WATER RESOURCES IN ARID REGIONS AND THEIR SUSTAINABLE MANAGEMENT

Dieter Prinz & Anupam K. Singh
Institute of Water Resources Management, Hydraulic and Rural Engineering (IWK)
University of Karlsruhe, Kaiserstr. 12
76131, Karlsruhe/ Germany Fax. +49- 721- 608 6165
E-mail. <prinz@iwk.uni-karlsruhe.de>

Abstract: *Arid land's imminent water problems are nowadays aggravating, as has been referred in many research publications. In general these problems are complex not only due to technical and economic parameters, but also due to policy and institutional framework, human resources development and socio-cultural reasons. The aim of this paper is to reflect the wide variety of water related topics with their inherent complexity and identify water resources research areas for next decades.*

The paper proceeds by reviewing the nature of problems that are emerging in water resources management, and the policy and institutional challenges that have been presented in various forums. It then suggests what water resources strategies and options will be important in research and policy in order to respond successfully to these challenges. Finally the paper suggests future research needs which will make difference for various communities and countries around the globe.

Key words: water resources, water management research, arid regions

1.0 INTRODUCTION

Water is essential for all forms of life and is a fundamental resource for human survival and socio-economic development besides for maintaining healthy ecosystems. Consequent to rising water demand, it is rapidly becoming a scarce resource for most of regions in Developing World which requires new methods and innovative approaches for conservation and judicious use. The dependence of arid and semi-arid agriculture on the irrigation holds a special place in the water scarcity and management debate, as it uses more than 70% of the world's total water supply- and up to 90% in some developing countries including Nepal (99%), Sri Lanka (96%), Cambodia (94%), Indonesia (93%), Thailand (91%) and Myanmar (90%) respectively (FAO, 1999). In many countries irrigation is viewed as an important input to the agricultural production systems owning to life support system. The increased pressure on water resources due to (1) population growth- demanding not only more water for food, but also inducing changes in hydrological cycle, (2) changes in life style and urbanisation and (3) climate change, lead to water scarcity and increased competition for water between agriculture, industries and the rapid growing cities.

Water tables are now falling in every arid and semi-arid region of the world. We are a part of water competitive world, where each year as 80 million people stake their claim to the earth's fresh water resources. UNFPA estimates that most population growth is taking place in the world's poorest and least-prepared countries. Unfortunately, nearly all the projected 3 billion people to be added over the next half century will be born in countries that are already experiencing water shortage. The world water deficit grows larger with each year, making it potentially more difficult to

manage. If we decided abruptly to stabilise falling groundwater tables everywhere by simply pumping less water, the world grain harvest would fall by some 160 million tons (8% of total production) and grain prices would go off the top of the chart (Brown, 2000). If the water shortage continue to widen, this will result in food deficit including population giant like China and India.

The overall result of population increase has been a dramatic decrease in the annual per capita availability of freshwater in Developing Countries. At current rates, by 2025 as much as two thirds of world's population will experience periods of water stress (Bakkar et al. 1999; Seckler et al. 1998). Water availability varies greatly within the region. For example, Singapore is currently meeting its freshwater demand by importing some of its supply from Malaysia (compiled from WRI, World Bank, UNDP).

Last decades have witnessed a dramatic shift in the priorities of water resources allocation and development. Some 70% of the freshwater consumed world-wide is used for irrigation, while 20% is used by industry and 10% for drinking and residential purposes. In the increasing intense competition for water among sectors, agriculture sector is losing against other sectoral water uses. Lester R. Brown (2000) cited the major reason for shift is due to high economic output from industrial and urban sector. For example the 1000 tons of water used in India to produce 1 ton of wheat worth perhaps US $ 200 can also be used to expand industrial output by easily US $ 10,000 (i.e. 50 times higher returns). Thus the present situation warrants urgent attention, since water, as a scarce and commonly shared resource, may become a cause of conflict.

2.0 RECOGNISING THE CHALLENGE

2.1 Water Resources Management Policies

The sustainable use and development of water and land resources is now a days a problem of paramount importance for all socio-economic sectors and agro-climatic regions. Imbalance between demand and supply, resources degradation, inter-sectoral interactions and competitions call for new water resources management. The water resources sustainability as described (Hamdy & Wrachien 1999, Bell & Morse 1998, Richter et al. 1996) have the following aspects:

a) **environmental aspects** of sustainable development: maintaining the integrity of ecosystems and bio-diversity of largest possible extent.
b) **economic aspects:** increased efficiency in water use and water as an economic good in the distribution of the resource.
c) **socio-cultural aspects:** sensitivity to the values and tradition of each society including participatory development, equitable access to resources, social services and employment opportunities.
d) **institutional aspects:** good governance and protection of natural resources and basic human rights.

According to Brundtland Commission (1987) sustainable development can be defined as the “development that meets the need of the present without jeopardising

the ability of future generations to meet their needs". Thus an assessment of sustainability would be incomplete without addressing all of the above aspects. As quoted in Bell & Morse 1998 (refer Table 1) the United Nations working list of sustainable development indicators;

Table 1: The United Nations working list of sustainable development indicators

Category	Main chapter heading
Environmental	promoting sustainable agriculture and rural development combating deforestation conservation of biological diversity protection of the atmosphere environmentally sound management of biotechnology
Economic	changing consumption pattern financial resources and mechanism
Socio-cultural	Combating poverty demographic dynamics and sustainability promoting education, public awareness and training protecting and promoting human health promoting sustainable human settlement development
Institutional	science for sustainable development information for decision making strengthening the role of major groups

Source: adopted from Bell & Morse, 1998 p.25

Water Resources Management in Agenda 21

The application of integrated approaches to the development, management and use of water resources including protection of the quality and supply of freshwater resources has been bases for implementation of Agenda 21 recommendations. The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population while preserving the hydrological, biological and chemical functions of the ecosystem, adapting the human activities within the capacity limits of nature.

The Agenda 21 identifies the following programme areas for fresh water sector considered important for action research and local implementation:

a) ***Integrated water resources development and management*** (IWRM) is based on the perception of water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilisation (UN Water Conference, Mar del Plata, 14-25 March 1977). IWRM including the integration of land and water related aspects, should be carried out at the level of catchment basin or watershed level. In case of trans-boundary water resources, there is a need to formulate water resources strategies, prepare water resources action plans or master plans.

b) ***Water resources assessment (WRA)*** is to identify potential sources of freshwater supply, dependability and quality of water resources and of human activities that affect those resources. WRA has been extended to predict possible conflicts between supply and demand and to provide specific data bases for rational water resource utilisation.

c) ***Protection of water resources, water quality and aquatic ecosystem*** is based on holistic freshwater management and balanced consideration of the needs of people and the environment. In particular, this consists of maintenance of ecosystem integrity, public health protection and human resources development.

d) ***Drinking water supply and sanitation*** is based on the need to provide, on a sustainable basis, access to safe water in sufficient quantities and proper sanitation to all (adopted at the Global Consultation on Safe Water and Sanitation in New Delhi from 10-14 September 1990) emphasising the "some for all rather than more for some" approach. This includes community management of services backed by measures to strengthen local institutions, and sound financial practices achieved through better management of existing assets and widespread use of appropriate technology, in implementing and sustaining water and sanitation programmes. The recent recommendation of World Water Commission (Hague 2000) further emphasise that "every human being, now and in the future, should have enough clean water, appropriate sanitation, enough food and energy at reasonable cost." Providing adequate water to meet these basic needs must be done in a manner that works in harmony with nature.

e) ***Water and sustainable urban development*** is the identification and implementation of strategies and actions to ensure the continued supply of affordable water for present and future needs in urban environments and to reverse current trends of resource degradation and depletion. The development objective of this program is to support local and central government's efforts through environmentally sound management of water resources for urban use. The development activities include protection of water resources, efficient and equitable allocation of water resources, promotion of public participation, support to local capacity building and enhanced access to sanitary services.

f) ***Water for sustainable food production and rural development*** depends on sound and efficient water use and conservation practices consisting primarily of irrigation development and management, water management for rainfed areas, water for aquatic and terrestrial ecosystems. Due to rising water demand in the agriculture sector, multiple use of water should be given priority.

g) ***Impact of climate change on regional water resources*** remains an uncertainty with respect to the prediction of climate change at global and/or at regional scale. It is assumed that average higher temperature and a more erratic precipitation of higher intensity would lead to decreased water supplies and increased water demands, putting strain on already fragile balance between water supply and demand in many tropical countries.

Dublin Statement on Water and Sustainable Development

Scarcity and misuse of fresh water pose a serious and growing threat to sustainable development and protection of the environment. During the International Conference on Water and the Environment (ICWE) in Dublin on 26-31 January 1992 a call for fundamental new approach to the assessment, development and management of fresh water resources was issued. Accordingly a concerted action is needed to reverse the present trends of over consumption, pollution, and rising threats from drought and floods. The Conference Report sets out recommendations for action at local, national and international levels, based on four guiding principles.

Principle No. 1 - Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment

Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.

Principle No. 2 - Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels

The participatory approach involves raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

Principle No. 3 - Women play a central part in the provision, management and safeguarding of water

This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women for specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

Principle No. 4 - Water has an economic value in all its competing uses and should be recognised as an economic good

Within this principle, it is vital to recognise first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognise the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient use, and of encouraging conservation and protection of water resources.

Calcutta Declaration for Implementing Sustainable Development Agenda

Recently concluded World Congress on Sustainable Development at Calcutta, India during 20-23 January 2000 under the aegis of World Federation of Engineering Organisations (WFEO) and supported by the Commonwealth Engineers Council (CEC) recommended the followings for implementing sustainable development agenda for water resources:

- The river basin-wise development is to be supported, in place of riparian right of the user.
- Complex river basin development with inter-basin transfer must be planned and managed to ensure ecological balance in the concerned basins.

- Dependence on groundwater for agriculture and drinking purposes should be limited to the extent that the use is sustainable.
- The national and international opinions must converge to support sharing of common water resource to the benefit of all concerned (IEI, 2000).

Effective water management policies will have their important role in guiding water sector strategies and options that sustain economic development and human capacity building, and protect the eco-regional environment. The following emerging principles for effective water sector functions and successful water sector activities are:

A. **Principles for essential water sector functions**

- National water resources management should be undertaken in a holistic and sustained manner to meet national development goals.
- Planning, development and management should be decentralised to an appropriate level responding to basin boundaries.
- Delivery of specific water services should be delegated to autonomous and accountable public, private or/and co-operative agencies providing measured water services in a defined geographical area to users for appropriate fees.

B. **Principles for successful water sector activities**

- Water use in society should be sustainable within a transparent policy framework.
- Shared water resources between nations and within states should be allocated efficiently for the mutual benefit of all riparian users.
- Water sector development activities should be participatory and consultative at each level, leading to commitment by stakeholders and actions that are socially acceptable.
- Successful water development requires a commitment for monitoring & evaluation, research and learning at all levels, to respond effectively to changing needs at community, regional, river basin and international level (Hamdy et al. 1999).

2.2 Sustainable Management Strategies

Integrated Water Resources Management is a dynamic and interactive multi-sectoral, inter-disciplinary process to reconcile conflicts between competing interests for water uses and sub-sectors supported by decision making at the appropriate level. This includes recognition of the interfaces with other water sectors outside irrigation systems, these involves work to understand the likely impact of competition on the quantity and timing of water available for irrigation. The various elements of an integrated water resources management approach include:

Adopting a Basin-wide Approach

It is widely accepted that the river basin is the most appropriate unit for planning water resources development and management. Resources development and management in one part of the basin will therefore have impact elsewhere in the

basin. River basin or watershed planning therefore resolve or unify planning processes at different levels and planning spheres. One of the evidence in all relevant case studies have shown the need for river basin or watershed planning and management.

As an example, the case of Nile water sharing among the riparian states of Ethiopia, Sudan and Egypt are all developing countries with agriculture based economies. In the downstream riparian states, Egypt and Sudan, there is limited rainfall and both have well developed irrigation systems on which they are socially and economically dependent. The upper riparian states are generally less developed and presently depend on unreliable rainfed agriculture, they are prone to drought and famine. There is a clear need for a new legal framework that would bring a more equitable balance of water rights and this can only be achieved through more integrated basin-wide planning (Walmsley & Hasnip, 1997).

Trans-boundary water resources development and management is linked strongly with political issues but there is much in common with national river basins, especially when there are several jurisdictions involved such as inter-provincial or inter-state river basins. The primary objective is to develop the resources of a basin for mutual benefit of all riparian countries or states through close collaboration.

Improving Environmental Planning

Environmentally-sound development is a key principle behind sustainable water resources utilisation. Environmental concerns and action plans need to be firmly routed in planning and management processes to ensure that adverse impacts are minimised and mitigation plans established. Environmental plans need to be developed and integrated in to basin planning activities.

The complex inter-relationship between surface and groundwater, water quality and quantity, land use and water need to be established through the application of Environmental Assessment Methodologies supported by expert advise. This can be achieved most effectively by creation of environmental units within basin planning organisations. As an example for water allocation and effective implementation of water resources in Tamilnadu state of India, has created a specialist Water Resources Organisation for inter-sectoral water planning and inter-state water allocation. The key responsibilities of the Environmental Unit are:

- prepare environmental management plans for river basins in Tamilnadu state.
- provide policy advice to Water Resources Organisation on environmental matters.
- establish state-wide water resources and environmental planning standards.
- plan for environmental mitigation and enhancement (vulnerability and hazards assessement)
- perform environmental review of projects to comply with regulation and acts
- undertake periodic reviews during operation and maintenance (Walmsley & Hasnip, 1997).

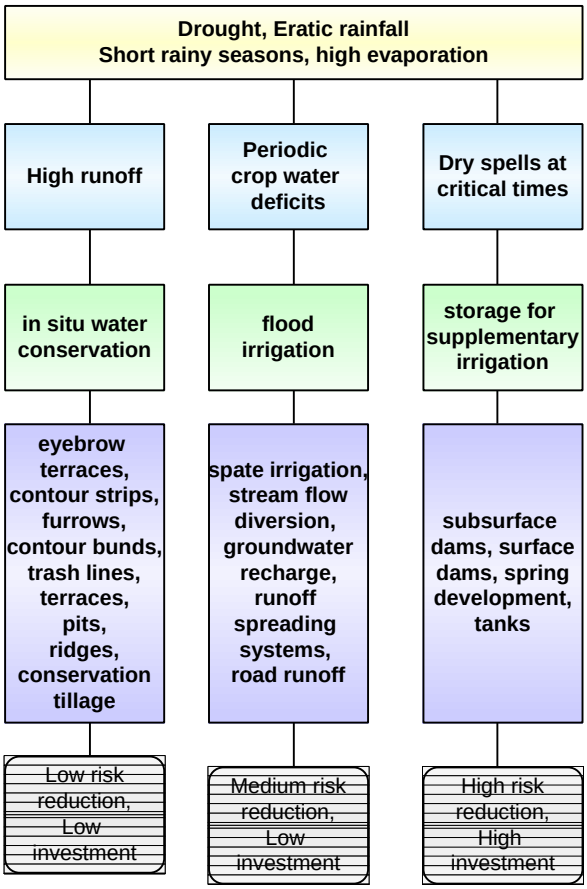
Basin-wide Water Accounting and/or Water Audit

The purpose of basin-wide water accounting is to establish a procedure for analysing the uses, depletion and productivity of water in river basin context (Molden, 1997). It should investigate the rate at which water use is increasing, review the effects of this increased use, describe the current levels of development, document trends, project trends for the future and assess the impacts of these changes. For example; changes in watershed vegetation can have profound impact on basin-wide water accounting. The emphasis needs to shift away from a purely water resources assessment focus to include greater consideration of water allocation, use and demand to support short and long term planning needs and overall policy and strategy formulation. Thus a water audit provides a basis for determining future course of actions such as changes to water allocations, restrictions on the construction of future storage and abstractions and reduction of water entitlements/ rights.

2.3 Water Resources Management Options

Improving Rainfed Production through Water Harvesting

Increasing the productivity of rainfed agriculture which still supplies some 60% of world food and occupies almost 75% of agricultural land, would make significant impact of global food production. However, the potential to improve agricultural yields depends strongly on rainfall pattern and its distribution. In dry areas, rainwater harvesting can both reduce risk and increase yields,as shown in the Figure 1:



There are various forms of rainwater harvesting:

- using microstructure in the fields to in situ water conservation;
- capturing and directing external water from the catchment area to the fields in which crops are grown (flood water harvesting);
- collecting external water from the catchment area and storing it in reservoirs, tanks and other structures for use during dry seasons (supplementary irrigation) (Prinz et. al, 1999).

Research results from ICARDA show substantial increase in crop yields in response to the application of relatively small amounts of supplementary irrigation. The average increase in wheat grain yield under low, medium and high annual rainfall at Tel Hadya, Syria were about 400%, 150% and 30% using supplementary irrigation of about 180 mm, 125 mm and 75 mm respectively.

When rainfall is low, more water is needed, but the response is greater. Supplementary irrigation not only increase yield, but also stabilises production. The coefficient of variation in production in Tel Hadya was reduced from 100% in rainfed crop to 10% when supplementary irrigation was practices (Oweis 1997).

Fig. 1 : Improving rainfed production with alternative water management in arid & semi-arid regions

Reuse of Treated Wastewater for Irrigation

Due to persistent water shortage for urban and peri-urban agriculture, use of treated wastewater is considered one of the potential alternative for irrigation. Biswas (2000) reported organised sewage farms by private farmers and controlled by municipal government in various cities across India. The average sale price for treated wastewater among the class-I cities ought to be INR 30/ha/year for Bhopal and INR 400/ha/year for Jaipur (1 US$ = INR 45 in February 2000). The volumes of wastewater used for irrigating crops are given in Table 2.

Table 2: Reuse of treated wastewater for irrigation in India

Location	*Area (ha)*	*Waste water volume (mld)*	*Treatment if any*	*Dilution if any*	*Application rate (m^3/ ha.day)*	*Soil type*	*Crops grown*
Ahmedabad	*890.3*	*299.9*	*Nil*	*Nil*	*336.8*	*sandy loam*	*paddy, maize, wheat, grass*
Bhilai	*607.0*	*36.3*	*secondary treatment*	*Nil*	*59.9*	*sandy loam*	*paddy, maize, wheat, pulses*
Delhi	*1214.1*	*227.2*	*primary & secondary*	*Nil*	*187.1*	*loamy sand, sandy loam*	*Barley, maize, pulses, vegetables*
Jamshedpur	*113.3*	*9.1*	*secondary*	*Nil*	*80.2*	*clay loam*	*grass, maize*
Kanpur	*1416.5*	*31.8*	*Nil*	*1:1*	*22.4*	*loam, silt loam*	*wheat, paddy, maize, potato, vegetables*

Source: Shende et al. 1997

Data available from agricultural farms using wastewater indicate that all types of crops are grown, irrespective of the extent of treatment received by the raw sewage and mode of consumption of such crops.

3.0 FUTURE RESEARCH AGENDA

Throughout mankind's history, water resources and irrigation development have played a major role in modernisation and human development. During the past decades, irrigation and water resources development provided a major part of the increase in agricultural production necessary to meet the growing food demand. By the mid-1980's, more than 35% of the total crop production came from less than 15% of the arable land which was irrigated (Pereira et al. 1996). Scarcity of water is a major constraint for further irrigation development in many arid and semi-arid countries including India, Pakistan and China. In many countries and regions, all available water resources which can be economically used have already been developed or are in the process of development. As the competitive demands for water continues to increase, it is imperative that this limited resource be used efficiently for agriculture and other uses. In some water scarce eco-regions, more

water will be diverted from agriculture to meet expanding needs for domestic, urban and industrial uses because of population growth and urbanisation.

Existing rural water resources management and irrigation methods are being placed under increased scrutiny from many fronts. Water resources management research must focus on other alternatives such as conjunctive use of water, increasing crop production per unit land, increasing crop production per unit evapotranspiration, including policy and institutional requirements. Yet, the fact remains that new water resources development and improved management of existing water systems must be capable of providing the needed food and fibre while simultaneously addressing key environmental issues.

The following issues are identified based on current on-going research projects, past technical workshops and conferences, development themes of multi-lateral and bilateral funding agencies and United Nations development charter for water resources management, agriculture and food production.

Merry & Perry 1999; Pereira et al. 1996 and other authors have identified some of the water resources and irrigation research needs for water resources utilisation:

a) ***Resource base issues***
- basin-wide integrated water resources planning;
- availability of water for irrigation;
- rainfed agriculture water management including water conservation and water harvesting;
- aquifer recharge
- environmental and health impacts.

b) ***water resources performance and impact assessment issues***
- rehabilitation and modernisation of irrigation systems;
- performance and impact assessment;
- technology and rules for use of drainage water, waste and saline water;
- water resources and irrigation system performance;
- water savings in irrigation.

c) ***institutional and policy issues***
- institutional issues;
- policy issues.

d) ***gender and socio-economic issues***
- economics of water resources development and rainfed agriculture;
- human resources development;
- user participation and gender involvement.

The priority topics related to resource-base issues as given in Table 3 are described. Basin-wide integrated water resources planning and the need for using non-conventional water resources in agriculture to face the increasing water scarcity and competition for water are considered to be important themes. The need to consider soil and water conservation measures as an integral part of basin-wide water resources planning is to be stressed.

Table 3: Priority research topics related to resource-base issues	
A. Basin-wide integrated water resources planning	
1.	develop a basin-wide water resources planning and management approach
2.	develop policies and procedures for transboundary basin planning
3.	develop strategies for water harvesting for arid regions
4.	develop decision support knowledge of drought and mitigation measures
5.	investigate the mechanisms for monitoring and controlling surface and ground water pollution/ salinity
B. Environmental and health impacts	
1.	study environmental impact resulting from non-maintenance of irrigation systems
2.	evaluate the potential of irrigation as a means for sustainable land use and food production
3.	assess potential for reuse of low quality and waste water for irrigation
4.	improve land evaluation criteria and methodologies used in water resources planning

The priority issues for water resources performance and impact assessment include all aspects for controlling the adverse impacts of irrigation on water quality. The need for developing new technologies and management practices at farm and basin levels are particularly to be stressed. Use of remote sensing, GIS and decision support modelling, field evaluation techniques are to be given priority (refer table 4).

Table 4: Priority research topics related to water resources performance and impact assessment	
A. Rehabilitation and modernisation of irrigation systems	
1.	adopt procedures for integrated planning and management of irrigation systems
2.	evaluate the impacts of irrigation modernisation on water distribution and irrigation efficiency
3.	develop locally adapted water-efficient on farm-irrigation technologies
4.	use of appropriate techniques improved for water regulation and control
B. Technology and regulation for use of saline and wastewater	
1.	develop methods, techniques and guidelines for use, control and management of low quality water for irrigation
2.	develop criteria and guidelines for use of saline water and coastal saline water table management
3.	improve knowledge on solute transport process
C. Water savings	
1.	develop reduced water demand cropping systems
2.	develop appropriate tools for implementing water savings to cope with drought
3.	explore crops and cropping patterns adequate for low water quality
4.	reuse/ multiple use of water

It is recognised that existing programs for transferring the managerial responsibility of irrigation and drainage systems to users are not always successful. This problem will require innovative solutions of policy and institutional nature. The priority research issues are listed in table 5.

Table 5: Priority research topics related to institutional and policy issues	
A. Institutional issues	
1.	determine the impact of land tenure and land reforms on irrigation development and performance
2.	investigate the mechanism to improve the co-ordination and responsibility between government, water user institutions and industry
B. Policy issues	
1.	develop appropriate procedure for allocation of surface and ground water for different uses
2.	establish water laws and rights which provide equity in water distribution and allocation

3.	develop legal instruments and procedure for implementing water conservation and efficient management practices

Policies, institutions and laws can be devised to increase water productivity at different levels. At local level, improved irrigation management would do much to improve efficiency, and give power to water users to plan and manage their own supplies. In addition, transparency and accountability must be improved as well as incentives will be provided for water savings. At the river basin level, a major priority is to improve integration not only between water and land use planning but also among the many other water users (see Figure 2).

The Nile basin initiative was launched in 1998 by the council of Ministers of Water Affairs of ten trans-boundary states that border the Nile river basin. UN Organisations has been helping nations improve the management of Nile basin for more than 10 years.

Food and Agricultural Organisation (FAO) has helped in to:

- develop a forecasting system for the Nile river and a control and decision support system for management of Aswan Dam reservoirs in Egypt;
- strengthen technical capability in the lake Victoria region to monitor water resources, develop modelling tools and establish a geo-reference database system for the region;
- built up capacity to manage the Nile basin water resources (FAO 1999b).

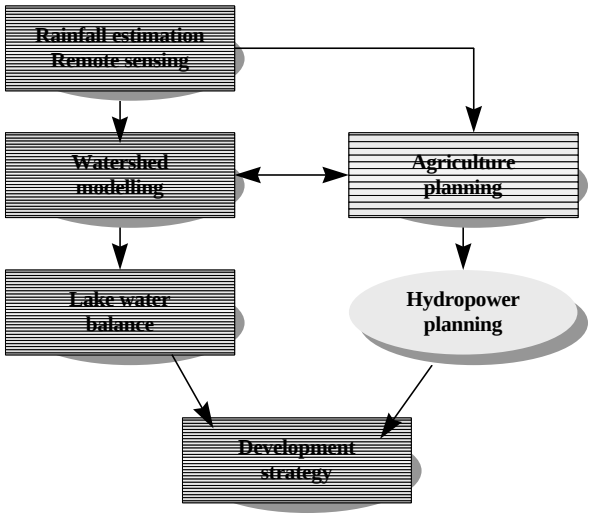


Fig. 2 Improving water resources management system for Lake Victoria

Generally, the gender and socio-economic issues are given less focus in water research, but are of significant importance. Training and local farmers capacity building, extension services, technology transfer tools are considered essential for specific and innovative approaches. The priority research issues are listed in table 6.

Table 5: Priority research issues related to gender and socio-economic

	A. Socio-economic issues
1.	determine socio-economic aspects of increasing water use efficiency in agriculture
2.	study impact of water pricing on water demand and consumption
3.	develop criteria to ensure the economic viability of water resources systems and financial responsibility of water users
	B. Gender and human resources development
1.	improve technology transfer at all levels of irrigation and water resources management
2.	involvement of women and minor groups in water management
3.	enhance institutional arrangements which enable appropriate training on water management

Gender equity and involvement of minority groups are crucial in relation to the maintenance and use of water resources. However, a gender approach to water resources management can be beneficial if women can decide and prioritise the water management and agricultural issues in the way they manage. Both innovative and traditional mechanism are needed to resolve these issues.

Legal reforms to improve access to water for women and minority group are needed in many Developing Countries of growing economies. Involving people to improve water management is internationally regarded as an important issues and should cover the following themes:

- allocation of water resources between different users, particularly those in rural and urban areas;
- minimising conflict between those who use the resources for water supply and those who use for waste disposal;
- promotion of efficient water use;
- reduction of the role of government in rural water projects, increasing the importance of local user groups
- ensuring legal access to land and water for women heads of household and women in general; and
- improvement of effective water rights administration to manage the water sector in general and the rural water sector in particular (FAO 1999b).

RECOMMENDATIONS FOR FUTURE RESEARCH

Planning and development of water resources Should be governed by the river basin and/or other natural units perspective. In view of the limited supply and increasingly competing demands, it is imperative to use limited water resources suitably. Since a large percentage of developed water is being used in agriculture production, it is all the most necessary to use water efficiently, productively and greater economic return. The efficiency and economy with which water is used for agriculture sector, will largely determine whether agriculture can take advantage of the changing economic opportunities.

The major research recommendation which emerged on the basis of above citations are as under:

Water Resources Assessment

- The procedure for assessment of water resources and their use in agriculture needs to be reinforced with improved scientific knowledge and precise field data. Assessment of minor irrigation and water harvesting potential should be effectively undertaken for additional irrigation development and utilisation.
- Water should be treated as an economic good and national asset which should be developed and planned for the benefit of the local users and regional stakeholders.

Agricultural Productivity in Irrigated Areas

- Conjunctive use of ground water and surface water to be given priority while preparing a water management plan for a watershed or irrigated area. This needs to be closely monitored through a widespread network of observation stations located within the watershed. Comprehensive water balance studies involving

rainfall, evapo-transpiration, soil and ground water recharge should be undertaken to ensure maintenance of conditions conducive to sustained agricultural production.

- Long term research investigation needs to be undertaken to assess the effect of canal, tanks and check dams irrigation on the agricultural production. Water accounting studies to be undertaken at river basin level to help planners and decision makers by giving a clear picture of their water resources for better timing of irrigation water application and reliability of irrigation water availability (Molden et al 1997).

Farm/Field Water Management

- When water delivered to farmers fields from canal network, the water need to be managed for efficient utilisation of crop production on a sustained basis. There is need to work out procedures to ensure equity and reliability of water supply, and minimise the mismatch between crop water requirement and canal water supply. Field water management will further suggest optimal allocation of water among competing crop uses under limited water supply, to develop procedure of performance assessment to determine the impact of irrigation from an economic, equity, environment and gender view point.
- Modern irrigation techniques such as sprinkler irrigation and drip irrigation should be promoted where water is scarce, and the topographic and soil conditions do not permit efficient irrigation by conventional methods.

Rainwater harvesting and water conservation

- Technical approach to rainwater harvesting, watershed management, planned development of groundwater resources and its conjunctive use with additional water sources, revitalising the village water bodies and tanks, active peoples participation at local level holds the key for economic betterment. An appropriate hydrological analysis research on rainfall-runoff, critical crop growth stages, design of irrigation systems, design of farm ponds, seepage control, assessment of benefits of supplementary irrigation to rainfed crops should be adopted for efficient use.
- Community based systems of rainwater harvesting and management need to be established for efficient irrigation water delivery, equity in water sharing and ensuring sustainable food security. Successful experience gained in watershed management and water conservation programmes in arid and semi-arid regions need to be adopted on micro or/and sub-watershed basis under various agro-ecological locations. Peoples participation and support of international donors for optimum and sustainable water resources development should be given priority.

Conjunctive Use of Surface Water and Groundwater

- Conjunctive use of surface water and ground water resources could mitigate the increasing problems of overuse and soil salinity. Specific conjunctive water use approaches and strategies have to be developed suitable for each agro-ecological region. There is need for research on devising strategies for implementation and for policy changes on pricing and legislation.

- Both conjunctive use and artificial recharge are governed by surface-ground water interactions. There is need to strengthen basic research on understanding these interactions in different regions and identify technologies for easy measurement of surface water flow, water quality, soil and aquifer parameters.
- In coastal areas, mining of ground water is to be regulated to avoid sea water intrusion. The use of skimming wells and fresh water recharge may be suitably adopted in coastal regions.

Irrigation Drainage and Water Logging

- The improvement of research on agricultural land drainage should be accorded high priority for arid and semi-arid areas through evolving suitable policies, and to determine their impact on economy and threat to sustainability of agricultural development.

Multiple Use/ Reuse of Wastewater

- In view of increasing demand from domestic, industrial sectors there is need for using marginal quality water and multiple use of water for irrigation. Research studies are required to be undertaken for developing site specific management strategies for sustainable agriculture under various socio-economic situations.
- Techniques for accurate, quick and low cost procedures for assessing water quality have to be developed through research. Such procedure will be helpful in advising farmers on the use of marginal quality water for irrigation.
- Research efforts for testing suitable crops and varieties on low quality water adoption through crop improvement and new resource management techniques are required to meet the future scenario of reduced good quality water availability and increased use of marginal quality waters.

Decision Support and Information System

- The concept of water resources assessment should reflect soil-water-plant relationship interaction, and be expressed in volumetric. Specific research studies on decision support modelling should be carried out for selected agro-climatic regions to confirm the water resources potential. Appropriate regional water development plans need to be evolved for applied research data generated within the particular agro-climatic region.
- Mathematical modelling and simulation provide useful tools to test how effective conjunctive use can be, to evaluate impacts on soil and ground water. Different scenarios of crop diversification, cropping intensity, irrigation scheduling, field drainage, surface and ground water use need to be analysed to examine if ground water depth and water quality can be maintained. In doing so use of new technologies like GIS and decision support models will help enhance the efficiency of simulation tools.
- A formal framework to identify, formulate and analyse resource management problems, and to evolve specification of methods and criteria for evaluating alternatives is needed to ensure accountability. Thus water resources

management needs to be made knowledge intensive and with improved capabilities for decision making at all levels need to be improved.

- Use of modern technologies such as GPS, remote sensing and geographical information systems (GIS), simulation and optimisation models, relational data base, medium range weather forecasts, and user friendly interface developing tools should be deployed extensively to improve the data collection, analysis and monitoring process for rural areas in developing economies.
- Informed decision making base on performance assessment is required for better water management in irrigation projects. Specific water resources management case areas and research teams must be created to deal with major requirements of decision making process. Additional investments in information technology software and hardware are necessary.

Indigenous Knowledge and People's Participation

- Traditional knowledge and indigenous water management practices should be revived, strengthened, modernised and proved for alternative development. This needs in depth-studies of socio-economic and legislative aspects for successful implementation.
- A mechanism to be devised to create awareness among the farmers about the latest technology developed and emphasis should be on out-reach transfer of technology with direct involvement of farmers. Development of local institutions involving community based organisations, NGOs and water user associations to be chalked out and monitored.
-

Policy and Institutional Issues

- A policy and legal framework should encourage the philosophy of water as economic good and water rights to be encouraged as a viable commercial proposition in regional context. Development of excess water resources should be motivated to develop their water resources through private intervention for greater availability and utilisation.
- Misuse of precious water resource can be minimised through a properly regulated pricing policy mechanism. The water supplied to farmers be charged and a research on irrigation water pricing and willingness to pay be conducted. Farmers should be free to choose appropriate cropping patterns that are sustainable under the given set of socio-economic and agro-ecological conditions.
- An integrated watershed based water resource approach should be adopted for making optimum and sustainable utilisation of land and water resources in selected agro-ecological regions through the national water resources development program.

REFERENCES

- Bakkar, M.; R. Barker; R. Meinzen-Dick; F. Konradsen. 1999. Multiple Uses of Water in Irrigated Areas. SWIM Paper 8. Colombo, Sri Lanka. International Water Management Institute.
- Bell, S.; S. Morse. 1999. Sustainability Indicators- Measuring the immeasurable. Earthscan Publication Ltd. London.
- Brown, L. R. 2000. Population Growth Sentencing Millions to Hydrological Poverty. World Watch Institute Alert, 21st June, 2000.
- Cadler, I.R. 1998. Water Resources and Land Use Issues. SWIM Paper 3. Colombo, Sri Lanka. International Water Management Institute.
- FAO. 1999a. Irrigation in Asia in Figures. Water Reports No. 18. FAO Rome
- FAO. 1999b. Water for Food. Approach Paper. FAO Rome
- Government of India. 1999. Water Resources Development and Management in India http://www.un.org/esa/agenda21/natlinfo/countr/india/natur.htm
- Hamdy, A.; D. Wrachien. 1999. New Policies and Strategies on Land and Water Development in the Mediterranean Region. In: Musy, A.; L. S. Pereira; M. Fritsch (eds.) 2nd Inter-regional Conference on Environment-Water. Sept- 1-3, 1999. EPFL Lausanne. CD-ROM.
- Institution of Engineers India. 2000. Sustainable Development: engineering and technological challenges of 21st century. IEI News, 50 (1), April 2000. pp. 1-3.
- Molden, D. 1997. Accounting for Water Use and Productivity. SWIM Paper 1. Colombo, Sri Lanka. International Water Management Institute.
- Oweis, T. 1997. Supplementary Irrigation: a highly efficient water use practice. ICARDA, Aleppo/ Syria.
- Pereira, Luis S.; J. R. Gilley; M. E. Jensen. 1996. Research Agenda on Sustainability of Irrigated Agriculture. J. Irrigation and Drainage Engineering, 122 (3), pp 172-177.
- Prinz, D.; S. Wolfer. 1999. Traditional Techniques of Water Management to Cover Future Irrigation Water Demand. Z. f. Bewässerungswirtschaft, 34 Jahrg., Heft 1/ 1999. pp 41-60.
- Seckler, D.; R. de Silva; U. Amarasinghe. 1996. The IIMI Indicators for International Water Scarcity. In: Richter, J.; P. Wolf; H. Franzen; F. Heim (eds.) Strategies for Intersectoral Water Management in Developing Countries- Challenges and consequences for agriculture. International workshop 6-10th May 1996. ZEL Feldafing, Germany.
- Shende, G. B.; C. Chakrabarti; R. P. Rai; V. J. Nashikkar. 1997. Status of Wastewater Treatment and Agricultural Reuse with Special Reference to Indian Experience, Research and Development Needs. Central Pollution Control Board, New Delhi.
- Singh, A. K.; D. Prinz; I. W. Makin. 1999. Water Assessment as a Basis for Watershed Management- A study from Huruluwewa watershed, Sri Lanka. In: Musy, A. et al. (eds.) 2nd Inter-regional Conference on Environment-Water. Sept-1-3, 1999. EPFL Lausanne. CD-ROM.
- UNFPA. 1999. The State of World Population. UN Population Fund, New York.
- Walmsley, N.; N.J. Hasnip. 1997. Case Studies on Water Resources Planning. Report OD 138. H.R. Wallingford, UK. August 1997.

Annexure- 1

Water Resources Development and Management in India

India's National Water Policy was adopted in September 1987 with the policy aims at planning, developing and conserving the scarce and precious water resources on an integrated and environmentally sound basis. The policy facilitates strategies on ground water development, water allocation priorities, drinking water, irrigation, water quality, water zoning, conservation of water and flood control management. The State Governments in India make their water policies within the overall framework of the National Water Policy 1987.

High investments made over the successive Five Year Plans (starting from 1951 onwards) have resulted in significant achievements in water resources and agriculture sector. While 82% of the population has access to safe drinking water supply in rural areas, the accessibility in urban areas is around 85%. Five Year Plans and Annual Plans contain the strategy for organised and systematic development. Important strategies in the Eighth Five Year Plan (1992-97) are similar to the programme areas of Agenda 21, and many of the strategies are based on the strategies outlined in the National Water Policy 1987.

With domestic and external assistance, there are a number of important ongoing National programmes and projects supporting the implementation of recommendations of Agenda 21 in India. Generally, the projects in the water resources sector are being implemented under categories of major, medium, and minor (surface water and also ground water) projects and schemes, and Command Area Development Programmes. Some of these initiatives include:

a) *guidelines for sustainable water resources development and management have been formulated;*
b) *a hydrology project with World Bank assistance is under implementation for the systematic collection and analysis of data;*
c) *Master Plans for river basins to optimise use and inter-basin transfers are under preparation;*
d) *flood and drought management, and environmental and social impact assessments are an integral part of project formulation, implementation, and monitoring in various States and are continuous processes of all plans;*
e) *documents on non-structural aspects of flood management in India have been prepared (a draft bill on the flood plan zone has been prepared and a National Flood Atlas is under preparation);*
f) *human resource development is being implemented through water and land management institutes, and other organizations and agencies;*
g) *Water Resources Day is being observed every year as part of a mass awareness programme;*
h) *research and development programmes on different subjects in the water resources sector are being undertaken through Indian National Committees by universities, research institutes, and other organizations;*
i) *pilot projects on recycling and reuse of waste water and artificial recharge of ground water are under implementation;*
j) *guidelines on the conjunctive use of surface water and ground waters have been prepared and are under implementation;*
k) *Command Area Development Programmes have been implemented since 1974;*
l) *Participatory Irrigation Management (PIM) through Water Users' Associations and women's participation is being actively encouraged and implemented;*
m) *a network of hydrological stations, hydrometric observation stations, and ground water measurement stations collect data, including water quality data, through organizations under the Central and State Governments on a continuous basis (water resource data are collected and transmitted through the network of the National Informatics Centre); and*
n) *standardisation is being carried out continuously through the Bureau of Indian Standards which participates in the International Standards Organisation.*

While all projects and schemes are being implemented in India with the objective of sustainable development, presently a number of policies/guidelines are being finalised through the NWRC. These are:

a) *the Water Information Bill;*
b) *a policy note on setting up a river basin organisation;*
c) *a National Policy for Resettlement and Rehabilitation of persons affected by reservoir projects;*
d) *modification of water allocation priorities specified by the National Water Policy;*
e) *overall policy guidelines for water management and pricing of water for industrial purposes;*
f) *an approach to organisational and procedural changes in the irrigation sector;*
g) *an irrigation management policy;*
h) *National policy guidelines for water allocation for inter-State rivers amongst States; and*
i) *guidelines for planning conjunctive use of surface and ground water in irrigation projects. After their adoption, the policies and guidelines will be monitored for ensure sustainable development. Other items not covered above, will also be framed by the National Water Board for adoption by the NWRC in the near future.*

Even though important ongoing National programmes are in progress at various stages, quite a few constraints are being faced in their implementation. Some of these are:

a) *deficiencies in systematic data collection and establishment of a good data base (a periodic review and implementation of the hydrology project may improve the situation);*
b) *proper implementation of a suitable blend of structural and non-structural flood management measures is needed;*
c) *effective control and improvement in water quality through water pollution control measures is required urgently;*
d) *degradation of fish habitat due to increased water abstraction, land development, and pollution;*
e) *improvement in catchment area treatment and compensatory afforestation is necessary to combat soil erosion, mismanagement, and other over-exploitation of natural resources;*
f) *the constraint of funds is seen as the greatest obstacle to the implementation of Agenda 21 and needs global consideration and assistance; and*
g) *greater human resource development including adequate training is necessary in all areas of concern (Government of India, 2000).*

Karlsruhe, Sept. 2000

Source:
Prinz, D. & Singh, Anupam K., (2000). Water Resources in Arid Regions and their Sustainable Management. Annals of Arid Lands, Special Issue on Research.