated by wells vary between villages affected by severe well interference problem and those, which are not. For instance, in LWIA, nearly 37% of the wells are irrigating

[7] Well density refers to the number of wells per unit area and the area per well is the reciprocal of the well density. While calculating well density total land holdings of the entire sample farmers and total number of all types of wells were considered whether working or failed.

gross area of more than 10 acre compared to 11.3% in HWIA (Table 6). Similarly, almost 7% of the wells are irrigating more than 5 acre of net irrigated area in both LWIA and HWIA (Table 7). The higher gross irrigated area (GIA) and net irrigated area (NIA) of LWIA is due to low well interference and the cropping pattern. However, in HWIA, the area irrigated per well (both GIA and NIA) appears to be low due to low yield rate of aquifers and mining the aquifers beyond threshold level.

Table 6: Gross Area Irrigated Per Well in LWIA and HWIA

GITA (Acre)	LWIA Number of wells					HWIA Number of wells						Grand Total
	Adrik Ate	Heggere	Huraliha	Maraba gatta	Total	Chand Ragiri	D V Hall	Garani	Kambada Halli	Madena Halli	Total	
0.01-2.5	1	1	0	3	5 (3.73)	3	3	10	4	7	27 (25.5)	32 (13.3)
2.51-5.0	8	9	0	9	26 (19.4)	4	12	13	4	1	34 (32.1)	60 (25.0)
5.01-7.5	9	18	2	10	39 (29.1)	3	6	9	4	1	23 (21.7)	62 (25.8)
7.51-10.0	7	1	2	5	15 (11.2)	0	4	4	1	1	10 (9.43)	25 (10.4)
> 10.0	9	17	12	11	49 (36.6)	3	0	5	4		12 (11.3)	61 (25.4)
Total	34	46	16	38	134 (100)	13	25	41	17	10	106 (100)	240 (100)

Source : Primary survey

Note : Gross area irrigated has been calculated only for those wells that are in working condition. Scarcity villages: Adrikatte and Marabgatta in LWIA and Chandragiri, Garani and Madenahalli in HWIA

The cumulative well interference induced water scarcity comes out clearly from Tables 6 and 7. In LWIA, area irrigated per well is higher than that irrigated per well in HWIA. In HWIA, gross area irrigated per well is declining as we move from smaller to larger landholding size. The difference is quite sharp between scarcity villages and non-scarcity villages in terms of gross irrigated area and net irrigated area. Such difference in the area irrigated by wells between scarcity and non-scarcity villages in HWIA is also reflected on crop productivity. We learned from our survey that majority of the farmers in HWIA removed arecanut plantation, which they depended on earlier, due to severe water scarcity problem. This is a clear indication of negative externality which poses severe threat to welfare of peasant families in terms of loss of income, food insecurity, employment insecurity and migration[8].

5.2.2. Change in area irrigated per well

The area irrigated by wells has been changing radically over time in both LWIA and HWIA. The change in area per well has been calculated by taking present extent of area irrigated by a well minus initial irrigated area

[8]These are the different forms of securities for human development in the world. Food security is said to be there when people have access to sufficient, safe, and nutritious food at all times to meet their dietary needs and food preferences for an active and healthy life (FAO, 1996a). Social security is a combination of economic, political and personal security, including equity and justice, that is necessary for life, liberty and pursuit of happiness. Similarly, Environmental security ensures that the eco-system and the environment are able to support the healthy pursuit of life, liberty, and happiness by present and future generations.

for working wells. A negative change is observed in HWIA compared to LWIA (Figure 3). Similarly, rapid change is taking place in terms of area irrigated per well in LWIA due to fast developing aquifer mining. In HWIA, the aquifer condition is deteriorating in terms of recharge capacity due to overexploitation of the aquifer since long time. Added to that the cropping pattern, soil condition, climatic condition are playing an important role for rapid change in area irrigated per well.

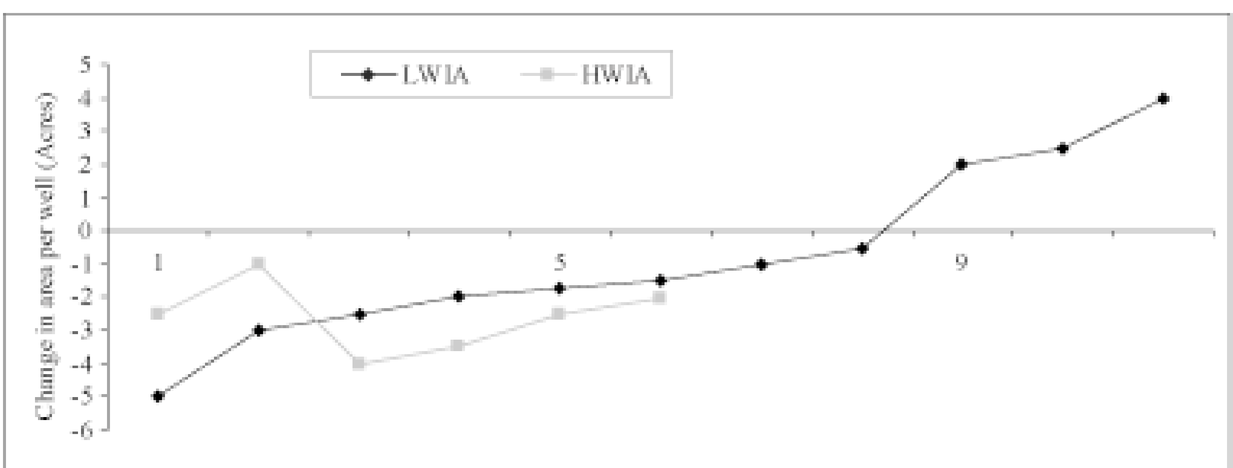
Table 7: Net Area Irrigated per Well Across Villages in LWIA and HWIA

NIA (Acres)	LWIA Number of wells					HWIA Number of wells						
	Adrik Ate	Heggere	Huraliha Halli	Maraba gatta	Total	Chand Ragiri	D V Hall	Garani	Kambada Halli	Madena Halli	Total	Grand Total
0.01-1.0	3	4	0	3	10 (7.5)	4	2	10	3	3	22 (20.8)	32 (13.3)
1.01-2.5	15	24	2	17	58 (43.3)	6	13	13	5	4	41 (38.7)	99 (41.3)
2.51-5.0	9	17	10	12	48 (35.8)	1	10	14	7	3	35 (33.0)	83 (34.6)
5.01-7.5	5	1	1	3	10 (7.5)	2	0	4	1	0	7 (6.6)	17 (7.1)
> 7.5	2	0	3	3	8 (6.0)	0	0	0	1	0	1 (0.9)	9 (3.8)
Total	34	46	16	38	134 (100)	13	25	41	17	10	106 (100)	240 (100)

Source : Primary survey
Note : Net area irrigated has been calculated only for those wells that are in working condition.
Scarcity villages: Adrikatte and Marabgatta in LWIA and Chandragiri, Garani and Madenahalli in HWIA

The cropping pattern in LWIA indirectly promotes resource conservation since it is dominated by plantation crops such as coconut and other tree plants. However, the water intensive crop such as paddy is a major hindrance in HWIA which consumes major share of and puts pressure on groundwater aquifer. We shall discuss this in the next section.

Figure 3: Change in area per well in LWIA and HWIA



5.2.3. Crop pattern

Paddy is by far the most important crop during kharif in HWIA along with arecanut, coconut and ragi. However, the major crop in LWIA is coconut. Although coconut is a perennial crop most of the time, due to infrequent rainfall, groundwater is the chief source of water during kharif season too. Water intensive crops such as paddy, arecanut/coconut and vegetables are to the tune of 7.1, 6.3 and 2.9 ha respectively (Table 8). The area under water intensive crops in the HWIA (39.4 %) is much higher than that in LWIA (6 %). Thus, crops selected also reflect the competitive extraction behavior in exploiting groundwater.

There are wide varieties of crops grown in both LWIA and HIWA. The cropping pattern of the area is due to location advantages, marketing facilities and availability of timely water sources. For instance, coconut is the predominant perennial crop grown largely in LWIA because weather condition and soil type encourages the production as well as crop growth. Similarly, paddy is the predominant food crops grown largely in HWIA due to its comparative advantage over other crops and traditional association with paddy as a staple food crop.

Table 8: Cropping Pattern in HWIA and LWIA (Area in Ha)

	LWIA				HWIA			
	Kharif	Rabi	Summer	Total	Kharif	Rabi	Summer	Total
Maize	0	0	0	0	7.5	0.8	3	11.3
Paddy	7.1	0	0	7.1	30.4	0	5.5	35.9
Ragi	2.9	0	0	2.9	14.8	0.9	1.6	17.3
Food crops	10.0	0	0	10.0	52.7	1.7	10.1	64.5
Areca/coconut	6.3	6.3	6.3	18.9	15.6	15.6	15.6	46.8
Banana	0.2	0.2	0.2	0.6	0.8	0.8	0.8	2.4
Coconut	154	154	154	462	14	14	14	42
Groundnut	4.6	0	0.2	4.8	5.4	0	21.5	26.9
Sapota	1.6	1.6	1.6	4.8	0.8	0.8	0.8	2.4
Other crops*	8.0	5.1	5.9	19.0	18.6	9.3	15.3	43.2
Cash crops	174.7	167.2	168.2	510.1	55.2	40.5	68.0	163.7
Gross area irrigated				520.1				228.2
Net area irrigated				184.7				107.9

Source : Primary survey
Note : * other crops include sunflower, floriculture, lemon, mulberry vegetables, mango and pomegranate.

Why is paddy cultivation popular in HWIA despite groundwater scarcity? This seems to be a very crucial issue from a resource economics point of view. Firstly, paddy is by far the most preferred staple food crop in this area along with ragi. Secondly, paddy is labeled as a lazy man crop. It doesn't require more attention and frequent human labours to monitor crop growth as it requires in other crop cultivation. However, because of rising groundwater scarcity, a majority of farmers have shifted from paddy to ragi, groundnut and other low water intensive dry land crops[9].

In principle, access to bore well irrigation enables rural households to engage in agricultural operations throughout the year and enhance returns from land. Groundwater ensures reliable water supply throughout the year (at least for some farmers), productivity of land is quite remarkable. Well owning farmers normally take 2

[9]In two out of nine villages, two farmers have shifted totally from high water intensive food crops to low water intensive tree crops such as Teak, Mango, Sapota and Lemon and two farmers planted eucalyptus due to water scarcity and cope with high expenditure on farming. They seem to maximize their marginal productivity by planting crops of longer duration. This reduces their operational cost as well as maintenance expenditure.

crops; and some times, a third crop as well, thereby maximizing the gross returns from farms. However, in practice, groundwater irrigation is working adversely for the resource poor farmers by posing severe threat to their living condition.

5.3. Consequences of groundwater overexploitation

Groundwater depletion is by far the most widely debated issue in the resource economics literature. Groundwater depletion problems are related to the question of resource management and the coalition of powerful property owners protecting their interests, under a capitalist society. Overexploitation of groundwater and its social consequences are the result of certain processes of development in irrigated agriculture that occur at the cost of depletion of aquifers and sustainable farming systems. The state intervened initially through agrarian reforms, and later by providing credit facilities and supporting marginalized groups to have irrigation facilities by implementing Million Well Schemes, Ganga Kalyan Yojana and politically influenced free power supply. All these led to rise in groundwater structures, shifting cropping pattern towards water intensive crops as well as resource abuse by overexploitation of the aquifer.

The distinctive impact of irrigation, in general, and groundwater irrigation, in particular, on farming begins to emerge more clearly and recognizably where irrigation permits extension of cultivation to additional seasons (Rao, 1978). This allows farmers' to benefit from surplus production which otherwise would not have been possible. As a result, groundwater became a chief source of irrigation primarily in arid and semi-arid areas and at the same time several problems emerge due to heavy pumping.

5.3.1. Growth, depth and cost of bore wells

Growth of groundwater structures (wells) is infouenced by many factors, the most notable being dropping water levels and competition among farmers. They have a variety of impacts. There has been a change in the type of wells. Traditional openwells/dug-cum-borewells cannot be used when water levels fall. Now large numbers of defunct open wells have turned into storage tanks in the wake of infrequent power supply and voltage fluctuations.

The growth of wells seems to be high in HWIA compared to LWIA (Table 9). The fast growth is because of frequent well failure problem. Since HWIA is suffering from cumulative well interference problem, frequent well failure and declining yield rate is quite common. Similarly, the depth of borewells is increasing constantly with the number of bore wells both in HWIA and LWIA but with more severity in HWIA. Table 9 reveals that the depth of bore wells in HWIA is always higher than that of LWIA. The difference is almost two times. This clear indicates the competitive extraction behaviour of farmers in HWIA.

Table 9: Depth and Cost of Bore Wells in LWIA and HWIA

	LWIA				HWIA			
Year	No. of borewells	Av. Depth	Av. Drilling cost	Av. HP	No. of borewells	Av. Depth	Av. Drilling cost	Av. HP
Prior 1985	8	154.4	7023	4.5	9	353.3	15448	7.5
1986 - 1990	12	164.2	9338	4.5	13	404.6	20008	9.1
1991 - 1995	36	187.1	8671	4.5	71	373.5	16485	8.4
1996 - 2000	80	179.2	8969	4.2	85	382.6	17836	9.4
2001 - 2005	71	209.6	10439	4.5	83	494.2	24469	9.2
2006 - 2007	13	247.7	13354	4.4	11	461.4	25441	9.2
Total	220	192.6	9602.81	4.43	272	417.6	19839.68	9.0

Source: Primary survey

Declining groundwater table and availability of drilling technologies has major implications for the cost of obtaining access to groundwater. The cost of drilling bore well is much lower in LWIA compared to HWIA because water tables are higher. Along with this, the water required by the crops is less in LWIA compared to HWIA due to cropping pattern.

The major implication of cumulative well interference is ever increasing cost. Primarily, our attempt is to estimate the cost of drilling bore wells in different situations across landholding size. Our survey results show that cost incurred on well drilling by individual farmers is quite high in HWIA compared to LWIA. In particular, cost incurred on well drilling looks quite disproportionate to landholding size (Table 10). For instance, amount spent per well located in the HWIA works out to Rs. 17152 compared to Rs. 9624 in LWIA. Further, the rate is disproportionate in in terms of landholding size as well. The current average cost of drilling per well is highest among small and marginal farmers in HWIA compared to their counter parts in LWIA. This implies that the implications of cumulative interference problem on access to resource are severe in HWIA.

Table 10: Cost of Drilling per Well Across Landholding Size

Year	LWIA		HWIA		Total	
	Total No. of farmers	Average cost per well (Rs.)	Total No. of farmers	Average cost per well (Rs.)	Total No. of farmers	Average cost per well (Rs.)
Marginal Farmer (Up to 1)	10	10978 (11)	15	21583 (46)	25	19537 (57)
Small Farmer (1.01 to 3.0)	37	9392 (55)	73	22723 (242)	110	20254 (297)
Medium Farmer (3.01 to 5.0)	26	9125 (62)	22	19220 (69)	48	14442 (131)
Large Farmer (More than 5.0)	29	9900 (104)	13	18509 (38)	42	12204 (142)
Total	102	9624 (232)	123	21573 (395)	225	17152 (627)

Source : Primary survey
Note : Figures in parenthesis indicate no. of wells (all types of wells).

Dropping water levels and competition have major implications for the types of well technology that can be used. This has had a variety of impacts. Well deepening and use of high power motors have huge impact on energy demand. Until 1990s, *yetha* was the main method of water extraction from open wells. That practice is extinct now. It was followed by pumping with low capacity (3.5 HP) pump sets. Later, with borewell technology, depending on the depth of well and horse power used. Maximum horse power used in the study area is 12.5 HP.

Such steep increase disturbed the balance between groundwater recharge and extraction resulting in decline of water levels in areas characterized by high well density. As a result of sharp and secular decline of water tables, the saturated thickness is reduced resulting in lower aquifer transmissibility. This implies that in the future even at the same rate of pumping, the rate of water table decline will be much faster. Water tables will stabilize only if pumping is reduced drastically.

Competitive deepening created incentives for use efficiency and movement away from ground water irrigated agriculture for some time. Until 1980s, open channels were used for conveying water from wells to fields. Now farmers often use underground pipelines and hose pipes. Over-ground storage tanks are common in HWIA to store water due to frequent power cuts and low voltage power supply.

5.3.2. Incidence of well failure

The total number of wells distributed across villages is given in Table 11. It is clear from the table that the total number of wells possessed was one and half times more in the case of HWIA (395) as compared to LWIA (232). It was observed that around 73% of the wells (bore wells+open wells) had failed in HWIA whereas in the LWIA the proportion of total failed wells was around 42%. Among the total failed wells, the rate of failure is high in the case of bore wells compared to open wells. For instance, in LWIA, around 89% of failed wells belong to bore well category and 11% belong to open wells. Similarly, in HWIA, the share of bore wells to total failed wells is about 58% and the share of open wells is about 42%. However, of late, all the open wells are defunct in both HWIA and LWIA.

In the LWIA, the proportion of still functioning wells is around 58% compared to 27% in HWIA. This negative externality could link with social and economic condition of the rural agrarian livelihood system. The most visible implications of well failure problem are increasing cost on additional wells, cost on well deepening, reduction in area per well and loss of gross and net income from agriculture.

Table 11: Incidence of well failure in LWIA and HWIA

Villages	Total No. of Borewells	Total No. of open wells	Completely failed borewells	Completely failed open wells	Total failed wells	Total working wells	Total wells
1	2	3	4	5	6	7	8
Adrikatte	61 (96.8)	2 (3.2)	28 (96.6)	1 (3.4)	29 (46.0)	34 (54.0)	63
Heggere	60 (96.8)	2 (3.2)	14 (87.5)	2 (12.5)	16 (25.8)	46 (74.2)	62
Huralihalli	44 (95.7)	2 (4.3)	28 (93.3)	2 (6.7)	30 (65.2)	16 (34.8)	46
Marabgatta	55 (90.2)	6 (9.8)	17 (73.9)	6 (26.1)	23 (37.7)	38 (62.3)	61
LWIA	220 (94.8)	12 (5.2)	87 (88.8)	11 (11.2)	98 (42.2)	134 (57.8)	232
Chandragiri	89 (69.5)	39 (30.5)	76 (66.1)	39 (33.9)	115 (89.8)	13 (10.2)	128
D. V. Halli	39 (75.0)	13 (25.0)	14 (51.9)	13 (48.1)	27 (51.9)	25 (48.1)	52
Garani	70 (66.7)	35 (33.3)	30 (46.9)	34 (53.1)	64 (61.0)	41 (39.0)	105
Kambadahalli	25 (64.1)	14 (35.9)	8 (36.4)	14 (63.6)	22 (56.4)	17 (43.6)	39
Madenahalli	49 (69.0)	22 (31.0)	39 (63.9)	22 (36.1)	61 (85.9)	10 (14.1)	71
HWIA	272 (68.9)	123 (31.1)	167 (57.8)	122 (42.2)	289 (73.2)	106 (26.8)	395

Source : Primary survey
Note : Figures in parenthesis indicate percentage to total wells.

5.3.2.1. Incidence of well failure across landholding size

In the HWIA, the burden of failed open well due to well interference fell equally on small and large farmers, as more than 50% of the failed wells in both categories were owned by small farmers. The ability of small farmers in bearing the burden of well failure is limited by the size of their holding, savings, re-investment and economic resilience potentials. Even if they are able to mop the capital required for additional well, they would bear greater risk of not striking (adequate) groundwater since their area is already suffering from acute well interference problems.

The proportion of bore wells owned in LWIA by small farmers is low due to the heavy investment requirement for bore wells. Our data shows that although small and marginal farmers own less number of wells in LWIA, this proportion is significantly high in HWIA. As a result, the groundwater *resource mining* is taking place.The extraction of groundwater resources is precarious in this area to the extent that even the low water required plantation crops have also gone dry due to unavailability of timely water to the crop[10]. The following are the observation from Table 12:

1. The burden of well failure is more or less equally shared by all farmers but small farmers are the first victims of *resource mining* in HWIA.
2. The burden of well failure is comparatively less in LWIA.
3. Only about 28% of the wells are working in HWIA. The proportion of working wells in LWIA is nearly 58% although the problem of interference is moving towards peak, the problem of well failure is less than that of HWIA.

Table 12: Incidence of well failure across landholding size

Landholding size (ha)	Borewells	Open wells	Completely failed borewells	Completely failed open wells	Total failed wells	Total working wells	Total wells
Marginal Farmer (Up to 1) N=10	11(100)	0(0.0)	2(100)	0(0.0)	2(18.2)	9(81.8)	11
Small Farmer (1.01 to 3.0) N=37	52(94.5)	3(5.5)	13(81.3)	3(18.8)	16(29.1)	39(70.9)	55
Medium Farmer (3.01 to 5.0) N=26	58(93.5)	4(6.5)	22(84.6)	4(15.4)	26(41.9)	36(58.1)	62
Large Farmer (More than 5.0) N=29	99(95.2)	5(4.8)	50(92.6)	4(7.4)	54(51.9)	50(48.1)	104
LWIA (N=102)	220(94.8)	12(5.2)	87(88.8)	11(11.2)	98(42.2)	134(57.8)	232
Marginal Farmer (Up to 1) N=15	27(58.7)	19(41.3)	16(45.7)	19(54.3)	35(76.1)	11(23.9)	46
Small Farmer (1.01 to 3.0) N=73	168(69.4)	74(30.6)	117(61.6)	73(38.4)	190(78.5)	52(21.5)	242
Medium Farmer (3.01 to 5.0) N=22	49(71.0)	20(29.0)	25(55.6)	20(44.4)	45(65.2)	24(34.8)	69
Large Farmer (More than 5.0) N=13	28(73.7)	10(26.3)	9(47.4)	10(52.6)	19(50.0)	19(50.0)	38
HWIA (N=123)	272(68.9)	123(31.1)	167(57.8)	122(42.2)	289(73.2)	106(26.8)	395

Source : Primary survey

Note : Figures in parenthesis indicate percentage to total wells

5.3.3. Declining water markets

Groundwater aquifers in the central dry zone are characterized by hard rocks and have low potential recharge capacity. These aquifers are mainly recharged through monsoon rainfall. Low yield levels, low storage and high risk nature of hard rock aquifers have important implications for the nature of water markets. Groundwater markets are disappearing in hard rock areas where well yields are low and often vary greatly across seasons. Surpluses are too smaller and tend to vary across seasons and locations (Janakarajan and Moench, 2006).

[10] Chandragiri - a village in Madhugiri taluk – bearing the brunt of well failure since 2003. The village was once arecanut and paddy granary, now became dry land due to water scarcity. Nearly 25 acres of areca plantation have gone dry in the village. Farmers who were realizing the problem adopted water saving methods such as drip irrigation. However, by the time they adopted such methods, entire crop area had become dry. This created a lot of debates among farmers themselves about interlinking of rivers to store water bodies such as tanks to facilitate aquifer recharge in the area. Unfortunatley nothing has happened.

Past studies on water markets have shown that since power is charged at a flat rate based on pump horsepower, marginal cost will be zero and sale of any surplus at any rate reduces average costs. In many such cases, the bargaining position of both buyers and sellers is relatively equal. Anantha and Sena's (2007) study in West Bengal reveals that diesel pump owners sell water to recover historical investment made on the equipments while electric motor owners sell to reduce annual average costs of operation and maintenance. In these situations, the bargaining power of both sellers and buyers is equal. However, the situation in hard rock areas is different from that of water abundant regions in India.

In the study area, the size of water market is insignificant and based on mutual understanding (Table 13). In most of the cases water sale is on kind transaction. Importantly, market exists between neighborhood farmers or relatives whose land is adjacent. In these instances the market operates on the basis of social obligations. Therefore, the purpose of profit maximization or reduction in average cost is negligible in all the situations.

Table 13: Distribution of Farmers by Water Selling Activity

Area	Water sale		Total
	Yes	No	
LWIA	2 [2.0] (11.8)	100 [98.0] (48.1)	102 [100] (45.3)
HWIA	15 [12.2] (88.2)	108 [87.8] (51.9)	123 [100] (54.7)
Total	17 [7.6] (100)	208 [92.4] (100)	225 [100] (100)

Source : Primary survey

Note : The figures in parenthesis indicate row and column-wise percentages to total respondents, respectively.

Increasing water scarcity poses severe threat to existence of water markets in the study area. In this situation, well owners cannot get surplus water to sell to potential buyers.

6. COPING MECHANISMS

To mitigate the groundwater scarcity problem most of the farmers adopted coping mechanisms and these mechanisms entailed sizable investments. These coping mechanisms include well deepening, additional well drilling, adoption of water saving technologies such as drip irrigation and shifting cropping pattern.

6.1 Well deepening/drilling additional wells

Well deepening or drilling an additional well is a common phenomenon in HWIA compared to LWIA. Drilling an additional well is a capital intensive mechanism adopted by large farmers (Table 14). The small and marginal farmers are constrained due to their poor capital base.

Most of the large farmers adopted coping mechanisms on a larger scale compared to small landholders. All large farmers in the area went for additional well due to the failure of previous well. More than 75% of the small and marginal farmers could venture in drilling additional well in HWIA compared to their counterparts in LWIA. The transfer of water from far off places to the arecanut garden was adopted by large farmers in HWIA[11].

The field observation during the data collection confirms that most of the small farmers who had gone for additional well, mobilized capital from their friends and relatives since institutional finance is not coming fourth[12].

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[11] Few farmers in Chandragiri village are transferring water from neighboring village since 2002 to protect arecanut plantation. Initially, group of households were coming together and hiring tractors to transfer water on daily rental basis. Later, they discovered that it is not economical. Therefore, they have installed pipeline for obtaining water. However, this mechanism could not sustain due to several reasons.

[12] The other sources of capital investment on well irrigation are sale of assets such as livestock, trees (eg., eucalyptus, teak etc.) and land. Gold Mortgage was also observed. Crop loan was used for repayment of old loans by several small and marginal farmers.

Table 14: Distribution of Farmers by Drilling Additional Well

Landholding size (ha)	LWIA		HWIA		Total	
	Total No. of farmers	No. of farmers drilled additional well	Total No. of farmers	No. of farmers drilled additional well	Total No. of farmers	No.of farmers drilled aditional well
Marginal Farmer (Up to 1)	10 [40.0] (9.8)	1 [6.7] (1.8)	15 [60.0] (12.2)	14 [93.3] (12.5)	25 [100] (11.1)	15 [100] (8.9)
Small Farmer (1.01 to 3.0)	37 [33.6] (36.3)	12 [15.6] (21.4)	73 [66.4] (59.3)	65 [84.4] (58.0)	110 [100] (48.9)	77 [100] (45.8)
Medium Farmer (3.01 to 5.0)	26 [54.2] (25.5)	18 [46.2] (32.1)	22 [45.8] (17.9)	21 [53.8] (18.8)	48 [100] (21.3)	39 [100] (23.2)
Large Farmer (More than 5.0)	29 [69.0] (28.4)	25 [67.6] (44.6)	13 [31.0] (10.6)	12 [32.4] (10.7)	42 [100] (18.7)	37 [100] (22.0)
Total	102 [45.3] (100)	56 [33.3] (100)	123 [54.7] (100)	112 [66.7] (100)	225 [100] (100)	168 [100] (100)

Source : Primary survey
Note : Figures in parenthesis indicates row and column-wise percentages to total.

6.2 Adoption of Drip Irrigation

The resource conservation through water saving technologies is taking place. Table 15 shows that the drip irrigation system is a recently adopted phenomenon.

Table 15: Distribution of Farmers by Adoption of Drip Irrigation

Area	1993	1994	1997	1998	2000	2002	2003	2004	2005	2006	Total
LWIA	0 [0.0] (0.0)	1 [3.2] (100)	2 [6.5] (66.7)	1 [3.2] (20.0)	1 [3.2] (100)	3 [9.7] (60.0)	7 [22.6] (100)	6 [19.4] (75.0)	5 [16.1] (100)	5 [16.1] (83.3)	31 [100] (72.1)
HWIA	2 [16.7] (100)	0 [0.0] (0.0)	1 [8.3] (33.3)	4 [33.3] (80.0)	0 [0.0] (0.0)	2 [16.7] (40.0)	0 [0.0] (0.0)	2 [16.7] (25.0)	0 [0.0] (0.0)	1 [8.3] (16.7)	12 [100] (27.9)
Total	2 [4.7] (100)	1 [2.3] (100)	3 [7.0] (100)	5 [11.6] (100)	1 [2.3] (100)	5 [11.6] (100)	7 [16.3] (100)	8 [18.6] (100)	5 [11.6] (100)	6 [14.0] (100)	43 [100] (100)

Source : Primary survey
Note : Figures in parenthesis indicate row and column-wise percentage to total respectively.

Interestingly, in HWIA, large majority of small farmers adopted drip irrigation as a coping mechanism though it is capital intensive (Table 16). This indicates resource exhaustion and way out for them to sustain agriculture. During our field visit, we learned that a large majority of farmers have adopted drip irrigation due to crop failure because of water scarcity. It is a welcome change that they have realized the importance of water saving technologies such as drip irrigation.

In the LWIA, scarcity of groundwater forced them to adopt drip irrigation system, which is effective as a water saving technology. The farmers have been striving to give protective irrigation to coconut plantation to alleviate the moisture stress to avoid drastic fall in productivity. However, in HWIA, the method of drip irrigation is not so popular because of food crops which do not really allow drip irrigation. The irrigation method should be flow method because of paddy and other field based crops which require water to be stored to prevent weeds.

Table 16: Expenditure on Drip Irrigation by Farmers

Expenditure on drip irrigation (Rs.)	LWIA				HWIA			
	Marginal Farmers	Small Farmers	Medium Farmers	Large Farmers	Marginal Farmers	Small Farmers	Medium Farmers	Large Farmers
Less than 10000	0 (0.0)	4 (57.1)	3 (50.0)	5 (29.4)	0 (0.0)	1 (10.0)	0 (0.0)	0 (0.0)
10001 to 25000	1 (100)	2 (28.6)	1 (16.7)	3 (17.6)	1 (100)	1 (10.0)	0 (0.0)	0 (0.0)
25001 to 50000	0 (0.0)	1 (14.3)	2 (33.3)	3 (17.6)	0 (0.0)	2 (20.0)	0 (0.0)	1 (100)
More than 50000	0 (0.0)	0 (0.0)	0 (0.0)	6 (35.3)	0 (0.0)	6 (60.0)	0 (0.0)	0 (0.0)
Total no. of farmers	1 (100)	7 (100)	6 (100)	17 (100)	1 (100)	10 (100)	0 (0.0)	1 (100)

Source : Primary survey
Note : Figures in parenthesis indicate percentage to total

6.3 CHANGING CROPPING PATTERN

Nearly one-third of the respondents in HWIA changed cropping pattern as a coping strategy to over come water scarcity problem whereas this proportion is nearly one-fourth in LWIA. The changing cropping pattern is mainly due to inadequate water supply for the crops. The cropping pattern is shifting from high water intensive crops to low water intensive crops such as coconut, ragi, groundnut and sunflower. The degree of shifting cropping pattern is high among small farmers as they are not able to cope with severely declining water table. The difference between LWIA and HWIA is clearly visible in terms of cropping pattern. For instance, initially, paddy was the major water intensive crops both in HWIA and LWIA. However, with increasing problem of water scarcity it has shifted to low water intensive plantation crops, coconut in LWIA and ragi and groundnut in HWIA. The rate at which the fallow land is increasing is also high in HWIA as they cannot cope with increasing water scarcity problem.

Majority of farmers are actively adopting coping strategies. Small farmers adopted less capital intensive coping mechanisms while large farmers adopted capital intensive measures. The results from the studies by Shyamsunder (1997) and Nagaraj and Chandrashekhar (un.d.) show that to cope with well failure farmers change cropping pattern in favour of less water intensive crops, go for deepening of well and drill additional well. Further, the adoption of different conservation practices by different categories of the farmers in the groundwater overexploited area supports the hypothesis that the overexploitation of groundwater has differential impact on different categories of the farmers in terms of the conservation measures.

7. CONCLUSION

The overexploitation of groundwater is evident at different scales in the study area, posing threats to sustainability, equity and efficiency. Given the current rate of groundwater development in the overexploited area of the study, irrigated agriculture can hardly sustain. Added to this, groundwater resource status is also deteriorating leading to bankruptcy of the aquifers. The existing institutional arrangement only promoted overexploitation of aquifers and failed to generate adequate incentives for the adoption of efficient water use technologies. Thus, appropriate policy measures aimed at regulation and control of groundwater for the development of integrated groundwater and surface water system is the need of the hour. Unfortunately, LWIA is also falling into the jar of overexploitation due to mining of aquifers to sustain capital intensive cash crops.

Analytical results of the study clearly suggest the following:

1. inter well distance in relation to groundwater availability should be strictly maintained;
2. wherever cropping pattern is dominated by perennial plantation cash crops groundwater exploitation is minimum, which has dampened negative externalities of overexploitation to a large extent. For instance, cultivation of low water intensive crops itself is a coping mechanism in LWIA. Therefore, there is scope to educate farmers to adopt light water crops and irrigation literacy;
3. traditional water bodies such as tanks and streams should be efficiently managed hence, groundwater recharge can be done while extracting required quantity of groundwater for sustaining crops. Therefore, there is a need to integrate institutional and technical aspects of surface and groundwater sources that can alleviate overdraft problem;
4. water saving technologies can be promoted for high water intensive crops to increase water use efficiency and to arrest overexploitation of aquifers; and
5. the problem of inequity existing in well irrigation could possibly be addressed by promoting group investments in well irrigation where sharing the cost and benefits among the farmers are crucial. The group investment on well irrigation could possibly solve the problem of over extraction of groundwater that would encourage the principle of *more crops per drop*!

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EQUITY, COMPARATIVE FEASIBILITY AND ECONOMIC VIABILITY OF GROUNDWATER INVESTMENT IN SAURASHTRA REGION

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Abstract

The paper tries to analyze two districts of Saurashtra from the point of equity and economic feasibility of groundwater abstraction and use. Using various simulation and economic analyses tools, the paper concludes that there is equity of access and consequently access of irrigation. For different pricing and discount rates, the BC ratio and IRR are positive. Thus groundwater withdrawal for irrigation seems feasible. However, if the electricity subsidy to the agriculture is removed, the investments are not feasible.

1. INTRODUCTION

Groundwater is gaining importance as a source to meet the needs of India's ever-increasing population, for drinking as well as industry and irrigation (Shaheen and Shiyani, 2005). India is the biggest groundwater user in the world, followed by USA and China (Shah et al., 2003). In South Asia, in addition to India, Pakistan, Bangladesh and Nepal are the major groundwater users. However, our estimate is that between them, these four countries pump about 210-250 km^3 of groundwater every year. In doing so, they use about 21-23 million pumps, of which, about 13-14 million are electric and around 8-9 million are powered by diesel engines (NSSO 1999, for India). If we assume that an average electric tube well (with a pumping efficiency of 25 %) lifts water to an average head of 30m, the total energy used in these countries for lifting 210 km^3 of groundwater is about 68.6 billion kWh equivalent per year. The demand for fresh water in the country has been rising over the years due to increased demand for food production and growing urbanization and industrialization. Currently, total water use (including groundwater) is 634 BCM, of which 83% is for irrigation. The demand for water is projected to grow to 813 BCM by 2010, 1093 BCM by 2025 and 1447 BCM by 2050, against utilizable quantum of 1123 BCM. Clearly, in 35-40 years, groundwater in particular will come under even greater pressure in the intervening years (GoI, 2007).

According to a World Bank estimate, groundwater irrigation contributes to about 10% of India's GDP (World Bank, 1998 and GoI, 1998). This is possible because groundwater irrigation uses about 15-20% of the total electricity consumed in the country. Groundwater with subsidized power to the farm sector plays an important role in sustaining the agrarian economy of north Gujarat. Groundwater contributes more than 90% of the total irrigated area in the region, which has experienced high rates of over-exploitation. The water table is falling at the rate of 5-8 m annually [Moench and Kumar 1997], coupled with high well failure. The depletion of the water table is chased by boring at deeper depths with huge investments, which can be afforded by large and financially sound farmers (Shaheen and Shiyani, 2005).

Most of the problems in the use and management of groundwater resources lack well defined property rights and appropriate institutions for regulating the use of water (Marothia, 1997). The ownership of groundwater is tied with the ownership of land in India, and the land owners have the right to extract groundwater beyond any time as long as it is available (Singh, 1991). Groundwater mostly lies in the open access regime throughout the country (Singh, 1995), as also in Gujarat.

2. STATEMENT OF THE PROBLEM

Groundwater plays a critical role in the agricultural economy of Gujarat. Over-exploitation and mismanagement of the resource have led to depletion and degradation of groundwater aquifers. Due to hard rock formation, the possibility of holding large quantity of water is low in many districts of Saurashtra. Thus, they are severely affected by groundwater over-exploitation and falling water table levels. Electricity is supplied to farm sector on flat tariff rate with high subsidy. Many researchers argue that the farmers of Saurashtra would benefit from pro rata pricing, given the fact that the amount of energy they use annually would be very small (Kumar and Singh, 2001).

In Saurashtra region, irrigation facilities have been growing rapidly and the sources of irrigation are both surface water and groundwater. Between 1999 to 1997, irrigation potential increased by 37.6 and 21.0% in Amreli and Bhavnagar districts respectively (Sharma, 2002). The tremendous growth of groundwater development for irrigation in this area, which faces frequent draughts, has added to the problem of lowering water levels. Withdrawal of ground water beyond recharge capacity caused the water table to decline beyond the recommended limits (Sikarwar, et. al., 2005).

This study not only focuses on equity issues but also examines comparative feasibility and economic viability of groundwater investment in Saurashtra region. The specific objectives of study are:

2.1 Objectives

(i) To study the equity issues among the selected respondents of Saurashtra region.

(ii) To examine comparative feasibility and economic viability of groundwater investment in Saurashtra region.

3. SAMPLING DESIGN AND DATA BASE

The study was conducted in the Saurashtra region of Gujarat state. Two districts viz., Amreli and Bhavnagar, which have severe groundwater problems were selected purposively. Two talukas from each district were selected adopting the same criteria. Again, two villages from each taluka were selected randomly. Ten farmers with metered (pro-rata tariff rate system) and equal number of farmers with flat rate were selected at random from each selected village. Thus, total of 160 farmers were interviewed to collect information. The study pertains to the agricultural year 2006.

4. ANALYTICAL FRAMEWORK

4.1 Equity

The equity of access to resource (groundwater) among the farmers was analyzed by comparing the number of wells and percentage share in well(s), gross irrigated area (GIA), income realized per ha of GIA, water used per hectare of GIA, net returns per-unit of water use, physical and economic access, and various inequality measures like Gini Concentration Ratio (GCR), Weighted Gini coefficient, Theil entropy index, Theil Bermoulli index and Exponential index. These measures are defined as follows:

Gini Concentration Ratio (GCR) was calculated to measure the inequality in the income among different farm classes using the following formula:

$$GCR = 1 - \sum_{i=1}^{n} P_i (Q_i + Q_{i-1})$$

Where,

P_i = Proportion of number of farmers.

Q_i = Cumulative proportion of income.

Q_{i-1} = Preceding cumulative proportion of income.

The weighted Gini coefficient is given as:

$$\text{Weighted Gini} = \sum_{i=1}^{j} W_i (y_i / \mu)$$

and

$$Wi = p_i \left[\sum_{i=1}^{j} (2p_j - p_i - 1) \right]$$

Where, W_i = A weight associated with the proportion of the population in the i^{th} group,

p_i = The proportion of the population in the i^{th} income group,

y_i = The average income in i^{th} group,

μ = The overall mean income.

The Gini coefficient is derived from the Lorenz curve and is defined as the area between the Lorenz curve and the diagonal line (line of perfect equality) divided by the area of the whole triangle formed by line of perfect inequality. The Gini coefficient therefore, has a value between 0 and 1; where a value of 0 means that all individuals in the population have the same earnings (Perfect equality). The value is consistent with the Lorenz curve lying along the 45^0 line. A Gini coefficient with a value of one means that one individual holds all the income and the Lorenz curve lies along the horizontal axis (Perfect inequality).

4.2 Bottom sensitive measures of inequality

Three other statistical measures used to measure income inequality viz., the Exponential index, the Theil-Entropy index and the Theil-Bernoulli index are given below. These measures assume slightly different income distributions in an effort to control peculiarities in the data, and are bottom sensitive, i.e. sign will change if transfers occur at the bottom of the income distribution.

Theil Entropy index: When the parameter 'C' of the generalized entropy index is equal to 1 or 0, we have the Theil index. For the natural logarithm of incomes, it is expressed as;

$$TE = \left[\frac{1}{N} \right] \sum_{i=1}^{N} \frac{y_i}{\mu} \ln \left[\frac{y_i}{\mu} \right]$$

Theil-Bernoulli index

$$TB = -\sum_{i=1}^{j} p_i \ln (y_i / \mu)$$

Exponential index

$$EXP = \sum_{i=1}^{j} p_i \exp (-y_i / \mu)$$

Where, ln = Natural logarithm

p_i = The proportion of the population in the i^{th} income group

y_i = The average income in i^{th} group in Rs

μ = The overall mean income in Rs

5. ECONOMIC FEASIBILITY IN WELL INVESTMENT

In order to evaluate the economic feasibility of investment on bore well/groundwater irrigation, the project evaluation measures such as Net Present Worth (NPW), Benefit Cost Ratio (BCR), Internal Rate of Return (IRR) and Pay Back Period were employed.

The mathematical forms are given below:

$$\text{NPW} = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t}$$

The formula for benefit cost ratio is:

$$\text{BC ratio} = \sum_{t=1}^{n} \frac{B_t}{(1+r)^t} \div \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}$$

The pay back period is the length of time taken to liquidate the investment on well from the commencement of the project. The pay back period was calculated as:

P = I ÷ E,

Where, P = Length of time in years, I = Investment in Rs.

E = Expected annual return in Rs.

The internal rate of return is the rate of return ' r ' at which

$$\sum_{t=1}^{n} \frac{B_t}{(1+r)^t} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}$$

Where,

Bt = Benefits in each year in Rs.

Ct = Costs in each year in Rs.

t = Number of years (1, 2, 3, ……… n)

r = Discount rate in percentage

The IRR was arrived through interpolation by using different discount rates, to confirm that NPW is equated with zero. At the outset, the project costs and benefits were discounted at an arbitrary discount rate (designated as the lower discount rate - LDR) so as to get a positive net worth. Similarly, a higher discount rate (HDR) was chosen so as to get a negative present worth. Using these, the IRR was computed through interpolation as follows;

IRR = LDR + (HDR-LDR) {(NPW at LDR) (Absolute difference between NPW at LDR and NPW at HDR)}

The IRR also facilitates ranking of different investments in order of their maximum earning capacity. The IRR should be greater than the opportunity cost of capital for economic feasibility and financial soundness.

6. INCOME INEQUALITY FROM GROUNDWATER IRRIGATION

The extent of inequality in gross income per hectare realized from the groundwater irrigation was assessed which can be taken as a proxy to examine the extent of inequality in access to groundwater irrigation. Various measures of income inequality were estimated which are presented in Table 1 and depicted in Lorenz curve (Figure 1).

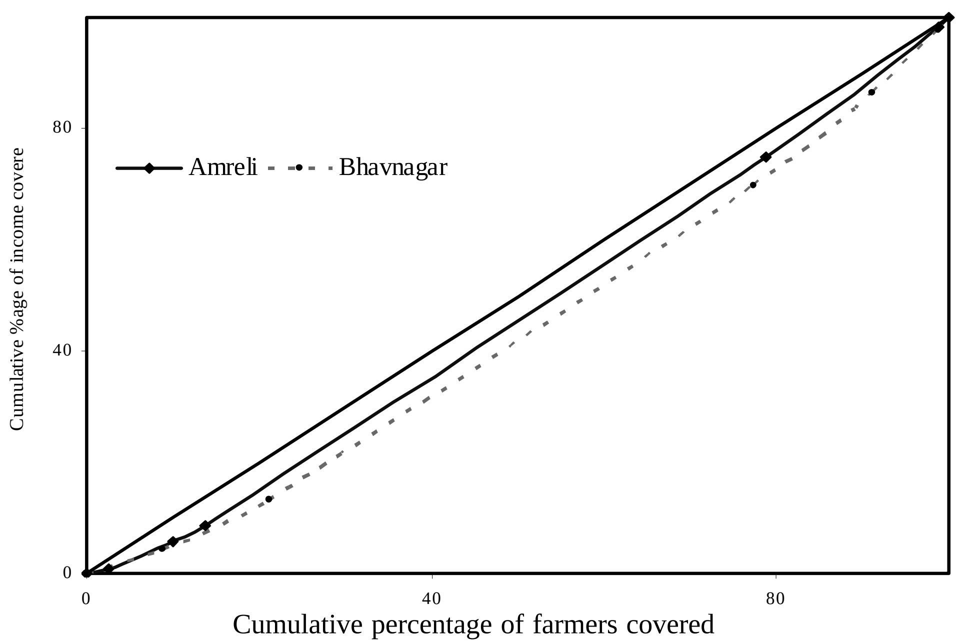
The Lorenz curve shows how the farm income from the groundwater irrigation is distributed among the sample farmers of both the districts. The inequality of income distribution is indicated by the degree to which Lorenz curve departs from the diagonal line: the farther the curve is from diagonal line, the more unequal is distributed farm income and vice versa. It is observed from the figure that the income inequality is less among the sample farmers of Amreli than the farmers of Bhavnagar district as in later case, Lorenz curve lies farther from the diagonal line.

Seven measures of income inequality were tried to measure the degree of inequality in the income realized from groundwater irrigation among the sampled farmers, which are presented in Table 1. In terms of Gini Concentration Ratio (GCR), the degree of inequality was 0.074 for Amreli and 0.129 for Bhavnagar districts, i.e. the degree of inequality is almost double. The pooled analysis of both the areas further aggravated the inequality measure (0.109). The GCR value clearly supports the Lorenz curve graph. Similar trend was also observed in Weighted Gini Coefficient and Coefficient of Variation measures. In case of Theil Entropy Index, Amreli district showed 0.010, whereas in Bhavnagar district, it was 0.217. In terms of Theil Bernoulli Index, Exponential Index and Standard deviation of logarithmic incomes, the degree of inequality was found higher in Bhavnagar district as compared to Amreli district.

Table 1: Measures of income inequality in study area

Sr. No.	Inequity Measures	Amreli	Bhavnagar	Overall
1.	Gini Concentration Ratio (GCR)	0.074	0.129	0.109
2.	Weighted Gini Coefficient	0.074	0.129	2.437
3.	Theil Entropy Index	0.010	0.217	0.144
4.	Theil Bernoulli Index	0.013	0.035	0.056
5.	Exponential Index	0.374	0.380	0.754
6.	Standard Deviation of Logarithmic Incomes	0.228	0.283	0.258
7.	Coefficient of Variation	0.180	0.261	0.223

Figure 1: Lorenz curve- distribution of income among sampled farmers



From all these measures as well as Lorenz curve, it can be concluded that the income realized from the farmers using groundwater irrigation in Amreli was more evenly distributed than that of Bhavnagar district. This was due to more skewed distribution of groundwater irrigation among the different classes of farmers in Bhavnagar district. The economic access to groundwater was higher for Amreli district than that of Bhavnagar district farmers. The physical access and economic access to groundwater with holding size in Amreli and Bhavnagar districts are presented in Figure 2 and Figure 3, respectively. Moreover, the proportion of the marginal and small farmers having access to groundwater irrigation in Bhavnagar district was also relatively less as compared to Amreli district.

7. ECONOMIC FEASIBILITY IN GROUNDWATER INVESTMENT

The economic feasibility of investment on well irrigation was evaluated by using standard discounted cash flow techniques. The measures used were benefit cost ratio (BCR), net present value (NPV), internal rate of return (IRR) and the payback period (PBP). The economic feasibility test was worked out at different discount rates because of changing banking policies and other market conditions. The sensitivity analysis was also done by taking into account three cost concepts; viz., paid out crop cost, C_1 crop cost and C_2 crop cost for cultivation of crops.

Sensitivity analysis for investment in wells at 6% discount cash flow is presented in Table 2. The IRR for the investment on well per farm was 8.13% for Amreli and 7.58% for Bhavnagar with the present tariff (Rs. 665/HP/year upto 7.5 HP motor and Rs. 807.5/HP/year above 7.5 HP) and paid out cost. However, the high IRR in Amreli reduced to 1.12 and 0.61% at C_1 and C_2 cost levels, respectively. The discounted BC ratio at 6% discount rate was 1.71 and 1.58 for Amreli and Bhavnagar districts, respectively, indicating that for every one rupee of present value of cost, the investment yielded Rs. 1.71 and Rs. 1.58 of the present value of return in the respective district over the economic life span of wells. The NPV, an indicator of the magnitude of total present value of stream of returns left with the investor at the end of economic life span of the well was Rs. 3,91,507 for Amreli and Rs. 2,65,703 for Bhavnagar districts. This implies a return in excess of the capital invested plus the specified rate of interest (6 %) of capital. The NPV was fairly high for Amreli district compared to that of Bhavnagar district. The payback period to recapture the investment was 1.44 and 1.64 years for Amreli and Bhavnagar districts, respectively. It can be concluded from the table that the returns to investment are highly feasible.

Figure 2: Physical and economic access to groundwater with holding size in Amreli district

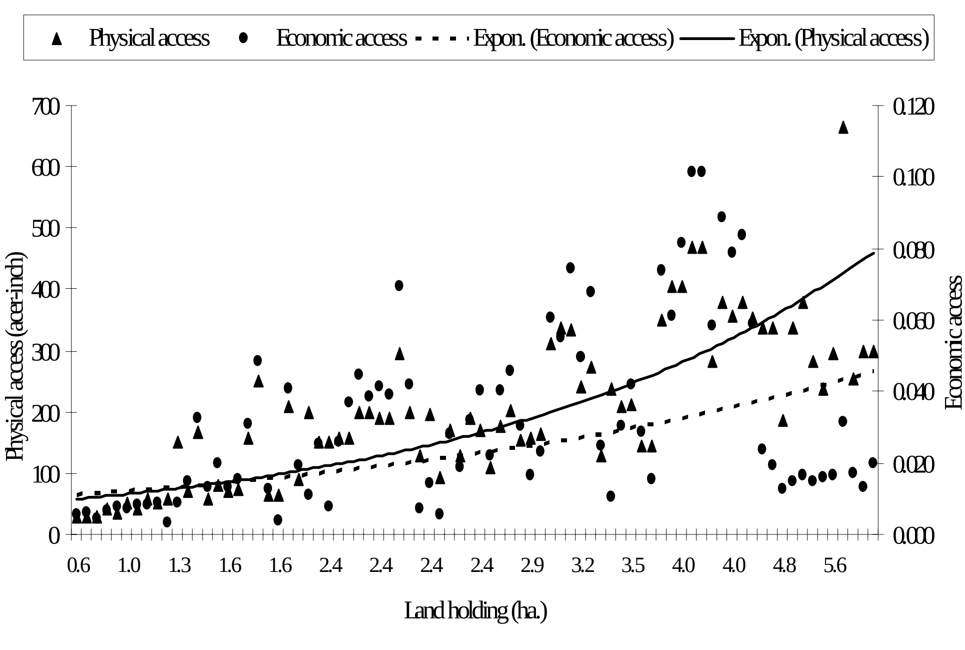
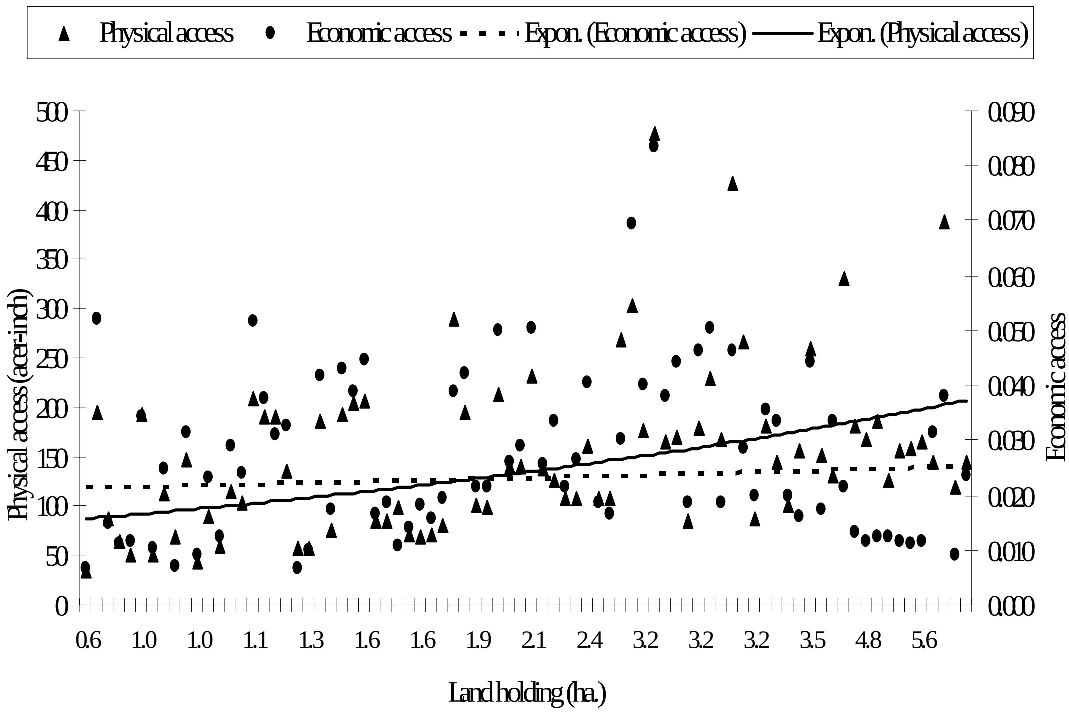


Figure 3: Physical and economic access to groundwater with holding size in Bhavnagar district



The results pertaining to BCR, IRR, NPW and PBP are in conformity with the results obtained by Neelakantaiah (1991), Kolavalli and Atheeq (1993), Nagaraj and Chandrakanth (1995), Shaheen (2004) and Talathi et al., (2005).

The project appraisal criteria were also estimated at higher discounted cash flow interest rates (8, 10 and 12 %). The results of which are presented in Table 2. At higher discount rates of interest, the feasibility measures decrease. It means that the returns on investment fall. If we look at BCR ratios at discount rates of 6%, 8, 10 and 12% for Amreli (at first combination - present tariff plus paid out crop cost), they come to 1.71, 1.69, 1.68 and 1.67, respectively, whereas in Bhavnagar, they come to 1.58, 1.56, 1.55 and 1.54. Similarly, all other measures come down at higher discount rates for all the combinations in both the districts. From these, it can be concluded that the investment in well irrigation is feasible at all the combinations in both the districts, even at a high discount rate of 12%. Furthermore, it was revealed by the sensitivity analysis that lower interest rates encourage the development of groundwater projects that generate high costs early in the project and benefits well into the future. The lower interest rate reduces the importance of early costs and values more gains that occur in future. The sensitivity results arrived at different interest rates are supported by the study of Fox and Hederfindahl (1964) on American Water Projects. They found that only 20% of projects were viable at an 8% discount rate, while 91% projects were viable at 4% discount rate.

Sensitivity analysis was also done at various pro-rata tariff rates. The energy consumed per farm was worked out by considering the pump HP and number of hours in a year, for which the pump was operated. The complete procedure for calculation of energy consumption is given in methodology chapter. The sensitivity analysis was done at three different pro-rata tariff levels viz., present rate of tariff with subsidy (Re. 0.50/kWh), an immediate next stage of tariff (Rs. 1.0/kWh) and the government purchase price of electricity (Rs. 2.50/ kWh). The discounted cash flow analysis was done at 6, 8, 10 and 12% interest rate.

The investment appraisal measures estimated when electricity is priced at Re. 0.50 per kWh with 6% discount rate are given in Table 3. It is observed from the table that BCR is 1.70 with an IRR of 71.75% for Amreli district at paid out cost level. Similarly, for Bhavnagar, BCR of 1.58 and IRR of 7.92% were estimated. The returns were worthwhile even on C_1 and C_2 costs for both the districts.

Table 2: Sensitivity analysis for investment in wells at different discount rate

Sl. No.	Combination	Amreli				Bhavnagar			
		BCR	NPV	IRR	PBP	BCR	NPV	IRR	PBP
	At 6% discount rate								
1	Present tariff + Paid out crop cost	1.71	391507	8.13	1.44	1.58	265703	7.58	1.64
2	Present tariff + C_1 crop cost	1.24	185573	1.12	3.05	1.11	74327	0.46	5.87
3	Present tariff + C_2 crop cost	1.15	122098	0.61	4.63	1.03	18498	0.11	23.57
	At 8% discount rate								
1	Present tariff + Paid out crop cost	1.69	368009	7.98	1.54	1.56	249383	7.42	1.75
2	Present tariff + C_1 crop cost	1.24	172321	1.08	3.28	1.11	67530	0.43	6.46
3	Present tariff + C_2 crop cost	1.14	112006	0.58	5.05	1.02	14478	0.09	30.11
	At 10% discount rate								
1	Present tariff + Paid out crop cost	1.68	346651	7.83	1.63	1.55	234550	7.27	1.86
2	Present tariff + C_1 crop cost	1.23	160277	1.05	3.53	1.10	61352	0.41	7.11
3	Present tariff + C_2 crop cost	1.14	102832	0.55	5.50	1.02	10825	0.07	40.27
	At 12% discount rate								
1	Present tariff + Paid out crop cost	1.67	327190	7.69	1.73	1.54	221034	7.12	1.97
2	Present tariff + C_1 crop cost	1.22	149303	1.01	3.79	1.10	55723	0.38	7.82
3	Present tariff + C_2 crop cost	1.13	94474	0.53	5.98	1.01	7497	0.05	58.15

Note: Present Tariff at the rate of Rs. 665 per HP/year upto 7.5 HP motor and Rs. 807.5 per HP/year above 7.5 HP

The project appraisal criteria were also estimated at higher discounted cash flow interest rates (8, 10 and 12 %), the results of which are presented in Tables 2. It was observed that at higher discount rates of interest, the feasibility measures decrease. It means that the returns to investment fall. If we look BCR ratios at discount rates of 8, 10 and 12%, for Amreli at first combination (Power cost (Rs. 0.5/kWh) plus paid out crop cost), they come to 1.69, 1.68 and 1.67, whereas for Bhavnagar they comes to 1.57, 1.56 and 1.55. Similarly, the values of all other measures declined at higher discount rates for all the combinations in both the districts.

The investment appraisal measures were estimated when electricity is priced at Rs. 1/kWh with discounted cash flow interest rates of 6, 8, 10 and 12%, the results of which are presented in Tables 4. The BCR ratios at different discount rates for Amreli district were found relatively higher as compared to Bhavnagar district. The value of BCR less than one at higher discount rate with cost C_2 implies that the project is not viable at that combination. This suggests that no further investment should be encouraged beyond that combination.

The investment appraisal measures estimated when electricity is priced at Rs. 2.5/kWh with discounted cash flow interest rates (6, 8, 10 and 12 %) are presented in Tables 5. The BCR ratios at different discount rates for both the districts were relatively low compared to that of lower tariff rates. It can be concluded that investment is viable at paid out cost and C_1 cost level in Amreli district, whereas in Bhavnagar district, the measures were found favourable only at paid out cost level. Thus, looking at overall picture of both the districts, the investment is economically viable at paid out cost at all levels of discounted measures.

Table 3: Sensitivity analysis for investment in wells at different discount rate for power cost at the rate of Rs. 0.5/kWh

Sl. No.	Combination	Amreli				Bhavnagar			
		BCR	NPV	IRR	PBP	BCR	NPV	IRR	PBP
	At 6% discount rate								
1.	Power cost (Rs. 0.5/kWh) + Paid out crop cost	1.70	390785	71.75	1.45	1.58	267256	7.92	1.63
2.	Power cost (Rs. 0.5/kWh) + C_1 crop cost	1.24	184851	1.12	3.06	1.12	75881	0.47	5.74
3.	Power cost (Rs. 0.5/kWh) + C_2 crop cost	1.15	121377	0.61	4.66	1.03	20051	0.12	21.74
	At 8% discount rate								
1.	Power cost (Rs. 0.5/kWh) + Paid out crop cost	1.69	367323	70.40	1.54	1.57	250859	7.75	1.74
2.	Power cost (Rs. 0.5/kWh) + C_1 crop cost	1.24	171636	1.08	3.29	1.11	69006	0.44	6.32
3.	Power cost (Rs. 0.5/kWh) + C_2 crop cost	1.14	111320	0.58	5.08	1.02	15954	0.09	27.32
	At 10% discount rate								
1.	Power cost (Rs. 0.5/kWh) + Paid out crop cost	1.68	345998	69.10	1.63	1.56	235956	7.60	1.85
2.	Power cost (Rs. 0.5/kWh) + C_1 crop cost	1.23	159624	1.04	3.54	1.11	62758	0.42	6.95
3.	Power cost (Rs. 0.5/kWh) + C_2 crop cost	1.14	102179	0.55	5.53	1.02	12231	0.07	35.64
	At 12% discount rate								
1	Power cost (Rs. 0.5/kWh) + Paid out crop cost	1.67	326567	67.85	1.73	1.55	222375	7.44	1.96
2	Power cost (Rs. 0.5/kWh) + C_1 crop cost	1.22	148680	1.00	3.80	1.10	57064	0.39	7.64
3	Power cost (Rs. 0.5/kWh) + C_2 crop cost	1.13	93850	0.52	6.02	1.01	8838	0.06	49.32

Table 4: Sensitivity analysis for investment in wells at different discount rate for power cost at the rate of Rs. 1.0/kWh

Sl. No.	Combination	Amreli				Bhavnagar			
		BCR	NPV	IRR	PBP	BCR	NPV	IRR	PBP
	At 6% discount rate								
1	Power cost (Rs. 1.0/kWh) + Paid out crop cost	1.59	349484	8.49	1.62	1.49	240088	4.26	1.82
2	Power cost (Rs. 1.0/kWh) + C_1 crop cost	1.18	143549	0.76	3.94	1.07	48712	0.29	8.95
3	Power cost (Rs. 1.0/kWh) + C_2 crop cost	1.09	80075	0.37	7.06	0.99	-7118	-	-
	At 8% discount rate								
1	Power cost (Rs. 1.0/kWh) + Paid out crop cost	1.57	328077	8.31	1.72	1.48	225042	4.16	1.94
2	Power cost (Rs. 1.0/kWh) + C_1 crop cost	1.17	132389	0.73	4.27	1.07	43189	0.26	10.09
3	Power cost (Rs. 1.0/kWh) + C_2 crop cost	1.09	72074	0.35	7.84	0.99	-9862	-	-
	At 10% discount rate								
1	Power cost (Rs. 1.0/kWh) + Paid out crop cost	1.56	308620	8.14	1.83	1.47	211367	4.06	2.06
2	Power cost (Rs. 1.0/kWh) + C_1 crop cost	1.17	122246	0.69	4.62	1.06	38170	0.24	11.42
3	Power cost (Rs. 1.0/kWh) + C_2 crop cost	1.08	64801	0.32	8.72	0.98	-12357	-	-
	At 12% discount rate								
1	Power cost (Rs. 1.0/kWh) + Paid out crop cost	1.55	290890	7.98	1.94	1.46	198907	3.97	2.19
2	Power cost (Rs. 1.0/kWh) + C_1 crop cost	1.16	113003	0.66	5.00	1.06	33596	0.22	12.98
3	Power cost (Rs. 1.0/kWh) + C_2 crop cost	1.08	58174	0.30	9.71	0.98	-14630	-	-

Table 5: Sensitivity analysis for investment in wells at different discount rate for power cost at the rate of Rs. 2.5/kWh

Sl. No.	Combination	Amreli				Bhavnagar			
		BCR	NPV	IRR	PBP	BCR	NPV	IRR	PBP
		At 6% discount rate							
1	Power cost (Rs. 2.5/kWh) + Paid out crop cost	1.31	225579	1.63	2.51	1.28	158581	1.35	2.75
2	Power cost (Rs. 2.5/kWh) + C_1 crop cost	1.02	19645	0.09	28.77	0.96	-32794	-	-
3	Power cost (Rs. 2.5/kWh) + C_2 crop cost	0.96	-43829	-	-	0.89	-88624	-	-
		At 8% discount rate							
1	Power cost (Rs. 2.5/kWh) + Paid out crop cost	1.31	210337	1.58	2.69	1.27	147592	1.31	2.95
2	Power cost (Rs. 2.5/kWh) + C_1 crop cost	1.02	14650	0.07	38.57	0.95	-34261	-	-
3	Power cost (Rs. 2.5/kWh) + C_2 crop cost	0.95	-45666	-	-	0.89	-87313	-	-
		At 10% discount rate							
1	Power cost (Rs. 2.5/kWh) + Paid out crop cost	1.30	196484	1.53	2.88	1.26	137603	1.26	3.17
2	Power cost (Rs. 2.5/kWh) + C_1 crop cost	1.01	10111	0.05	55.89	0.95	-35595	-	-
3	Power cost (Rs. 2.5/kWh) + C_2 crop cost	0.95	-47335	-	-	0.88	-86121	-	-
		At 12% discount rate							
1	Power cost (Rs. 2.5/kWh) + Paid out crop cost	1.29	183861	1.49	3.07	1.26	128501	1.22	3.39
2	Power cost (Rs. 2.5/kWh) + C_1 crop cost	1.01	5974	0.03	94.59	0.94	-36810	-	-
3	Power cost (Rs. 2.5/kWh) + C_2 crop cost	0.94	-48855	-	-	0.88	-85036	-	-

Hence, it is concluded that, without heavily subsidized electricity to farm sector it is not possible to sustain the economy. In other words, with raised power tariff, some crops (high water intensive) would become unviable. (Kumar, 2005) studied that with pro rata pricing (which induced marginal cost of electricity and water) farmers could not only make irrigation more efficient, but also adopt crops that are highly water efficient, with the result that the economic viability will not get altered. If social and environmental aspects of project analysis are also taken into consideration, then it forms a strong basis for non investment in groundwater irrigation where the aquifers are depleting. For the improvement of power sector, seven more Ultra Mega Power Projects by the GoI are under process and at least two have been awarded in July, 2007. Accelerated Power Development and Reforms Project (APDRP) are being restructured to cover all district headquarters and towns with a population of more than 50,000. The budgetary support for APDRP has been increased from Rs. 650 crores to Rs.800 crores. Allocation of this budgetary support to different states if done evenly, it would help the farmer community.

8. MAJOR FINDINGS

The findings from the paper are mention below:

- Lorenz curve and from other inequality measures revealed that the income realized from groundwater irrigation was more evenly distributed among the farmers of Amreli district than that of Bhavnagar district.
- The sensitivity analysis was done by taking into account three cost concepts; viz., paid out crop cost, C_1 crop cost and C_2 crop cost for cultivation of crops at 6%, 8%, 10% and 12% discount cash flow. The results showed that the investment is feasible for both the districts in all the combinations.
- The sensitivity analysis was also done at three different pro-rata tariff levels (Rs. 0.50, Rs. 1.0 and Rs. 2.50/kWh) with all above indicated rates of discount. It was observed that the investment is viable at paid out cost and C_1 cost level in Amreli district, whereas in Bhavnagar district, the measures were found favourable only at paid out cost level. In other words it can be said that with raised power tariff, some crops would become unviable.
- The development of groundwater markets particularly in Bhavnagar district will stimulate aquifer depletion and create a monopoly of water lords.

9. SUGGESTIONS AND POLICY IMPLICATIONS

Given that under pro rata pricing of electricity, groundwater irrigation become unfeasible, there is a need to conserve groundwater. Various measures can be taken to manage groundwater such as:

1. There should be well defined property rights setting absolute limits to collective and individual withdrawals of water.
2. There should be water zoning within the state and the cropping pattern should be guided and regulated in accordance with such zoning.
3. The government should fix the maximum time limit for providing power subsidy for the long term sustainability of groundwater.
4. There is a need for establishing training and awareness program to the farmers regarding groundwater scarcity and power tariff.

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DUEL AMONG DUALS? POPULAR SCIENCE OF BASALTIC HYDROGEOLOGY IN A VILLAGE OF SAURASHTRA

Sunderrajan Krishnan[1]

Abstract

Just as scientific data collection forms the backbone for national-level policy making on groundwater, there is a parallel stream of popular science that is used in decision making by farmers. These two 'dual' streams of knowledge exist together, sometimes complement, and at others times at conflict with each other in a 'duel'. People's knowledge on hydrology is not 'dying', but thriving and growing well, being refreshed continually by interfaces with science. It may be crude and unpolished, but it is localized, pervasive and relevant to needs of people. Especially in case of hard rock areas, the high hydrogeologic variability makes observation as important as theory. Such observation over decades leads to a developing science such as found in hard rock Saurashtra. It is this innate knowledge in society that has energised the action on conservation of water over the past two decades. Pockets of knowledge sources in villages are repositories of this science. Tapping such pockets, example that of well drillers, and harnessing them towards the state-organized data collection can potentially open up a new direction for localized groundwater management. The Jasdan area of Rajkot district has stirred in terms of groundwater recharge and conservation. In this area, the main actors of groundwater, apart from farmers are well drillers and related professionals of different vocations. Each professional has their own role, but as the main risk-taker, the farmer is the final decision-maker. Decisions on well drilling, location of ponds or recharge structures are made within these multiple points of knowledge sources. Innate terminology such as Kanh, Aadwan and Pad are used for describing hydrogeology, but these words have their roots in the local language. The main structures such as dykes and pore interspaces are easily located by knowledge generated through years of both, vertical and extensive horizontal drilling. Further, using these basic concepts, other applied subjects such as, well hydraulics, can be explained in these same terms. Comparison of this village hydrogeology with regional-level databases shows that there is rich information stored within these knowledge sources. The large level picture of surface lineaments available through geophysical and remote sensing studies, imparts a global picture to this localized knowledge and a potential fusing of these two can be highly potent.

Perhaps, this apparent duality between formal science and people's science is just an illusion, a product of our point of observation, and both of these possibly belong to the same process of societies' program of knowledge generation. Thus, as this case study shows, instead of launching new data collection programs at village-level or persisting with the nation-wide monitoring networks for groundwater as is the current practice, it might be better to listen to the people and tap the right knowledge sources. There might be a large treasure hidden beneath just by scratching the surface.

1. INTRODUCTION

Groundwater, especially in the hard rock regions is best managed locally. 65% of India is covered by basaltic and crystalline hard rock terrain spanning mainly the peninsular part of the country. Many parts of this region are drought-prone and are heavily dependant on groundwater for irrigation and domestic purposes. The management of scarce and highly variable groundwater resource is very important over time. However, the question has been, who takes responsibility for managing groundwater? What incentive do farmers have in community management of groundwater? Do farmers have enough information to make decision on groundwater?

Some recent experiments and research answers some of these questions. Firstly, it is evident that centrally managed government programs of data collection and policy are effective only to an extent. The high

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costs involved and management structure necessary for implementing schemes over the entire country is daunting. On the other hand, experiments are pointing towards community management of groundwater externally stimulated and enabled by civil society organizations or government agencies. Experiences from Andhra Pradesh are inspiring. For any such local management, the strengthening of local people's institutions in terms of knowledge building is essential. The Andhra Pradesh programs have a local knowledge generation process in place that is producing results in terms of local water budgeting and water planning.

Local knowledge on groundwater, therefore, is highly valuable and can be channeled in positive directions towards management of critical local resources. Such local knowledge can be tapped in different ways from different sources: for example by involving farmers in monitoring of well water levels. The point put forward in this paper is that non-formal local knowledge on groundwater already exists in abundance in many parts of India and plays a crucial role in decision making on local groundwater resources. Such knowledge also has an interface and is fed continually by the mainstream science and engineering based knowledge through technologies and surveys. However, the different sources of such knowledge and their relevance to management and policy have not been brought out completely yet.

Several research studies have tried to document local knowledge in hydrology. Rosin's study of a village in Rajasthan talks about groundwater irrigation and water management practices in this arid region based upon a rich knowledge of local water resources (Rosin, 1993). His study, spanning 25 years of observation, looks at how local water harvesting structures are built with knowledge of siltation, runoff, groundwater recharge, salinity processes and groundwater flow. Dying Wisdom (CSE, 2001), documents examples of traditional water management practices from across India. Traditional water harvesting structures show sound understanding of local hydrological processes and intuitive knowledge of essential geology. Shah in his study of a coastal village of Junagadh district of Gujarat describes how farmers built their own picture of local groundwater hydrology through observation of water level dynamics during pumping (Shah, 1993). Sengupta (1993) documents cases of proper planning for local water resources development and the aggregate effects of many small water harvesting and extraction structures at the regional level. He suggests that there must have been some sort of regional level planning at basin level in the past and ancient cultures may have survived because of such integrated planning of water resources. Shaw and Sutcliffe (2003), in their documentation of ancient small dams in the Betwa basin of central India links the size of these structures to the runoff from their catchments. This leads us to believe that the builders of these structures followed some variant of rainfall-runoff curve during design and sound understanding of local hydrology.

Krishnan et al., (2008) carried out a research project in the Alluvial plains of the Ganges river in north Bihar in 2006-07 and found that well drillers are an efficient knowledge source about local groundwater. In Vaishali district of Bihar, a new methodological approach was used to identify and sensitize well drillers towards creating a local groundwater database. A localized lithology of current practices in a single village was created using the experience and knowledge of these drillers. The compiled knowledge was verifiable and cost effective though it had subjective and tangible sources of uncertainty. There is potential for upscaling this approach and creating accurate regional groundwater databases at low cost. However the idea needs to be tested in different terrains and areas with different practices of well drillers. The current study is a step forward in this direction.

2. AIM AND OBJECTIVES OF THIS STUDY

The aim of this study is to document the role of local non-formal knowledge of well drillers, farmers and other local resource persons in decision making around groundwater and to explore how such knowledge can be used for better implementation on policies related to groundwater.

2.1 They Specific Objectives of this Study are

1. To document local knowledge on groundwater hydrology and practices in hard rock area of Saurashtra and build a local database using this local knowledge. Compare this with science-based information available currently for the same area

2. To chalk the relevance of this local knowledge in current decision making on groundwater related practices

3. TO UTILIZE THIS KNOWLEDGE IN IMPLEMENTING FUTURE POLICIES RELATED TO GROUNDWATER

Table 1 shows a framework for differentiating between scientific and local knowledge. If scientific knowledge is conceptual, focused, sparse, potentially unbiased, repeatable and communicable; local knowledge is specific to the observation, unfocused, dense, possibly biased, generally non-repeatable and relatively difficult to communicate. As can be seen from the characteristics, each of these approaches at information-collection has their own advantages when seen with respect to a particular objective. If the objective is to build a national picture of groundwater across India, then the approach of local knowledge would hardly make any sense because of the time and effort needed; what makes sense in that case is the approaches used for example, by CGWB (CGWB, 2004). But if the objective is to bring about better management of groundwater in small aquifers and micro-watersheds, then one needs to pay more attention to local knowledge, but within a larger scientific context and concept.

Table 1: Comparing science-based knowledge and local knowledge about groundwater

Characteristic	Science	Local knowledge
Scale	Large scale, general, conceptual *Aquifers*	Smaller scale, specific, practical *Can describe nature of local flow*
Tool	Designed instruments, limited, focused recorded *Rain gauge, Water level recorder, drill logs*	Many undefined instruments, unfocussed observation, mostly unrecorded *Different sensors, word of mouth, passing of information through generations*
Spatial coverage	Time and space sparse, interrupted time-series *Depends on monitoring network*	Dense in space and time, long term observations *Every individual is an observer*
Precision	More precise, errors more objective and amendable *Results from repeated measurements*	Perceptive, individual, errors difficult to evaluate *Every individual has different perception, possible bias*
Repeatability	Repeatable measurements *Can use same monitoring equipment at different places*	Possibly poor repetition *Cannot expect similar perception and experiences for same observation*
Communication	Easy to translate and communicate *Somewhat standardized terms, such as porosity*	In local language and need to be interpreted Terms such as *Kanka, Pathar, Khara Nadi*
Purpose	Observations useful for scientific interpretation and modeling *Measurements such as hydraulic conductivity*	Observations of importance to daily life and water use *How fast does water fill into a well?*

Note: *Kankar:* gravel; *Pathar:* stones; *Khara:* saline; *Nadi* river

A right mix of these different knowledge sources can bring about an improved knowledge-based management of groundwater.

4. METHODOLOGY OF STUDY

The approach followed here is to first explore all the knowledge sources (KS) present within the study area with regards to hydrogeology and extract the appropriate information from each of them. The following step-wise process was followed:

Step 1 : Identify all knowledge sources who can inform about hydrogeology of the study area

Step 2 : Based on initial conversations with each KS, develop tools and methods for obtaining information from each of them

Step 3 : Apply tools to each of the KSs

Step 4 : Identify the terminology and concepts used in local science. Compare these with scientific terms. Cross-verify collected information with linguists and with organizations which have worked in this area.

Step 5 : Merge all the acquired information towards developing the local science picture of hydrogeology of the study area

Step 6 : Compare developed hydrogeology picture of study area with any available scientific study of the area

All these steps in this study were performed with the help of an NGO named Saurashtra Voluntary Action in Rajkot (SAVARAJ), which has been working in the study area for the past 20 years. Within the course of this study, a total of 7 KSs were identified in this area, right from a regional district level to that of the farm. These are enlisted in the next sub-section. Apart from these KSs, the guidance of a linguistics professor was utilized in understanding terminologies. Further, officers of Centre of Environmental Education (CEE) in Ahmedabad and Jasdan were useful in confirmation of the summarized results and wider expansion of these.

4.1 Knowledge Sources

4.1.1 Rajasthan Well Drillers (RWD)

Description: Bulk of the well construction in Saurashtra, especially those of open wells is performed by laborers from Rajasthan. They migrate to Saurashtra during the drilling season which starts from November and proceeds till May every year. These laborers are mainly from the southern and western Rajasthan districts such as Bhilwara, Barmer and Kota.

Area of influence: Each such group of laborers, generally numbering 4-5, construct 5-10 wells in a season. Their area of influence circles around 3-4 villages at most. In most cases, the leader of the group keeps visiting the same area every year and hence, keeps developing his knowledge about the area's hydrogeology. Even though they follow instructions from the farmer and do not make decisions regarding well location or depth, the RWDs due to the nature of their work of spending days literally inside a well, have a very close observation of local hydrogeology. Some of them, after years of experience, graduate to become well construction contractors and manage several teams of laborers.

Nature of method and tool used: With regard to RWDs and also several other KSs, the mode of knowledge gathering has been to approach them when they are involved in their work. After this, a specific interview schedule was administered to the KS, here, RWD. The different sections of this were:

a) Personal information
b) Professional information
c) On process of drilling
d) On knowledge about hydrogeology
e) Linking their knowledge to groundwater management

As an example, the specific interview schedule for RWD has been provided in the Appendix. The schedules for other KS are different, but follow a similar structure of sections.

4.1.2 Horizontal Well Drillers

Description: These drillers are mainly concerned with horizontal boring within open wells. These borings exist from 1-2 to upto as many as 20 in a single well at different depths and towards different directions. Such drilling is performed using hand-held drilling tools by these drillers who are locally based, generally farmers.

Area of influence: These drillers operate within a radius of maximum, 2-3 villages at most.

Nature of method and tool used: The nature of method is the same as for RWD except that in Section 5, there are more questions, which are provided in the Appendix. These mainly concern with the impact of horizontal bores on the local groundwater hydrology.

4.1.3 Well Owners

Description: The nature of Saurashtra's groundwater is that there is tendency to have a well in almost every farm. There is very less trade in water, so the density of wells is very high compared to others parts of Gujarat. Most of these are open wells from 50-80 ft deep.

Area of influence: Each well owner is aware of the groundwater hydrology within surrounding area of the well i.e. interactions with neighboring well, or for farther away wells what are the hydraulic connections.

Nature of method and tool used: For this KS, one needed to move through the village and use tool similar to that of RWD.

4.1.4 Small Drill Rig owner

Description: The mode of well drilling for open wells is such that mostly, the RWDs rent the drilling equipment i.e. the compressor and drill from a drill rig owner. Such drill rig owners are located 1 in every few villages and have much control on the drilling procedures.

Area of influence: Generally, such small drill rigs are operated over a radius of 4-5 villages.

Nature of method and tool used: A tool similar to that of RWD was employed with some variations and the KS located in the field of action.

4.1.5 Experienced Former Drillers (EFD)

Description: Formerly, most drilling in Saurashtra was done locally. Villages have several drillers who have been in operation for several decades.

Area of influence: The EFDs contacted in this study have had an area of influence of almost a taluka since there were fewer drillers when they used to operate.

Nature of method and tool used: In this study, the EFD came out as the principal source of local knowledge. Therefore, the mode of interaction required extensive interviewing, recording of information and cross-verification with other sources. The tool used with EFD was similar to that with the RWD.

4.1.6. Water Diviners

Description: Most of the previous water-prospecting in this area was performed by persons using traditional techniques knows as 'Water Diviners' and locally as '*Pani Joa-wale*' or 'those who can see water'. Such persons use many methods which are now considered as experiential or location-specific for water-prospecting. Many of these techniques are now debunked by scientists, but are still used in villages example of those of using the avantika branch or using a coconut. In this study, the approach has been to view the diviners with a perception of 'respectful skepticism'.

Area of influence: Since most villages possess atleast one diviner, the area of influence of each is within a few villages at most.

Nature of method and tool used: The mode of approaching the diviner in this study has been to observe if the diviner also uses any experiential or observation-based knowledge in their practice. Similar tools such as for EFD has been used for the diviner and then their practice been recorded.

4.1.7 Blasters

Description: The blasters or the providers of dynamite are located in small towns from where they provide material for the surrounding areas.

Area of influence: Generally, each blaster would provide dynamite material for 15-20 villages, depending on the towns in that area with such shops.

Nature of method and tool used: A simple tool was administered to the blaster to gain information on the occupation and magnitude of drilling.

4.1.8 Regional Well Driller

Description: Located in the larger towns and cities, there are deep bore drillers who drill up to 500-100 ft and more. These drillers have large rigs and operate over a wider area. In this study, 2 such regional drillers, RegWD were identified in Rajkot and Aatkot.

Area of influence: Some of these RegWD operate over a district or even larger area. They therefore know of drilling practices and hydrogeology over vast areas.

Nature of method and tool used: The nature of tool was similar to that of RWD with some changes to account for scale.

4.2 Sampling procedure

Since, a wide variety of knowledge sources have been identified in this study and that too over different scales, a judicious selection was required. Keeping in mind the focus on 1 village unit for the study, but obtaining a regional picture as well, the sampling procedure showed in Table 2 was followed.

Table 2: Sampling of Knowledge Sources

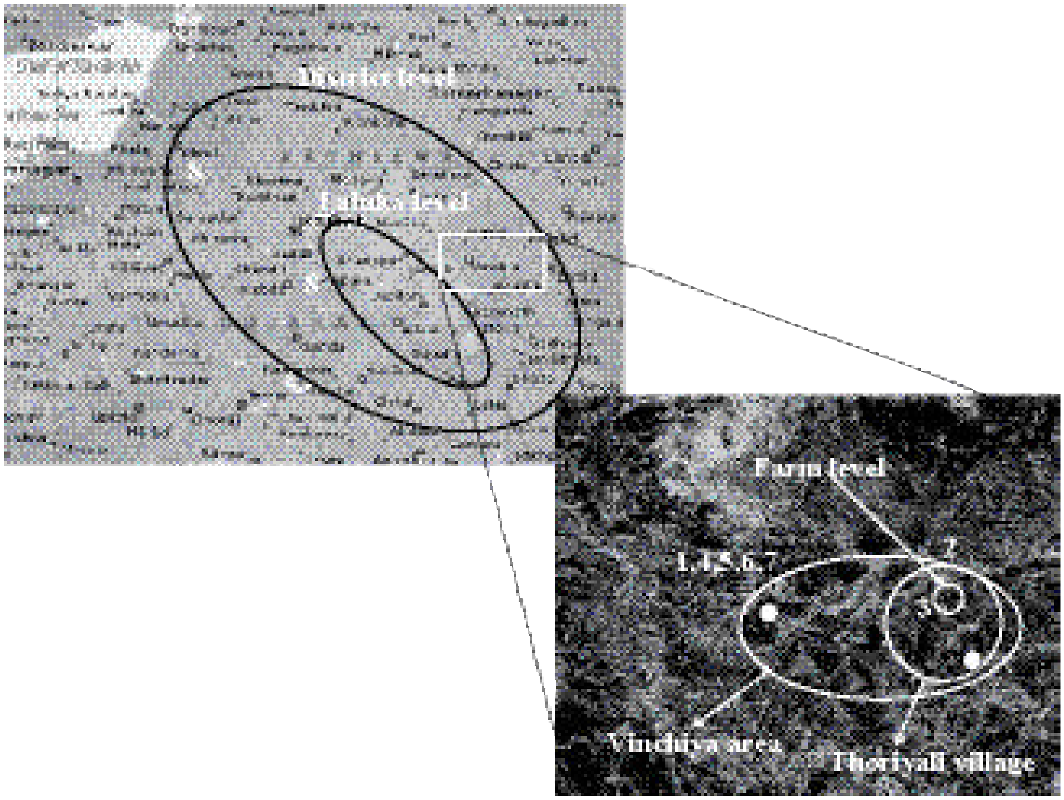
Sl. No	Knowledge Source	Number of Samples	Locations
1.	Rajasthan Well Driller	3	Thoriyali (Rajkot D), Vangedhra (Bhavnagar D)
2.	Horizontal Well Drillers	2	Thoriyali
3.	Well Owners	17	Thoriyali
4.	Small Rig Owner	1	Vangedhra
5.	Experienced Former Driller	1	Thoriyali
6.	Water Diviner	1	Thoriyali
7.	Blaster	1	Vinchia
8.	Regional Well Driller	1	Aatkot

4.3 Traditional Knowledge vis-à-vis People's Current Science

It is important to distinguish between the 2 concepts. As mentioned earlier, there have been several documents on the traditional knowledge of hydrology in the Indian subcontinent and other places (CSE, 2001; Shaw and Sutcliffe, 2001; Rosin, 1993). That kind of knowledge has developed over the ages and has been mentioned in scriptures (NIH, 1999). Here we do not refer to that type of traditional knowledge. Here we refer to a living science that is continuously being developed because of drilling and groundwater use. For example in our KSs above, the KS no. 6, i.e. a Water Diviner follows that traditional knowledge using the stick of an avantika branch in searching for water. All other KSs have their knowledge built out of their current experience and observations, therefore, they can be trusted more. Here we are dealing with current science as opposed to traditional knowledge.

5. STUDY AREA

Figure 1: Location Map and Area of Influence of Different Knowledge Sources



The following criteria were used for selecting the village for this study:

a) Primarily basaltic hydrogeology

b) Neither too flat terrain nor highly undulating so that there is some dynamics of groundwater hydrology which can be captured.

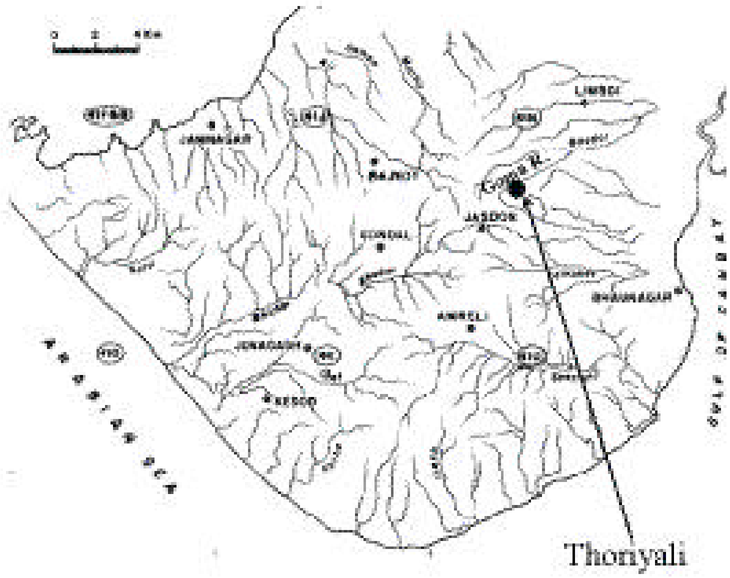
c) Some level of water conservation activity such as check dams, but not to saturation level

d) Presence of a known NGO whose help can be sought in implementation of this study

With these criteria in mind, many different areas were considered and finally Thoriyali village of Jasdan Taluka in Rajkot district of Saurashtra was chosen. The nearest town is Vinchiya, which is around 5 kms away from village Thoriyali, shown in Figure 1. The region of influence of each knowledge source is marked approximately in this map. With our approach, we try to pan out into a larger area such as a district and also zoom into the level of a farm by identifying these multiple scales of KS.

Figure 2 shows the study village within the stream network map of Saurashtra. The Goma river which is a tributary of the Bhadar river, passes through Thoriyali. Note that Goma river, like most rivers of Saurashtra, originates from the central upland region of Chotila-Jasdan. The Goma river originates from the Jasdan uplands that lie within the Hingolgad forest reserve. The total length of the main river bed is approximately 42 kms until it merges with the Bhadar river. It is an ephemeral river characterized by intense storm flow for few days of the year typical of arid and semi-arid regions. The study area being a highly wet monsoon, there was base flow and seepage from check dams even in February.

Figure 2: Location of Thoriyali within Stream Network Map of Saurashtra



The village has a population of around 1500 and total area of around 10 km^2. The total relief of the village is 70 ft and maximum NS and EW transects are 4 km and 3 kms respectively. The Jasdan-Botad highway passes through the village. Just 10 kms west to the village lie the Hingolgad forest reserve which is the source of many rivers such as Goma and Gehlo. Right from the catchment area down to the plains and beyond, the vestiges of the Saurashtra water conservation movement can be seen. Dotted along the landscape, one finds several check dams which were constructed mainly from 2000-05. Within Thoriyali village, there are 2 main check dams and 2 smaller ones. There are currently around 250-260 wells in Thoriyali, almost all of which are open dug wells in the range of 50-70 ft in depth. There are no deep bore wells in the village, except for 1 drilled for drinking water and failed soon after construction.

6. PEOPLE’S VIEW OF HARD ROCK GROUNDWATER HYDROLOGY

Before going further into the study of Thoriyali, it is necessary to understand the language of the ‘people’s science’. The understanding of terminology used by people was captured by this non-native language speaking author with the help of an interpreter. Further, these concepts have been verified by conversation with a linguist Professor and officers of CEE. These concepts have been formed from conversations during the period of field work i.e. from July 2007 – February 2008. The main source of these terminologies has been an ‘Experienced Former Driller’ (EFD) of the Thoriyali. They have been verified by cross-verifications with the other KSs used in this study.

6.1 Terminology

The concept of hydrogeology is hierarchical and adapted to a Basaltic terrain that is dominated by surface lineaments and dykes. It is to be noted that these concepts would not hold true for ‘groundwater hydrology’ in general and also, to this specific terrain when going into details. The 3 main concepts identified are:

6.1.1 *Kahn*

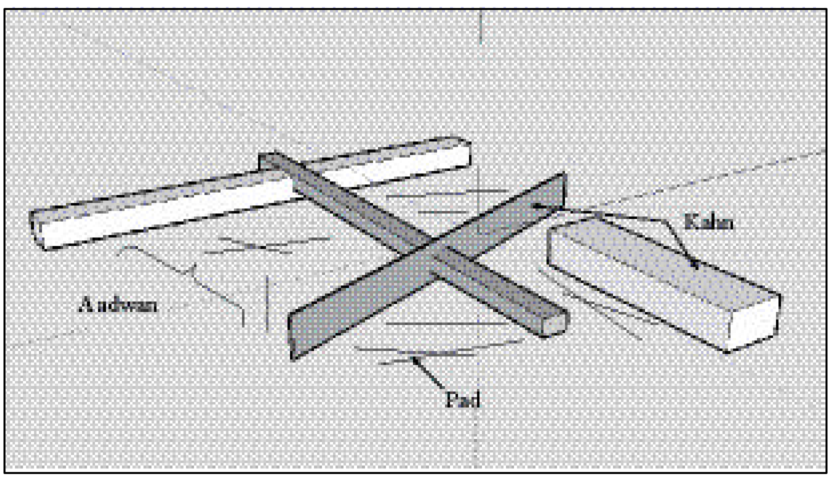
The largest and most important structures in this terrain are referred to as *Kahn* (pronounced with a half-emphasis on the ‘*hn*’). *Kahn* is used to refer to surface lineaments and dykes which are most critical as transmitters of groundwater. In regular language of Saurashtra, the word *Kahn* refers to the *essence* or *substance* of any entity. Perhaps it is this meaning which has gotten transmitted over to groundwater. *Kahns* can be as short as few metres in length, and can run to many kilometers. The important dykes of Saurashtra have been identified using Remote Sensing and gravity measurements (Mishra et al., 2000). The *Kahns* identified in villages can be much smaller than these large scale structures.

In most cases, *Kahns* cuts up the base basalt rock vertically and forms flow barriers on either side. If there are pore spaces connecting them to the surrounding rock, then there can be some transmission, otherwise, the flow is mostly longitudinal along the *Kahns.* The tilt can be vertical to as much as 15-20^0 from the vertical. The width can vary from 2-3 ft to as much as 20-30 ft. Hydraulically, *Kahns* are excellent transmitters of water, depending on the fractures within it and orientation. However, they are difficult to drill into and do not support wide-diameter open wells. Also, they are not stable to horizontal drilling.

6.1.2 *Aadwan*

The second level within the local hierarchy of hydrogeology conception is the *Aadwan*. The spaces of rock enclosed *between* the *Kahns* are referred to as *Aadwan.* This word perhaps springs from other similar words such as *Aada* etc., i.e. on the side. The *Aadwans* are all that space which consists of the upper soft *Murrum*, and base basaltic rock. Within a village with 5-6 *Kahns* cutting across there could be 15-20 such *Aadwans* and there is identity of farmers lying within an *Aadwan* of being on the same patch of aquifer. So, in some ways, the *Aadwans* enclosed by *Kahns* can be said to comprise of 1 aquifer unit with flows to and from the *Kahn* and from surface recharge/discharge units such as ponds, river, wells, etc.

Figure 3: Local concepts on Hydrogeology
(Scale can be assumed as 1 km x 1km in plan and 20 m in depth)



6.1.3 Pad

The third and final level of concept in this hierarchy is the *Pad*. A word used to refer to as *layer* in the local language, *Pad* is the *pore spaces* within the *Aadwan* which can store and transmit water. They can be a few cm to a few ft thick. In a single well of 50 ft depth, one can encounter not a single *Pad* or can hit 4-5 *Pads.* The practice now, however, in face of high uncertainty, is not to be bothered about striking a *Pad* during drilling. Horizontal bores are dispatched from different depths and directions of the well to try and encounter *Pads*. What matters are *Pads* that are recharged by either rain water or some surface recharge body and also those that are not connected to or shared by other users. The search is always for that elusive undiscovered *Pad.* However, looking at the current density of wells and network of horizontal bores, it is surprising how new and yielding *Pads* would exist at all.

6.2 Storage and Transmission

The key concepts of hydrogeology science are those of storage and transmission (Todd, 2004). They are measured by parameters such as specific yield, storativity and storage coefficient (for storage) and hydraulic conductivity and permeability (for transmission). In the local equivalent, similar ideas are prevalent. The *Kahn* and *Pads* are the key receptacles. However, transmission needs connectivity between these storage structures. If such connectivity is not present, it is artificially made by horizontal boring. Both storage and transmission reflect together in well yield. Well yield is measured mainly in terms of time for which water can be pumped from a well, which can vary from 30 minutes to as much time as electricity or diesel is available. For example, a well far away from any *Kahn* or *Pad* bearing water can have a low yield of just 30 minutes. Whereas another well that is connected to a pond through a *Pad* or *Kahn* or horizontal bore will yield as long as the source is available.

6.3 Well Hydraulics

Hydraulic head fluctuations, flow directions and interference are key concepts , which are understood in terms of local concepts. Sharing a single *Kahn* causes interference for wells within the *Kahn* and less to none for wells across it even close by. On the other hand, wells sharing the same *Pad* are also affected mutually by interference. Deeper wells are at an advantage since *Pad* water flows to the lowers *Pads.* Each well owner has acute picture of interference with all surrounding wells and other wells which are hydraulically connected. This concept of interference is mainly through drop in hydraulic head and in reduction in the duration of availability of water for pumping.

7. INNATE PICTURE OF A VILLAGE HYDROGEOLOGY

After an understanding of the basic terminologies and their observation on the field, we proceed to utilize these concepts for the study village.

7.1 Knowledge sources and their contribution

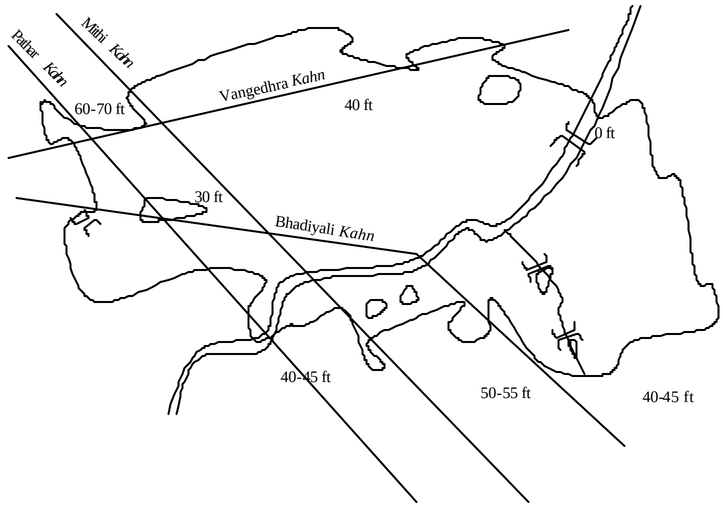
In this particular study, out of all KSs mentioned in Table 2, the most important was the experienced former driller. The understanding of terminology and overall picture of the village hydrogeology was made possible through this EFD who was also a horizontal well driller once. This particular EFD had 5 years of experience in drilling and 15 years in horizontal drilling. In all he has drilled around 50 wells and drilled horizontal bores in around 300 wells. Further, the KS no. 3 i.e. well owner added some local complexities and corrections to the larger picture. The KS no. 6, i.e. the water diviner through years of prospecting for water, also possesses good local knowledge, which was used for verification. The other KSs were mainly used for insights into the drilling process and their roles into that process.

7.2 Village Hydrogeology and Current Well Arrangements

As shown in Figure 4, the main pond of the village is located in the western part of the village. There is a much smaller pond in the north-eastern part and 2 small ones, with almost no catchment and hence dry, in the south part. The large check dam is built right on the Goma river in the north-eastern part. Apart from these, there is 1 check dam in the north-west side of the village which has an inundation zone of around 2-3 ha and 2 small cascading check dams in the south-east which have (< 1 ha) small indundation areas.

The relief of the village is saucer-shaped with dip towards the river that passes through the middle. The river flows from west to east, so there is a general slope downwards along that direction too. The map shows the relative elevation of different points in the village as compared to the bottom-most point i.e. the river bed at the north-east edge. The central wasteland of the village, very recently cultivated, lies on the north-central part.

Figure 4: Constructed map of village with water bodies and geologic features



The village has 4 main *Kahns* that cut across the village boundaries. These have been named during the course of this study for convenience as the Badiyali *Kanh*, Vangedhra *Kanh*, Pathar *Kanh* and Mithi *Kanh* as shown in Figure 4. These *Kahns* form a total of 8 *Aadwan* regions. Apart from these major 4 *Kahns*, farmers are also able to locate a multitude of smaller *Kahns*, that are 10-15 ft or so in length. All these *Kahns* are doleritic and some gabbroitic.

7.2.1 Badiyali Kanh

The oldest well of the village, perhaps a few 100 years old lies on this *Kanh* which is 5-20 ft in thickness. It is a well of very large diameter of around 20 ft, having expanded along the *Kanh* over the years (a common problem for all wells situated on *Kanhs*). Since this well used to be very high yielding, all further wells started being constructed along this *Kanh*. Most of the old wells, 30-40 years or more old, are located along this *Kanh*.

7.2.2 Vangedhra Kanh

This is a 10^{o} from the vertical tilted *Kanh* that is 10-40 ft in thickness. It cuts across from east to west and possibly forms one of the large dykes cutting across the Saurashtra region. This *Kanh* also forms the northern boundary of the village and passes into Vangedhra village, hence the name. Since in Thoriyali, this *Kanh* mainly is adjacent to the erstwhile wasteland, there are not many wells along it as compared to the Badiyali *Kanh*. In contrast on the northern side of this *Kanh,* i.e. in Samadiyala village, there are more wells located along it.

7.2.3 Pathar Kanh

This Kanh runs roughly north-south and is composed of entirely brittle material with large crevices. It has less sand material within these crevices, hence the name.

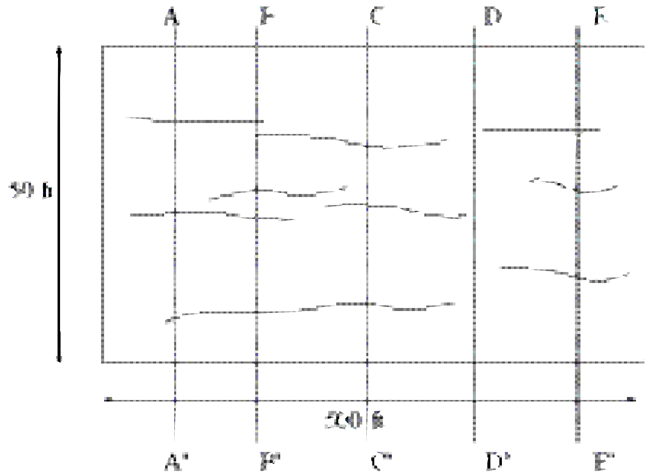
7.2.4 Mithi Kanh

Running almost parallel to the Pathar *Kanh*, this *Kanh* has more of sand material within the crevices. It has relatively poorer transmission properties than the Pathar *Kanh.*

The *Pads* of the village mainly start occurring from 20 ft onwards and below, but the depth at which these *Pads* start becoming useful and bear water are between 35-40ft. The thickness of the *Pad* is very small here, from 1-5 inches. There could be a minimum of 0 to maximum of 5 *Pads* in a vertical cross-section of up to 50 ft. The mode of distribution of *Pads* is around 3 in number for any vertical cross-section.

As shown in Figure 5, which is a conceptual 2-D distribution of *Pads*, we have 5 equi-spaced cross-sections, A-A' through E-E' with number of *Pads* equal to 3, 5, 3, 0 and 3, i.e. minimum of 0, maximum of 5, mode of 3 and average of 2.8.

Figure 5: Conceptual picture of *Pads* distribution within the *Aadwan*



7.3 A Case of Well Interference

Most of the wells in the village lie in the range of depth 40-60 ft. The water bearing layer, *Pad*, is struck within such depth and the next *Pad* cannot be struck till 100 ft or so. In such a situation, any single well being drilled to a deeper level causes much interference and capture from the neighboring wells.

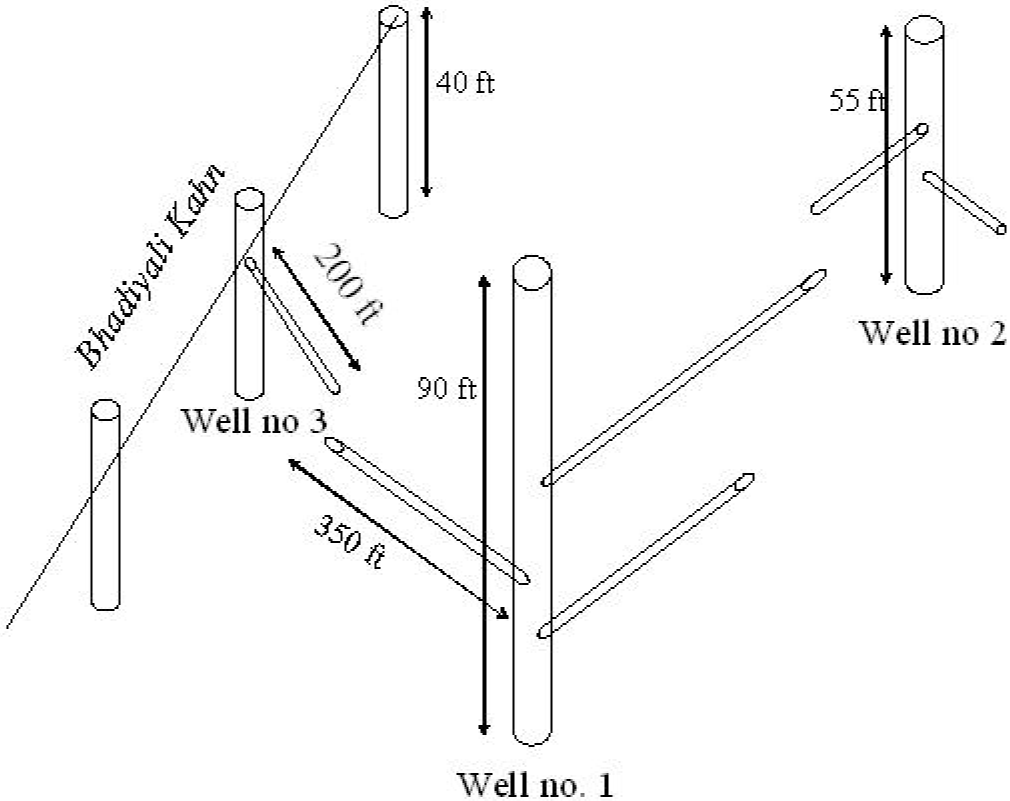
This example is from the eastern part of the village close to the check dam near *Badiyali Kahn*. There lies a series of wells along this *Kahn* at a separation of around 50 ft. There are also other wells in the *Aadwan* region to the west of the Kahn, but lying more than 500 ft distance away. But, one farmer's break of implicit rule led to a serious altercation in this region arising from well interference. Figure 6 illustrates the situation currently. Well no. 1 was drilled up to a depth of 50 ft and did not strike a single water bearing *Pad*. The well owner here is the village's water diviner. He decided to go deeper and reached up to 90 ft, which was much deeper than all neighboring wells. He struck a *Pad* at that depth which abstracted water from all neighboring wells. Due to the downward gradient, he benefited immensely at the cost of neighboring wells such as well no.2. Further, the well owner started drilling horizontally as shown in the Figure. Well no. 3 used to obtain continuous supply of water by being on the *Kahn* fed. This led to abstraction of water from one of the *Kahn* wells, leading that well owner to drill towards well no. 1, but to no avail.

Here, the levels of interference reported at each step go as follows:

- Before the well no. 1 was constructed, the well no 2 used to obtain water in his well for 2 hr during post-monsoon period in January for a normal rainfall year. But, after well no. 1 was drilled, this well went dry until well no. 1 stopped pumping.
- Similarly, well no. 3 used to obtain continuous supply of water by being on the *Kahn* fed by the check dam. But, this went down to 3 hr of water supply only after well no. 1 was constructed.

All these reductions in water availability to well no. 2 and 3 directly benefited well no. 1 because of the depth of 90 ft and several horizontal bores arising from it.

Figure 6: Example of Well Interference triggered by Well no 1 drilling deep



7.4 Level of development and knowledge

An observation of Figure 4 will show that the biggest *Aadwan* of the village lies south of the Vangedhra *Kahn*. It is interesting to note that this region also consists of the erstwhile wasteland of the village therefore an area of poor density of old wells. A relationship exists between the level of development of groundwater in an area and the amount of knowledge generated. Here, there are certainly small sized *Kahns* in this *Aadwan* region, but they are not known properly since there has not been much observation of hydrogeology here. Over the years, as there is more observation, there would be better knowledge of the hydrogeology in this part too.

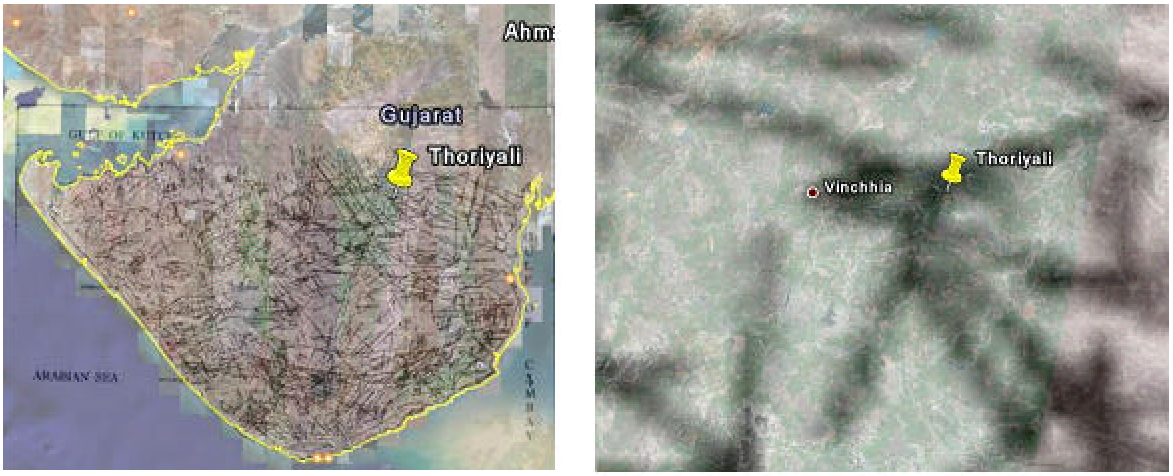
Extending this observation, if one compares an intensively explored groundwater area such as Saurashtra with some other area with similar basaltic hydrogeology, such as upland western Madhya Pradesh, one would not find as much observation and innate knowledge as in Saurashtra since knowledge matures with experience, in this case groundwater development. As stated before, this knowledge is slowly expanding and developing as more and more areas develops groundwater intensively.

7.5 Comparisons with Available Surface Lineaments Map of Saurashtra

The surface lineament map of Saurashtra has been mapped using gravity and magnetic measurements by an NGRI team using false colour thematic maps provided by NRSA on 1:250,000 scale (Mishra et al., 2000). This map was overlaid using the public available Google Earth software that uses satellite imagery from DigitalGlobe's Quickbird satellite. Note that this overlay has several potential source of errors:

a) Scale errors: Both these images are at different scales of resolution
b) Overlaying errors: The location and orientation of these images can produce an error of maybe range of a km.

Figure 7: Overlay of Saurashtra Surface Lineament map over the satellite map of village



But in spite of these errors it is surprising to find the similarities in Figure 4 and Figure 7. Figure 8 shows the comparison of these 2 pictures of Thoriyali village, one generated by interpreting the people's knowledge and the other by processing of 2 satellite measurements. The major *Kahns* of the village appear distinctly on Figure 8b. Such a comparison has to be seen with some degree of doubt until this process of overlaying of maps is performed rigorously using ground observation points for anchoring.

If this overlaying is indeed true, then it is heartening to note how much more of information the people's knowledge can add since the inherent knowledge is that of much smaller *Kahns* of few ft in length. On other hand, maybe, using a satellite image of resolution finer than 1:2,50,000 scale used by the NGRI study could also result in such similar features. In any case, it is interesting to note the same degree of resolution obtained by both approaches, which are completely different from each other.

Figure 8: Comparing Information from the (a) People's Knowledge of *Kahns* and
(b) Scientific Studies on Surface Lineaments in Thoriyali Village

(a) (b)

8. DECISION MAKING AND KNOWLEDGE

One of the key decision making process regarding groundwater is well drilling. Since the well owner or farmer has to finally take the risk, he is the final decision maker, even though there might be better knowledge sources than him. In this process, the farmer may choose to get the expertise of different KSs, and sometimes not. At each stage of drilling however, a different set of KS are involved and they exercise their knowledge in helping the farmer. In all, 3 stages can be identified:

Stage 1: Well Location

Here, the farmer spots a location within his land or in some cases even buys land for drilling a well there. This decision of locating the spot of drilling is often the most crucial and perhaps, one of greatest risk. In some cases, the farmer might use the help of a water diviner. There is also a practice of performing exploratory boring which might cost up to Rs.10,000 for around 50 ft of boring. This could give a fair idea of whether to go for blasting at this spot or not. Following factors go into this decision of well location (not in the order of importance):

a) Farm topography: tendency to locate well at higher location on farm for water to flow under gravity
b) Connectivity to water source: The hint of being connected by a *Kahn* or *Pad* to a water source such as pond, check dam or river.
c) Isolated capture zone: To try and assure a safe capture zone for the well and avoiding well interference. In some cases, farmers also try the opposite i.e. to capture a known *Pad* which is already being tapped.
d) Possibility of being able to bore horizontally from this location and tap a *Pad*, *Kahn*, or a water source.
e) Minimizing well construction cost: The type of rock is one important factor in minimizing well construction cost. For this reason, many farmers prefer to drill in *Kahn* since there is no need to drill to deeper level in a *Kahn*. However, well stability is an issue for *Kahn* wells.

Stage 2: Vertical Well Drilling

This is the most important step in drilling which involves the RWDs and small rig owners. It is an interaction between these 2 KSs under the supervision of the well owner which results in vertical drilling. One important thing here is that since the RWD gets a full contract from the well owner for the well and rents equipment such as the well rig, he tries to minimize cost. But the rig owner gains by more boring. So there is a push-pull between these 2 KSs in trying to minimize-maximize the number of boring which are used for planting dynamites for blasting. A rough cost of Rs. 800-1000 is paid by the farmer to the RWD per foot of vertical drilling. The RWD then handles all other cost such as:

a) additional labour (which is also obtained from Rajasthan) and their upkeep
b) rent to the small rig owner at Rs. 30 for every 25 ft of boring
c) cost of dynamite sticks

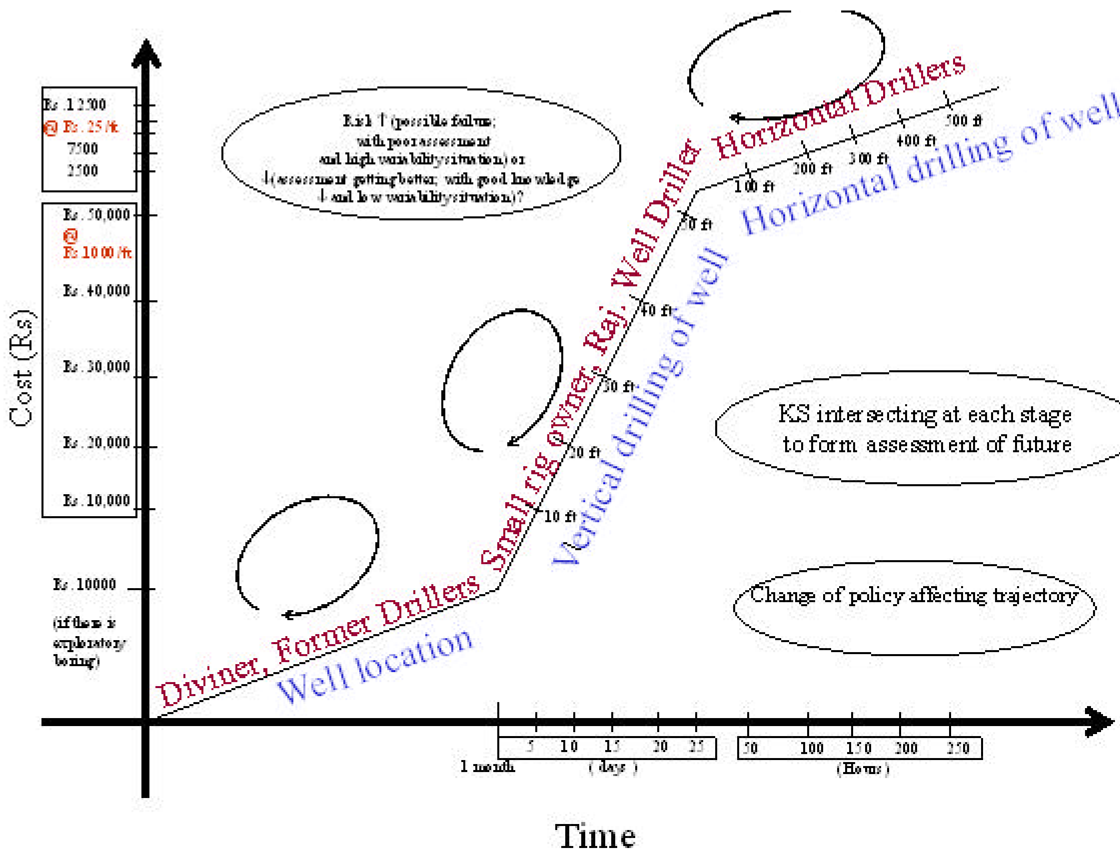
Stage 3: Horizontal Well Drilling.

Once vertical drilling is complete, the HD arrives in the scene to decide along with the farmer where to drill horizontally and at how much distance. Note that an important ethic followed here is not to drill outside the extant of the farm on the ground. There are exceptions, though, to this rule, as mentioned earlier in this paper for the example of well interference. The rate of horizontal drilling is around Rs. 25/ft. For every such direction, one might choose to go up to 300 ft and around 150 ft on an average. It is common to find 5-7 such bores placed at various levels within the well.

Figure 9 shows the following for each step of Well Drilling
a. Cost to the farmer
b. Time taken for that step to be executed
c. The KS involved in that step apart from the farmer himself

Note that the scales of cost and time vary with each stage of drilling, so one needs to accumulate the incremental time and cost at each stage to get the total time and cost. All estimates of time and cost shown here are from the primary survey made in this study. Note that these numbers are at best representative since they vary with the local hydrogeology. However, they can be useful for comparison across the 3 stages of well drilling since what matters is the orders of these numbers. Also, note that we have provided here for an iterative process at each stage.

Figure 9: Cost, Time and Knowledge Sources in Well Drilling
(estimates from primary survey)



This might always not be followed, for example seldom does one back off after starting vertical drilling. But here we offer that possibility for generalization. There are 2 important concepts to be discussed:

8.1 Perception of risk to well owner at each stage of well drilling

It is natural to perceive that the farmer is taking the biggest risk at the first step i.e. to drill a well or in choosing a location for the well. But, as the farmer commits more and more investment (Rs.10000 for the first stage, Rs.1000/ft for the second stage and so on), he is unable to back off from the drilling process and expects a good return from this investment i.e. good yield from the well. If the farmer is drilling within a hydrogeology of low variability and the combined KS-knowledge accessible to him is of a good quality, then this risk is well covered. But, in a situation of high hydro-geological variability and poor KS-knowledge, he is operating in a situation of high risk.

Therefore, the quality of combined KS-knowledge in informing about the potential well yield is critical to the farmer in making decisions on well drilling under an environment of high hydro-geological variability.

8.2 Impact of groundwater policies on this decision-making process

Within such a scenario, what happens when new policies are brought into this situation. For example, consider policies such as cap on depth of well drilling, ban on horizontal drilling and minimum well spacing.

a) A cap on depth of well drilling will result in the farmer to pay more attention to horizontal boring. In that case the HD acquires greater importance than before.

b) A ban on horizontal drilling on the contrary, would force the farmer to choose the well location more prudently since he has to strike a good *Pad* in that vertical drilling. In that case, the farmer would perhaps invest more in the initial exploratory drilling in the first stage. The water diviner could also assume an important role in that case if the farmer cannot afford such exploratory drilling and wishes to make a judgement based on belief.

c) Imposition of minimum well spacing will surely affect the well location, and therefore potentially more water-yielding locations. So the farmer will try to access these *Pad* locations by more horizontal drilling. Again the HD gains importance.

Therefore, policies will affect the trajectory shown in Figure 9 and the relevant KS would come to the help of the farmer in such a case. The farmer is interested finally in yielding maximally under a given budget of well drilling. For that, he has to utilize the appropriate KS at each stage of drilling. He continuously makes adjustments and adapts to new situations with the help of the KSs.

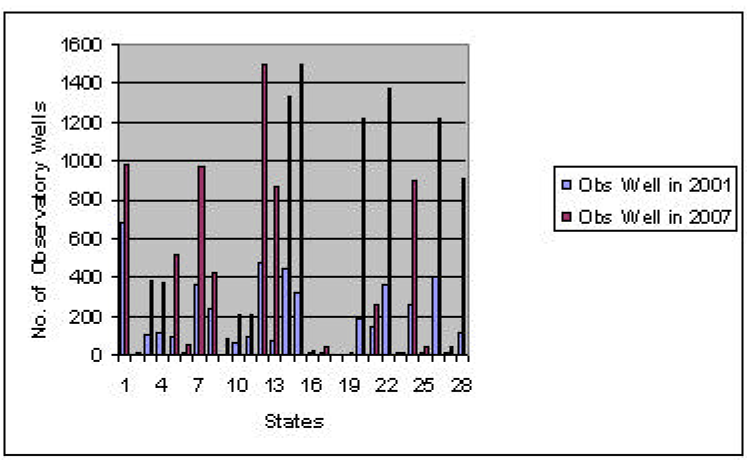
9. CONCLUSIONS

The local knowledge of this village in basaltic Saurashtra has been documented. Further, it has been confirmed from other conversations that the similar terminology, i.e. the hierarchical triplet of *Kanh-Aadwan-Pad* (K-A-P) is used widely in the region north of Junagadh and south of Chotila in Saurashtra. The basic ideas of well hydraulics have been interpreted in this context.

This understanding has been applied to the case of a single village by using a variety of Knowledge Sources. This picture of the village has been compared with a previous scientific study on surface lineaments and some coincide is observed, but this should be viewed with caution because of the possible uncertainties.

The role of Knowledge Sources in decision making, i.e. in well drilling has been described. We have looked at how cost and time build up at each stage of the well drilling process and how the knowledge sources would behave under different policy changes such as a cap on well depth, imposing ban on horizontal drilling and minimum well spacing.

Figure 10: State-wise number of CGWB Observation Wells in 2001 and 2007



1	Andhra Pradesh
2	Arunachal Pradesh
3	Assam
4	Bihar
5	Chhatisgarh
6	Goa
7	Gujarat
8	Haryana
9	Himachal Pradesh
10	Jammu & Kashmir
11	Jharkhand
12	Karnataka
13	Kerala
14	Madhya Pradesh
15	Maharashtra
16	Manipur
17	Meghalaya
18	Mizoram
19	Nagaland
20	Orissa
21	Punjab
22	Rajasthan
23	Sikkim
24	Tamil Nadu
25	Tripura
26	Uttar Pradesh
27	Uttaranchal
28	West Bengal

Finally, we look at this case study within the larger context on the national level. Figure 10 shows the total number of observation wells maintained by the Central Groundwater Board (CGWB) in India for every state in 2001 and now in 2007 with data obtained from the CGWB website and from the India Stat website.

Gujarat state had 359 observation wells in 2001 and had 1049 wells in 2007. On average, for each district, there would be around 40 such wells in say, Rajkot district and around 4 such wells in Jasdan taluka, for around 50 villages. Whereas, the current study looks at 17 wells in just 1 village and puts forth the view that each of the 300 wells in Thoriyali is an observation well. At the current rate of increase in number of observation wells across the country and the budget expense required to maintain the organization support to manage this monitoring, it seems to be more important to tap this inherent information within the village. If groundwater needs to be managed locally, then information needs to be generated locally, with a scientific basis. This paper shows one way to do it entirely with people's participation.

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APPENDIX

WELL DRILLER STUDY: TOOL FOR RAJASTHAN WELL DRILLERS (RWD)

CAREWATER, A Division of INREM Foundation
Elecon Premises, Anand - Sojitra Road, Vallabh Vidyanagar, 388 120 Gujarat

1. Personal Information

District: _________________; Taluka: ______________________; Village: _________________________

1.1 Name of the Respondent: ____

1.2 Address (in Saurashtra) ____

1.3 Address (in native place): ____

1.4 Telephone Nos. with STD Code / Mobile: ____

1.5 Age: _________ Sex: _________ Education ________________ Occupations__________________

1.6 Family size and its distribution:

Male	Female	Total	1-5 yrs		6-18 yrs		19-60 yrs		61 yrs & above	
			M=	F=	M=	F=	M=	F=	M=	F=

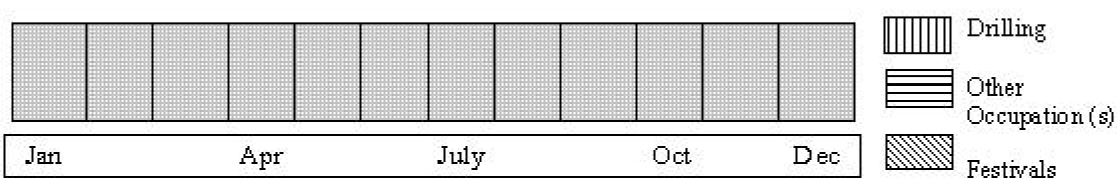
1.7 Do they own land in native? _____ Y/N

If Y, then how much land? _____ Bigha

2. Professional Information

2.1 Number of years in Well Drilling Profession: ____________ Years

2.2 Annual Cycle of Occupation/Migration



2.3 Which other profession, you are involved in? : ____________________

2.4 Does he own his drilling equipment? ___________ Y/N

2.5 If yes, when did he buy it? _______Year

2.6 If No, from whom does he rent? _________ , How much it costs ? __________ Rs.

2.7 Any injuries to himself during Drilling? _________ Y/N
If yes, what ? ______________________ Has he seen other injury in front ? _______ Y/N

2.8 How many well he drills in a season ________ Number

2.9 Depth of wells drilled : min ______ ft ; average ______ ft ; max ______ ft

2.10 In total since beginning, how many wells he must have drilled ________ Number

2.11 Does he see any slack/rise in rate of wells ________ 0 – slack, 1- rise, 2 – no trend

2.12 What is his estimate of total numbers of wells drilled annually in Rajkot ____ Number

3. On Process of Drilling

3.1 Who decides the well spot location? _____ 0- himself, 1- farmer, 2- other, specify

3.2 Is there any drilling done before ____ Y/N

3.3 How much dynamite is used per feet of drilling:

____ kg/ft (Rock type ________) ; ____ kg/ft (Rock type ________)

____ kg/ft (Rock type ________) ; ____ kg/ft (Rock type ________)

3.4 People and roles:

Sr no.	Person Name	Is Originally from 0- Sau, 1- Raj, 2- Other	Key Role of Person	How person is paid
1 2 3 4				

3.5 Time for drilling:

a) Initial Blasting ____ Days

b) Time for each foot of drilling/blasting ____ Days

c) Fitting Pump etc. ____ Days

3.6 Economics of Drilling Procedure:

a) Cost of Machine ______ Rs <u>or</u> Rental Cost of Machine _____ Rs

b) Total Labour Costs _____ Rs/day and/or _____ Rs/ft

c) Cost of Dynamite _____ Rs / kg

d) Other Costs : _____ Item ____ Unit Cost ___ Total Units

_____ Item ____ Unit Cost ___ Total Units

_____ Item ____ Unit Cost ___ Total Units

4. On Knowledge about Hydrogeology

General

Major layers of Stone and their Colours
Draw them pictorially

Regional

The trend of the layers in this region

Near and at Thoriyali
The layers at Thoriyali

5. Linking their knowledge to Groundwater Management

Do they advice farmers on spacing of wells ? _____ Y/N

Can they have a say on the depth of the wells drilled? ______ Y/N

Do they feel currently there are too many wells ? _____ Y/N

Wells are more deep than necessary _____ Y/N ?

Well Driller Study: Tool for Horizontal Well Drillers (HD)

CAREWATER, A Division of INREM Foundation
Elecon Premises, Anand - Sojitra Road, Vallabh Vidyanagar, 388 120 Gujarat

5. Linking their knowledge to Groundwater Management

5.1 When locating new well, does farmer keep into account future HD ____ Yes/No

5.2 How has horizontal drilling affected local hydrology?

a) Is the yield in single well more because of HD _____ Yes/No

b) How does overall yield in village affected due to HD _____ 0-Same, 1- more, 2- less

c) If there are 2 wells 500 ft apart, then what is minimum distance of HD so that yield of 1 well gets affected, 0: <50 ft, 1: 50-100 ft, 2: 100-200 ft, 3: > 300 ft

d) Do farmers do HD towards pond, WHS , water body ____ Yes/No

e) Should there be a limit on how long HD can be drilled ____ Yes/No

If Yes, then how much/well : _____ Number, _____ ft

5.3 Horizontal bores and well recharging

a) Just as water is pumped out of HB, can water also recharge through it? ____ Yes/No

b) Because of HB, would the rate of recharge have increased? ___ Yes/No

c) Because of HB, would the volume of recharge have increased? ___ Yes/No

If yes, then by how much % : 0: < 10%; 1: 10%-25%; 2: 25%-50%; 3: > 50%

MARKET-BASED INSTRUMENTS FOR WATER ALLOCATION IN INDIA: ISSUES AND THE WAY FORWARD.

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Abstract

Institutions do matter in managing water scarcity. Institutional reforms in water sector in recent years have tried to replace the existing 'command-and-control approach' with more innovative and comprehensive market-based approach. Based on a comprehensive literature review, this paper highlights various issues involved in market-based institutional reforms in the water sector in various countries. This paper finds that even though there are some problems, the market-based institutional reforms are capable of generating relatively higher benefits through efficient, equitable and sustainable water allocation mechanisms. This paper also provides policy suggestions on introducing market-based instruments formally in the water sector in the Indian context.

1. INTRODUCTION

The existing literature dealing with water scarcity that causes negative externalities in agriculture sector mainly revolves around three major aspects namely, physical scarcity of water (Rosegrant, 1995), financial scarcity affecting water sector (Winpenny, 2003) and institutional scarcity of managing water resources (Saleth and Dinar, 2004). Conventionally, the literature has focused mainly on how physical scarcity of water arising from depletion and degradation of water resources causes adverse impact on production, productivity and profits in the agriculture sector. The major argument in this literature is that addressing water scarcity, especially in physical terms through various water augmenting measures, can be the solution to reducing the negative impact of water scarcity. In this direction, policy measures such as introducing watershed programs, rain water harvesting and rejuvenating water bodies have been initiated. Another section of the conventional literature treats financial scarcity as a major cause for water induced negative externalities in the agriculture sector. Declining investment and lack of adequate amount of public investments on water conservation measures, caused mainly by low level of capital formation, have attributed to the problem of water scarcity and the resulting impact of negative externalities. The implication is that the water sector experiences a relative scarcity phenomenon (see Barbier, 1989) characterized by lack of financial resources to augment water resources and therefore, reducing the financial scarcity is viewed as a solution for resolving the problem of physical scarcity of water. In this regard, policy measures such as participatory irrigation management that reduces the financial burden of the governments, tariff reforms and introducing user-pay-principle in order to increase the government revenue became some of the highlights of the government policies. Basically, that part of the literature dealing with physical as well as financial scarcity of water looked at the issues within the framework of either market failure or government failure or both. More precisely, the underlying fundamental assumption is that resource allocation within the water sector at present is inefficient and this inefficient allocation is guided mainly by incomplete markets for water or by misguided government policies in the relevant sectors. However, a substantial amount of water scarcity related negative external impacts still prevalent in the regional economies could not be fully explained by the analysis that utilizes the above theoretical frameworks and therefore, it is felt that the policies should adopt more innovative and comprehensive institutional framework to reduce the negative externality impacts. Need for such as an innovative framework has arisen from the fact that in many areas where neither

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water scarcity in physical terms nor financial scarcity discussed above is predominant, the impact of negative externalities is still felt substantially suggesting that water related issues fall beyond the purview of physical and financial scarcity. This generated a new wave of studies that focused on institutional scarcity. The major argument of the institutional literature is that the 'institutions do matter' (North, 1990) and therefore, restructuring the existing inefficient institutions and devising appropriate efficient institutions to manage water scarcity will result in expected outcomes in the relevant sectors. The present paper attempts to highlight some of the advantages as well as issues involved in introducing such alternative institutions in the water sector. The major focus of this paper is how market-based institutions such as tradable permits in the water sector can play a crucial role in allocating scarce water in an efficient manner, and what kinds of issues are involved in introducing such alternative institutions for allocating water resources. To highlight the feasibility of introducing tradable water rights, especially in the Indian context, the paper draws largely from the empirical studies on tradable water rights from different parts of the world. Appropriate theories are also put forward to support the arguments.

1.1 Need for Institutional Reforms in Water Sector

It should be noted that in most of the developing countries, existing water policies in general and polices pertaining to irrigation in particular are mainly supply-side oriented; major components in the water policies, such as, tariff rate and institutional components for supplying irrigation water, do not adequately reflect the actual preferences of the farmers using irrigation water. The supply-side oriented policies are embedded in the 'command-and-control' type approach followed by the governments, where the rules and regulations within the policies are framed on the basis of what the agents of the governments think. This may not be adequate to reflect the preferences of the farmers because the preferences of farmers towards irrigation water are influenced by various kinds of region-specific, socio-economic, political, geographic and institutional factors. In other words, the government agents cannot predict the preferences of the farmers whose mental models influencing their preferences differ. Capturing these mental models and the preferences associated with them is a costly affair as far as the government agents are concerned. Therefore, these agents will have to use certain assumptions about the farmers' behavior in relation to water scarcity, which in many cases do not exactly predict the farmers' actual behavior. Since government policies are formulated with a limited amount of information on farmers' preferences, there arises a discrepancy between what the government agents want to do and what the farmers actually expect them to do. This discrepancy leads ultimately to failure of the policies in achieving the expected goals in the relevant sector, which is broadly described as government failure or policy failure. Many empirical studies in the developing country context have documented how the above mentioned discrepancy has become a dominant phenomenon in the water sector policies. For example, a macro level study has highlighted how government failure in the water sector has resulted in pervasive negative externalities in the economy (Venkatachalam, 2004). At micro level, a study in the Malaprabha river basin in Karnataka reveals that farmers are willing to pay many times greater than the existing government fixed water rates, provided they are supplied with reliable irrigation water under alternative institutional arrangements (Durba, 2008). Very often, the discrepancies and the associated failures observed in the present policies can be attributed mainly to the existing command and–control policies prevailing in the water sector. When incentive-based institutional arrangements are introduced, we would expect the farmers to receive different types of incentives and this will not only result in increasing their farm income but also their willingness to pay (WTP) for water since the WTP value is influenced mainly by the expected income. It is strongly felt that devising the incentive-based institutions can be an appropriate strategy to break the vicious circle in the water sector (Gulati and Narayanan, 2001), which is induced by lower level of farmers' WTP and capital formation in this sector.

Since the government or policy failure has become an inherent feature in the water sector, a modern economic philosophy in water allocation is essential to deal with the present water scarcity problem; one such philosophy is to use appropriate market-based instruments under a new institutional regime to allocate water in an economically efficient, equitable and sustainable manner with adequate concern for ecosystem preservation (see Crase et al., 2001). Among different types of market-based instruments, the tradable water rights (Thobani, 1997), stemming from the theory of property rights by Coase (1960), has been proposed as an efficient instrument in terms of allocating scarce water resources in an efficient, Pareto-optimal manner. Advantage with tradable property rights systems is with its inbuilt incentive and disincentive mechanisms that promote water use efficiency and conservation at the end user level. As we have already seen, secured property rights over water will provide incentives for the farmers to conserve water, use it efficiently and trade it with other users on the basis of opportunity cost principle (Rosegrant, 1995).

2. ADVANTAGES WITH MARKET-BASED INSTITUTIONS

Thobani (1997 and 1998) highlights various benefits from introducing market-based institutional regime in the water sector. Under tradable water rights regime, the production system is expected to automatically adjust to the new scarcity regime. With the new efficiency level in the water use system, the economic system also settles down at a new, efficient level of equilibrium. Similarly, adjustment to the changed level of scarcity will take place with time as well. It should be noted that the command-and-control system does not adequately respond to the increasing demand for water. To fill this gap between supply of and demand for water, informal water markets emerge. Since, groundwater sector experiences a problem of tragedy of commons (Hardin, 1968) all suppliers in the informal market will tend to exploit the groundwater in such a way that they could maximize their profits through water sale. Thus, nobody will have any incentive to conserve water but everybody would be willing to free-ride generating enormous social cost due to over-exploitation. All these arise because of ill-defined property rights over water resources. Therefore, economists insist on the importance of ensuring tradable water rights (Thobani, 1998) to the farmers so that the formal market mechanism can ensure efficient utilization of scarce water on the basis of buyers' willingness to pay and sellers' willingness to accept compensation for a particular quantity of water exchanged.

Within a Coasian framework, assigning water rights to the buyers implies that these rights could be appropriated at a cost, reflected in terms of their WTP for acquiring the rights. The WTP value, which reflects the true scarcity value of water at the existing level of scarcity, would automatically compensate the sellers of water, provided that the willingness to accept (WTA) compensation by the sellers is at least equivalent to the WTP value of the buyers. The water rights to the sellers on the other hand implies that they could sell the water to the buyers with high value uses, based on the opportunity cost of their water use. As economic theory suggests, the market brings equilibrium between demand for and supply of water irrespective of who owns the initial property rights, provided that a conducive, competitive environment is created for minimizing the cost of transaction. Therefore, the concept of water rights fundamentally recognizes that acquiring property rights over water involves a considerable amount of opportunity cost of resource transfer in terms of its alternative uses. Any alteration of quantity or quality of the stock of the water due to transfer would cause both positive and negative externalities altering the existing level of distribution of welfare among the farmers. So, at level of scarcity an efficient outcome arises.

In a world of absolute water scarcity, a market-based approach is justified on the ground that the water has become an economic commodity[1] (Rogers et al., 2002) and therefore, it is argued that the market can be a more efficient institution to allocate this scarce resource to its optimum use. Many economists put-forward different types of economic arguments to support this normative stand. One of the arguments is based on the 'big-bills theory' articulated in mainstream economics. If the big-bills theory is extended to the water sector, it implies that there is a substantial amount of unexploited benefits in this sector due to inefficient policies followed under the command-and-control regime. When the market-based instruments are introduced, the rational farmers would be able to exploit these benefits appropriately, which in turn will increase their WTP for water. The enhanced benefits under the new regime is realized in terms of increased producer surplus and reduced transaction cost[2] due to efficient use of water. Under the market-based regime, a win-win situation arises where not only the farmers could exploit considerable amount of previously unexploited benefits but also the governments

[1]For an excellent critical review on water as an economic commodity, please see Hanemann (2006).

[2] Saleth and Dinar (2004) define transaction cost as follows: 'The transaction costs cover both the real and monetary costs of altering the regulatory, monitoring and enforcement mechanisms related to water development, allocation and management'.

could garner larger amount of benefits (or, the big-bills) through enhanced revenue. As we have already seen, many empirical studies on farmers' WTP for improvements in irrigation water supply have also provided strong evidence to strengthen the big-bills theory argument in the water sector. Moreover, studies on informal water markets in the agriculture sector reveal that farmers are already spending a substantial amount of their farm income on obtaining irrigation services. Therefore, introducing tradable water rights system is assumed to transfer a major part of their income to the government sector while reducing the transaction cost incurred by them in the informal water markets.

3. MEASUREMENT OF TRANSACTION COST

The underlying theory on tradable permits in water sector derives broadly from a blend of inputs from new welfare economics and new institutional economics. The welfare economics framework is essential in the sense that any institutional or policy change is to be viewed in terms of change in the welfare effects it brings to the users of resources. More precisely, an institutional arrangement is efficient when the net benefits under the new institutional regime are greater than that under the old regime. Changes in the welfare affected by the alternative institutions are realized broadly at two levels : at government level and at the farmers level. While the welfare change at the government level can be estimated by using the transaction cost incurred or saved by the government sector under the new institutional regime, the same at the farmers' level can be done by measuring marginal change in 'producer surplus' that includes savings on transaction costs under the new institutional regime. Transaction cost analysis of alternative institutional regime is a special case in the analysis of water scarcity. Analysis of transaction cost is an integral part of institutional change because institutions without transaction cost do not matter much in any economic analysis (Coase, 1992) of water scarcity. Saleth and Dinar (2004), based on their stage-based perspective, classify stages of institutional change into four major categories: the first stage where change in the mind set takes place; the second stage with political agreement for change; the third change where institutional supply occurs; and the forth one with behavioral changes reflected in terms of water allocation and management. All these stages are associated with different transaction costs. However, there are certain difficulties in measuring the transaction cost of institutional changes. One such difficulty arises from the fact that the users of enhanced water availability resulting from alternative institutional arrangements may not always be aware of the transaction cost involved in those arrangements. This is due to asymmetry of information obtained for taking decisions to minimize the transaction cost. This implies that such decisions are constrained mainly by the availability of information; if additional information is provided to the farmers or the policy makers, then the decision will lead to a new, efficient equilibrium level. The farmers or the policy makers are assumed to be unboundedly rational in processing additional information and are capable of moving to the appropriate equilibrium position, accordingly. However, asymmetric information about the transaction cost may sometimes lead to sub-optimal decisions as well. This being the case, the studies measuring the transaction cost that rely on farmers' information may provide biased results for policy making. The second type of difficulty arises from bounded rationality of the farmers or the policy makers in minimizing the transaction cost. Under this bounded rationality assumption, it is found that even if full information is available on transaction cost under the new institutional regime, the farmers may not be able to minimize the same due to cognitive constraints in processing the information. While errors in measurement due to asymmetric information can be corrected by adopting a methodology in which changes in decision making can be observed for changes in the information made available, the error coming from the bounded rationality can not be corrected because of the scarcity of cognitive abilities. Moreover, if the researchers measuring the transaction cost are also boundedly rational, then the error in predictions will be acute. Therefore, it is argued that more bounded rationality based economic models will have to be used for measuring the transaction cost (Conlisk, 1996) in water sector in coming years. Despite these theoretical difficulties, it should be noted that work in measuring the transaction cost in the water sector is progressing with the assumption that the transaction cost is measurable with minimum error.

The fundamental principle of introducing innovative institutions like tradable water rights is that institutional arrangements that facilitate functioning of market-based instruments in water sector, with appropriate regulation, are capable of bringing spontaneous order among the rational farmers towards achieving efficient allocation of water. It should be noted that market-based instruments are not treated as perfect substitutes for the present command-and-control regime. Rather, there is a right mix between the command and control method and the market-based methods, which is determined mainly by the socio-economic, political and institutional factors prevailing in a particular region. Indeed, one of the major challenges in the ongoing water sector reforms in many of the developing countries revolves around identifying what is the right-mix of government and market, for a given level of the region-specific factors that determine this mix (see Williamson, 2005). It should be noted that as the new institutional economics (Williamson, 2000) suggests, the right-mix of institutions is to be determined mainly by the transaction costs involved in alternative institutions.

The transaction cost analysis is based on the assumption that the interest groups (Olson, 1965; see also Livingston, 2005) will bring in collective action among themselves (leading sometimes to conflicts as well) based on the expected costs and benefits of institutional change, as well as the transaction cost under the new institutional regime. Change in the transaction cost at government level and change in the producer surplus at the farmer level lead to welfare change at the macro level through cascading effect. The cumulative welfare effects of the institutional change at the macro level, both in terms of change in the utility and producer surplus – will have to be captured through computable general equilibrium (CGE) models. At present, the welfare change at the macro level is captured using partial equilibrium analysis due to various constraints such as availability of data on welfare at macro level, inadequate information about institutions influencing changes, etc. Within the partial equilibrium analysis, a sector-wise approach is warranted. Measurement of transaction costs at the government level needs to be captured through change in the cost incurred by the government in order to administer, implement and monitor the new institutional arrangements. It should be noted that many studies that attempt to measure the transaction cost of institutional change in the water sector look mainly at change in the transaction cost at the government level (see Saleth and Dinar, 2004). However, the change in producer surplus (opportunity cost of existing institutional regime) realized at the farmer level does not figure in adequately in these studies, with few exceptions such as, Crase et al. (2002). It is to be noted that the major economic actors involved in the institutional change need to be properly accommodated in the partial equilibrium analysis. This is because the institutional change sometimes may result in improvements in the efficiency in one sector by transferring the inefficiency to another sector. This may lead to a situation where the reduction of transaction cost in one sector can be off-set by the increase in transaction cost in another sector. Alternatively, transaction cost may increase in one sector while it might have reduced in another sector, leading to net increase in the transaction cost altogether. So, the outcome is only zero-sum in nature. Therefore, partial equilibrium analysis should take into account any trade off between different sectors involved in the institutional arena.

The measurement of transaction cost at the farmer level is a challenging task. It should be noted that the benefits enhanced due to water availability –*citeris paribus*- in the changed institutional regime should be treated as transaction cost incurred by the farmers under the *status-quo* institutional regime. Nevertheless, the enhanced benefits may be due to various other factors such as increased inputs and overall cropping pattern change due to innovative technologies. The issue here is, whether the change in the benefits due to change in all other factors should be treated as reduction in the transaction cost or only that part of the benefits which occur over and above the influence of normal factors should be treated as transaction cost. The 'opportunity cost approach' used in some of the studies at present treats entire benefits as an indicator of change in the transaction cost. This is because the benefits forgone are considered to arise from the non-availability of water, which is now being eased by new institutional change. So, the entire change in the benefits is considered to be enhanced by new institutional arrangements. However, this approach will be misleading in assessing the efficiency of alternative institutions. Appropriate methodologies are available from environmental economics to deal with this particular issue and these standard methodologies should be used extensively in empirical studies, in the coming years.

4. INSTITUTIONAL REFORMS IN WATER SECTOR: INTERNATIONAL EXPERIENCE

There exist relatively rich empirical literature that deal with country specific studies on market-based institutional reforms in the water sector (e.g. Backeberg, 2005; Bjornlund, 2004; Brennean, 2001; Doukkali, 2005; Garrido, 1998; Griffin, 1998; Hearne and Easter, 1998; Howe, 1998; Horbulik and Lo, 1998; McKay, 2005; Saleth, 1998 and so on). The existing literature on market-based reforms provide insights into the nature of water sector reforms carried out in the respective countries and regions, institutional arrangements for water sector reforms, factors influencing such reforms, the cause and effect relationship between reforms and transaction cost in the water sector. It should be noted that the institutional reforms, in one way or other, deal with assigning user rights over water, though the degree of control over these rights by the users differs across different countries.

When we look at the country level experience on market-based instruments, we find that the US pioneered in introducing formal water markets in the area of water allocation. The nature and intensity of these formal markets differ between surface water and groundwater; they also differ between different states depending on factors such as scarcity of water and nature of the law facilitating water trade (Griffin, 1998; Howe, 1998). In many parts of the US where the formal markets are active, trade in water takes place mainly between agriculture and urban sectors. In the US, water scarcity has been the driving force behind these formal markets which brought spontaneity among different agents through proper incentives and disincentives towards conserving water. But a most crucial aspect is that this spontaneity has been brought about by appropriate laws enacted by the governments (Griffin, 1998). So, appropriate mix of government and markets plays a major role in making water trade more efficient. Australia is another pioneering country, which has adopted institutional reforms with more roles for formal tradable water rights in allocating water in some of the scarce regions such as, New South Wales (Crean and Young, 2001). The ongoing institutional changes in Australia are essentially tuned to provide an integrated approach to water management where the role of market, the role of government and the role of community are recognized as instrumental in managing scarce water resources (McKay, 2005). While the exogenous factors (such as, economic reforms at the macro level) provided conducive environment for water sector reforms, it is the endogenous factors (such as, water scarcity) which warranted a more focused reform in the water sector in Australia. Also, the political structure at the federal level and the social structure in relation to water use have also been taken into account adequately in the water reform measures in this country (McKay, 2005). The Chilean experience suggests that water sector reforms with market instruments became an integral part of overall economic reforms at macro level (Hearne and Easter, 1998). The institutional arrangements were made in such a way that the farmers could continue to trade water rights while the government controlling the full property rights over the entire water resources (Crase *et al*., 2001). It should be noted that in Chile, relevant institutional arrangements were put in place, prior to taking up the reform measures in water sector. For example, special water law providing exclusive rights for water use was enacted in 1981; water user associations (WUAs) have been created exclusively for managing water at local level and the irrigation administration has been strengthened adequately to provide overall support; appropriate regulation and conflict resolution mechanisms were established so that full potential of the markets could be adequately tapped; and, in order to learn lessons and correct the mistakes, a step-by-step approach has been adopted to introduce reform measures at the river basin level (Hearne, 1998). However, Chilean water markets still experience problems like, unregistered markets adversely affecting the efficient transfer and use of water, as well as investment on water.

In Morocco, historical and colonial factors played a role in enhancing reforms in water sector in the initial period but the social, economic and political factors strengthened such reforms in the latter period (Doukkali, 2005; see also, Saleth and Dinar, 2005). It should be noted that it is the macroeconomic crises in Morocco which led to major reforms in the water sector in the latter years (Saleth and Dinar, 2005). Experience in South Africa also reveals that reforms have been influenced mainly by the macro economic reforms carried out during the 1990s; the endogenous factors such as drought and issues related to water sharing with other neighboring countries also provided strong justification for such reforms in the water sector (Backeberg, 2005). In order to achieve maximum benefits from reform measures, the government took certain specific initiatives such as change in the constitution, formulating water policies and water legislation, integrating water policy with policies in relevant sectors, etc. (Backeberg, 2005). In Mexico, the water reform measures initiated in a comprehensive manner progressed over 20 years time period with mistakes being corrected regularly; the reform measures are characterized by number of government regulations of private property rights over water (Shah et al., 2004a). Reform measures in China are lauded for their ability to provide market-like incentives for the communities to participate in water management effectively, while the overall control over water lies with the government (see Shah et al., 2004b).

The stage-based institutional reform measures in water sector in Sri Lanka are considered an integral component of the macroeconomic reform measures initiated at macro level (Samad, 2005). In the first stage of reforms, a micro-based approach has been adopted in which the irrigation sector reforms were given more priority and this yielded substantial benefits in the agriculture sector with minimum political risk; the second stage of reforms, which are at the maco level, focused mainly on the entire water sector, which generated only meager benefits, apart from attracting political risk. However, present reform measures in Sri Lanka focus mainly on overcoming the issues encountered in the past and this provides lot of scope for making these measures more effective in the coming years (Samad, 2005). Other countries in Asia such as Thailand and Vietnam have also ventured into reforming the water sector in a rigorous manner, especially in recent years. In Thailand, for example, water reform measures embody IDRM approach at the river basin level. Similarly, water reform measures with substantial amount of economic inputs are being carried out at specific river basins in Vietnam (Turrol and Malano, 2001). It should, however, be noted that since the results of these micro level reforms in these Asian countries are not available adequately, we could not arrive at any conclusion on the issues and the outcomes of these reforms. Countries such as Namibia which adopted water reforms very recently are learning through their experience since adequate institutions and skills have not yet been developed to support full reforms in the water sector (Heyns, 2005).

International experience on institutional reforms and tradable water rights within the market setup provides us different kinds of lessons. Let us first discuss certain theoretical and methodological issues involved in these studies. Many empirical studies have utilized mainly the new institutional economics framework to analyze issues related to institutional reforms in the water sector. Majority of these studies have utilized one particular approach of new institutional economic namely, the transaction cost approach. All these studies give an impression that the major objective of the institutional reform measures carried out in many countries was mainly to reduce the transaction cost at the government level. It should, however, be noted that the transaction cost approach is not sufficient to capture all kinds positive and negative changes in the welfare resulting from change in institutions. For example, as we have already pointed out, the transaction cost approach does not address the issue of estimating the benefits derived from the institutional changes at the farmer level while the transaction cost at the government level could be measured relatively easily, mainly in terms of comparing the costs borne by the government sector under different institutional regime. However, there are non-quantifiable transaction costs at the government as well as the farmers' level, which cannot be measured easily in economic terms. Suppose, the non-quantifiable transactions costs are greater than the quantifiable ones, then the conclusions about the efficiency of individual institutions or the mix of institutions will be misleading. Since water generates substantial non-market benefits as well, these benefits should be properly identified and measured in economic terms so that the true opportunity cost of water use and the associated efficiency can be assessed effectively. In order to measure the change in overall transaction cost both at the government and at the farmer level, economic valuation methodology from environmental economics, which can be extended to accommodate the institutional features in a systematic manner, should provide better results. Another problem with the transaction cost approach is that the entire transaction cost analysis is based on the standard neoclassical nassumption that the economic players influenced by the institutions are unboundedly rational in terms of minimizing transaction cost. There are reasons why this kind of assumption may not be valid in the transaction cost analysis. For example, the government agents' objective may not always be transaction cost minimization. As new political economy literature (see Olson, 1967) suggests, the rational government agents who adopt rent seeking behavior may even try to maximize the transaction cost if such a measure would bring additional private benefits to them. It should be noted that in many countries, water sector reforms are resisted by the bureaucrats themselves since they have strong apprehensions that reform measures would dilute their power to generate side-payments. Moreover, the review of case studies suggests that the alternative theories of new institutional economics such as, bounded rationality theory (Williamson, 2000) that deals with non-minimizing objectives of the economic agents, have not been adequately used in analyzing water sector reforms. The point is that when the economic agents have difficulty in minimizing the transaction cost due to cognitive constraints, the standard models using rationality assumption will provide biased results. Therefore, the theoretical approaches used in the present empirical studies are too narrow and they need to be expanded to accommodate other profound issues involved in measuring the transaction costs in water sector, in future.

What we understand from the empirical studies reviewed above is that the degree of control over property rights depends mainly on the political set-up, historical factors and the nature of institutions existing at the ground level. In certain countries, the user rights are strictly regulated by the governments (e.g. China) while in certain other countries the users enjoy more power over these rights (e.g. USA). Another lesson we have learnt is that the institutional reforms in water sector are considered an integral part of the overall macroeconomic reforms in the countries studied. In other words, the major objective of the water sector reforms in these countries seems reducing the financial burden of the government - especially, the burden realized in terms of transaction cost of managing water resources. While doing so, it might have so happened that even the efficiently run water supply systems in the irrigation sector in some of these countries would have been brought under the market domain. The empirical studies we have reviewed seem to be silent on these cases, however. Similarly, the institutional models used across different countries are found to adopt 'one-size-fits-all' type of approach, with some minor modifications on the basis of regional and local level socio, economic, political and other institutional factors. The models used, in many cases, are found to have been prescribed by the external funding agencies; this is evident from the fact that almost all water sector reform measures were preceded by macro economic reform measures promoted by such agencies. Moreover, the failure cases of institutional reforms are not reported in the mainstream, scientific literature. The studies that report failure cases are available mainly from the popular literature and therefore, using the results of these studies in reviews is constrained due to lack of scientific validity of these results. It is very important that in future, scientific studies should be initiated to analyze the failure cases so that we can understand under what circumstances some models fail.

5. CASE FOR TRADABLE WATER RIGHTS IN INDIA

It should be noted that the problem of water scarcity in India has reached such an extent where it constraints – both directly and indirectly - the economic development in general and agriculture development in particular. India adopted economic reform measures in the middle of 1980s and subsequently, some reform measures were initiated in the water sector during the 1990s (see Gulati and Narayanan, 2001). The initial reform measures focused mainly on the financial reforms in the irrigation sector in order to eliminate huge amount of subsidies given to the agriculture sector, which contributed to negative consequences such as over-exploitation of groundwater (Dubash, 2008; Gulati and Narayanan, 2001). The reform measures included pricing of irrigation water in such a way that wastage of water use could be discouraged. These measures gradually moved onto the institutional aspects such as introducing water user associations under the Participatory Irrigation Management System (PIMS) (Marothia, 2005). It should be noted that the institutional reforms are vague and are not adequate to manage India's scarce water resources; indeed, it is argued by Shah et al., (2004a) that India's water sector is still crying for real institutional reforms.

A meaningful institutional reform to address acute water scarcity in different parts of the regions in India comes in the form of introducing formal markets in managing water in an efficient manner. Like many other countries in South Asia, one of the unique features of India's water sector is the existence of informal water markets at a large scale (Shah, 1991; Saleth, 1996; see Meinzen-Dick, 1998) especially in the groundwater sector. These informal groundwater markets emerged as a strong institution to address the increased level of water scarcity in different pockets of India (Saleth, 1996). A good summary about economics and institutional aspects of these informal water markets in India is available in Saleth (1998). Saleth (1998) made a rough estimate of total monetary value of groundwater sales in the informal sector at US$ 1.38 billion per year, based on the assumption that 15% of the total groundwater irrigated area is benefited from purchased water. Since the informal water markets are very strong in the scarce regions of India, introducing formal markets should not pose any major problem in terms of transaction costs, as suggested by Easter et al. (1998). However, the existing informal water markets in different regions of India suggest that they are indeed inefficient in terms of minimizing the transaction cost and therefore, the existing institutional set-up under the informal markets may not be conducive to introducing formal markets in the water sector. The informal markets, for example, are not competitive because of monopoly power of sellers who indulge in price discrimination and non-price discriminations such as, irregularities practiced in supplying quality and reliability of irrigation water. It is localized and highly fragmented in nature; characteristics such as, monopoly power of the seller, trade on the basis of surplus supply, trade being influenced by social factors, variation in payment place to place and time to time and inefficient use and over-exploitation of groundwater (Mohanty and Gupta, 2002) contribute largely to increased transaction cost, than reducing it. Since the tariff prevailing in these markets is usually greater than the competitive tariff, exploitation of consumer surplus becomes a predominant strategy of the sellers. Moreover, unregulated, informal markets lead to over-exploitation of groundwater, causing environmental problems that increase the social cost in the regional economy; availability of free electricity in different parts of the country intensify the existing adverse impacts arising from over-exploitation of groundwater (see Dubash, 2000).

It should be noted that huge amount of private investment on tube-wells and bore-wells to augment groundwater suggests that the farmers have already appropriated the water rights indirectly through their legal right over private land. In other words, informally the private water rights are being established through investment on groundwater augmenting measures, linked to the land rights (see Kumar, 2007). As demonstrated by many earlier studies on water markets, the farmers who do not have land rights could not acquire water rights and part of their producer surplus is being exploited by those land owners from whom they purchase water. The argument against the exploitation thesis is that if the exploitative informal water markets had not come into being in the water scenario, even the existing level of producer surplus enjoyed by the buyers would not have been produced; the end result would have been nothing but more farmers' distress in the country. The negative consequences of informal water markets suggest that these water markets indeed increase the transaction cost in the water economy and therefore, introducing formal water markets would reduce both the visible and invisible transaction cost in a substantial manner (see Saleth, 1998). The important questions that arise in this context are: Why the inefficient institution, namely, the informal market, emerged strongly and sustained itself in the water sector? If the formal water markets are efficient in minimizing transaction cost, then why these institutions have not emerged in the water sector at all? Is it due to initial burden imposed by additional transaction costs involved in moving from the present regime to a more market-based regime? It is due to the information constraint at the farmers' level that prevents them from switching over to formal trade? Is it due to the existing policy and institutions that facilitate trading activity at individual level informally but impose constraints on large scale formal trading of water? Is it due to physical constraints emanating from the hydrological features of the water related dynamics at river basin level? Switching from informal market to formal markets requires restructuring the existing institutional and policy arrangements and devising additional institutions that would support formal water trading. Let us discuss this issue in the subsequent section.

As far as India is concerned, no concrete policy exists to facilitate formal markets (Mohanty and Gupta, 2002) in the water sector. Rather, the existing polices dealing with water allocation are highly fragmented, embedded in piecemeal approach and highly ad hoc in nature. The Integrated Water Resource Management (IWRM) approach adopted in India's Water Policy 2002 prescribes introducing water rights for managing water resources at the river basin level (see Shah and van Koppen, 2006). However, very few states in India have adopted this IWRM approach and that also, only partially. The approach is also subject to various criticisms. For example, Shah and van Koppen (2006) argue that implementing the withdrawal permits for augmenting groundwater suggested in the IWRM requires effective monitoring; the very presence of informal groundwater markets at large scale makes the monitoring part more difficult and economically costly. Moreover, IWRM will work in those areas where the primary water diverters are large in size, body corporate are few in number, most water users are supplied by organized water providers and capital accumulation in terms of infrastructure creation is already high (Shah and van Koppen, 2006). Effective implementation of IWRM in the Indian context is hindered by existence of a large number of households who are the primary water divertors who self-supply water from the natural sources and generate very low level of capital accumulation in the water sector (Shah and van Koppen, 2006). Another major issue that has not been properly addressed in the IWRM approach relates to pricing of irrigation water appropriately so that the formal markets could function efficiently. However, no proper institutional mechanism is available for generating such information on pricing. Dharmadhikary (2007) points out some of the major problems embedded in the IWRM approach. For example, Maharashtra Water

Resources Regulatory Authority (MWRRA) has been created to implement IWRM in Maharashtra and the authority has been assigned with the task of creating trading water entitlements. The MWRRA is responsible for distributing the entitlements between various users so that these entitlements can be transferred, bartered, bought or sold on annual or seasonal basis within a market system. However, due to lack of information and guidance the prospect of the authority to effectively regulate the water markets has become grim. Also, many fear that tradable water rights suggested in the IWRM approach will lead to allocation of water to economically powerful people (Dharmadhikary, 2007) and therefore, there will be stiff resistance especially from the resource poor users of water (Kumar, 2003 cited in Kumar, 2007). Similarly, implementation of IWRM requires local or regional level institutions such as, the Catchment Management Institutions (CMAs) existing in countries like South Africa where the IWRM is more effective. Formation of CMAs, involving water user associations and developing appropriate technologies are some of the challenges in implementing the IWRM in the Indian context (Shah and van Koppen, 2006).

From the above analysis, one could get an impression that introducing formal markets in the Indian scenario is a difficult task, though not an impossible task. While discussing institutional options for water management in India, Saleth (1998) argues that '…a legally instituted and locally managed water quota system defined within an ecologically consistent overall withdrawal limit could eliminate the negative effects of markets and magnify their positive efficiency and conservation benefits. While the magnitude of benefits from observed water markets is tremendous, their contribution is only a fraction of the efficiency, equity, and sustainability gains possible from formal markets emerging within well-managed water quota system. The prevailing institutional vacuum thus makes the currently observed water markets only a distant second-best option' (Saleth, 1998).

6. THE WAY FORWARD

How to make the distant, second-best option as a practicable, 'best option' in the near future is an important question that we have to address here. As we have already discussed, the need for moving to the first-best option arises from the fact that water scarcity under the existing institutional and policy regime in India is becoming acute and generates huge social cost that is mainly invisible. This being the case, the importance of establishing tradable water rights especially for managing the groundwater in India has been already underlined by many researchers (e.g. Kumar, 2007; Saleth, 1996). However, we have no acceptable blue-print on how to introduce formal markets in the water sector which is characterized by a lot of complexity and what kind of the additional institutional arrangement is required for allowing formal markets so that water could be managed in an efficient, sustainable and equitable manner under the new regime. Since bounded rationality poses greater difficulty in understanding the required level of institutions, we need to look at those institutions in other parts of the world, which facilitate achieving the expected goals in the water sector under the market-based institutional regime.

In the case of macro level institutions, we have seen that many countries have introduced various kinds of institutional and policy measures such as enacting and amending water laws, introducing regulatory authorities, reforming water pricing, etc. that provide conducive environment for water trade. However, the actual implementation of these measures at the ground level depends mainly on the institutions at micro level that provide appropriate incentives and disincentives to the stakeholders to use manage water efficiently. In Texas, USA, for example, water districts or river authorities play an important role in managing surface water by way of facilitating markets through the tradable water rights. While partial ownership is exercised over the surface water, farmers enjoy absolute ownership over the groundwater in places like Texas. This means that the individual farmers having water rights are the basic entities in the water markets. Griffin (1998) argues that absolute ownership has not been effective in reducing the scarcity of groundwater because, transfer of invisible groundwater from one farmer to another that takes place due to reduction in one farmer's use of groundwater leading to increase in another farmer's use is not practicable. Similarly, the free-riding problem in the groundwater use encourages many farmers to exploit more water, rather than conserving it. However, measures such as metering of pumping wells, monitoring committees and establishing water banks have been put in place to transfer groundwater across farmers and to manage it in a sustainable manner (Griffin, 1998). In Spain, trading of water takes place at community level. It has been demonstrated that in Spain, if the trade is allowed to take place across larger communities instead of individual communities the gains from water trade would be more (Garrido, 1998). In Canada, introducing water markets across sub-basins is found to result in increased benefits (Horbulik and Lo, 1998). In the developing country context, the institutional arrangements at regional and local level are somewhat different. In China, for example, the irrigation service providers play a major role in allocating water under the new regime, while the government has full right to water resources (Shah et al., 2004b). In Thailand, the basin working committees consisting of different stakeholders take up overall responsibility of managing water at the river basin level, while local water user associations control the allocation of water through market exchange (Patamatamkul, 2001).

In Indian context, both the central and the state governments have taken a few steps at macro and micro level to moot institutional reforms in the water sector. For example, the IWRM approach has been adopted in the national water policy, recognizing river basin as planning unit, water an economic commodity, etc. However, the IWRM approach is not being effectively implemented due various kinds of problems at the ground level. For instance, many issues such as, how to generate adequate information about the water use and values so that water could be allocated on economic principles, are not being properly spelt out in the approach. In the case of groundwater sector, many state governments have introduced groundwater laws to curb the over-exploitation of aquifers. But, these laws do not provide any incentive for the farmers to conserve groundwater because they restrict farmers' freedom of opportunities to use the groundwater efficiently. Moreover, there is no proper monitoring mechanism to control the extensive groundwater exploitation taking place among the unorganized users in the scarce regions. The transaction cost of monitoring and controlling groundwater exploitation becomes extremely high and therefore, the resource-poor government agencies are not able to properly monitor and control the overexploitation of groundwater. On top of everything, electricity subsidy provided to the farmers also intensifies the over-exploitation in already water scarce areas, apart from causing inequality among different categories of farmers. Similarly, some of the state governments like Maharastra have established regulatory authorities in the water sector to guide water allocation (Dharmadhikary, 2007). But these authorities are not effective because their roles and functions are not properly defined and they do not have access to required information for water allocation decisions. In some other states like Tamil Nadu, River Basin Boards have been created for some specific river basins. These boards consist of various kinds of stakeholders and the major aim of these boards is to resolve water scarcity problem at the basin level through efficient conflict resolution mechanisms. However, these boards are also not functioning well because of issues such as lack of political interest and lack of information available for decision making. In many state governments, WUAs have been created for managing water at local level, under the umbrella of 'Participatory Irrigation Management System (PIMS)'. However, the results are not satisfactory here as well (see, Marothia, 2005). Apart from these bodies which are directly involved in managing water resources at regional level, other organizations at local level such as village panchayats and non-governmental organizations are also involved in water managements especially, in watershed management in dry regions. The outcomes of these arrangements are also not satisfactory, on an average. Altogether, it should be noted that the governments in India have established more than adequate level of institutions to manage water but in a fragmented basis. In the existing policies related to water sector, a piecemeal approach is glaring everywhere. Therefore, if at all water scarcity needs to be addressed properly in the Indian context, an integrated approach is warranted for. One of the important aspects that is completely missing in the existing institutional arrangements is that there is no proper guiding principle on the basis of which the institutions function. One can bring in numerous institutional changes but if the overall policy guiding water allocation is still within the conventional regime, then the outcomes would be counterproductive. The existing fragmented institutions suggest that the transaction cost of creating and operating these institutions are enormous and in the present form, all these institutions are scarcity inducing rather than scarcity minimizing. Keeping this in view, it is argued that there is a need for redesigning water policies in such a way that more market-based instruments such as tradable water rights can be introduced in the future so that the existing institutions can be systematically integrated for achieving the goal of efficient, equitable and sustainable water management.

Once the appropriate policy regime has been created, then other practical problems related to water trade may crop up in the scenario. For example, at what level the trade in water should take place, what kind of trade is transaction cost minimizing, who has to be responsible for regulating water trade, what kind of infrastructure is required for facilitating water trade, etc. are some of the questions which need to be answered. It should be noted that the answers for these questions will have to come from the regional and local level factors affecting water trade. For example, though water trading may not be possible between individual farmers or between individual farmers and urban buyers, such trading can be effective across sub-command areas or across WUAs in each canal within the sub-command. Similarly, trading may take place between WUAs and urban water supply authorities, rather than on individual to individual basis. However, when the markets mature the individual farmer level trade becomes a viable option. In the case of groundwater, Kumar (2007) suggests that assignment of equal property rights over water irrespective of the size of the land will lead to equitable allocation of water since the large landowning farmers needing water over and above their own quota will end up buying water from small land farmers who have got surplus water to sell, bringing equity among the farmers. It may be noted that even if the small land farmers do not have adequate infrastructure to pump their own share of water, the rationality of the farmers will lead to arrangements in such a way that the big land farmers can pump water and share it with small land farmers depending on the total costs and benefits of doing so. At local level, the individual tradable permits may be issued on the basis of the renewable amount of water so that over-exploitation of aquifers will be avoided, especially in the scarce regions. In case the water trade causes negative externality, the institutions such as village level institutions, watershed committees and aquifer management committees can be established exclusively for addressing these negative externalities (Kumar, 2007). The overall regulation of trading in order to avoid any conflict or negative externalities at regional or basin level, may lie with the basin boards or with the regulatory authority.

Sometimes, the standard economic prescriptions such as enacting laws, formal institutional arrangements, under the broader model applied everywhere may not be effective because of huge amount of uncertainties about appropriate institutions and behavior of the economic agents to be shaped by laws. At the national and local level, the market operations are facilitated by non-conventional, behavioral factors such reciprocal behavior and rule rationality. Adequate inputs on these aspects need to be generated through scientific studies and should be incorporated in the design of instruments for water allocation. On top of everything, different types of institutional arrangements and their effectiveness need to be assessed in terms of the net gains achieved through transaction cost minimization. Studies within the new institutional economics frameworks - including bounded rationality framework are warranted for at the river basin level in order to assess the net gains of market-based institutions for managing water, in the coming years.

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IMPACT OF ORGANIC SUGARCANE FARMING ON ECONOMICS AND WATER USE EFFICIENCY IN MAHARASHTRA

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Abstract

This study examines the impact of organic farming on economics and water use efficiency in sugarcane cultivation in Maharashtra. The study is based on primary data collected from both certified organic sugarcane (OS) and inorganic sugarcane (IS) growing sample farmers in the water scarce and groundwater dependent district of Jalgaon in Maharashtra. The study finds that OS cultivation increases human labour employment by 20.2% and its overall cost of cultivation is also lower by 14.67% than IS farming. Although the yield from OS is 6.2% lower than the conventional crop, it is more than compensated by the price premium received and yield stability observed on OS farms. The OS farming gives 15.72% higher profits and profits are also more stable on OS farms than the IS farms thereby enhancing the economic well-being of OS farmers. Crucially, OS farming substantially enhances the water use efficiency (WUE) measured by different indicators. Thus, OS farming offers ample opportunities for enhancing farmers' income and improving water use efficiency in the cultivation of a highly water-consumptive and important sugarcane crop in the state. Finally, the paper discusses the emerging issues and outlines the task ahead for advancing OS farming in Maharashtra.

1. INTRODUCTION

India occupied second position in world in both sugarcane area and production. It shared 21.45% of the total area and 23% of the total sugarcane production in the world during triennium ending (TE) 2002-03 (GoI, 2005)[a]. Sugarcane contributes about 7.5% to agriculture GDP from only 3% of the cultivated area and provides sustenance to about 45 million farmers, their dependents and a large mass of agricultural labours for their livelihood (GoI, 2004). Maharashtra, the study state, is the second largest sugarcane growing state in the country. It contributed 0.58 mha (13.53%) to total area and 45.78 million ton (15.06%) to total production of sugarcane in the country in TE 2002-03 (GoI, 2005)[a]. The potential of Maharashtra has been shown by the steady growth in area and production of sugarcane over the years. However, the unceasing decline in productivity in recent decades is a cause of great concern.[1]

Sugarcane is the second most important cash crop covering less than 3% of the total cropped area of the state but it utilizes more than 60% of the total water available for irrigation in the state. This has already exerted a considerable strain on the limited water resources of the state[2]. The demand of water for sugarcane irrigation has led to an increase in number of tube wells and had resulted into the decrease of water table by more than 4m over the past decade in several areas in the districts of Jalgaon, Ahmednagar and Aurangabad (World Bank, 2003). This has significantly enhanced the number of open wells going dry over the years. The excess use of water combined with higher doses of chemical fertilizers is observed to be resulting in enhanced rate of degradation of water and land resources in certain parts of the state. This is reflected in the secular decline of sugarcane productivity in recent decades in Maharashtra (Samui et al., 2005).

Organic farming is a holistic agricultural production management system that sustains and ameliorates the health of agro-ecosystem encompassing biodiversity, nutrient bio-cycles and soil microbial and bio-chemical activities. It avoids the use of chemo-synthetic fertilizers and pesticides and emphasizes socially and environmentally beneficial practices such as crop rotations, intercropping, green manuring, use of organic

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manures, vermi-compost, bio-fertilizers and bio-pesticides in preference to the use of off-farm inputs considering that regional conditions require locally adapted systems. Thus, organic farming prohibits the use of harmful synthetic chemicals and promotes the use of renewable organic resources for sustainable agriculture.

The organic farming is the fastest growing sector in both land use and market size in the world. It is being cultivated in more than 120 countries covering about 31 mha of area in the world (Willer and Yussefi, 2007). The global market for organic food products was valued at US $ 25 billion in 2003, US $ 50 billion in 2006 and is estimated to reach to more than US $ 100 billion in 2010. Europe is the largest market for organic foods followed by North America. These two markets together share more than 95% of the global market for organic food products. Although the Indian market for organic food products is relatively miniscule, it has great potential to grow in near future and to reap the benefits of the rapidly growing lucrative market for organic products.

Organic farming is as old as agriculture in India. But presently it is being cultivated on relatively very small area. For example, the certified area under organic farming was only 76,326 ha during 2003, which is about 0.05% of the total cultivated area in the country (Willer and Yussefi, 2007). This is negligible when compared with the top 10 countries in organic farming in the world.[3] However, organic farming had received better attention in recent years in India and concerted efforts are being made by the state and central governments, NGOs, farmers and other organizations to promote it in the country. For example, the states of Uttaranchal and Sikkim have been declared as organic states by their respective governments. These initiatives may help in boosting the area under organic farming in near future in the country.

Maharashtra is an important organic farming state. It is at the forefront in developing, adopting and spreading organic farming technologies in the semi-arid regions of the country. Different parts of Maharashtra have developed their own local organic farming systems for various crops. Recognising the importance and potential of organic farming, Government of Maharashtra (GoM) has implemented the centrally sponsored scheme for promotion of organic farming in the state since 2003-04. The provision of Rs. 73 million and Rs. 154.50 million were made during the year of 2004-05 and 2005-06 for promotion of organic farming in the state (GoM, 2007). These efforts have helped in increasing the awareness about the organic farming, reducing the use of chemicals, and enhancing the area under organic farming and boosting the organic production in the state. It has been reported by the GoM (2007) that the area registered for organic certification in the state was 51,000 ha in 2006-07. The GoM intends to convert about 650,000 ha of area to organic farming in the state in near future. Organic sugarcane is an important crop grown in the study district. The practice of organic farming is very popular in Jalgaon district and the registered area to be converted to organic farming in the study district increased from 42,696 ha in 2004-05 to 49,000 ha in 2006-07 (GoM, 2007). Thus, the area under organic farming is rapidly expanding in study state as well as in study district.

The findings of several previous studies have shown that excessive use of chemicals in agriculture results in adverse effects on human health, animals, biodiversity and contributes to degradation of water, soil and environmental resources (Ghosh, 2003; Pachauri and Sridharan, 1998; Parrott and Marsden, 2002; Singh et al., 1987). On the other hand, organic farming had beneficial effects on human health, animals, biodiversity, water, soil and environmental resources (Blaise, 2006; Gareau, 2004; Rahudkar and Phate, 1992; Rajendran et al., 2000; Schwank et al., 2001; Singh and Swarup, 2000; Thakur and Sharma, 2005). It is recognized that the results of these studies are valuable to understand the harmful effects of intensive chemical farming and the benefits of various practices followed under the organic farming. However, a keen perusal of these studies indicates that there is dearth of systemic studies probing into the impact of organic farming on economics and water use efficiency (WUE) of sugarcane cultivation in Maharashtra.[4] Therefore, the present study is designed to assess the impact of organic sugarcane (OS) farming on input use, costs, yields, risks, returns and WUE in relation to conventional inorganic sugarcane (IS) farming in the state. The paper also explores the emerging issues and suggests policy measures for advancing organic farming for sustaining the sugarcane cultivation in Maharashtra.

The paper is organized in 7 sections. The next section provides brief information on study area, sampling design, data and its sources. Section 3 delineates the salient characteristics of sampled farmers. The impact of

OS farming on input use, costs, yields, risks and returns is analysed in Section 4. Section 5 examines the impact of OS farming on WUE. Section 6 discusses the emerging issues and outlines the task ahead. Concluding comments are made in the final section.

2. DESIGN OF THE STUDY

The importance of organic farming is steadily growing in Maharashtra. Organic sugarcane is an important crop grown in the state. Jalgaon, the only district in the state that has the largest number of "certified" OS growing farmers was selected for this study. Moreover, the district is also facing the serious problems of water scarcity and sustainability due to sugarcane cultivation. We selected only those certified OS farmers who have obtained certification from nationally accredited and internationally designated and recognized certification agency for their organic sugarcane. These certified OS growing farmers were few in selected villages. Therefore, purposive sampling technique was used for the selection of certified OS sample farmers. The organic and inorganic sugarcane growing sample farmers were selected from the same villages to minimize the edaphic and other agro-economic differences between the two groups of sample farmers. The sample included 72 farmers, 38 certified OS growing farmers and 34 IS growing farmers.

The study is based on primary data collected from OS and IS farmers through personal interviews with the help of a specially designed questionnaire. The questionnaire covered information on household resource base, cropping pattern, input use pattern, cost of sugarcane cultivation, yield, etc. Moreover, farmers perceptions on different parameters of OS and IS cultivation were also elicited. The data pertains to the sugarcane crop, both organic and inorganic, planted and harvested during the 2004-05 agricultural year.

3. IMPORTANT FEATURES OF SAMPLE FARMERS

There are wide differences in the resource endowments across the sample groups. The average family size of OS households was found to be smaller (4.18) than IS households (4.94) in the selected district (Table 1). The heads of OS households are younger and better educated than their counterparts from IS households. Generally, the large land holding is associated with higher and early adoption of agricultural technologies in India. Therefore, it was expected that the size of land holding of OS sample farmers would be larger than IS sample farmers. This notion was found to be valid as the average size of land holding of OS farmers was found to be 6.93 ha compared to 6.43 ha for IS farmers.

Most of the sample farmers used well irrigation for their sugarcane crop. The well irrigation has some advantages over the surface irrigation sources. The well irrigation is relatively less affected by vagaries of monsoon and farmer has better control over water supply. However, the use of wells for sugarcane irrigation in Jalgaon district is now often being associated with certain negative externalities due to over exploitation of groundwater resources. The excessive mining of groundwater for irrigation had jeopardized the sustainability of limited water resources in this district. The issue of equity is also not less important as resource rich farmers are found to be exploiting this resource rampantly.

The livestock position given in Table 1 reveals that OS farmers not only owned more number of livestock but the value of livestock owned by them was also higher than IS farmers. The better livestock position of OS farmers may be attributed to their higher demand for manures and other livestock products for cultivation of organic crops. Sugarcane and cotton, the most important cash crops of the state also prevailed over the cropping pattern on sample farms. From the point of view of present study, it is important to note that the OS crop occupied largest coverage at 17.19% of gross cropped area (GCA) on sample farms in the study district. The percentage area under high value fruit and vegetable crops and low water intensive chickpea crop was substantially higher on OS farms than the IS farms.

Table 1: Important Features of Organic and Inorganic Sample Farmers

Sr. No.	Characteristics	Organic Sugarcane Growing Farmers	Inorganic Sugarcane Growing Farmers
1.	Family Size (No.)	4.18	4.94
2.	Age of Family Head (Years)	42.35	43.50
3.	Education of Family Head (Edu. Years)	10.55	9.88
4.	Average Size of Land Holding (ha)	6.93	6.43
5.	Average Net Irrigated Area (ha)	5.60	5.48
6.	Per cent of Well Irrigated Area	90.74	88.08
7.	Livestock (No./Household)	12.41	10.05
8.	Value of Livestock Owned (Rs. '000' / Household)	70.67	56.21
9.	Major Crops Grown (Percentage of GCA)		
	● Organic Sugarcane	17.19	0.00
	● Inorganic Sugarcane	0.00	15.72
	● Cotton	16.90	28.27
	● Wheat	13.95	16.43
	● Fruit crops	11.59	6.49
	● Sorghum	9.75	11.91
	● Chickpea	7.82	2.37
	● Vegetable crops	3.13	2.15

4. IMPACT OF ORGANIC FARMING ON ECONOMICS OF SUGARCANE CULTIVATION

Even if OS farming is found to be superior in the context of the water use efficiency, it is necessary to examine its performance in terms of its economics which ultimately influences the adoption. Therefore, this section examines the impact of organic farming on the economics of sugarcane cultivation with specific focus on input use pattern, cost of cultivation, yields, gross returns and profits. The results of this analysis are presented in Tables 2 - 4 and are discussed in the following sub-sections.

4.1 Impact on Input Use

The sugarcane sector is one of the important employment generating sector employing over 7.5% of total rural population in India (GoI, 2004). The data presented in Table 2 also indicates that sugarcane cultivation, especially the OS cultivation, needs large number of human labour days. For example, on an average, the per hectare human labour use was found to be 247.80 days on OS farms and 206.15 days on IS farms, showing 20.20% higher use on OS crop than the IS crop. This is mainly attributed to increased labour requirement for carrying out operations such as preparatory tillage, manuring, green manuring and managing the weeds, pests and diseases on OS farms. Furthermore, the intercropping typically found on OS farms, with crops having various planting and harvesting schedules, may distribute the labour demand more evenly which could help stabilize employment. This implies that OS farming may provide an opportunity to rural masses of sustained gainful farm employment throughout the year.

The quantity and quality of seed influences the crop stand and productivity. The use of sugarcane seed was found to be 2.97 and 3.35 ton/ha for OS and IS crop respectively in study district. On an average, 11.34% less seed was used by OS farmers mainly due to use of 2-bud setts, and use of strip method of planting. Besides reducing the seed requirement, the strip planting facilitates intercropping with sugarcane. The use of organic manures is quite high on OS farms. The OS farmers used about 5 ton/ha more manure than the manure used by IS farmers. This is obvious considering the dependence of OS farmers on organic manures for augmenting and sustaining the soil resources. In addition, about 180 kg/ha of bio-fertilizer was also used by OS farmers.

Table 2: Input Use Pattern on Organic and Inorganic Sugarcane Sample Farms

Sr. No.	Input	Organic Sugarcane (OS)	Inorganic Sugarcane (IS)	% increase over Inorganic
1.	Human Labour (days)	247.80	206.15	20.20
2.	Bullock Labour (pair days)	9.72	8.51	14.22
3.	Tractor (hours)	6.42	5.96	7.72
4.	Seed (ton)	2.97	3.35	-11.34
5.	Organic Manures (ton)	11.40	6.36	79.25
6.	Bio-fertilizers (kg)	178.70	-	-
7.	Chemical Fertilizers (kg)			
	• Nitrogen (N)	-	341.37	-
	• Phosphate (P)	-	110.25	-
	• Potash (K)	-	77.42	-
8.	Insecticide/ Pesticide (kg)	2.03	2.50	-18.80
9.	Number of Irrigations	21.45	26.51	-19.09

Source: Field Survey

As the sugarcane crop produces huge quantity of biomass, its nutrient requirements are also very high. It could be found from Table 2 that IS farmers used 341.37 kg N, 110.25 kg P, and 77.42 kg K per ha for their sugarcane crop. This is quite high when compared with the levels of 110.10 kg N, 44.70 kg P and 30.10 kg K per hectare for irrigated sugarcane crop in the country (GOI, 2000). The IS farmers also augmented their soil resources by complementing chemical fertilizers with organic manures. In terms of the average use of bio-pesticides for OS crop and chemical pesticides for IS crop, IS farmers used 18.80% more quantity compared to OS farmers. This is mainly because, along with bio-pesticides, OS farmers also used other practices such as crop rotation and intercropping for management of pests and diseases. The average number of irrigations given to OS crop were 19.09% less than the IS crop. We will return to this issue in the next section.

Another notable aspect reported by most of the OS farmers which is important from the point of view of present study is that they did not purchased inputs from the market, rather they used self-produced inputs such as seeds, manures, green-manuring, vermi-compost, bio-fertilizers, Amrutpani, Jivamrut, bio-pesticides, etc. This reduced their dependence on external costly inputs and consequently enhanced their self-reliance in crop production. The OS farmers also expressed their satisfaction on being saved from the risk of getting sub-standard inputs. The water use for sugarcane irrigation is discussed in next section.

4.2 Impact on Cost of Cultivation

This sub-section explores the relative impact of organic farming on operation-wise cost of cultivation of sugarcane in the study districts.[5] This analysis shows that average cost of cultivation of OS crop was Rs. 36,573.74/ ha as against Rs. 42,861.84/ ha for IS crop, reflecting 14.67% lower cost on OS farms than the IS farms (Table 3). The lower cost of cultivation observed on OS farms is not surprising. This is because, first, the highest cost reduction observed on OS farms is on account of non-use of chemical fertilizers. The OS farmers spent Rs. 9,822.65/ha on manures and manuring, mostly produced by themselves, which is 59.65% higher than IS farmers. In addition, Rs. 1,651.15/ha were spent on bio-fertilizers, etc., by the OS farmers. These 2 together cost Rs. 11,473.80/ha which is quite less than the cost of Rs. 15,842.32/ha incurred by IS farmers on chemical fertilizers and manures. Thus, OS farmers saved 27.58% expenditure on account of soil nutrient supplements alone.

Table 3: Cost of Cultivation of Organic and Inorganic Sugarcane (Rs./ha)

Sr. No.	Operations	Organic (OS) Sugarcane (OS)	Inorganic Sugarcane (IS)	Per cent over Inorganic
1.	Land Preparation	5834.73 (15.95) [a]	4995.48 (11.65)	16.80
2.	Seed and Planting	5524.27 (15.10)	6834.95 (15.95)	-19.18
3.	Manure and Manuring	9822.65 (26.86)	6152.77 (14.35)	59.65
4.	Bio-fertilizers	1651.15 (4.51)	-	-
5.	Chemical Fertilizers	-	9689.55 (22.61)	-
6.	Weeding and Interculture	5168.24 (14.13)	4951.19 (11.55)	4.38
7.	Irrigation	5899.56 (16.13)	7378.67 (17.22)	-20.05
8.	Plant Protection	862.35 (2.36)	1193.42 (2.78)	-27.74
9.	Others	1810.79 (4.95)	1665.81 (3.89)	8.70
	Total Cost (GCC) [b]	36573.74 (100.00)	42861.84 (100.00)	-14.67

Note: a : Figures in parentheses are percentage of total cost.
b : This does not include the cost of harvesting, transport and marketing.

Secondly, the irrigation cost was found to be 20.05% less on OS farms. Thirdly, OS farmers spent about Rs. 1,310/ha less on seed and planting as compared to IS farmers. Fourthly, the average per ha cost on plant protection was lower on OS farms as most of this material was prepared by OS farmers themselves and they also used other methods. Besides this, the OS cultivation was also found to be more cost efficient than IS cultivation as the per ton cost of production of OS cane was 9.03% lower on OS farms (Table 4).

The increased cost of cultivation due to increased input prices has also increased the requirement of credit for agriculture. However, several studies have concluded that the inability to payback the credit is one of the important reasons for creating distress among farmers (Mishra, 2006; TISS, 2005). The foregoing results indicate that OS farming reduces the cost of cultivation of a crop implying reduced requirement of credit for crop production.

4.3 Impact on Yield

The capacity of organic farming in achieving the yield levels obtained under the conventional inorganic farming is under doubt (Bhattacharyya and Chakraborty, 2005; Das and Biswas, 2002). Some studies have also noted that the change from conventional intensive farming to organic farming reduces the yield, at least during the initial years (IFAD, 2005; Rajendran et al., 2000). This study also found that the average yield of OS crop was 95.16 ton/ha as against 101.45 ton/ha of IS crop showing that OS farmers realised 6.2% lower yield than IS farmers (Table 4). However, the OS farmers were confident and it has also been reported by some scholars that in subsequent years, the OS farming is able to reduce this yield gap (Rajendran et al., 2000) and some times have also given higher yields than conventional methods (Thakur and Sharma, 2005).

Table 4: Yield, Value of Production and Profits from Organic and Inorganic Sugarcane

Sr. No.	Particulars	Organic Sugarcane	Inorganic Sugarcane	% over Inorganic
1.	Sugarcane Yield (ton/ha)	95.16	101.45	-6.20
2.	CV of Sugarcane Yield (%)	29.84	44.38	-14.54
3.	Cost of Production (Rs./ton)	384.34	422.49	-9.03
4.	Gross Value of Production (Rs./ha)	114,017.85	109,784.25	3.86
5.	Gross Profit (Rs./ha)	774,44.11	66,922.41	15.72
6.	CV of Gross Profit (%)	41.63	49.81	-8.18
7.	GVP/GCC	3.12	2.56	21.71

A stable yield is an important feature of sustainability. The yield stability measured by coefficient of variation (CV) indicates that the CV of yields was substantially lower at 29.84% in OS crop as against the 44.38% in IS crop suggesting that yields were more stable under OS farming than the IS farming (Table 4). It is also to be noted here that lower yields on OS farms were more than compensated by the price premium fetched by organic sugarcane and the sugarcane yield stability observed on OS farms.

4.4 Impact on gross value of production and profits

The increase in price of inputs in conventional agriculture had inflated the cost of cultivation and had reduced the profitability (Sen and Bhatia, 2004). Therefore, the issue of profitability is intimately related to economic well-being and livelihood security of the farmers. In this context, the examination of Table 4 shows that the gross value of production (GVP) and profits were higher on OS farms than the IS farms. For example, the GVP from OS farm amounted to Rs. 114,017.85/ha as against Rs. 109,784.25/ha from IS farm. This has resulted in higher profits by 15.72% from OS crop than the IS crop thereby enhancing farmers' income. This is mainly due to lower cost of cultivation on OS farms and relatively higher price fetched by organic sugarcane. Moreover, the CV of gross profits was also lower on OS farms than IS farms denoting greater stability of profits on OS farms. Thus, OS farming not only enhances the farmers' income but also provides greater stability to farm income.

Higher output-input (GVP/GCC) ratio is another feature of OS farming. The ratio was found to be 3.12 on OS farm as compared to 2.56 on IS farm. This indicates that after investing a rupee in the cultivation of OS crop, GVP was 21.71% higher than IS crop. In fact, the higher GVP/GCC ratio on OS farms is the reflection of higher input use efficiency observed on OS farms. In summary, these features of OS farming are critical for ensuring not only the economic well-being and livelihood security of the farmers but also for the sustainable cultivation of sugarcane crop in the state.

5. IMPACT OF OS FARMING ON WATER USE EFFICIENCY (WUE)

In Maharashtra, the coverage of irrigation for sugarcane crop is 100% (GoI, 2005)[a]. Therefore, water is essential not only for cultivation of sugarcane crop but also for increasing its productivity. However, water is the most limiting resource for sugarcane production in Maharashtra. About 80% of the water is utilized for agriculture in Maharashtra (World Bank, 2003) and more than 60% of it is utilized for sugarcane crop alone. Sugarcane crop produces huge quantity of biomass and it also consumes large quantity of water. The water requirement of sugarcane crop varies from 200 cm to 300 cm depending upon the type of soil and agro climatic conditions. It may be recalled that the main source of irrigation water for sugarcane crop was observed to be wells in the study district. Farmers are virtually mining water from deep aquifers for sugarcane crop. This is a cause of great concern and demands its conservation and judicious use as it has endangered the stability and sustainability of agriculture. However, the concern shown by individual farmers is rather circumscribed. This is mainly because the individual farmers are only interested in their own gains and costs and paying no attention at all to the social costs of over exploitation of groundwater resource (Vaidyanathan, 1996).

To study the comparative use of water under OS and IS farming, one may need actual measured data on use of water on both OS and IS farms. However, we concede that we do not have such a irrigation water measured data for sample farms. In absence of actual measured data, other indicators such as irrigation cost, number of irrigations given, productivity per irrigation, and returns per irrigation can be used to assess the WUE in the cultivation of OS and IS crop. The survey data is used to work out the various WUE indicators. The results of this analysis are presented in Table 5.

The results from preceding section revealed that irrigation cost is the second highest cost in the cultivation of sugarcane crop. However, it was considerably lower on OS farms as compared to IS farms. The average per hectare expenditure incurred on irrigation was found to be Rs. 5899.56 on OS farms as compared to Rs. 7378.67 on IS farms. In other words, OS farmers spent Rs. 1479.11/ha less on account of irrigation as compared to IS farmers. Another aspect to be noted from Table 5 is the lower irrigation cost per unit of cane production on OS farm. The average irrigation cost per ton of cane production on OS farm was Rs. 62 while it was Rs. 72.73 on IS farm, meaning 14.75% less irrigation cost per tonne of cane production on OS farm. In other words, it indicates higher sugarcane productivity per unit of irrigation expenditure on OS farms in

Table 5: Water Use Efficiency in Organic and Inorganic Sugarcane Farming

Sr. No.	Indicator of Water Use Efficiency	Organic Sugarcane	Inorganic Sugarcane	% over Inorganic
1.	Irrigation cost (Rs./ha)	5899.56	7378.67	-20.05
2.	Irrigation cost (Rs./ton)	62.00	72.73	-14.75
3.	Number of irrigations applied	21.45	26.51	-19.09
4.	Productivity per irrigation (ton/ha)	4.44	3.83	15.93
5.	GVP per irrigation (Rs./ha)	5315.52	4141.24	28.36
6.	Profits per irrigation (Rs./ha)	3610.45	2524.42	43.02

comparison with IS farms. It follows from this analysis that the irrigation costs incurred on per unit of area as well as per unit of cane production were lower on OS farms implying less use of water, saving of groundwater by OS farmers for cultivation of sugarcane crop.

Another result that comes out very clearly from Table 4 is the number of irrigations given to OS crop were quite less than the IS crop. The OS crop was given 21.45 irrigations while the IS crop was given 26.51 irrigations by the selected sample farmers. This indicates that OS needs 19.09% less number of irrigations than the IS crop. The water use efficiency expressed as the productivity of sugarcane per irrigation was found to be higher at 4.44 ton/ha on OS farm as compared to 3.83 ton/ha on IS farm suggesting 15.93% higher WUE on OS farm. Furthermore, the GVP per irrigation was 28.36% higher on OS farm. Yet another measure, the profits per irrigation was also substantially higher at 43.02% on OS farm than the IS farm.

The foregoing results revealed that various water use indicators performed better under OS farming as compared to IS farming. This suggests that OS farming is very effective and superior in saving water as compared to conventional IS farming. This may be mainly attributed to the fact that incorporation of organic matter to soil improves its structure and enhances its micro-porosity leading to improved infiltration of rain water and increased soil moisture retention capacity (Kumar and Tripathi, 1990; Sarkar et al, 2003). Rahudkar and Phate (1992) also observed that irrigation requirement of OS crop reduced by 45% than the conventional production method. Thus, OS farming has substantial potential in enhancing the sugarcane productivity and profit per unit of water use and saving the scarce groundwater thereby providing an opportunity for its conservation and sustainable use. No doubt, this is crucial for a relatively water scarce state like Maharashtra.

6. EMERGING ISSUES AND FUTURE POLICIES

The preceding results from this study indicate that organic farming is quite successful in the study area. Some of the key factors that are important for the success of OS farming, and not discussed so far, are related to conversion to organic farming, certified organic inputs, low yields and certification. These and few other issues are discussed in this section.

6.1 Conversion to organic farming

The sample farmers reported that the period involved in conversion from conventional farming to organic farming is the most difficult one. This is mainly because (a) lack of knowledge about the principles of organic farming, (b) shift to organic farming brings in several significant changes in agricultural practices, (c) at least it takes three years to complete the conversion successfully, (d) decrease in sugarcane yield with the beginning of the conversion period, (e) no premium prices, (f) due to (d) and (e) there is reduction in farmers income during the conversion period, and (g) non-cooperation from neighbouring farmers who practice conventional agriculture. These factors form the major hurdle in the adoption and spread of organic farming. Therefore, it is recommended that the beginners should receive not only the training but also the support in organic production methods, certification and marketing during this period. If feasible, the beginners should shift to organic in stages rather than trying to convert all their landholding at once. It is also suggested that the beginners themselves should prepare for the transition period in terms of time required, crops to be taken, inputs management, financial provision, etc., to pass the period of transition rather smoothly. Moreover, all the farmers having contiguous fields should be encouraged to shift to organic methods to avoid problems related to leaching and or contamination of chemical fertilizers and pesticides.

6.2 Certified Organic Inputs

The use of organic inputs such as organic manures, bio-fertilizers, vermi-compost, bio-pesticides, etc., was found to be higher on OS farms compared to IS farms as organic farmers substituted chemical fertilizers and pesticides with these organic inputs. The demand for these inputs is likely to increase with the expansion of area under organic farming. Therefore, it is most essential to ensure the smooth flow of these inputs so that they do not form the hurdle in the progress of organic farming in the state. In this context, the involvement of self-help groups (SHGs) of landless households for production of certified inputs would be most useful. Therefore, it is recommended that specific schemes may be developed for involvement of SHGs in production of certified inputs required for OS farming. The transfer of technology for production of certified organic inputs along with training, financial assistance, facilities for distribution and marketing should form the major components of such schemes for the SHGs. This may help in smooth supply of quality organic inputs at a reasonable price to organic farmers. At the same time it may also help in providing gainful employment opportunities to the landless rural people in their own area.

6.3 Low Yields

The sugarcane yield on OS farms was observed to be 6.20% lower than the IS farms. It is thus necessary to resolve the yield limiting issues in OS farming on priority basis. A fairly well developed infrastructure for agricultural research, training, and education exists in Maharashtra. The use of this infrastructure can be made effectively to resurrect the productivity by developing and spreading package of practices for water and soil nutrient management, as well as biotic and abiotic stress management in OS farming. Involvement of farmers by the researchers, where possible, should prove beneficial for developing and transferring the new technologies within the shortest possible time.

6.4 Certification

The certification of organic products is essential to distinguish it from those produced by conventional methods and to get an appropriate price in the market. The OS sample farmers operated certified farms. Even the study district has the largest number of certified OS farmers in the state. The credit for this goes to farmers associations. The association facilitated the certification of organic produce through an internationally recognised certification agency under the group certification programme. Thus, the association made organic certification easy, less costly and beneficial for its member farmers. This emphasizes the need of such associations which play an important role in not only helping the farmers in organic certification but also during the difficult period of conversion and post harvest operations. Such associations can also play an important role in stimulating the rapid adoption and spread of organic farming. Therefore, public and private agencies and NGOs may encourage farmers to form their own associations.

6.5 Other issues

Water is one of the most important resources essential in the cultivation of sugarcane crop in Maharashtra. Therefore, further research is necessary to critically assess the actual water requirements of organic vis-à-vis inorganic sugarcane crop in the state. In this context, the researchers may accurately measure the quantities of water applied to OS and IS crop with different water saving technologies and soil types. It is also necessary to study the impact of OS farming on the quality of groundwater resources in the state of Maharashtra. This kind of studies may help in making the specific recommendations for the use of irrigation water in the cultivation of OS crop in Maharashtra.

Some OS sample farmers complained of being deceived by traders by selling them spurious organic inputs. This resulted in heavy losses to victimized farmers. Therefore, efforts may be made to enhance the awareness among the organic farmers and strict vigilance by the quality control and regulatory authorities to prevent such malpractices involving pseudo-organic inputs.

The foregoing results of this study clearly indicated that the benefit of OS farming is not in enhancing the yield but in other crucial benefits. Therefore, it is essential for extension agencies to project these crucial benefits such as superiority of OS farming in saving water, low cost farming, higher farm employment, higher profit, farmers' increased self-reliance and reduced risk in right perspective for its rapid adoption in the state. The growing of crops by following organic practices in conformity with certain standards is a process beginning from land preparation to finally reaching the produce in the hands of consumers. Therefore, it is essential to impart scientific training not only to farmers but also to other stakeholders to make them knowledgeable, skilled and efficient in production, processing and marketing of organic products

The organic farming does have social benefits in terms of saving water, conservation of soil resources and benefits to human health and environment. Therefore, it is suggested that the social benefits as well as the social costs of OS farming may be properly measured and quantified to get an idea about the extent of incentives that could be justified for promotion of OS farming in the state.

In summary, it is essential to resolve these emerging issues in order to realize its full potential for ensuring sustainability of sugarcane cultivation and for enhancing the economic well-being and livelihood security of the farmers in the State.

7. CONCLUSIONS

The study finds that farmers practicing OS farming are relatively younger and more educated having larger landholding and better resources. The OS farming was found to be superior than IS farming on account of increased human labour employment, lower cost of cultivation, higher profits, better input use efficiency and reduced risk leading to increased income, enhanced self-reliance and livelihood security of the farmers. Moreover, OS farming had positive impact on water use efficiency demonstrating substantial potential for conservation and sustenance of water resources in a water scarce state like Maharashtra. Thus, OS farming has greater potential in achieving the goal of sustainable cultivation of sugarcane crop and ensuring economic well-being of the farmers. Besides addressing the emerging issues from this study, it is crucial to formulate policies and strategies to promote OS farming in order to realize its full potential in selected regions of Maharashtra.

Notes

1 The sugarcane productivity in Maharashtra attained a high level of 95.15 ton/ha in TE 1982-83 from just 70.95 ton/ha a decade earlier (TE 1972-73). After that the productivity declined to 80.98 ton/ha in TE 1992-93 and further dwindled to 78.33 ton/ha in TE 2002-03.

2 The area under irrigation was only 18.10% of gross cropped area of the state as compared to 40.20% at the national level in 2002-03. Thus, Maharashtra is on one of the water deficient states of the country. Despite this, the coverage of irrigation for sugarcane crop is 100% in the state. Sugarcane being a relatively long durational water intensive crop producing huge quantity of biomass, it requires enormous quantity of water for its cultivation.

3 The top ten organic countries in the world are Australia, Argentina, China, USA, Italy, Brazil, Spain, Germany, Uruguay, and UK. The area under organic farming in these countries varies between 620,000 ha in U K to 11,800,000 ha in Australia. These ten countries cover more than 77% of total area under organic farming in the world (Willer and Yussefi 2007).

4 In fact, we have not came across a single comprehensive study that is based on farm level data looking at the impact of organic farming on input use, costs, yields, returns and WUE in the cultivation of sugarcane crop in Maharashtra.

5 The cost of cultivation is referred to cost A_2 plus family labour which includes all actual expenses in cash and kind incurred in production by owner plus rent paid for leased-in land plus imputed value of family labour as defined by the Commission for Agricultural Costs and Prices (CACP), Government of India (2005)[b]. The gross profit is calculated as gross value of production minus the cost of cultivation.

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