Advances in integrated water resources management research in agriculture

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Abstract

This paper presents an overview of integrated water resources management (IWRM) with particular reference to agricultural water use in sub-Saharan Africa (SSA). The importance of adopting an integrated, river basin based approach to analyse water availability and to assess the possibilities for water resources development, water productivity improvements, and water savings is highlighted. The role of storage, the merits and demerits of different techniques for improving water productivity, the need for sustainable management of groundwater, and the potential for recycling wastewater for agricultural production are discussed. The importance of effective and user-friendly policy and institutional mechanisms to promote uptake of and derive optimum benefits from technological and management advances is underlined.

What does integrated water resources management mean?

The concept of integrated water resources management (IWRM) was born of the realisation that water policy and water management were often too fragmented to effectively address important questions such as:

- how can society's needs for water be met in a sustainable way?
- how can the aspirations and priorities of different categories of users at local, national and regional levels be addressed?
- how to strike a rational balance between beneficial utilisation of the resource and resource protection?

Population growth and greater demand for water exert increasing pressure on available water resources and lead to water scarcity in many countries and regions, especially during dry seasons and droughts. In addition, rising demand intensifies competition among water uses and water users and may trigger disputes and conflicts.

IWRM is a comprehensive approach to water management that takes into account different types of water (e.g. surface water and groundwater, brackish and fresh water), combining both quantitative (e.g. floods, droughts, consumption) and qualitative aspects

(e.g. pollution, water temperature changes, ecological functions). IWRM also offers a platform for managing actual and potential conflicts among various interests and users (e.g. households, industries, agriculture, nature, fisheries, energy and navigation).

In general, IWRM means making decisions on the development and management of water resources from a multi-disciplinary, quantitative, qualitative and ecological perspective involving all uses and users of water. IWRM is founded on an understanding of the interactions and interfaces between those different uses and users, particularly the impacts of water use by a particular sub-sector, or at a particular location, on other sub-sectors or locations.

Scope of the paper

This paper reviews concepts and issues related to IWRM in relation to the challenge of meeting the expanding food and fibre requirements of growing populations in SSA. The many facets of agricultural water use, with particular reference to tools and approaches for increasing water availability and realising water productivity improvements in light of the multiple uses and users of water in river basins are discussed. The need for an enabling environment, including policies, institutions and support services, in seeking strategies to improve and sustain agricultural water use, is highlighted.

Water and food security challenges in sub-Saharan Africa

Achieving the goal of food security in SSA has to contend with the fact that some of the world's most water-scarce countries are located in the region. Research carried out by the International Water Management Institute (IWMI) (Seckler et al. 1998; Seckler et al. 1999) shows that almost all countries in Africa would face either absolute or economic water scarcity in 2025. In the first case, countries will simply not have sufficient water resources to meet their projected agricultural, domestic, industrial and environmental needs, even if water is used with the highest feasible efficiency and productivity. The second set of countries, although having sufficient water resources, will be limited by their capacity to develop the additional storage, conveyance and distribution facilities needed to harness those resources for agricultural development and food production. In addition, these studies project that almost all the African countries will have to import over 10% of their total cereal consumption in 2025.

In many countries in the semi-arid regions of SSA, rainfed agriculture is practised extensively. But rainfed agriculture is highly dependent on the quantity and reliability of rainfall, which determine critical decisions such as crop choice and planting dates. Irrigation, if properly designed and managed, helps overcome many of the disadvantages inherent to rainfed agriculture. It overcomes the need for shifting cultivation and reduces the pressure on fragile environments. The risk of crop failure is minimised and farmers can

hope for higher and more reliable agricultural production and better levels of income. However, large-scale irrigation expansion is slowing down as the best sites are progressively exploited, the cost of developing the less favourable sites rises, and the availability of investment capital diminishes. The generally disappointing performance of large irrigation systems and the social costs associated with large-scale developments act as further disincentives.

Increasing competition for available fresh water resources means that countries are obliged to make hard choices in developing and allocating water between agriculture and other uses. If water allocations to agriculture are reduced and instead diverted to sectors considered to be more lucrative, prospects for increasing food production, which even now is hard-pressed to keep pace with population growth, may be further undermined.

Appropriate decision-support tools and techniques can play a significant role in water allocation. The Water Evaluation and Planning System (WEAP) is one such example (SEI 2001). IWMI has begun using it as a research tool to simulate and analyse water allocation scenarios in river basins in response to various sources of supply (e.g. rivers, groundwater, and reservoirs) and variations in abstractions, demands, and ecosystem requirements etc. The scenarios address a broad range of 'what if' questions, such as: What if population growth and economic development patterns change? What if ecosystem requirements are tightened? What if irrigation techniques and crop patterns are altered? What if various demand management strategies are implemented? Preliminary results of an application of WEAP to the Steelpoort basin in South Africa are reported in Lévite et al. (2002).

So, the challenge before us is how to make the most productive use of the available land, water, financial and other resources, including the adoption of policies and institutional arrangements, to promote economically and ecologically sustainable soil, water and crop management practices, and agricultural production.

Agricultural water use and IWRM in the basin context

Agriculture is the world's biggest user of land and water resources; it accounts for over 85% of water withdrawals in Africa (Rosegrant and Perez 1995). But at the same time, not all of the water withdrawn for irrigated agriculture reaches the crops—it either evaporates, seeps through canals, or leaks through pipes. Sally et al. (2000) pointed out that the imprecise nature of many canal water delivery systems and surface irrigation methods leads to more water being applied than crop transpiration needs because of the difficulty in (a) ensuring that all crops in the field receive a uniform and adequate water supply and (b) knowing when enough water has been applied. Water applied in excess of crop transpiration evaporates from soil surfaces, or percolates past the root zone to groundwater, or ends as surface runoff and return flows to the drainage and supply systems. Some of this 'lost' water is thus available for reuse especially if pollutants such as agro-chemicals, salt residues, or domestic and industrial waste have not adversely affected its quality (Seckler et al. 1998). In terms of a basin, irrigation return flows are therefore externalities that are sometimes positive, as for

instance when groundwater is recharged, and sometimes negative, for example when salinity build-up is exacerbated; hence the need to take a basin perspective to ascertain if such excess water is desirable or not.

Water savings: Some misconceptions

It is recognised that the river basin is the appropriate unit for planning, developing and managing water resources, and for analysing water availability and water use, and thereby, the scope for water savings. Sakthivadivel et al. (2001) pointed out that water saving means different things to different people. If a farmer uses less water in his fields, he may well consider that he has also saved water. But increases in efficiency (which typically relates the quantity of water beneficially used to the amount of water diverted) at a local level do not necessarily lead to water savings at a basin scale, especially if return flows are being reused or contribute to groundwater recharge. In such situations, any reduction in the amount of water diverted for irrigation will have an adverse impact on water-related activities downstream, especially if the basin is 'closed'.[1] But in cases where there are drainage flows out of the basin or to sinks, then using less water in the field will also translate into water savings at the basin level.

Agriculture and irrigation projects on the one hand, and technological and management interventions on the other, are often justified on the basis of water savings. But, as shown above, this may sometimes be misleading. The adoption of these techniques may result in less water use per hectare and an increase in water productivity on some fields. But to determine whether water was really saved or not, we have to find out what happens to the water that is not used. If water is not affected by pollutant loading and can be used productively at another location, then there is no net change in water use (i.e. water productivity increases, but there is no overall water saving).

Some tools and techniques

When contemplating water resources development, we therefore see the importance of properly accounting for water flows in a river basin, including return flows from seepage, percolation and surface runoff traditionally counted as 'losses' at farm and system level. Molden and Sakthivadivel (1999) showed how this could be done using a water accounting framework that integrates water balance information with the various water uses within a basin. The different ways in which water flows into and out of basins can be assessed and potential areas of water scarcity and those where further development of water resources can occur identified.

1. In a closed basin, all of the water in the basin is fully committed and depleted by various uses within it and there is no outflow of utilisable water. Any further depletive use in one part of the basin will thus affect users in other parts. In such cases additional water needs can only be met through gains in water productivity (e.g. by reducing non-beneficial evaporation, by reallocation or by augmentation from an outside source). In an open basin, on the other hand, there are outflows of utilisable, uncommitted outflows all year round and more water could be developed even in a low flow season without diminishing existing uses.

While there are many proven hydrologic models that can estimate likely runoff given particular combinations of rainfall, land cover, topography etc. rather less is known about water abstractions for irrigation and other uses. Many water abstractions are private and small scale, and do not enter directly into the official records of water use in a basin. But they can have a significant cumulative impact that ultimately will affect natural hydrologic regimes. Approaches combining analysis of past records, field surveys, interviews of key informants, and the use of remote-sensing images and data contained in global databases such as the IWMI World Water and Climate Atlas (IWMI 2000) may be useful in this regard. Droogers (2002) provided an overview of the available global datasets on irrigated areas and an evaluation of their strengths and weaknesses and shows that remotely sensed data can usefully complement existing field-based approaches and land-use classification information to map irrigated areas and to assess actual evapotranspiration from both irrigated and non-irrigated areas.

The foregoing discussion shows that, in reality, water used for agricultural purposes may have a variety of other uses; the full potential of agricultural water use cannot be realised without an overall knowledge and understanding of basin-level water use and availability.

Meeting increased demands for agricultural water use

There are two ways of meeting this increased demand: developing additional water supplies (e.g. reservoir construction, trans-basin diversions), or making effective use of existing facilities. The role of storage will be discussed as an example of the first approach; in the case of the second, attention will be focused on improving water productivity. Discussions of the potentially important contributions of (a) groundwater and (b) the recycling of wastewater towards enhancing agricultural production will conclude this chapter.

Role of storage

Different rainfall regimes result in different levels of availability of fresh water resources. In permanent humid climatic zones, rainfall distribution is regular and runoff is quite stable. In many seasonally humid and semi-arid climates, river runoff is irregularly distributed within the year—heavy rain alternates with dry spells resulting in alternating flood and drought periods. Such areas stand to benefit from suitable measures to capture and store excess water for irrigation, industry and domestic use.

The essential function of storage, whether in reservoirs, tanks, farm ponds, or groundwater aquifers, is to help meet water demand in the face of spatial and temporal variations in natural water supply. Keller et al. (2000) discussed different ways of storing water: in the soil profile, in underground aquifers, and in reservoirs. They point out that storage of water in the soil profile, though important for crop production, is very short-term, lasting only a few days. Small reservoirs can store water for some months whereas in the case of large reservoirs or aquifers, the storage horizon can extend to years.

While recognising that each storage technology would have strong comparative advantages under specific conditions of time and place, they show that substantial gains can be achieved in water resources development projects by integrating aquifers and reservoirs, wherever possible.

Enhancing the productivity of water

When managing water for agriculture, especially in areas where water rather than land is the limiting resource, the focus should shift to increasing the productivity of water. That is, to identify and adopt agricultural and water management practices that achieve more output per unit of water consumed, thereby easing the strains of water scarcity and reducing the need for additional storage.

Techniques such as deficit, supplemental or precision irrigation that allow better control, timing and reliability of water supplies will enable farmers to apply limited amounts of water to their crops in the time and amount that help realise optimum crop response to water. One can select crops or crop varieties that are less water consuming or which yield higher physical or economic productivity per unit of water, or adopt improved land preparation and fertilisation practices. Any water thereby freed up can, in turn, be reallocated to other uses with potentially dramatic increases in overall economic productivity of water.

Sally et al. (2000) discussed issues related to the adoption of precision irrigation techniques in a basin perspective: what they are, where in the basin they could be promoted, and how they could benefit poor people. It is emphasised that such techniques are not always high-technology options but include a broad range of innovative and affordable technologies and water management practices such as simple bucket and drum kits for drip irrigation, small sprinkler systems, level basins, and conventional drip and sprinkler systems. They enable farmers with limited access to water to make effective use of that water; in addition, non-beneficial evaporation can be minimised and water diversion requirements from the source reduced. Overall, small, resource-poor farmers in water scarce areas thus have an opportunity to improve agricultural production, household food security and income. This is especially important for farmers in marginal areas of SSA given that the 'costs' of water scarcity invariably tend to fall more heavily on the poor, particularly women who constitute nearly half the agricultural labour force (van Koppen 1999).

In light of the spatial and temporal interactions between different water users in a basin, it is important that water conservation interventions be properly located within the basin. The concept of 'hydronomic zones' (*hydro*: water, *nomus*: management) introduced by Molden et al. (2001) provides a simple framework for interpreting water use, evaluating water-balance based performance measures, and formulating strategies for the development and management of basin-wide water resources. It provides guidance on whether the geographic location and quality of outflows would allow reuse or not, thus helping to target and prioritise efforts and investments for more productive use of water.

Sustainable management of groundwater[2]

Groundwater development offers major opportunities for promoting food production and improving livelihoods in many countries with high levels of rural poverty. Groundwater is also an increasingly important source of water for urban and industrial uses. Affordable water-lifting devices such as small diesel or electric pumps, or muscle-powered treadle pumps have dramatically improved poor people's access to groundwater in Bangladesh, eastern India and Nepal (Shah et al. 2000). At this scale, the capital requirements to develop groundwater irrigation are generally low and its productivity is higher compared with surface irrigation. It offers farmers irrigation water 'on-demand' and reacts slower to drought.

Benefits of groundwater development have to be balanced against the risks of over-exploitation and contamination. Groundwater is being heavily depleted in many areas—the 1 to 3 metres annual decline in water tables occurring in pump intensive areas of India and China illustrate the gravity and magnitude of the problem. This is compounded by problems of inequitable access to water and health problems arising from contaminants such as arsenic, fluoride or other contaminants.

Management of groundwater resources is a typical example of how to reconcile resource use against resource conservation. The lack of reliable data on water availability, quality and yield and aquifer characteristics in many semi-arid areas of SSA is a serious constraint to establishing the limits to groundwater use. Measures to regulate groundwater overdraft should be combined with approaches to promote groundwater recharge and increase water productivity. The associated challenges are formidable. But they have to be faced if we hope to make use of the available reserves of groundwater in a rational and sustainable way.

Recycling of wastewater in peri-urban agriculture

Although the rural population remains in the majority, the rate of urbanisation in SSA is higher than in any other continent (Merrey et al. 2002). Driving this phenomenon are demographic growth and migration to cities. A common feature of growing cities is that they generate large volumes of wastewater but possess little or no sanitation infrastructure. Poor sanitation results in wastewater entering waterways used for agriculture in urban and peri-urban areas and hence *de facto* recycling of wastewater.

Urban and peri-urban agriculture is increasingly becoming an important source of livelihoods, income and nutrition. It fills a niche for perishable products such as fruits and vegetables, produced and marketed directly with very little processing. It contributes to household food security of the urban poor and marketable surpluses provide a regular source of income to peri-urban farmers, particularly women. But very often, the source of water and nutrients in peri-urban agriculture is city 'waste', far more reliable than rainfall, but with attendant health implications.

The global extent of peri-urban agriculture is not known but available estimates indicate that about 900 thousand hectares of cropland worldwide are irrigated using treated or

2. Adapted from Sakthivadivel and Sally (in press).

untreated municipal wastewater, with Mexico alone accounting for over 600 thousand hectares (Raschid and Abayawardena 2002). It is suspected that this is just the tip of the iceberg and comprehensive assessment at a global level is needed to understand its significance. Countries in Africa (such as Botswana, Ghana, Kenya, Mozambique, Namibia, South Africa, Zambia and Zimbabwe) are examples where wastewater (with varying degrees of treatment) is used for agriculture. In fact, the National Agricultural Master Plan in Botswana makes provision for treatment facilities to ensure the reuse of wastewater for agriculture. In Ruai, Kenya, the effluent has been treated to a degree compatible with World Health Organization (WHO) micro-biological quality guidelines for irrigation of crops without risk to workers and the public (Hide et al. 2001; Inocencio et al. 2002).

On-going research is focused on developing and promoting technical, management and policy options to support wastewater use in peri-urban agriculture that adequately address concerns such as the possible health hazards to workers and the consumer, the effect of repeated application of wastewater to the soil, and the possible accumulation of contaminants in the soil and groundwater. They include crop restriction, low cost treatment at the point of use (such as short-term retention of water in pools before applying to the crop), additional pre-treatment, alternative irrigation methods (furrow, drip and trickle irrigation are supposed to reduce risks to farm workers) and controlled use of effluent.

Further details and discussion on the subject of reuse of waste for irrigation can be found in Drechsel and Kunze (2001) and Hussain et al. (2002).

Institutions, policies and support services

Sound institutions and policies, together with the development of the requisite organisational capacity and skills for enforcement and regulation, are vital to ensure uptake of technological innovations and advances and that the ensuing benefits are equitably distributed, particularly among the most disadvantaged sectors of society.

Key institutional attributes include:

a. demarcation of the roles, rights and responsibilities of the various actors in the water sector
b. promotion of new forms of partnerships for investment, operation and maintenance of facilities
c. participation of stakeholders at all levels and scales and
d. emergence of financially self-reliant service delivery organisations that are responsive and accountable to water users.

But there are huge challenges ahead. Traditional, sectoral and fragmented approaches to water resources management with different agencies and departments pursuing divergent interests (e.g. the promotion of irrigation development at the expense of ecological services) must be overcome. Upstream and downstream water-users need to develop a better understanding of their inter-dependencies. Water management

decision-makers should not only have good technical skills and competencies, but should also be encouraged to consult with, and be sensitive to the views of, all stakeholders.

When agricultural water stakeholders are provided with reliable and responsive support services, they are more likely to invest in improved technologies and practices, usually resulting in improved performance, increased production, and higher incomes. The support services on offer should therefore be commensurate with the (often scarce) skills and resources available in rural environments. Reliable service delivery requires the establishment of:

a. clear rules and agreements between providers and users giving details of the nature of the service, including the compensation arrangements for providing and receiving such services
b. mechanisms for monitoring and control of obligations
c. modalities for resolution of conflicts and disputes and
d. procedures for modifying and updating agreements.

These factors take on added significance in light of the progressive disengagement of public agencies from many aspects of agricultural water management accompanied by the transfer of responsibilities to the beneficiaries.

Concluding remarks

Feeding the world's population means contending with growing demands for food and nutrition, more pressure on arable land, increasing competition for water resources, and dealing with major concerns about deteriorating ecosystems. The challenge therefore is to manage land, water and other natural resources to achieve food and environmental security, alleviate poverty and raise living standards in an equitable and sustainable manner.

Water rather than land is generally the limiting resource in SSA—whereas some countries just do not have sufficient water resources, others do not have the means to develop the additional supplies to meet their needs. In this paper, emphasis has been placed on improving the productivity of agricultural water use, as part of an integrated and holistic approach to water resources management.

The use of models and indicators at field, system and basin levels to understand water use, water availability, water productivity and water allocation has been discussed. Identifying and promoting affordable but effective technologies to capture, collect and distribute water that are commensurate with local conditions, organisational skills and expertise, have significant scope for improving household food security and the livelihoods of the poor. The importance of effective policy and institutional mechanisms that reflect the aspirations of all stakeholders to derive the full benefits of technological innovations and approaches has also been underlined.

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