Watershed Management and Water Harvesting as Strategic Tools for Groundwater Augmentation

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Abstract

The conservation, development and management of water are pivotal to the concept of 'watershed management'. Watershed management envisages a systematic and scientific approach towards conservation, harvesting, proper utilization and safe disposal of flowing water from the moment it strikes the land surface as a tiny drop till it joins the ocean for optimum production on sustained basis. After the successful implementation of Operational Research Projects by Central Soil & Water Conservation Research & Training Institute, Dehradun in 1970's, the Government of India launched a massive National Watershed Development Programme for Rainfed Areas in 1991. Many other programms funded by national and international agencies followed this. By the end of IXth Five Year Plan, an expenditure of INR 92.7 billion has been incurred in watershed programes by the Ministries of Agriculture and Rural Development covering an area of 29M ha. By the end of XIIIth Plan, it is envisaged to cover an area of 88.5M ha under watershed development programs at an estimated cost of INR 727.50 billion. With the shift in paradigms, participatory watershed management ensuring transparency and equitable sharing of resources and benefits among different stakeholders is being emphasized. Thus, watershed based development has been accepted as a single-window strategy for harmonizing simultaneously joint management of land, water, vegetation and human resources for sustainable productivity.

Water harvesting and its utilization is one of the major components of the watershed development programs which is realized through: (a) in-situ rain water harvesting measures, (b) surface water development measures, such as ponds, earthen reservoirs, small harvesting tanks, gully control structures and, drainage line treatments (c) sub-surface or ground water development measures such as percolation tanks, ponds, sub-surface dams, barriers, and, diaphragm dams (d) roof top collection and runoff water cistern and, (e) improved water management practices including micro-irrigation and on-farm water management. It has been estimated that about 24M ha-m rainwater can be harvested into water storage structures, of which one fourth can be harvested into ponds and percolation tanks in rainfall zone upto 1000 mm/annum. This runoff water can provide life saving irrigation of 5 cm each for more than 60-percent of the rainfed area in the country. Apart from providing water storage for supplementary irrigation, the integrated watershed

development programs help in moderating the floods in down stream areas and improve in-situ moisture conservation for increased biomass production. Besides, ground water recharge and rise in water table up to 2-meter height due to integrated watershed management were experienced in different regions of India with tremendous environmental externalities.

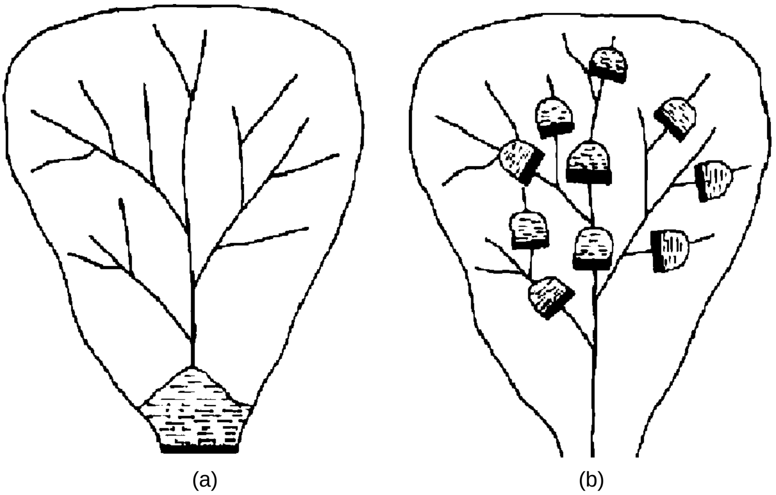
With an investment of INR 92.7 billion during IXth Plan, an additional area of 40,299 ha was brought under irrigation and most of the dug wells and tube wells have been rejuvenated with round the year water availability. However, the effect of water harvesting structures on ground water recharge has not been properly understood except by employing crude methods of studying rise and fall in water table of open or tube wells in different regions. A core project to analyze the relationships between water harvesting structures and ground water recharge in different agro-ecological situations has been initiated recently by CSWCRTI, Dehra Dun. The preliminary results in one of the watersheds at Antisar in Kheda district of Gujarat have shown that about 6.5 percent of the annual rainfall is effective in recharging the ground water aquifer. It was further observed that a minimum of 103.6 mm runoff is needed to trigger 1.0 mm of potential recharge in this agro-climatic setting. The results were obtained by employing water table fluctuation and chloride mass balance methods, which need further investigations and comparison with other modern tools and techniques for arriving at logical conclusions.

Introduction

Why does water-harvesting matter more today than any other time? There are several reasons (Jackson et al., 2001): (1) over half of the accessible freshwater runoff globally is already appropriated for human use; (2) more than one billion people currently lack access to clean drinking water and almost three billion people lack basic sanitation services; (3) because the human population will grow faster than increase in the amount of accessible freshwater, per capita availability of freshwater will decrease in the coming century; (4) climate change will cause a general intensification of the earth's hydrological cycle in the next 100 years, with increased precipitation, evapo-transpiration, occurrence of storms and significant changes in bio-geochemical processes influencing water quality. Human society now uses 26% of the total terrestrial evapotranspiration and 54% of the runoff that is geographically and temporally accessible. New dam constructions could increase accessible runoff by about 10% over the next 30 years, whereas the population is projected to increase by more than 45% during that period (Postel et al., 1996). Under such circumstances, *in-situ* rainwater harvesting shall be crucial.

As summers get hotter, and anthropogenic climate changes exert further strain on socio-economic and natural systems, water scarcity is likely to grow in regions such as South Asia and elsewhere. Addressing water problem holds the promise in future for a world compounded by climate change, growing population, and decreasing water-impounding area of traditional tanks due to urban and industrial settlements. In addition, extreme bio-climatic events are registering a monotonically increasing trend. A significant proportion of the global land area has been increasingly affected by a significant change in climatic extremes in the recent past.

A recent study projected, that in India, winter rainfall may decline by 5 to 25% and may lead to droughts during the dry summer months in coming decades (Lal et al., 2001). Thus, we will have to take into account the large-scale, natural climate variations as well as human-induced climate change in the management of natural, social and economic systems. If extreme climate events increase in future due to climate change, human society will use different means of adaptation. Additionally, regardless of climate fluctuations, population growth will put extra stress on natural resources. Alternative to ecologically damaging, socially intrusive, and capital-intensive water management projects that fail to deliver their desired benefits, it would be useful to invest in decentralized facilities, efficient technologies and policies, and human capital to improve overall productivity rather than to find new sources of water supply. Such efforts would need to be encouraged with innovative policy regimes that concurrently promote rainwater harvesting. Traditionally, such systems have been integrated with agro-forestry and ethno-forestry practices, and remain useful in contemporary conservation and ecological restoration of degraded ecosystems (Pandey, 2002). A systematic support to local innovations on rainwater harvesting could provide substantial amounts of water. Simple indigenously adapted techniques such as ponds and earthen embankments can help in harvesting and storage of rainwater. Rural and urban water use, restoration of streams for recreation, freshwater fisheries, and protection of natural ecosystems are all competing for water resources earlier dedicated only to food production. Decentralized rainwater harvesting adaptations (Figure 1) therefore become crucial for meeting the competing needs for water. For instance, in the Negev Desert, decentralized harvesting of rainwater in micro-catchments from rain falling over a 1-ha watershed yielded 95,000 litres of water per hectare per year, whereas collection efforts from a single large unit of a 345 ha watershed yielded only 24,000 litres per hectare per year (Pandey, 2001). Thus, 75% of the collectible water was lost as a result of the longer distance of runoff.



(a) (b)

Figure 1. Schematic of types of rainwater harvesting adaptation (a) case of single structure at the remote outlet, (b) decentralized water harvesting structure based adaptations

Traditional systems would become more efficient if scientific attempts are combined to enhance productivity of local knowledge. But some local technologies may already be at par with scientific attempts. Rainwater harvesting also has great potential as a solution to mitigate wide spread arsenic poisoning (Mandal et al 1996). In West Bengal and Bangladesh, alluvial Ganges aquifers used for public water supply are polluted with naturally occurring arsenic, which adversely affects the health of millions of people by causing arsenicosis (Pandey et al., 1999) and increasing the risk of cancer. Millions of people are at risk in Bangladesh alone (Dhar et al., 1997). Arsenic mobilization is associated with the advent of massive irrigation pumping that draws relatively young water directly into the aquifer (Harvey et al., 2002). Deep wells are being advocated as a remedy, that may provide a source of clean water; but the solution is only a provisional one. Rainwater harvesting is a better option to provide arsenic-free, safe water in a cost-effective and accessible manner, particularly for drinking and food preparation. We must, however, address several challenges to make rainwater harvesting efficient, particularly treatment of harvested rainwater in areas where pollution is rampant (Naik et al., 2002).

Water Harvesting and Integrated Watershed Management

Rainwater harvesting can be promoted as a core adaptation strategy for achieving the global security and sustainability of water resources in an era of anthropogenic climate change. However, this requires an insightful policy. Over thousands of years, people living in various geographical and climatic regions of the world have evolved diverse, indigenous rainwater harvesting and management regimes as an adaptation to climate change. Some of these practices continue to remain in use, particularly in South Asia. Rainwater harvesting in South Asia differs from that in many parts of the world – it has a history of continuous practice for at least the last 8000 years (Pandey et al., 2003). Water has been harvested in India since antiquity, with our ancestors perfecting the art of water management. Many water harvesting structures and water conveyance systems specific to the eco-regions and culture has been developed. Civil society institutions and government agencies are increasingly taking up water harvesting projects in rural areas. There are several initiatives where the traditional water harvesting practices have been modified depending upon the domestic and irrigation needs of the local community. Such improvisations initiated by the communities in different parts of the country and eco-region (Figure 2) is more scientifically adaptable. A few of them are listed in Table 1.

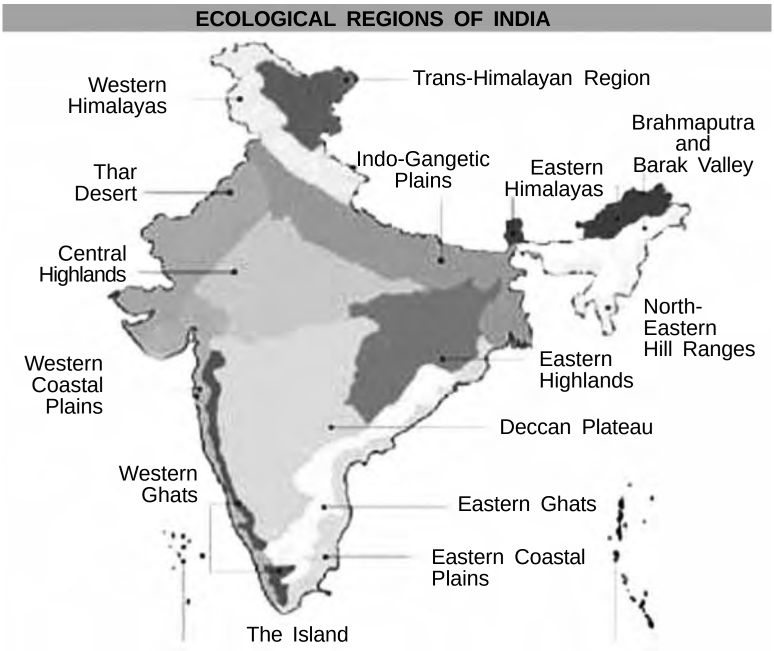


Figure 2. Ecological regions of India
(*Source: http://www.rainwaterharvesting. org/eco/eco-region.htm)*

Table 1. Traditional and contemporary water harvesting systems practiced in different agro-ecological zones of India

Ecological regions of India	Traditional water harvesting practices	Contemporary water harvesting systems
Trans-Himalayan region	Zing	Artificial glaciers
Western Himalaya	Kul,Naula, Kuhl, Khatri	—-
Eastern Himalaya	Apatani	—
Northeastern hill ranges	Zabo, Cheo-oziihi, Bamboo drip irrigation	—
Brahmaputra valley	Dongs, Dungs/jampois	—
Indo-Gangetic plains	Ahars-pynes, Bengal's Inundation channels, Dighis, Baolis	—
Thar Desert	Kunds/kundis, Kuis/beris, Baoris/bers, Jhalaras, Nadi, Tobas, Tankas, Khadins, Vav/Vavdi/Baoli/Bavadi, Virdas, Paar	Nadis, Polymer Kundis
Central highlands	Talab/Bandhis, Saza Kuva, Johads Naada/bandh, Pat, Rapat, Chandela tank, Bundela tank	Chaukas
Eastern highlands	Katas/Mundas/Bandhas	Jaldhar Models
Deccan plateau	Cheruvu, Kohli tanks, Bhandaras, Phad, Kere, The Ramtek Model	Tudum/Monga Networking of farm ponds
Western ghats	Surangam	—
Western coastal plains	Virdas	—
Eastern ghats	Korambu	—
Eastern coastal plains	EriOoranis	Horizontal roughening filters
The Islands	Jack Wells	—

(Source: http://www.rainwaterharvesting. org/eco/eco-region.htm)

Water harvesting has to be done on watershed basis, as watersheds are natural hydrologic units. Management of water resource done in this way is more effective. Watershed is characterized by many parameters such as land use, soil, hydro-geomorphology, and morphometric characteristics among others. Output from similar watersheds is often similar. With a suitable structure it is possible to harness maximum amount of water from the watershed. Location and type of structures depend upon soil, land use: land cover, drainage pattern, and geomorphology among others.

Integrated watershed management programs often envisage a holistic approach on development of water resources. This way *in-situ* water harvesting in the way of decentralized networks of water harvesting structures often prove to be more effective in augmenting groundwater recharge. Qualitative and quantitative information on the rise of water table consequent upon a successful implementation of watershed management program is a key for impact assessment. There are many case studies, which demonstrate that water harvesting for aquifer recharge is a great success (Table 2)[1]. They benefit from being low energy requiring and sustainable systems that can provide a long term supply of high-quality water without the need for modern technology. However, there are also different reasons due to which the various systems described wouldn't be effective, especially if they are not well planned prior to construction or if they are not maintained.

Table 2. Effect of watershed management strategies on groundwater recharge in different regions of India

Watershed	Surface storage-capacity created (ha-m)	Observed rise in groundwater table, m
Bazar Ganiyar (Haryana)	79.0	2.0
Behdala (H.P.)	18.0	1.0
Bunga (Haryana)	60.0	1.8
Chhajawa (Rajasthan)	20.0	2.0
Chinnatekur (A.P.)	5.6	0.8
GR Halli (Karnataka)	6.8	1.5
Joladarasi (Karnataka)	4.0	0.2
Siha (Haryana)	42.2	2.0

Source: Samra, 1997.

To state the obvious, water harvesting for augmenting groundwater recharge are only suitable in areas where aquifers exist. The recharge process is much simpler where unconfined aquifers exist and simple damming techniques, with percolation, can be used. It is important to carry out a thorough survey prior to selecting the site and deciding on the method of recharge. To analyse all the affecting themes and come up with a solution for water harvesting, resource information and decision support systems are the essential needs. Knowledge about the following parameters is critical to ensure proper placement of water harvesting structures to augment and ameliorate the aquifer:

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[1] See Samra (1997) for further details.

- climatic records- rainfall, humidity, evaporation rates;
- topographical maps including drainage networks and ephemeral streams;
- data on soil thickness (types and distribution);
- distribution of rock types, especially surface features;
- definition of pore networks;
- recognition of recharge, discharge areas and the flow direction of the groundwater.

Moreover, series of studies have been conducted world wide to establish both diagnostic as well as prognostic interaction between the surface and groundwater processes. However, only few studies could address the realistic solution to the impact of water harvesting structures on groundwater recharge. To address this issue efforts have been made by CSWCR&TI, Dehradun to formulate a core project on the field scale monitoring of watersheds implemented under Integrated Wasteland Development Program (IWDP) funded by Ministry of Rural Development, Government of India. The regional centre at Vasad was the first among all the cooperating centres, which had initiated this project at Antisar in Gujarat. The project has become a classical effort in successful implementation of water harvesting technologies for groundwater recharge.

Water Harvesting Experiences: A Case Study (Antisar, Gujarat)

In Antisar a watershed development program was undertaken by focusing on water harvesting and artificial recharge structures. Antisar is located in Kapadwanj taluk of Kheda district in Gujarat. The findings from the program shows that the benefits accrued are worth the capital investments incurred on program activities. Twenty-three (23) artificial recharge filters and 16 check dams were constructed in the span of five years between 1998 to 2003 (Figure 3). Renovation and deepening works with five water-harvesting structures were also carried out. 139 tube wells/ open wells have been used to monitor the trend of water table rise or fall during the year 2002 and 2003. The salient findings of the studies are as under (Kumar et al., 2004):

Water Table Increase in Influence Zone of Water Harvesting Structures

The incidence of successive drought years (1999-2001) had resulted in reduced water table situation in the area. Therefore, between 1999-2001 the people in the watershed could not go for *Rabi*(winter) crops in a large scale due to early drying of the wells. Most of the recharge or water harvesting structures were constructed during the year 2001-2002 under the IWDP program. The influence of water recharged from different water harvesting structures such as check dams, recharge filters and ponds was studied using storage volume fluctuation technique in the area. It was observed that the average days that the water percolated from ponds and check dams would reach groundwater table in approximately 6 days, where as for the recharge filters it took one or two days.

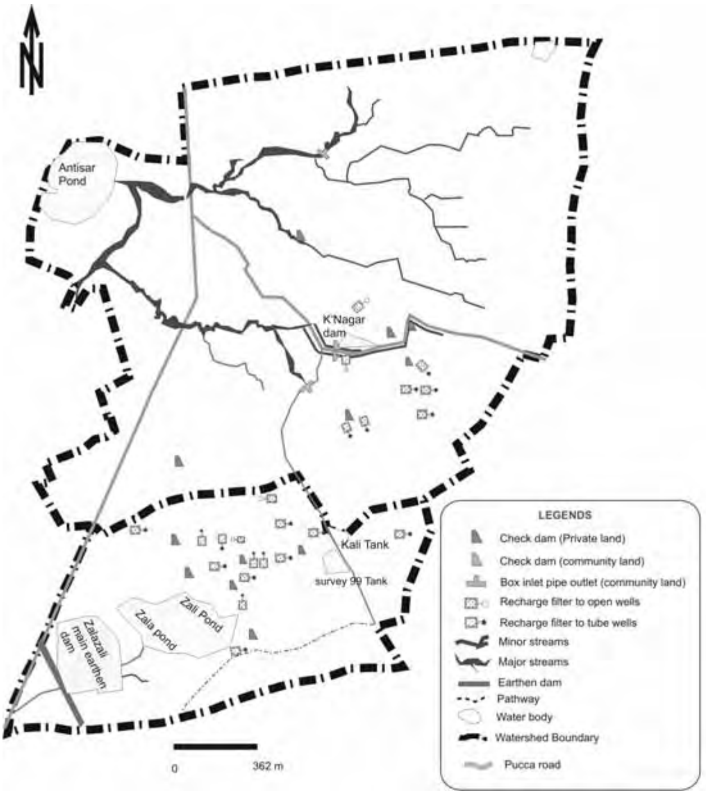


Figure 3. Details of the water harvesting structures in the Antisar watershed

The ground water mound under a structure recedes in 15 days to attain a dynamic equilibrium with the water table. The influence was found to be higher in the down stream side well of the water harvesting structure with a differential water table gain from 3.62 m to 10.66m.

Number of Wells Influenced

Based on the water table data recorded between July 20- August 5, 2004, 101 tube wells/open wells (73%) out of the designated 139 tube wells / open wells got influenced by the recharged water. The rainfall during this period was 234 mm. The net rise in water table during this period was 4.99 m.

In the successive fortnight (August 5-20, 2003) there was no rainfall. Therefore, the net rise in water table was 0.69 m, which is due to percolation of water from water harvesting structures coupled with internal distribution of water in the aquifer and gradual recession of the mounds formed under different water conservation structures (check dams, water harvesting ponds or recharge filters). By this time, almost all tube wells and the recharged water influenced open wells in the watershed. Therefore, it was observed that due to increased water harvesting at strategic positions, a better distribution of water occurs in the watershed.

Increase in Well Recharge Rate

Considering the rate of rise per unit of rainfall depth, about 23 per cent increase in recharge rate has been estimated during 2003. This is due to relatively more permeable characteristics of the recharge filter units that contribute better to the ground water table rise as compared to the more time consuming natural recharge from water harvesting structures which were present before the inception of the project.

Pumping and Recuperation Hours

The farmers in the Antisar watershed area are in the habit of withdrawing water in a whimsical and indiscriminate manner. The time of pumping water from the wells depends on the availability of the electricity, which is supplied in a fixed slab of eight hours a day. The pumps are attached with an auto timer unit that starts the pump the moment electricity is available and runs until the end of the duration of the supply hours. This implies a fixed pumping rate of 8 hours and 16 hours of recuperation until the next pumping. The rate of recuperation of the aquifer is estimated to be 0.101 m/day. When the water table is high, the time for recuperation to the initial level is approximately 8 hours after pumping for 8 hours continuously. This is due to the fact that a relatively more permeable fracture units (Fractured murrum with amygdaloidal basalt) near the ground surface (8 to 20m below the ground surface) results in faster water movement to the wells (Sena et al., 2003).

Increase in Irrigated Area

Compared with the area under *rabi* during 2000-01 and 2001-02, which was only 16.05 and 1.08 ha, respectively, a command area of 30.51 ha (total 71 ha including summer and *kharif*) has been brought under irrigated agriculture in rabi season with crops having intense water requirements. A total of 342 irrigations (including 120 supplemental irrigations during *kharif* and summer in the drought year) have been applied (irrigation number varying from 1 to 15) which is a major contribution of the ground water recharge works carried out in the area even though 2002 was a drought year. The total amount of water utilized for irrigations during 2002 was worked out as 1663 ha-cm assuming the depth of irrigation as 5 cm out of which summer and *kharif* accounts for a supplemental irrigation of 646 ha-cm.

The potential recharge / percolation from major water harvesting structures (Table 3) was measured during the water availability period. The recharge from these percolating ponds was estimated for the years 2001 to 2004 (Table 4).

It was found that in a watershed, a minimum of 103.6 mm rainfall is required to induce a one- mm potential recharge of the aquifer. The rainfall that induces maximum recharge (12.07%) in the watershed amounts to 714.4 mm. These may be reckoned as indices for comparison of different water harvesting structures in a particular area or extended to study the behavior of water harvesting structures in different agro-ecological zones (Sena et al., 2003).

The total recharge in the Antisar watershed is 6.33% of the annual rainfall (864 mm) and amounts to 4436.94 ha-cm using storage volume fluctuation method

Table 3. Specifications of major water harvesting structures in the study area

Sl.No.		Structure capacity, ha-m	Catchment area, ha	Ponding area, ha
1.	Zalazali E/D	163.00	9.40	10.13
2.	Zali pond	100.80	6.42	10.33
3.	Zala pond	43.20	8.99	10.80
4.	Antisar	612.00	4.50	11.27
5.	Khodiar nagar	7.48	0.83	0.41
6.	Kali tank	2.38	1.37	3.73
7.	Survey 99	1.06	0.61	0.58

Source: Sena et al, 2003.

Table 4. Volume of water recharged (R_e in cu-m) due to seepage from water harvesting structures/ponds for years 2001- 2004

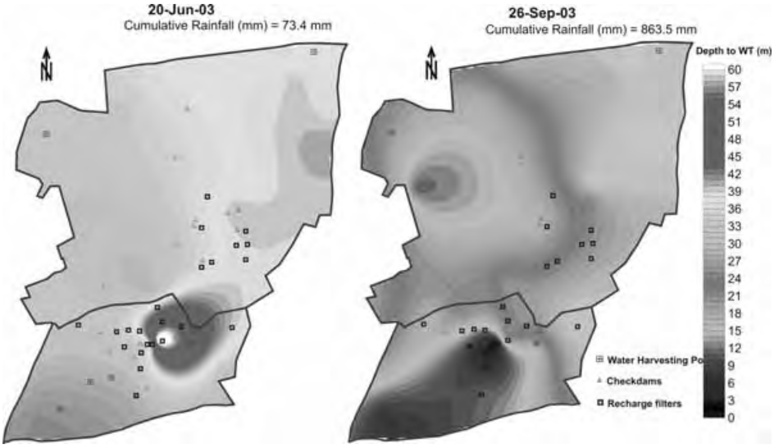
Sl.	Water harvesting	R_e (cu-m)			
No.	structure/pond	2001	2002	2003	2004
1.	Zalazali earthen dam	33919	77646	120803	89466
2.	Zali pond	51932	28562	83273	81568
3.	Zala pond	32833	80611	107065	92493
4.	Antisar main pond	48999	4673	53606	39128
5.	Khodiyarnagar pond	3210	795	1307	2151
6.	Kali Tank	—	—	11617	10116
7.	Survey 99	—	—	3048	3683
Total (cu-m)		170893	192287	380719	502914
Rainfall (mm)		421	538	864	826

*4 years average (Long term annual average (1983-2004) is 835 mm)
Source: Sena et al., 2003.

during 2003 (Figure 3), where as during 2004, the total recharge in the watershed is 8.024% of the annual rainfall (826 mm) and amounts to 5381.61 ha-cm (Figure 4). This recharge includes both direct recharge to the aquifer from recharge filters and potential recharge quantities from water harvesting structures.

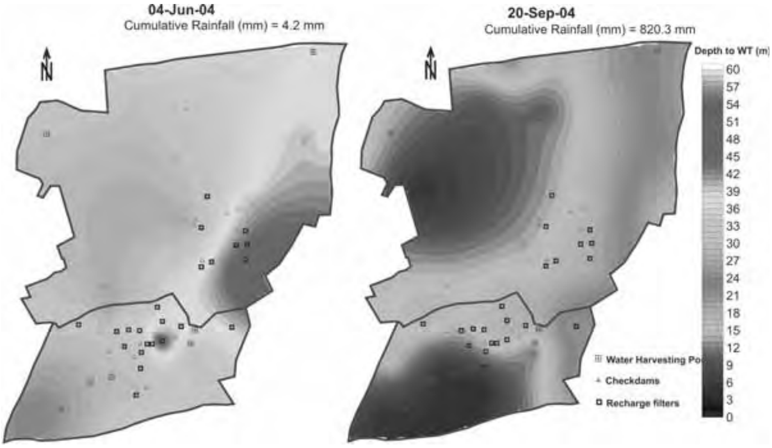
Water Quality Studies in the Watershed as Affected by Groundwater Recharge

It was observed during 2003 that the quality of water (from irrigation perspective) was found to be better in the area having recharge structures (Figure 5). The better quality class C_2S_1 has gained an area of 326.1 ha after the monsoon from a mere 60.9 ha before monsoon. The poorer quality classes C_3S_3 and $C_4S_{2,}$ which had an aerial extent of 3.2 ha and 13.8 ha, respectively, were found to disappear after the monsoon. The predominant quality class of the watershed was C_3S_1 (Table 5).



(a) Pre-monsoon (b) Post-monsoon

Figure 3. Pre-monsoon and post-monsoon (2003) groundwater table scenario of the watershed (Source: Sena et al., 2003)



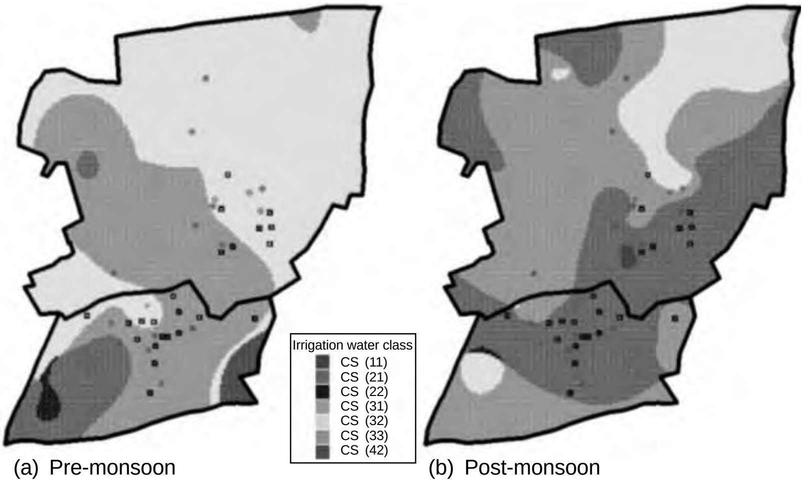
(a) Pre-monsoon (b) Post-monsoon

Figure 4. Pre-monsoon and post monsoon (2004) groundwater table scenario of the watershed. (Source: Sena et al., 2003)

Table 5. Change in water quality class and their areal extent before and after the recharge period

Class	Pre-monsoon		Post-monsoon	
	(%)	Area (ha)	(%)	Area (ha)
C_1S_1	0.0	0.0	0.1	0.4
C_2S_1	7.5	60.9	40.2	326.1
C_2S_2	0.8	6.5	0.2	1.2
C_3S_1	35.7	289.9	44.6	361.8
C_3S_2	53.9	437.7	15.1	122.5
C_3S_3	0.4	3.2	0.0	0.0
C_4S_2	1.7	13.8	0.0	0.0

Source: Sena et al., 2003.



(a) Pre-monsoon (b) Post-monsoon

Figure 5. Irrigation water quality as affected by groundwater recharge during 2003. The rectangular symbols depict the recharge filters and the circular 'dots' represent the water harvesting check dams (Source: Sena et al., 2003)

Conclusions

Integrated watershed development programs (IWDP) promote *in-situ* water harvesting through decentralized network of water harvesting structures as exemplified by the case study in Antisar watershed. Efforts have been made to critically appraise the characteristics of water storage structures in relation to their position and size. The case study also shows the impact of water harvesting structures on inducing the potential recharge. The effect of various water harvesting activities comprising both direct and indirect recharge techniques on the quantity and quality of water has also been analyzed.

The IWDP initiatives not only augment the groundwater recharge but also improve the water quality of the aquifer. Adopting the methods undertaken in Antisar case study can only check the alarming rate at which the water table is declining. It is important to note that the recharge by a structure is limited to a certain maximum value; hence the recharged water should be used judiciously and sparingly.

Once a suitable site is selected to build the structure, it is very important to involve the local community in the construction of the structures. The community involvement would ensure sustainability of the system in the long run. Groups of local people need to be put in charge of the system to ensure that water is equitably distributed amongst all the stakeholders. Further, contrary to natural water harvesting techniques, when rainwater is being injected straight into the aquifer system, there may be severe consequences if the injected water is contaminated, as this may contaminate the good quality water already stored in the aquifer. Therefore, proper filter to trap any debris and a suitable water treatment plan, if necessary, is a must before allowing the water to enter the groundwater system.

Eco-efficiency alone cannot meet our water resources appetite following current utilization patterns. Utilization is a key to understanding the policy challenges as it focuses on our ever-increasing demands for water. One very important factor that also needs to be considered is to look into the consequences of storing the water upstream and its impact on communities downstream. If the downstream communities rely heavily on the surface waters for their survival, storing of water in the upper catchments may lead to social conflicts. Hence, water harvesting should be based upon realistic requirements and consumption patterns to meet the basic needs of people in a harmonious manner. Close look at consumption pattern will illustrate vividly that poor not only consume less water but they also pollute little. Investigation about consumption can tell a great deal about problematic relationship between economic growth and satisfaction of basic needs and human aspirations.

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