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# Water Management in the Indus Basin in Pakistan: Challenges and Opportunities

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*The Indus River basin supplies water to the largest contiguous irrigation system in the world, providing water for 90% of the food production in Pakistan, which contributes 25% of the country's gross domestic product. But Pakistan could face severe food shortages intimately linked to water scarcity. It is projected that, by 2025, the shortfall of water requirements will be ~32%, which will result in a food shortage of 70 million tons. Recent estimates suggest that climate change and siltation of main reservoirs will reduce the surface water storage capacity by 30% by 2025. The per capita water storage capacity in Pakistan is only 150 m<sup>3</sup>, compared with more than 5000 m<sup>3</sup> in the United States and Australia and 2200 m<sup>3</sup> in China. This reduction in surface supplies and consequent decreases in groundwater abstraction will have a serious effect on irrigated agriculture. Supply-side solutions aimed at providing more water will not be available as in the past. Current low productivity in comparison with what has been achieved in other countries under virtually similar conditions points to the enormous potential that exists. To harness this potential, Pakistan needs to invest soon in increasing storage capacity, improving water-use efficiency, and managing surface-water and groundwater resources in a sustainable way to avoid problems of soil salinization and waterlogging. Building capacity between individuals and organizations, and strengthening institutions are key elements for sustaining irrigated agriculture in the Indus Basin.*

**Keywords:** Water management; food security; irrigated agriculture; salinity; water-logging; Indus Basin; Pakistan.

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## Introduction

Irrigated agriculture and, consequently, water have always played an important role in the economic development of Pakistan and are likely to continue to do so in the future. Agriculture is the single largest sector of Pakistan's economy, accounting for around a quarter of the country's gross domestic product. Agriculture employs ~44% of the labor force, supports ~75% of the population, and accounts for >60% of foreign exchange earnings. Agriculture in Pakistan, perhaps more so than anywhere else in the world, is dependent on irrigation. Irrigation is used on 80% of all arable land in Pakistan and produces fully 90% of all food and feed (Government of Pakistan 2008).

However, water in Pakistan is under pressure, and irrigation is threatened. A rapidly growing population means that more food needs to be produced, but there are almost no new supplies of water to produce it. If anything, there will be less water than before as nonagricultural uses grow and compete for irrigation water and the melting of the western Himalayan glaciers gives tangible meaning to climate change (Archer et al 2010). The Government of Pakistan's Poverty Reduction Strategy Paper 1 of 2003 (Government of Pakistan 2003) in fact identified water shortage as the most critical challenge, because water for agriculture is the key engine of

agriculture growth and poverty reduction.

Unfortunately, the problem goes beyond quantity. Deficiencies in surface water supplies are now often met by farmers through exploitation of unregulated groundwater. The concurrent use of surface water and groundwater water now takes place on more than 70% of irrigated lands (Qureshi et al 2004). However, secondary salinization associated with the use of poor quality groundwater for irrigation is a major threat to the sustainability of irrigated agriculture. Pakistan is now home to probably the worst salinity problem in the world (Briscoe and Qamar 2005). Successful irrigation requires successful conjunctive management of surface water and groundwater resources (Qureshi et al 2010).

At the same time, agriculture in Pakistan is changing rapidly. Contract farming is increasing, more progressive and commercial farmers are emerging, high-value crops are displacing food grains, and increasing prices for agricultural commodities are attracting people to agriculture. Taking advantage of these new agricultural opportunities requires new forms of water control. Solutions will require a paradigm shift in water-resource development and management strategies.

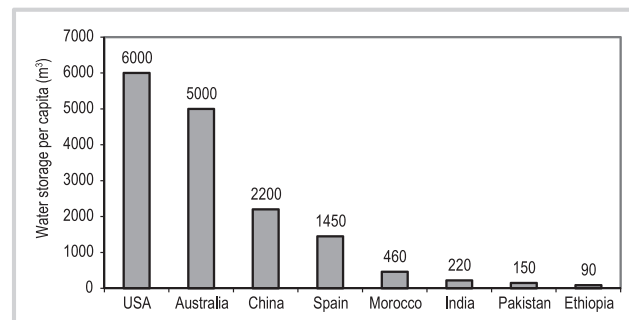
Irrigation dominates water use in Pakistan and is expected to continue as the major user of both surface water and groundwater resources into the future. As development proceeds and the population and the country's economy both grow, competition for water resources will become a major concern. Present water use for municipal and

industrial supplies in the urban sector is of the order of 5.3 billion m<sup>3</sup> (BCM). The demand for municipal and industrial supplies in urban areas is expected to increase to ~14.0 BCM by the year 2025. Total nonirrigation water use is expected to increase to 18.9 BCM. As a result, irrigation water will face increasing competition from the municipal and industrial sectors (USAID 2009).

It is projected that, in 2025, per capita water availability in Pakistan will be reduced to less than 600 m<sup>3</sup> (Bhutta 1999), which would mean a shortfall in water requirements of ~32%, which will result in a food shortage of 70 million tons by the year 2025 (ADB 2002). The surface irrigation system of the Indus Basin was originally designed to provide low-intensity irrigation to cover larger areas in the canal commands. However, as cropping intensities increased, demand for more water also increased, putting additional pressure on surface irrigation systems (Bhutta and Smedema 2007). This reduction in surface supplies and consequent decreases in groundwater abstraction will have serious effects on irrigated agriculture, which accounts for most of the agricultural production in Pakistan. This situation has threatened the sustainability of irrigated agriculture and consequently the food security of 170 million people living in Pakistan.

The very future of Pakistan depends on how it manages its agricultural water. There is both an imperative and an opportunity to improve irrigation performance in Pakistan. The question is how. The gap between demand and supply of water has increased to levels that are creating unrest among the federating units. Extended drought in recent years has exacerbated the problem. Therefore, the need for further development of new resources, adoption of water conservation measures, and judicious use of water are being stressed in all forums. The present article provides a

FIGURE 1 Storage per capita in different semiarid countries (World Bank 2006).



comprehensive review of the current water resources of Pakistan, the challenges faced by irrigated agriculture, and possible future strategies to overcome these problems and ensure sustainability of irrigated agriculture in the Indus Basin of Pakistan.

#### Indus Basin irrigation system

Surface-water resources in Pakistan are based on the flows of the Indus River and its tributaries (Jhelum, Chenab, Ravi, Sutlej, and Beas to the east and the Kabul River to the west). The Indus River has a total length of 2900 km and a drainage area of ~966,000 km<sup>2</sup>. The inflow to these rivers is mainly derived from snow and glacial melt and rainfall in the catchment areas. Outside the Indus Basin, most of the rivers are ephemeral streams, which only flow during the rainy season and thus do not meet the water needs of the Indus system inside the basin as do the other rivers.

The irrigation system commands a gross irrigable area of 16.85 million ha, 14 million of which are culturable command area to which water is allocated. The perennial canal supply is available to 8.6 million ha, although the remaining area is entitled to irrigation supplies only during the summer (*kharif*) season. The Indus River and its tributaries, on an average, bring 175 BCM of water annually, which includes 165 BCM from the 3 western rivers (Indus, Chenab, and Jhelum) and 10 BCM from the eastern rivers (Ravi, Beas, and Sutlej). Most of this, ~128 BCM,

is diverted for irrigation; 35 BCM flows to the sea and ~12 BCM is wasted as through system losses (Zuberi 1997).

The Indus Basin is underlain by an extensive unconfined aquifer that covers ~16 million ha of surface area, of which 6 million ha are fresh and the remaining 10 million ha are saline (Haider et al 1999). The average safe groundwater yield is estimated to be ~63 BCM, whereas extraction for the agriculture, domestic, and industrial sectors is of the order of ~52 BCM. Thus, the remaining groundwater potential is ~11 BCM (PWP 2001). However, evidence, such as increasing salinity in the groundwater due to redistribution of salts in the aquifer and declining groundwater levels, confirms that the potential for further groundwater exploitation is very limited.

#### Challenges of water management in the Indus Basin

##### Low storage capacity and poor irrigation infrastructure

Relative to other arid countries, Pakistan has very little water storage capacity, that is, 15% of the annual river flow. The per capita water storage capacity in Pakistan is only 150 m<sup>3</sup> compared with more than 5000 m<sup>3</sup> in the United States and Australia, and 2200 m<sup>3</sup> in China (Figure 1). The dams of the Colorado and Murray Darling rivers can store 900 days of river runoff, South Africa can hold 500 days in the Orange River, and India can hold between

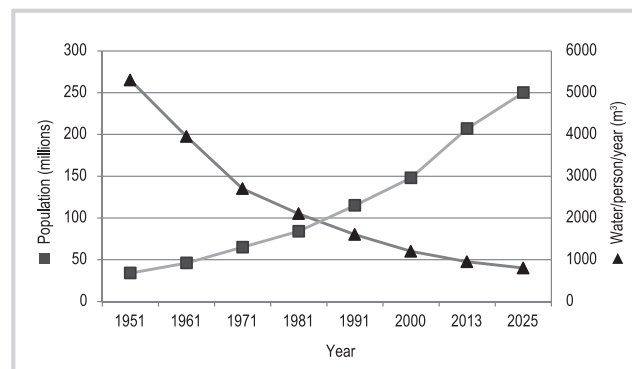
120 and 220 days in the peninsular rivers. In contrast, Pakistan can barely store 30 days of water in the Indus Basin (Briscoe and Qamar 2005). If no new storage is built in the near future, canal diversions will remain the same, and the shortfall will increase by 12% in the next decade. The Pakistan Water Sector Strategy estimates that Pakistan needs to raise its storage capacity by 22 BCM by 2025 to meet the projected requirements of 165 BCM. Therefore, it is of paramount importance that Pakistan gives serious attention to building new storage facilities. It is unfortunate that, even after completion of Terbela Dam 30 years ago, no decision could be taken on the construction of new storage capacity.

#### Increasing gap in supply and demand

The population of Pakistan is increasing at a rate of 2.8% and is projected to increase to 250 million by 2025. The percentage of the urban population will increase from its current 35 to 52% by 2025. As a result, water demand for domestic, industrial, and nonagricultural uses will increase by ~8% and is expected to reach 10% of the total available water resources by the year 2025 (Bhutta 1999). In Pakistan, water availability already fell from 5000 m<sup>3</sup> per capita in 1951 to just 1100 m<sup>3</sup> per capita in 2005 and is expected to fall to as little as 800 m<sup>3</sup> per capita by 2025 (Figure 2) (WWF Pakistan 2007), which is roughly the value below which water availability becomes a primary constraint to life (Engelman and Leroy 1993). Available land per person for cultivation is also decreasing. Moreover, agriculture is threatened by severe waterlogging and salinity due to a lack of drainage facilities and good-quality irrigation water. Therefore, a multidimensional approach needs to be applied for sustainable development of land and water resources.

The water requirements for irrigation in the Indus Basin are

**FIGURE 2** Declining availability of water in Pakistan (m<sup>3</sup>/capita/y) (WWF–Pakistan 2007).



estimated at 250 BCM in 2025 against a projected potential availability of 185 BCM from surface water resources. Even if the full groundwater resources are exploited, the water availability will not be more than 190 BCM. When considering the reduction in present storage capacities due to siltation, the shortfall in water requirements would be ~32% by 2025. In the “business as usual” scenario, the shortfall in water will result in serious food shortages in the years to come and will severely hurt the national economy and livelihood of millions. Agricultural commodities estimated as required for the projected population in 2025 are given in Table 1 (ADB 2002).

#### Low system efficiency and crop-water productivity

Due to age and poor maintenance, the delivery efficiency of irrigation systems is low, ranging from 35 to 40% from the canal head to the crop root zone (Tarar 1995). The overall irrigation efficiency is only ~30% (Bhutta and Smedema 2007). The average yields in Pakistan are low for wheat and rice, at 2276 kg/ha and 1756 kg/ha, respectively. There is great variability in crop yields, with some farmers achieving yields of 3874 kg/ha for wheat and 3545 kg/ha for rice (Qureshi et al 2004). In addition to water shortage, lack of inputs, poor irrigation practices, and secondary salinization are the other major factors in low crop yields. The productivity of water in Pakistan is

about the lowest in the world. For wheat, for example, it is 0.5 kg/m<sup>3</sup> compared with 1.0 kg/m<sup>3</sup> in India and 1.5 kg/m<sup>3</sup> in California (IWMI 2000). Maize yields in Pakistan are very low, which means that there is tremendous scope for substantial improvement. In terms of water productivity, maize has a factor of 9, between the lowest, in Pakistan (0.3 kg/m<sup>3</sup>), and the highest, in Argentina (2.7 kg/m<sup>3</sup>). The flip side of current low water productivity is the enormous potential for radical improvement and increased product for Pakistan, which can bring much more jobs and income—per drop of water.

#### Degradation of the resource base—soil salinization

The water diverted from the Indus River to the canal system for irrigation brings in ~33 million tons of salts, whereas the salt outflow to the sea is only 16.4 million tons. This means an average annual addition of some 16.6 million tons to the salt stored in the Indus Basin. Of this, only 2.2 million tons is deposited in a series of evaporation ponds located in the desert area outside the irrigated plain in southeast Punjab; the remainder accumulates in the irrigated land and its underlying strata and aquifer (NESPAC/MMI 1993). In short, an average of 1 ton of salts is added to each hectare of irrigated land. As a result, salt-affected soils have become an important ecological problem in the Indus Basin: an estimated 4.5 million

**TABLE 1** Projected food requirements and productions for the year 2025 (in million tons).

Crops	Requirement	Production	Shortfall
Food-grains	50.0	31.5	18.5
Sugarcane	82.0	46.4	35.4
Cotton (lint)	3.5	2.7	0.8
Pulses	1.9	1.4	0.5
Oilseed	3.3	1.5	1.8
Vegetables	14.3	9.0	5.3
Fruits	16.1	9.0	7.1
<b>Total</b>	<b>171.0</b>	<b>102.8</b>	<b>69.4</b>

Source: **ADB [Asian Development Bank]**. 2002. *Water Resources Strategy Study*. Draft Report Vol. 1. Islamabad, Pakistan: ADB.

ha are already afflicted, about half of which are located in irrigated areas (Qureshi et al 2004).

Problems of soil salinity, shown in Figure 3, are more serious in Sindh Province (54% of the irrigated area is saline) due to low rainfall, high evapotranspiration rates, and shallow saline groundwater. Land degradation is reducing the production potential of major crops by 25%, with an estimated loss of US\$ 250 million per year (Haider et al 1999).

The salinity of groundwater in the Indus Plains varies widely, both spatially and with depth, and is related to the pattern of groundwater movement in the aquifer (Qureshi et al 2007). The salinity of the groundwater generally increases away from the rivers and also with depth. In Punjab, 23% of the area has hazardous groundwater quality,

whereas this figure is 78% in Sindh (Haider 2000).

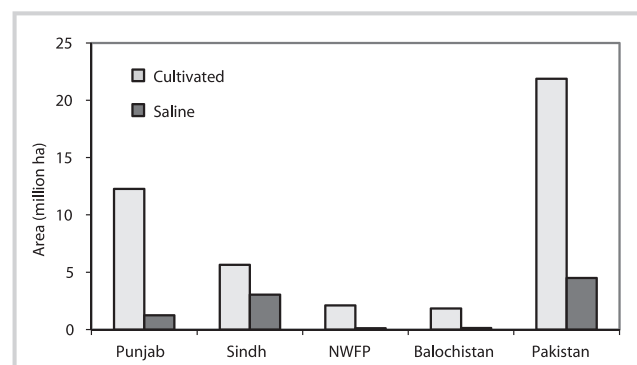
#### Unsustainable use of groundwater

Over the past 3 decades, farmers have largely taken the problem of surface water scarcity into their own hands, and “solved it” by sinking hundreds of thousands of tube wells to feed their thirsty crops. The number of private tube wells increased from 10,000 in 1960 to ~0.6 million in 2002 (Qureshi et al 2003) and more than 1 million in 2007 (World Bank 2007). The total groundwater abstraction from these tube wells is estimated at  $51 \times 10^9 \text{ m}^3$  against a recharge of  $40\text{--}60 \times 10^9 \text{ m}^3$ . Investment in these private tube wells is of the order of 30–40 billion rupees (US\$ 500 million), whereas, annual benefits in the form of agricultural production are to the tune of US\$ 2.3 billion (PKR [Pakistan Rupees] 150 billion),

accruing to over 2.5 million farmers, who exploit groundwater directly or rent irrigation services from neighbors (Shah et al 2003). The management challenge is to stabilize the groundwater table at levels where the cost of pumping is affordable. Overexploitation of groundwater has already caused severe water table decline in most canal command areas in Punjab and Sindh provinces (Figure 4). The average decline in the groundwater table is ~1.5 m/y. The overexploitation of groundwater in rain-fed areas has made them less resilient to drought, resulting in social, economic, and political problems.

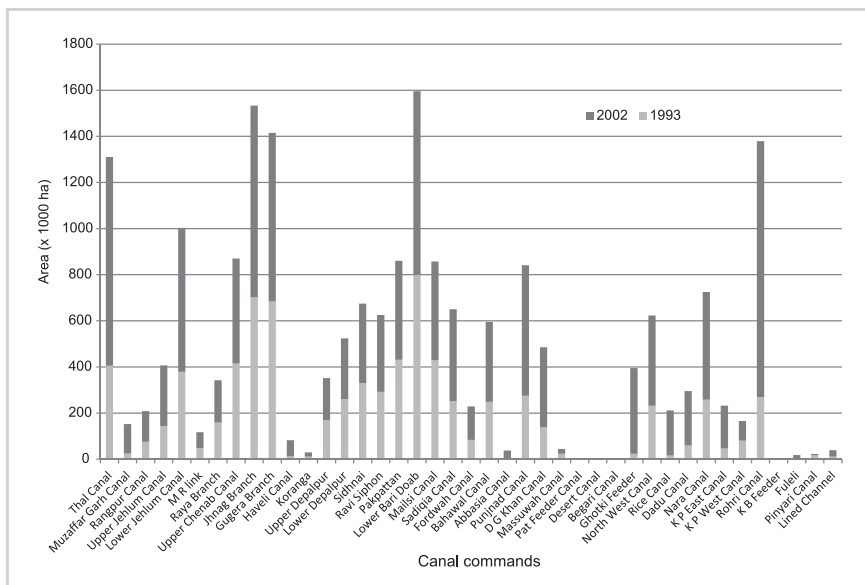
#### Disposal of drainage effluent

The Indus Plain is characterized by a lack of any well-defined natural surface drainage. Because of the flat nature of the Indus Basin, natural subsurface drainage through down-valley movement of groundwater is also restricted. Therefore, inundation of agricultural lands after intense rainstorms, with consequent crop and property damage, has become a recurrent phenomenon in many parts of the Indus Plains. Even though ~15,000 km of surface drains have been constructed to date, crop losses caused by rain flooding remain excessive, especially in the Punjab and Sindh provinces (Afzal 1992). Economic disposal arrangements of saline effluent to the sea are possible

**FIGURE 3** Province-wise distribution of cultivated area and salt-affected area (WAPDA 2007).



**FIGURE 4** Increase in area with a groundwater table depth of 300 cm over a period of 10 years (1993–2002) in different canal commands of Punjab and Sindh provinces (Qureshi et al 2010).



if the drainage system is designed and regulated in the same way as the canal system. The ultimate drainage requirements of saline drainage effluent are 13.5 BCM, that is, 3.63 BCM from Punjab and 9.82 BCM from Sindh and Baluchistan. The requirements of drainage in Sindh are high due to the extent of saline groundwater as well as relatively high water allowances for the crops grown, particularly rice.

### Vulnerability due to climate change

The bulk of the Indus waters are derived from the river's high mountain headwaters. The main water reservoir, Terbel, receives 80% of its flow from snow and ice melt. Most of the flow of the left bank tributaries, traversing the Punjab Province, is derived from snowmelt during spring and summer, with a major contribution from monsoonal rains during the late summer. The upper Indus Basin consists of a series of mountain ranges of extreme and exceptionally high elevations. With hundreds of peaks in excess of 6000-m elevations, this consists of a wide belt of mountain ridges and high valleys. The glaciers of the Karakoram cover an area of  $\sim 16,300 \text{ km}^2$ , of which  $\sim 13,000 \text{ km}^2$

lie within Pakistan. The major characteristic of the Indus Basin is great spatial variability in precipitation. Surface air temperatures exhibit extreme spatial variability dependent primarily on elevation but with strong seasonal and diurnal cycles.

Pakistan is highly dependent on its water resources that originate in the mountains of the upper Indus to sustain its irrigated agriculture, which is the mainstay of its economy. Hence, any changes in the available water resources through climate change or other human interventions will lead to serious challenges of food security and livelihood for millions of poor people. Although research on climate change in Pakistan is still in its infancy, there is evidence that future changes in climate will have adverse effects on agricultural production. It is predicted that, due to a rise in temperatures, there will be excessive glacier melt of the Karakoram glaciers and the flow of the Indus at Besham Qila will be increased by  $\sim 50\%$ . Thereafter, there will be great reduction in flows, which will be reduced to  $\sim 40\%$  of their value for 2000 by the end of the century (Rees and Collins 2005). The increase in flow during the second

decade of the century will be 6.4 BCM annually, after which there will be a steady decline of 27 BCM in Besham Qila in the next 80 years.

Climate change also is expected to affect the South Asian monsoon. The International Panel on Climate Change, in its Third Assessment Report, has reported that there will be an increase in the South Asian monsoon by 8–24%, which will bring additional water and cause floods and damage to the infrastructure (Rasul et al 2008). This means that Pakistan should start preparing itself for possible future climate change and its impact on Pakistan. Better water management would probably be the best strategy to cope with projected climate change and its impact on Pakistan's agricultural economy and environment.

## Transboundary water issues

After the Indus Basin Treaty of 1960 between India and Pakistan, Pakistan was allowed exclusive use of 3 western rivers (Indus, Jhelum, and Chenab), and India was entitled to 3 eastern rivers (Ravi, Sutlej, and Beas). This treaty also provided provision for the construction of a number of link canals, barrages, and dams on the Indus and its 2 tributaries. The Indus Basin irrigation system has now developed into the world's largest contiguous irrigation system. The existing surface water system, which is now all weir controlled, consists of 4 storage reservoirs (Warsak, Chasma, Mangla, and Tarbela), 16 barrages, 12 inter-river link canals, 2 siphons, 44 canal commands (23 in Punjab, 14 in Sindh, 5 in Khyber Pakhtunkhwa, and 2 in Balochistan), 59,000-km-long irrigation canals, and 107,000-km-long watercourses. Over the last few years, serious differences have emerged between Pakistan and India over sharing water resources. The situation has become serious due to construction of a series of dams on these rivers, which has affected the flow regime of the rivers with the consequence of decreasing flows,

which has created great unrest in Pakistani society; therefore, these issues need to be resolved as soon as possible to avoid any further damage to Pakistani irrigated agriculture.

The Kabul River contributes a maximum of 42 BCM and a minimum of 15 BCM, with an annual average of ~25 BCM to the Indus (IUCN 2011). Short-term possible uses by Afghanistan on the Kabul River would be ~10 BCM. It is time to settle the impeding water dispute with Afghanistan, otherwise, much blue Kabul River water may be lost once Afghanistan becomes strong enough to begin to establish new water storage on the river. Afghanistan is already conducting feasibility studies with India to make new dams on the Kabul River. It, therefore, is urgent that negotiations be opened with Afghanistan to reach an agreement on water sharing.

### **The way forward: recommendations for improving the sustainability of the Indus Basin irrigation system**

The viability of irrigated agriculture in the Indus Basin is threatened by a multitude of factors, including seepage from unlined canals, waterlogging and soil salinization; poor on-farm water management practices; insufficient canal water supplies; and use of poor-quality groundwater for irrigation. However, 40% more food would be required to feed the increasing population by the year 2025. It is also perceived that, due to decreased investments in the water sector, combined with environmental and ecological threats, the scope for expansion of irrigation areas will be very limited. Therefore, increasing the performance of existing irrigation systems and, wherever possible, developing new storage and irrigation schemes are the logical ways forward. To increase productivity and sustainability of the irrigation systems in the basin, the following potential solutions are suggested.

### **Increase water availability: develop new storage and improve water infrastructure**

Pakistan is extraordinarily dependent on its water infrastructure and has invested heavily in it. Due to a combination of age and neglect, much of the infrastructure is in decay. There is no modern asset management plan for repair and/or replacement of irrigation infrastructure. The amounts usually designated by government for repair and maintenance of infrastructure are only 5–10% of the required amount. The cumulative effect on the river barrages and head works has left these strategic structures very vulnerable to unforeseen damage, with enormous consequences. Due to deferred maintenance and lack of rehabilitation, the delivery capacity of canals is 30% lower than designed. Therefore, immediate investments are needed to secure these strategic structures to ensure food security of the 170 million people living in Pakistan.

### **Grow more food with less water: improve agricultural water productivity**

The future prosperity of Pakistan will depend to a considerable extent on how well freshwater resources are harnessed and how efficiently they are used. The way water is being used will have to be changed significantly if sustainable development is to be achieved in Pakistan. It is estimated that, to meet the food requirements of the country, the cultivated area of wheat would need to increase by 46% at present yield levels. Similarly, areas for other crops will need to be increased. However, given the present situation of water resources, this will not be possible. Therefore, the only way to achieve this food target is to improve water management to increase land and water productivity. Introducing water conservation technologies such as precision land leveling, zero tillage (ZT), and bed and furrow planting can also help a great deal to improve

water productivity. Farmers should also be encouraged to use high-efficiency irrigation systems, such as sprinkler and drip irrigation systems to reduce irrigation water demands.

Studies done by International Water Management Institute (Ahmad et al 2007) have found that, in the Rechna Doab sub-basin, ZT, and laser-leveling technologies for wheat were considerably increased during 2000–2003, from ~15% to >35%. The area under ZT increased exponentially during 2003–2004, with wheat sown on an area of 400,000 ha. Presently, more than 5300 ZT drills are owned by farmers in the Punjab province, and 45 manufacturers are involved in the production of ZT drills. Different farmers have different reasons for the adoption of Resource Conservation Technologies (RCTs). Approximately 97% of farmers adopted new RCTs, primarily to increase farm profitability, and 87% to manage the scarce water resources.

ZT technology was adopted by a maximum number of farmers (27%) in the upper Rechna Doab, where the rice wheat cropping system was dominant. Similarly, laser land leveling was more acceptable in the middle and lower Rechna (4 and 12% adopters, respectively) where wheat and sugar cane are the major cropping patterns and where a shortage of irrigation water is the major problem. Farmers in these areas have reported a decrease in input cost and an increase in crop yields and net farm incomes while adopting ZT and laser land leveling. Approximately 54% and 96% adopters of ZT and laser land leveling, respectively, reported an increase in yield.

### **Manage groundwater resources: rationalize cropping patterns and manage aquifers**

Over the past few decades, the water economy of Pakistan has survived largely because of the tapping of unmanaged groundwater by millions of farmers, by towns, and by villages

and industries. It is clear that this era of “productive anarchy” is now coming to an end, since groundwater is now being overtapped in most of the areas. Therefore, there is an urgent need to develop policies and approaches for bringing water withdrawals into balance with recharge.

Traditional crops, such as rice and sugar cane, have benefited from increased irrigation supplies. Because rice is a water-intensive crop, it is essential to assess whether Pakistan should continue to grow rice for export or instead use this water for other crops that represent a comparative advantage for the country. Similarly, strategies should be developed to replace sugar cane with low-water-demanding and high market-value crops. Introduction of high-value crops, such as sunflower, pulses, vegetables, and orchards, can also increase farm incomes substantially. Presently, the country is importing edible oils valued at more than US\$ 1 billion (Qureshi et al 2010).

In the rice-growing areas of Pakistan, more than 70% of irrigation water is supplied through tube wells (Qureshi et al 2006). Therefore, restricting rice production to domestic need could reduce the pressure on groundwater. Adoption of innovative irrigation practices, that is, alternate wet and dry irrigation for rice, can help save groundwater. Similarly, direct seeded rice requires 23% less water compared with transplanted rice under Pakistani conditions (Qureshi et al 2006).

Aquifer management is considered the most-effective way of establishing a balance between discharge and recharge components. This practice is widely used in industrialized countries such as Germany, Switzerland, the United States, the Netherlands, and Sweden. The share of artificial recharge to total groundwater use in these countries is between 15 and 25% (Li 2001). In recent years, India has also taken serious steps to use

harvested rainwater to recharge its aquifers and recently allocated significant funds in the Union, or central government, budget for further promotion of the practice.

Due to the peculiarities of Pakistan's groundwater socioecology, a multidimensional approach is needed. In Balochistan Province, for example, subsidies for electricity need to be reviewed. Currently, the annual subsidy for agricultural tube wells is Pakistan rupees 8.5 billion (US\$ 140 million), which encourages excessive groundwater extraction. Cropped areas for different crops should be fixed on the basis of the availability of water resources. In desert and rain-fed areas of Pakistan, farmers have invested in rainwater harvesting structures for supplemental irrigation and for recharging aquifers. These initiatives should be encouraged by the government to protect the livelihoods of the poor.

#### **Maintaining the resource base: manage salinity in the fields and basin**

Pakistan lacks a good network of drainage systems, which is essential for evacuating salts from the system. Therefore, there is a need to invest in rehabilitating the existing drainage systems and in constructing a new drainage system for salinity management in the Indus Basin. In the longer term, a sustainable solution is to carry the excess salts out of the irrigated areas to the sea. The whole concept of interprovincial main drain for evacuation of salt from the basin needs the urgent attention of the government, and its construction should be undertaken as soon as possible. In Pakistan, too much emphasis has been given to engineering solutions, with very little on the management front. Although engineering solutions help increase cropping intensities and yields, they fail to halt the emergence of similar environmental problems in adjacent areas.

For reclamation of salt-affected soils, the government should

promote the use of gypsum and other physical methods, such as acids and organic matter. For the success of saline agriculture in Pakistan, selection of the most salt-tolerant crop varieties and the use of improved planting techniques and fertilizers are important factors to be considered. A large number of varieties of different crops have been developed for Pakistani conditions. The growth of perennial forage grasses has been quite successful in Pakistan. Rhodes grass (*Chloris gayana*), tall wheatgrass (*Elytrigia elongate*), and Puccinellia (*Puccinellia ciliate*) are the most popular examples (Qureshi and Akhtar 2002). The incorporation of salt-tolerant trees and salt bushes into agricultural systems on salt-affected lands has the potential to increase crop and animal production and to decrease land degradation. Such land improvements combined with improved agricultural practices will ensure that current unsustainable trends in agriculture are reversed.

The biological approach emphasizes use of highly saline water and lands on a sustained basis through profitable and integrated use of the genetic resources embedded in plants, animals, fish, and insects, as well as improved agricultural practices. This approach attempts to promote bioreclamation techniques such as salt-tolerant plants, bushes, trees, and fodder grasses. Plants, particularly trees, are commonly referred to as biological pumps and play an important role in the overall hydrological cycle in a given area. Studies done in Pakistan (Qureshi and Barrett-Lennard 1998; Hussain et al 1990) have shown that highly saline waters could be used to grow salt-tolerant fodder grasses to improve the quality and quantity of livestock. Management practices with these waters include use of chemical amendments, organic matter, and mineral fertilizers, and the judicious selection of salt-tolerant forages and grasses. Trees and plants act as biological drainage agents, helping to



lower water table depths, a very simple as well as energy-saving method. This is basically a “pro-poor” approach that enhances the income of poor farmers who otherwise might leave their lands barren.

In Pakistan, plants that can be used for biodrainage include poplar, eucalyptus, tamarix, maskit, and acacia. Similarly, nonwoody plants, such as bushes, sedges, grasses, and herbs, can develop deep-rooted systems that contact groundwater (Choudhary and Bhutta 2000). Any significant effect of such plantation on the water table would be expected only when the plants occupy a large enough portion of the catchments so that their total water use approaches the total recharge for the catchments. In Pakistan, the capacity of productive tree plantations to extract shallow groundwater is seen as a valuable tool for controlling rising water tables and salinity.

#### Accelerate reform process: strengthen institutions for change

Agriculture in Pakistan is changing rapidly, with the emergence of progressive and commercial farmers, and the replacement of conventional crops with high-value crops. It is obvious that the need for water is changing substantially as a result of agricultural diversification, urbanization, industrialization, recognition of environmental needs, climate change, and the evolution of the natural resource base. Therefore, a new water economy needs to be more flexible, a key to which will be the reallocation of water from those who need it less to those who need it more. For this to happen, Pakistan needs to invest in institutions that enable it to take on the future challenges of water management. The capacity of institutions should be developed to undertake legislative and organizational changes to solve entitlement, pricing, and regulatory issues.

In Pakistan, for example, groundwater is usually used in conjunction with surface water.

Farmers tend to decrease the salinity of irrigation water in an attempt to avoid soil salinization. In most of the canal command areas, concurrent use of surface water and groundwater is practiced equally in the head and tail ends of the canal system. One of the key disadvantages of this unmanaged concurrent use is that upstream areas are subjected to rising water tables and waterlogging, whereas tail-end users are aggravating their salinity problems due to the bad quality of the groundwater.

In Pakistan, the canal water delivered to the head-end farmers is generally 32 and 11% more than to the farmers of tail-end and middle-end, respectively (Haider et al 1999). Therefore, upstream farmers should be encouraged to make better use of the groundwater supply (because it is fresh), whereas tail-end users should be provided with more surface water supplies to decrease their dependence on saline groundwater and avoid soil salinization and loss of production. For this purpose, the canal department needs to regulate the canal flows to match the requirements of the tail-end farmers. It might not be easy to convince farmers to adopt these practices; however, continuous logical motivation might help. Farmers also need to be educated about proper mixing ratios of surface water and groundwater resources to foster crop production and halt soil degradation. Moreover, farmers should use precious groundwater to grow high-value cash crops rather than traditional crops to increase their income base.

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