WATER KNOWLEDGE NOTE

Groundwater and Surface Water in the Mega-Irrigation Systems of Pakistan

The Case for Conjunctive Management

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Groundwater use has increased across Pakistan, nowhere more than in the large canal-irrigated areas of the Indus basin irrigation system (IBIS). These mega-irrigation systems use surface water and groundwater, often in equal measure. The two water sources are the same source and should be managed as such. Groundwater supplied by seepage from the surface system is pumped up to complement surface water supplies. The delivery of surface water supplies determines how much groundwater is used and how much recharge will happen. In most cases, such conjunctive management will not "cost" extra water to make significant gains in yields and support drought resilience. This case study discusses Pakistan's contrasting experiences with conjunctive use in the Punjab and Sindh provinces and attempts to move toward conjunctive management.

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The information in this case study was prepared as part of the South Asia Water Initiative (SAWI) technical assistance project, Managing Groundwater for Drought Resilience in South Asia. SAWI is a multidonor trust fund supported by the United Kingdom, Australia, and Norway and administered by the World Bank.

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Introduction

Most of Pakistan's estimated 1.2 million groundwater wells are within the Indus basin irrigation system, the world's largest. In this mega-irrigation system, groundwater use has offset inadequacies in surface water deliveries, increased the amount of water available, and helped end the waterlogging that cripples agricultural production and causes unhealthy living environments. The availability of groundwater also ensures that drought periods are dealt with effectively.

In Pakistan's large-scale irrigation systems, as elsewhere in South Asia, there is now a "conjunctive reality." In the irrigation systems, a large part of the water comes from groundwater, not from direct surface supplies (Shah 2009). The high density of wells in the surface irrigation systems is sustained by seepage water from cultivated land (47 to 81 percent, depending on the season) and irrigation canals (16 to 48 percent) (Solangi, Qureshi, and Jatoi 2017). Irrigation water in this way is then used and reused in an example of extending the chain of water uses for greater efficiency. In conjunctive systems, surface and groundwater are artificial distinctions used to describe the hydrological process. In mega-irrigation systems, groundwater and surface water are closely connected and ideally should be comanaged.

This case study discusses how conjunctive management should be implemented in Pakistan's mega-irrigation systems. Conjunctive use is widespread, and some conjunctive management is already happening, but there is much to gain by integrating management of surface and groundwater in mega-irrigation systems.

This paper discusses two trajectories in Pakistan, largely coinciding with the country's two main provinces in the Indus basin irrigation system – Punjab and Sindh. In Punjab, conjunctive use has taken off in the last 35 years with high tube well densities, often more than 20 per 100 hectares. Conjunctive use has ended water logging and sustained increased cropping intensities, even to the point of groundwater overuse in parts of the province. In contrast, in Sindh a similar transformation has not taken place and water logging is still a persistent problem. Groundwater use accounts for a much smaller portion of water deliveries for two reasons: (a) the existing high and outdated irrigation water supplies in Sindh, which could be altered, and (b) the salinity underneath a large part of the Sindh canal system, which cannot be changed. Table 1 shows the contrasting extent of waterlogging, which should be considered in terms of impact on human and animal health, crop yields, houses, and infrastructure. About 38.5 percent of the area in Sindh has a depth to groundwater table within 1.5 meters, classifying it as waterlogged. In the current era of concerns on water scarcity and climate-induced drought, such massive waterlogging is almost an aberration.

TABLE 1. Distribution of Depth to Groundwater Table Zones in Canal-Irrigated Areas (June 2000)

Depth to groundwater (meters)	Province	
	Punjab (% Irrigated area)	Sindh (% irrigated area)
Less than 1.5	6.2	38.5
1.5 to 3.0	18.9	50
3.0 to 4.5	29.3	6.1
4.5 to 6.0	14.8	2.9
More than 6.0	30.8	2.5
	100	100
Total area (irrigated) Million hectares	9.96	5.74

Source: Salinity Control and Reclamation Projects (SCARP) Monitoring Organization

Groundwater Situational Analysis in Punjab and Sindh

Punjab

With a population of 90 million people, Punjab is Pakistan's largest province. About 65 percent of the population lives in the rural areas, and agriculture remains an important source of income; therefore, dependable irrigation is essential. Average annual rainfall in Punjab is about 390 millimeters, and evaporation is about 1,500 millimeters. Almost half of the total land area is irrigated with water diverted from the Indus and tributary rivers, adding up to 9.96 million hectares of irrigated command area.

Since 2013, Punjab's political leadership has been consistently upbeat about the future of the province and ambitions to create a regional agricultural powerhouse. The Punjab Bureau of Investment and Trade[2] pointed out the province's unique selling points: a geographical location close to export markets in China and the Gulf states, the world's largest single irrigation system, and agro-processing facilities.

Groundwater is remarkably important in Punjab's mega-irrigation system, both for quantity and reliability.

Agricultural expansion and intensification in Punjab have been driven largely by the development of at least 900,000 privately operated pumped tubewells in the past 35 years.[3] Most are powered by small-capacity engines, either diesel or electric, driving a centrifugal pump and lifting water from shallow depths of less than 10 meters. It is estimated that at least 75 percent of the increase in water supplies in the past 25 years is from public and private groundwater exploitation.

Development is also facilitated by a near-perfect aquifer underneath this massive irrigation system. Punjab is underlain by different types of geological formations, but the main source of groundwater is its alluvial aquifer with water-bearing formations ranging in thickness of up to 500 meters. It is this alluvial plain that underlies the main irrigation commands. These areas are subdivided into six interfluves or doabs. Good-quality land is generally close to the river. But in the center of the doabs, far away from the flushing effect of the rivers, groundwater is more saline.

Groundwater generally occurs under water table conditions in the alluvial aquifer. Depth to water below the land surface in Punjab ranges from close to the surface near the major rivers to more than 20 meters deep away from the rivers. In 2000, only 6.2 percent of the irrigated land was waterlogged with water tables within 1.5 meters.

This was not always so. The current conjunctive reality in Punjab is a remarkable transformation from the situation in the 1960s and 1970s, when the so-called twin menace of waterlogging and salinity prevailed. In these years, groundwater represented only 8 percent of the total usage (van Steenbergen and Oliemans 2002). In the 1930s, groundwater tables began rising in Pakistan's irrigation systems because of excessive seepage from canals, overirrigation, and the lack of drainage. It led to a massive crisis in the 1960s, with 52 percent of the land in the entire country, including Punjab, faced with waterlogging for most of the year. At the time, this was considered a global security issue and even debated in the United States Congress.

The response was what may be called a first attempt at conjunctive management in Pakistan. Under the Salinity Control and Reclamation Projects (SCARP), starting in 1962, batteries of deep-drainage tubewells were installed and typically pumped from 40 to 120 meters. They were to draw down the groundwater table, reduce waterlogging, and bring farmland into cultivation again. In some places, where the deep water pumped up was fresh enough, it served as an additional supply of water. In many areas, especially in the Punjab province, these early SCARP projects lowered water tables and succeeded in bringing land into cultivation again.

The controlled and reduced water tables set the scene for a new era of agricultural development. A big boom in private tubewell development started in the 1980s, triggered by the availability of locally manufactured high-speed diesel engines. These engines (modeled on the vintage Peter engines) had a capacity of 12 to 16 horsepower and operated with centrifugal pumps, lifting between 20 and 30 liters per second. Investment costs were relatively low (usually less than US$1,200), which opened the sector to small farmers. At first, most farmers accessed groundwater by renting pump sets, but over time, more farmers developed their own tubewells. The rapid increase in groundwater use completely changed the agricultural landscape in Punjab, leading to increased production and cropping intensity and changes in crops, such as a shift from cotton to more vegetables and high-value crops.

Sindh

As table 1 shows, the groundwater situation in Sindh province is in stark contrast to the one in Punjab. Although groundwater is the prime source of irrigation water in the canal commands of Punjab, Sindh has a different conjunctive reality. In no canal command does the water reused as groundwater exceed 30 percent; in most canal commands, it is far less (Habib 2008). The groundwater transformation that occurred in Punjab did not happen in Sindh to the same degree.

As in Punjab, the irrigation system in Sindh is underlain by a massive alluvial aquifer but with two important differences. First, a large part of this aquifer system contains groundwater that is too saline for irrigation, especially at greater depth. As in Punjab, salinity increases in Sindh with distance from the rivers, resulting from millennia of flushing. But in Sindh, there is only one river and salinity is more persistent.

According to Ahmad (1995), many sites have shallow, usable groundwater. The total fresh groundwater zone at shallow depth (15 meters) is tentatively estimated at 46 percent (van Steenbergen, Basharat, and Lashari 2015), but further investigations are needed to precisely assess groundwater qualities at shallow depths. In these areas, a managed recycling of fresh groundwater and surface water should be possible.

The second important explanation for the limited use of groundwater is the high surface irrigation supplies in several canal commands in Sindh. Van Steenbergen, Basharat, and Lashari (2015) reviewed canal water supplies to all canal command areas in Sindh, highlighting the wide variety of irrigation allocations across them. The Rice Canal command area receives the maximum canal supplies (areal average of about 1,700 millimeters), whereas other command areas receive 400 to 800 millimeters. The annual reference crop evapotranspiration at the nearest meteorological station in Rohri is 1,931 millimeters. Irrigation duties in Sindh are high. The overabundance is further amplified by the widespread indiscipline in the shape of diversions into the main canals beyond the official allocations and furthermore from the presence of direct outlets, tampered offtakes, or canal seepage, reaching high above the ground level. The ample availability of free surface water has made pumping of groundwater unattractive.

These high surface-water deliveries and limited groundwater use have given rise to widespread waterlogging (table 1). The twin menace in Sindh is still there. According to more-recent data (October 2011), 69.6 percent of the area has a root zone that is waterlogged (Basharat, Ali, and Azhar 2014). The waterlogging conditions in the area remain about the same every year, except before the monsoon, because of the lower canal supplies during rabi season. In acreage, the affected area is colossal at 2.19 million hectares in post-monsoon 2011. This has a major effect on production of rabi crops. For the Sindh province, some 74 percent of the water available is lost in the form of nonbeneficial evaporation (WaterWatch and Osmani 2005). The large extent of land that is waterlogged and unproductive further reduces interest in using groundwater for agriculture. It also undermines the capacity to deal with floods because high groundwater tables have limited capacity to store flood water in the soil profile.

Waterlogging is particularly persistent in areas served by so-called nonperennial canals. These canals are meant to receive copious supplies in the wet kharif season, causing the water table to rise significantly and then fall again in the winter season (rabi season), when the canals are not flowing. In the Rice Canal in the District Larkana area, for instance, the water table fluctuates between 1 and 3 meters during the kharif and rabi seasons. The annual cycle of rising and falling water tables brings salts to the upper soil strata (Mukarram 1984). In some nonperennial canals, waterlogging problems are compounded because the canals are converted, officially or unofficially, into perennial canals. The problems in the perennial channels in Sindh are different. There, water duties are generally lower, although still higher than elsewhere in the Indus basin irrigation system. Salinity is concentrated in areas with deficient surface water supplies, where there is not enough water for leaching accumulated salts. This often concerns the tail reaches of the channels.

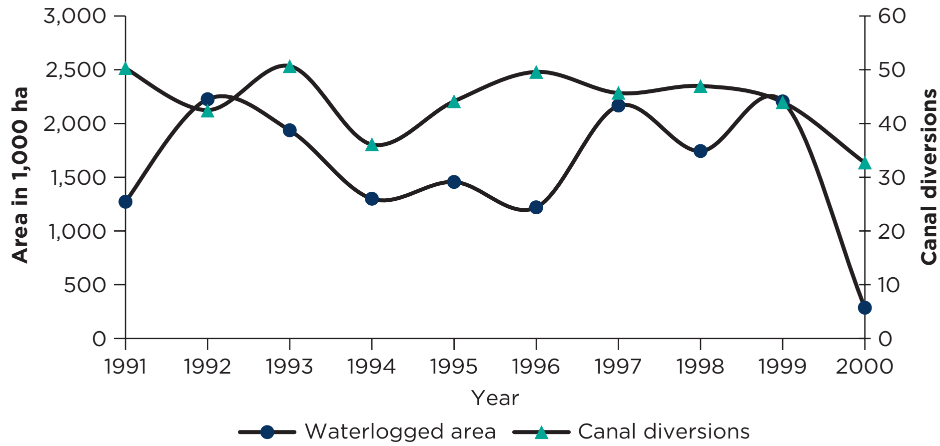
Although waterlogging is persistent, there has been one main exception in recent years. In 1998 to 2002, the El Niño effect caused rainfall to reduce by more than 50 percent, and releases from the main irrigation reservoirs in the country, Tarbela and Mangla, dropped by 9 percent and 37 percent, respectively. This resulted in a reduction of Pakistan's surface canal deliveries by 12 to 25 percent compared to preceding years (Saeed et al. 2009). This drought had a remarkable and unforeseen effect on Sindh's irrigated areas. Unexpectedly, crop production did not suffer from the drought and, in fact, increased. Production of wheat, rice, cotton, and sugarcane increased by 0.8 percent, 6 percent, 4 percent, and 6 percent, respectively, during the 1998–2002 drought period compared to the decade before the drought. Wheat, rice, cotton, and sugarcane crop yields rose by as much as 18 percent, 15 percent, 9 percent, and 4 percent, respectively. The effect was most pronounced in areas with uniform high groundwater tables.[4]

The explanation for this unexpected response to the drought—less water but more yield—was a significant reduction in waterlogged areas resulting from the reduced inflow and increased use of groundwater to compensate for the shortfall in irrigation canal supplies. Waterlogging and salinity disappeared, particularly in low-lying areas with heavy soils. Figure 1 is a snapshot of this period, showing how the area under waterlogging responded to canal supplies. Figure 2 has the same message but zooms in on Sindh's largest canal, the Rohri Canal.

The gist of figures 1 and 2 is that:

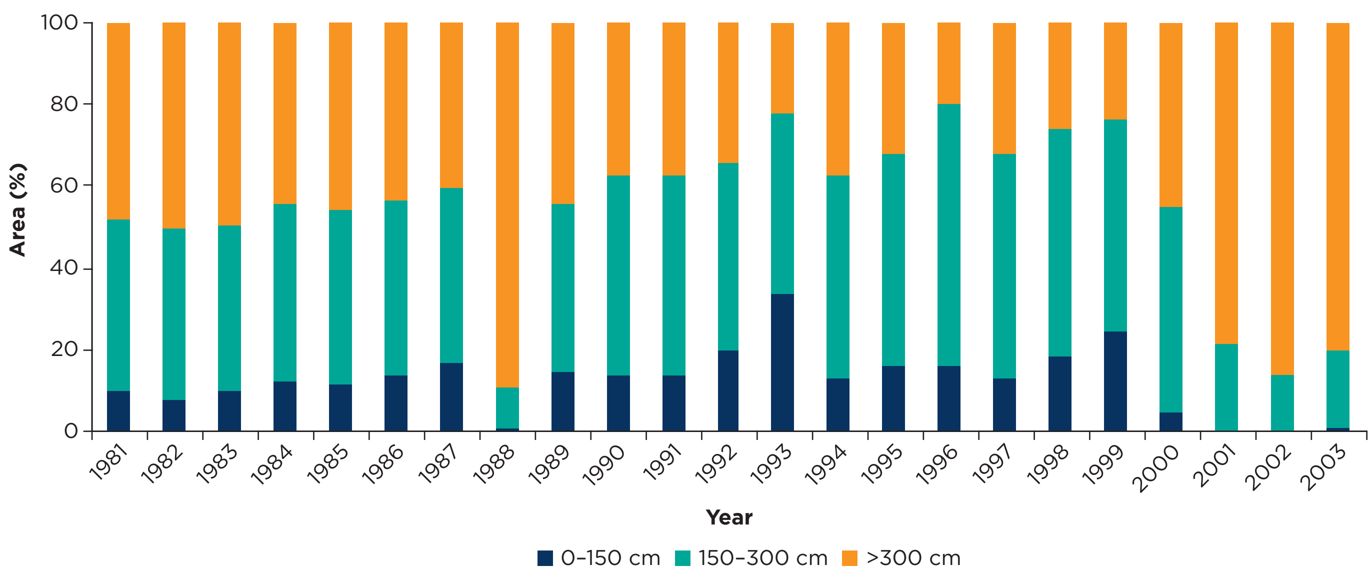
- The waterlogged area increased from 1.27 million hectares in 1991 to 2.26 million hectares meters per hectare in 1992, responding to high canal diversions of 62 billion cubic meters (BCM) in 1991–92. It then dropped to 1.30 million hectares in 1994 as the surface water flows reduced to 44.5 BCM. With increased canal supplies, waterlogging in 1998 again touched the 1992 levels.
- In 1999–2000, following a drastic reduction in available supplies, the waterlogged area shrank to

FIGURE 1. Waterlogging and Canal Supplies in Sindh (1991–2000)



Source: van Steenbergen, Basharat, and Lashari 2015.
Note: ha = hectare.

FIGURE 2. Pre-Monsoon Area under Different Water Table Depths in the Rohri Canal Command



Source: Saeed et al. 2009.
Note: cm = centimeters.

285,000 hectares. The same was true for the Rohri Canal, where groundwater tables within a 3-meter depth almost disappeared up to 2003.

Impact of Groundwater Development—The Current Challenges

As demonstrated above, the impact of groundwater development has been marked in Punjab and Sindh but has followed a different trajectory in each of these provinces, leading to a slightly different presentation of the current challenges in each province.

Punjab

As mentioned earlier, a virtual groundwater revolution has occurred in Punjab, where a major portion of Pakistan's million tubewells are located. These have made up for the unreliability and shortfall in surface water supplies from the canal system and boosted crop intensity to 172 percent. In some areas, such as Punjab's sugarcane wheat zone, crop intensities of 234 percent are reached (Mirza and Latif 2012). This may be compared to crop intensities in the pre-groundwater days of 103 percent, 111 percent, and

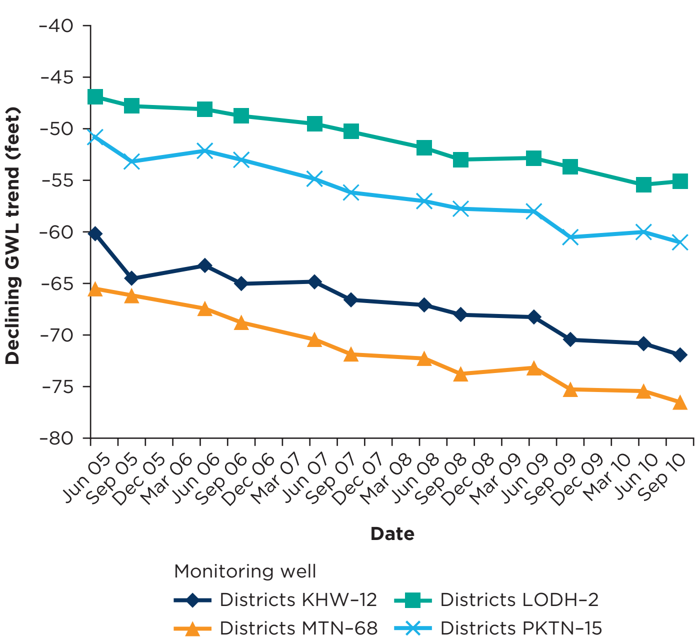
122 percent during 1960, 1972, and 1980, respectively (Ahmad 1995).

The tubewell transformation was a major factor removing waterlogging in the freshwater and some of the saline groundwater zones in the province. It further helped reduce soil salinity—waterlogging's companion menace. A comparison of the 2001–03 soil salinity survey for Punjab with an earlier main survey in 1976–79 shows that surface salinity declined from 14 to 7 percent after the intense use of shallow groundwater lowered the groundwater table.

The omnipresent tubewells in Punjab also helped increase drought resilience. The 1998–2002 drought did not result in a crop loss in Punjab because additional pumping compensated for the shortfall in canal supplies. In some areas, crop yields even increased because of the disappearance of waterlogged conditions.

This intense groundwater pumping in the canal command areas in Punjab is largely driven by farmers' investment. Since the mid 2000s, concerns that there may be a limit to this success story have risen. Monitoring in 2003–11 indicates that the overall system is getting slightly out of balance, with groundwater levels dropping in 28 of 38 districts. In most cases, the decline is less than 20 centimeters over the period. The most pronounced decline (of more than 3 meters) occurred in Kasur, Khanewal, Multan, and Pakpattan (figure 3). In other areas, the decline was far less (PISIP 2014). The main concern, however, is not so much declining groundwater levels but the upconing (upward movement in response to pumping) of deeper saline groundwater in areas of intensive pumping (Alam 2015).

FIGURE 3. Water Table Decline in Tail Reach Areas in Punjab shown in individual monitoring wells



Source: PISIP 2014.
Note: GWL = Groundwater level; KHW-12 = Khanewal-12; LODH-2 = Lodhran-2; MTN-68 = Multan-68; PKTN-15 = Pakpattan-15.

The 2010 floods reversed the trend somewhat. But, overall, the pattern is for water tables to rise in districts lying in head reaches of large canals and to decline in districts in tail reaches of irrigation systems with sometimes a deterioration in water quality. Another concern is the areas with a relatively thin layer of freshwater perched on top of saline groundwater, where overpumping or inadequately placed skimming wells can jeopardize the resource.

A snapshot of what is happening is in the longitudinal study of the Lagar Distributary in Rechna Doab (Ertsen and Kazmi 2015). Researchers examined the area in 1989 and revisited it 20 years later. During that period, the number of tubewells increased fourfold, mainly in the head and middle reach, because of the generally better groundwater quality in the head reaches. This occurrence reversed an earlier trend when tubewells compensated for the inadequacy of canal supplies and were overrepresented in the tail. It should be noted that a fourfold increase in tubewell numbers does not mean a similar increase in pumping. As more farmers obtained a tubewell of their own, utilization rates have dropped (van Steenbergen and Oliemans 2002). Another trend during those two decades is an increase in electric wells (from 18 to 29 percent) and the virtual disappearance of tractor-driven wells. The most important and worrying development, however, is that there are not only more wells but also deeper wells. In 1989, 7 percent of all wells were deeper than 50 meters, but by 2009, this number rose to 30 percent—thus augmenting the risk of increased salinity in irrigation water and thereby that of the soil and shallow groundwater.

Despite the intense groundwater use, or overuse, agricultural productivity remains relatively low in the province compared to other parts of the subcontinent. Under the existing field conditions, average wheat production in the Pakistan Punjab is 1.08 kilograms per cubic meter of water used, compared to the Indian Punjab's production of 1.42 kilograms per cubic meter of water used (Bastiaansen, Miltenburg, and Zwart 2010). This finding is partly related to the timing of the cultivation season. To make Pakistan's Punjab a food basket of the region, more can be done in water management and advanced irrigation practices.

Sindh

The situation in Sindh has been less dynamic. A major intervention was the development of the Left Bank Outfall Drain, a mega-investment in drainage with a budget of nearly US$1 billion to reduce waterlogging. The project targeted 525,000 hectares of land in the Sanghar, Nawabshah, and Mirpurkhas districts, some of the areas most severely affected by waterlogging. However, the project impact was short-lived because of the lack of maintenance and funding.

Waterlogging in Sindh remains a massive challenge. Except during the 1998–2002 drought, waterlogging affects an area of 1.5 to 2.3 million hectaresout of an irrigated command of 5.5 million hectares. Soil salinity is also a challenge. Salinity increased from 46 percent of irrigated land in 1979 to 51 percent in 2003. Cropping intensities are significantly lower than in Punjab with, for example, 116.7 percent in Sindh's cotton and wheat zone. This low performance comes despite much higher water deliveries and, as discussed previously, is partly caused by it. As may be expected, water productivity for wheat in Sindh is low and ranges from 0.32 to 1.15 kilograms per cubic meter (WaterWatch and Osmani 2005). The top score in Sindh is equal to the average value in Punjab.

Waterlogging impacts more than agricultural production. It hurts public health, with higher rates of waterborne diseases such as malaria, and makes it difficult to dig rural pit latrines. It also affects livestock and animal health by increasing diseases such as liver fluke. Housing and infrastructure are damaged by damp conditions (Abdel Dayem et al. 2004). High groundwater tables add up to water management disaster areas such as the tail-end Badin and Thatta districts. Here groundwater is saline because of high irrigation supplies (often in the rainy season when there is less demand elsewhere), flat topography, and poor natural drainage as a result of the tidal effect moving upstream after the scouring out of the tidal link. The impact extends beyond agricultural productivity to drinking water supplies. With groundwater levels close to the surface, no fresh or brackish water lens can form in the area to provide relief as a drinking water source. The main source of drinking water is the highly polluted water in irrigation canals in the area. The situation in Badin and Thatta worsened after the 2011 floods—consolidating and further spreading the high water tables.

Prevailing Groundwater Management Regime Versus Desired Groundwater Outcomes

At present, there is no centrally coordinated management of groundwater in the canal system of Pakistan. It is part of a bigger picture in which the canal system is operated as a utility but with little water management. Many initiatives by farmers and others have promoted the conjunctive use of surface and groundwater, but there is no central water resource management. During the drought of 1998–2002, reliance on private tubewells—some quickly installed—managed to overcome drought effects in the mega-irrigation systems. Even more importantly, the wells helped reduce waterlogging and caused a remarkable rise in production instead of a decline during the drought. That experience was an unrealized opportunity to develop a full-fledged conjunctive management program. Four steps described in the following section could be explored to develop systematic conjunctive management.

Recalibrate Irrigation Duties

Irrigation duties in Pakistan's mega-irrigation system are outdated. Updating and rationalizing them could be a main instrument to promote conjunctive management of surface and groundwater. Such work would need to account for current deliveries from the main storage reservoirs, the widespread use of groundwater, and even future climate scenarios. Surface water deliveries affect the amount of recharge and determine demand for groundwater supplies.

The challenge in Punjab at this stage is the overuse of groundwater. Basharat, Ali, and Azhar (2014) investigated the scope for the reallocation of irrigation duties in Punjab and established that only a few canals in Punjab have excess supplies and that irrigation water supplies could be better spread in some of the larger canals.

Updating duties would bring bigger gains in Sindh because of high surface irrigation supplies in many of its canal commands. These high irrigation allocations contribute to extensive waterlogging and create disincentives for farmers to use groundwater, even in areas where groundwater is fresh. The drought years of 1998–2002 effectively showed how "less was more" (Saeed et al. 2009). Current irrigation duties follow no logic. There is a compelling case to readjust outdated irrigation duties, accounting for current Indus basin irrigation system water availability, the storage capacity of Tarbela and Mangla, and the need to optimally manage the groundwater buffer. After the commissioning of the Tarbela and Mangla dams, 24 percent more water became available from the flow regulation, but canal duties were not officially recalibrated after the additional water became available. Irrigation duties should be set to develop an optimum balance between surface water supplies and groundwater availability and usage guidelines developed in support of this. This approach requires that surface water seepage be equivalent to groundwater use or, in other words, surface water supplies be set at an optimum scarcity to encourage groundwater pumping as a complementary source. Where groundwater is of marginal quality, the mixing of supplied surface water and pumped groundwater should result in usable water quality.

The gains may be substantial. Following Sindh's experience from the drought period of 1998–2002, the rationalization of irrigation duties would make possible huge water savings that can support the creation of new command areas, preferably areas with relatively fresh or marginal quality groundwater and relatively sandy soils so that highly conjunctive systems can develop right from the start. Going by the experience of the drought period, it may be possible to develop an additional area of 500,000 hectares. At present, some of this expansion is already happening in an uncontrolled manner, with water in drains being fresh from large excess flows and being pumped by farmers. In reassessing the irrigation duties, the current reuse from drains may need to be considered and regularized as well. Moreover, more groundwater irrigation by the promotion of shallow irrigation wells will also make it possible to intensify and extend the cropped areas. In areas where freshwater overlays saline water, there is a need to carefully promote multistrainer skimming wells that exploit water at a very shallow depth.

Improve Field Water Use Efficiency

In addition to rationalizing irrigation duties, it is important to look at field water management practices. Some systems have tremendous scope for improved water productivity, such as the rice-wheat system (Aslam 1998). Precision land leveling and mechanized land preparation can boost agriculture production and water saving up to 50 percent. Direct seeding and alternative wetting and drying, or the introduction of the system of rice intensification, promises to save water and increase yields at the same time.

In addition, there is a large range of smart water techniques now available. Some of these methods are in use by farmers in different areas. There are several examples of farmers applying water-saving techniques, achieving high yields, and avoiding waterlogging that is pervasive in the land around them. Examples are the systematic use of mulch (from banana or mango leaves) that reduces evaporation, the practice of ridge tilling, the use of micro-irrigation systems, and the use of low-cost greenhouses.

Selected Investments in Drainage and Canal Lining

A third recommendation is to promote select, well-targeted investments in drainage and in canal lining. The non-functionality of drainage systems (70 to 90 percent) in Pakistan (van Steenbergen, Basharat, and Lashari 2015) gives a clear message to be judicious in drainage investment. Drainage is nevertheless essential for conjunctive management, especially in low-lying areas where care should be taken to address persistent waterlogging but not to "over drain" so that beneficial effects on soil moisture from water tables are safeguarded. Investment in drainage, in fact, is the measure of last resort, if only because of the large cost implications; where possible, better managing surface supplies should prevent the problem.

When considering drainage investments, the priority in many areas should be to improve storm water drainage and restore natural drainage paths that are often blocked by road and railway development or urban expansion. Next, selective root zone drainage is required in areas with high waterlogged conditions. The main aim is to create enough storage space in upper soil layers to ensure adequate soil aeration for crop growth. Ideally, storage space in saline areas should allow for the development of freshwater lenses that can be used for local drinking water systems. In addition, root zone aeration would help avoid rainfall flooding.

There is no reason to develop or maintain public drainage facilities in fresh groundwater zones because private pumping will normally take care of most of the drainage requirement in such areas. Such private pumping will be further stimulated by the curtailing and rationalizing of surface supplies, as described earlier. Ideally, where root zone drainage is provided, there should be flexibility in water levels because some crops such as rice can tolerate high water tables, whereas other crops benefit from sub-irrigation. Finally, canal lining should be focused on areas where seepage from the canals system cannot be easily retrieved as groundwater recharge, primarily in areas with high salinity.

Make Better Use of Salinity

A fourth recommendation is to make better use of salinity. There are several options to achieve high yields by using relatively saline groundwater, and this needs to be better developed. One direction is the use of bio-saline systems, such as special farming and fisheries rooted in saline conditions but with good returns in areas that are otherwise considered wasted. A second powerful option is cultivation of common crops under saline conditions, using selected varieties and adjusted management practices. Research by Salt Farm Texel indicates that several existing varieties of common crops—wheat, sorghum, sugar beet, and potatoes—adapt surprisingly well to brackish water, particularly in free-draining soils. Salt-tolerant potato varieties were introduced over three seasons in 2015 to 2017 on 13 hectares in saline areas in Punjab and Sindh. Farmers planted the varieties in areas with salinity levels in the range of 8 to 10 deciSiemens per meter (approximately 6500 ppm – 8000 ppm total dissolved solids), areas usually considered out of bounds for potato cultivation. Yields of the best-performing varieties were 23 tons per hectare on average, with some varieties producing 40 tons per hectare. Considering that the national average on non-saline soil is 20 tons per hectare, this finding shows that salt-affected soils can be very productive and even outcompete crops on non-saline soils when the right potato variety is used in combination with a cultivation strategy for saline soils. In Sindh, the potatoes grown in salt-affected soil could enter the market early at premium prices.

All these measures come at high benefits and low cost, but they require an organizational regime to put them in place. Currently, the attention paid to groundwater policy in Pakistan is lacking in commitment. There are also some hard constraints in the prevailing water management regime. The first is that there is no capacity in the irrigation administration to go beyond supervising the irrigation utility. There is no manpower, skills, or interest to manage water resources within the mega-irrigation system. In Sindh, for instance, a graduate engineer will typically manage 300,000 hectares of irrigated land with the support of two or three sub-assistant engineers. Compared to other mega-irrigation systems, this is very thin coverage. There is simply not enough staffing to do more than keep the infrastructure running. A second constraint is the politicization of Pakistan's water resources management. The main issue is the upstream-downstream rivalry between the country's two main provinces, in which Sindh politicians contend that irrigation water is diverted upstream in Punjab, depriving Sindhi farmers. The reality is different, with high irrigation duties in Sindh further augmented with unauthorized diversion. This current political narrative in Sindh precludes a systematic look at the province's water resources and opportunities for distributing and spreading it better. There is hope, however. In 2018, the National Water Policy (Government of Pakistan 2018) was adopted with one chapter dedicated exclusively to groundwater. The policy has several elements that are closely intertwined with making conjunctive management a reality, such as preparing groundwater budgets for canal command areas and promoting higher water productivity. The systematic promotion of conjunctive management of surface and groundwater fits with all these cornerstones of the National Water Policy.

Conclusions

The provinces of Punjab and Sindh are each endowed with a massive alluvial aquifer underneath their mega-irrigation systems, which makes it possible to collect seepage from irrigated fields and canals and reuse it. The practice has been in use for several decades, but conjunctive management could be strengthened to realize benefits such as an expanded command area, reduced waterlogging that would reduce health problems and damage to housing, and improved capacity to absorb floods or unusual rainfall in the topsoil and shallow aquifers.

Putting in place a proper conjunctive management regime in Sindh will require some steps, including documenting and recording present water use and water productivity (with help of remote sensing), preparing water balances per canal sub-command and discussion, communicating with all stakeholders including farmer organizations, and removing political resistance. This can all be planned and budgeted. The substantial benefits of doing so would far exceed the investment.

NOTES

1. MetaMeta Research, s-Hertogenbosch, The Netherlands.
2. Punjab Agricultural Sector Profile.
3. Based on tubewell densities in the selected area, the author of the case study is of the opinion that the number is much higher—probably close to 2.5 million shallow tubewells.
4. The increase in production was not uniform in areas with limited surface supplies (higher land and tail reaches). Crops with no access to fresh groundwater declined.

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