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Managing Water and Salt for Sustainable Agriculture in the Indus Basin of Pakistan

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Abstract: The Indus basin of Pakistan occupies about 16 million ha (Mha) of land. The Indus River and its tributaries are the primary sources of surface water. An estimated 122 km³ of surface water is diverted annually through an extensive canal system to irrigate this land. These surface water supplies are insufficient to meet the crop water requirements for the intensive cropping system practiced in the Indus basin. The shortfall in surface water is met by exploiting groundwater. Currently, about 62 km³ of groundwater is pumped annually by 1.36 million private and public tube wells. About 1.0 million tubewells are working only in the Punjab province. Small private tubewells account for about 80% of the pumped volume. Inadequate water allocation along the irrigation canals allows excessive water use by head-end farmers, resulting in waterlogging. In contrast, the less productive use of erratic supplies by tail-end farmers often results in soil salinity. The major issues faced by irrigated agriculture in Pakistan are low crop yields and water use efficiency, increasing soil salinization, water quality deterioration, and inefficient drainage effluent disposal. Currently, 4.5 Mha (about 30% of the total irrigated area) suffers from adverse salinity levels. Critical governance issues include inequitable water distribution, minimizing the extent to which salt is mobilized, controlling excessive groundwater pumping, and immediate repair and maintenance of the infrastructure. This paper suggests several options to improve governance, water and salt management to support sustainable irrigated agriculture in Pakistan. In saline groundwater areas, the rotational priorities should be reorganized to match the delivery schedules as closely as possible to crop demand, while emphasizing the reliability of irrigation schedules. Wherever possible, public tubewells should pump fresh groundwater into distributaries to increase water availability at the tail ends. Any substantial reform to make water delivery more flexible and responsive would require an amendment to the existing law and reconfiguration of the entire infrastructure, including thousands of kilometers of channels and almost 60,000 outlets to farmer groups. Within the existing political economy of Pakistan, changing the current water allocation and distribution laws without modernizing the infrastructure would be complicated. A realistic reform program should prioritize interventions that do not require amendment of the Acts or reconstruction of the entire system and are relatively inexpensive. If successful, such interventions may provide the basis for further, more substantial reforms. The present rotational water supply system should continue, with investments focusing on lining channels to ensure equitable water distribution and reduce waterlogging at the head ends. Besides that, the reuse of drainage water should be encouraged to minimize disposal volumes. The timely availability of farm inputs can improve individual farmers' productivity. Farmers will need to have access to new information on improved irrigation management and soil reclamation approaches. Simultaneously, the government should focus more on the management of drainage and salinity.



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1. Introduction

Agriculture is the backbone of the rural economy of Pakistan and a significant contributor to food security. It provides 21% of the gross domestic product (GDP) and accounts

for more than 60% of foreign exchange earnings [1]. It occupies 45% of the total workforce, and about 80% of the population is involved directly or indirectly in agriculture for their livelihoods [2]. The surface water resources of Pakistan mainly come from the Indus River and its tributaries. After the Indus Basin Treaty of 1960 between India and Pakistan, Pakistan was accorded exclusive use of three western rivers (Indus, Jhelum, and Chenab), and India was entitled to three eastern rivers (Ravi, Sutlej, and Beas) (Figure 1). Pakistan's reduced access to the western rivers was compensated by constructing Mangla Dam and "link" canals that transferred water stored in the dam to the areas previously dependent on inflow from the western rivers. Inflows are mainly derived from snow and glacier melt, and rainfall in the catchment areas. Most rivers are ephemeral streams outside the Indus basin, which only flow during the rainy season and do not contribute significantly to the country's surface water resources.



Figure 1. Map of Pakistan showing the Indus basin and the main rivers, dams, and lakes.

The Indus River has a total length of 2900 km and a drainage area of almost a million square kilometers. The Indus basin supports the world's largest contiguous irrigation system, comprising 4 storage reservoirs (Warsak, Chasma, Mangla, and Tarbela), sixteen barrages, 12 inter-river link canals, 2 siphons, and 44 canal commands (23 in Punjab, 14 in Sindh, 5 in Khyber Pakhtunkhwa (KPK), and 2 in Baluchistan). The system is served by 59,000 km of irrigation canals and 107,000 km of watercourses [3].

Productive irrigated agriculture is constrained by multiple factors, including poor maintenance of unlined canals, poor on-farm irrigation practices, locally low-quality water for irrigation, inadequate drainage resulting in waterlogging and soil salinity in irrigated areas, and inadequate farm support services. Decreasing investments in the water sector, water scarcity, declining freshwater aquifers, and ecological problems combine to constrain increased agricultural output. The primary strategy must therefore be to increase the productivity of renewable water resources.

In the 2030 Agenda for Sustainable Development, the challenge of water scarcity and water quality deterioration is tackled through one of the Sustainable Development Goals (SDG-6), which aims to ensure water and sanitation for all. The latest assessments suggest that countries like Pakistan are not on track to achieve SDG-6 by 2030 [4]. This paper (1) reviews the current situation of deteriorating soil and water resources in Pakistan,

(2) reviews water allocation and distribution options, and (3) recommends policy options for enhanced, sustainable crop production to ensure food security in the Indus basin.

2. Surface Water and Groundwater Resources of the Indus Basin

2.1. Surface Water Resources

The annual surface flows in the Indus basin vary from 120 km³ to 230 km³, depending on the rainfall and snow patterns. There are also significant seasonal variations in the surface flows. The average inflow during the summer season is 160 km³, whereas the winter season flow is only 30 km³, which requires storage in the summer to meet water requirements in the winter. The average annual surface water and groundwater withdrawals in Pakistan are about 184 km³ (122 km³ from canal withdrawals and 62 km³ from groundwater extraction) [3]. However, this represents a significant double counting, as most of the extracted groundwater consists of leakage from the canal system. Considering this inter-connectivity between surface water and groundwater, estimation of the actual water availability requires caution. After adjusting this double counting of 48 km³, the net surface withdrawal is about 136 km³. About 94% is used for agriculture, 5% is allocated to domestic use, and the remaining 1% goes to industry [3]. A summary of the Indus basin's water budget based on the mean annual river flows and mean annual canal diversions is given in Table 1.

The Indus Basin Irrigation System (IBIS) irrigates about 16 Mha, contributing more than 90% of the national grain production. Perennial canal supplies are provided to 8.6 Mha, while the remaining area is non-perennial (i.e., only irrigated in the summer). Considering total canal diversions of 122 km³ and an irrigated area of 16 Mha, the annual surface water availability is 7625 m³/ha/year. This means an availability of 2.21 mm/day, compared with the average evapotranspiration demand of about 5 mm/day in wheat–cotton cropping systems and 6–7 mm/day in the rice and sugarcane cropping areas [5]. This amount is insufficient to meet the evapotranspiration demand for the year-round intensive cropping system practiced in the Indus basin, necessitating access to groundwater. The surface water quality is excellent for irrigation (200–300 ppm at the rim stations). However, it adds about 1.0–1.5 tons of salts per ha per year to the irrigated lands [6].

Rainfall in the basin is neither sufficient nor reliable. About two-thirds of the rain is received during the summer months of July–September. The mean annual precipitation ranges from 100 mm in the lower Indus plain to over 750 mm in the upper Indus plain. Due to the concentration of rainfall in the monsoon season, the direct contribution of rainfall to the total crop water requirement is only 15% [6].

Table 1. Water budget of the Indus basin irrigation system (all values are in km³).

Parameters	Inflow	Outflow/Losses	Available
Mean annual withdrawals	184		
Mean annual canal diversions			122
Losses in the canal system		29	
Available supplies at the watercourse head			93
Watercourse losses		27	
Available canal supplies at the farm gate			66
Groundwater contribution	62		
Available water at the farm gate			128
Field channel losses		13	
Available water at field level			115
Field application losses		29	
Available water for consumptive crop use			86
Rainfall contribution	16		
Total available water for consumptive crop use			102

Data source: [5,7].

2.2. Groundwater Resources

The Indus basin irrigation system is underlain by an extensive unconfined aquifer covering the whole 16 Mha of surface area, of which 6 Mha are fresh, and the remaining 10 Mha are saline [5]. Most of the groundwater is recharged from the seepage from canals and watercourses, inequitably distributed between the head and tail areas. In most fresh groundwater areas, water tables are falling due to excessive pumping to supplement surface supplies. Seepage from canals (~25%) and watercourses (~30%) [7] and percolation from farmers' fields are thus only "losses" when they reach an unusable saline aquifer, with the eventual outcome of waterlogging and salinity.

In sum, a little more than half of the water diverted into canals reaches the farm gate [2]. The annual groundwater extraction is estimated at 62 km³, of which 48 km³ is sourced from surface water seepage from irrigation channels and farmers' fields. At the same time, the remaining 12 km³ is unsustainable aquifer depletion in fresh groundwater areas [3,8].

Defining groundwater depletion in large, heterogeneous areas such as Pakistan is complex, and the estimates differ. Yoshihide and Bierkens (2014) [9] estimated an annual depletion of 35 km³; Famiglietti (2014) [10] assessed the regional depletion (including the Indus basin areas within India) at 17 km³; and Young et al. (2019) [3] concluded that the net annual depletion in Pakistan was only 1 km³. Some of these differences can be rationalized. The first estimate is likely to be excessive, as crop water consumption in irrigated areas is assumed to be at the maximum potential levels, which is inconsistent with the low average yields achieved in Pakistan. The latter estimate was based on GRACE data at a very coarse resolution, potentially including areas outside of IBIS. For both the second and third estimates, a particularly complicating factor was the need to distinguish between fresh and saline groundwater areas. If water tables are rising in saline areas and falling in fresh groundwater areas, then the observed net depletion rate may be small. Still, the sustainability of groundwater irrigation is decided only by the depletion of fresh groundwater. Since all estimates agree that depletion is underway, the conclusion that fresh groundwater consumption needs to fall locally is uncontested.

Presently, 62 km³ of groundwater is exploited in Pakistan by over 1.36 million private pumps [3,11], substantially exceeding the "safe yield" in some fresh groundwater areas—where water tables are falling at around 1.0 m/year—while saline groundwater areas are prone to waterlogging, as pumping is much lower than the recharge rate. About 1.0 million tubewells are working only in the Punjab province [2] (Figure 2). About 15% of the pumps are electric, and the remaining 85% use small diesel pumps of 10–12 horsepower (hp). In the Indus basin, access to groundwater is unregulated; anybody can extract any amount from beneath the land they own or farm without considering the detrimental effects of that action on the resource and other users [2]. The legal underpinning of this situation stems from the Act of Easement (1882). Groundwater abstraction increased sixfold between 1965 and 2020. More than 80% of groundwater exploitation is done by private tube wells, creating various management and equity problems [2]. Uncontrolled access to groundwater has allowed farmers to grow water-intensive, remunerative crops (e.g., rice and sugarcane) and assured higher crop yields. Currently, groundwater discharge in freshwater areas exceeds the recharge rate, turning this boon into an impending catastrophe; water levels are declining, pumping costs are increasing, and groundwater quality is deteriorating [12,13].

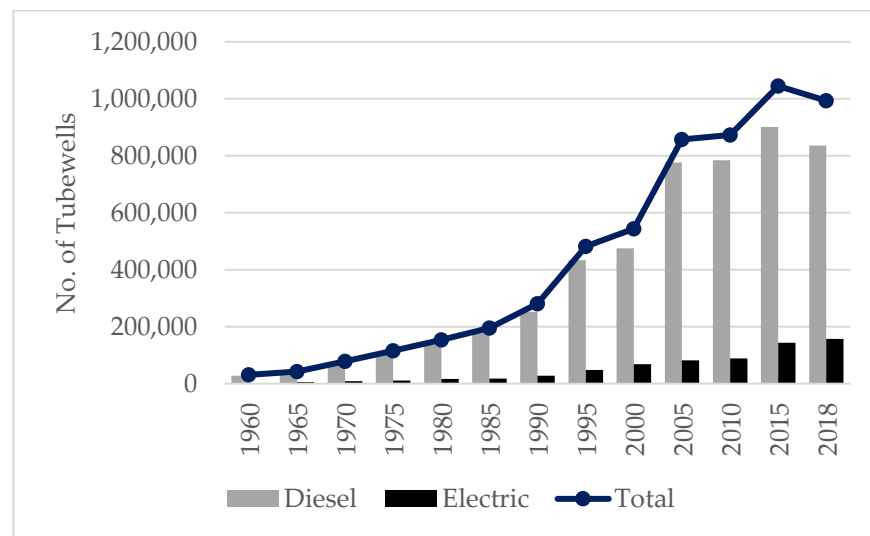


Figure 2. Growth of private tube wells in the Punjab province of Pakistan. (Source: Punjab Agriculture Statistical Department).

The groundwater table in the Indus basin is declining at a rate of 1.5 m/year in some areas. The situation is even more challenging in the Baluchistan province, where groundwater tables fall at a rate of 2–3 m annually. The smallholder farmers in 15% of Punjab and 20% of Baluchistan may lose groundwater access by 2025 [2]. Excessive lowering of the groundwater is making pumping more expensive, and wells are going out of production. The changes in groundwater levels are less pronounced in Sindh, owing to restricted exploitation due to quality concerns. In Khyber Pakhtunkhwa (KPK), the situation is better due to a surplus canal water supply and less groundwater dependence.

3. Sustainability Challenges in the Indus Basin

3.1. Increasing Gap between Supply and Demand

Pakistan is the world's sixth most populous country, with a projected population of 250 million in 2025 and 335 million in 2050 [14]. The urban population is expected to increase to 52% by 2025. Therefore, future water demand increases are also likely to come from domestic, industrial, and non-agricultural uses. Evidence points to a broadening gap between the renewable water supply and demand. Considering population growth projections, increasing demand from industrial, domestic, and environmental sectors, and assuming no or little change in the renewable freshwater resources in Pakistan, the current annual renewable water resources (ARWR) are 1100 m³ per capita and are expected to decrease to 1000 m³ per capita in 2030 and 900 m³ per capita in 2050 [3]. In the Central and South Asia regions, Pakistan would be the third most water-scarce country after Afghanistan and Tajikistan [15]. These scenarios are based on (1) the ARWR projections for 2030 and 2050 based on freshwater availability [13]; (2) water needed to support ecosystems (i.e., environmental flows requirements (EFR, referring to the amount and timing of freshwater flows and levels necessary to sustain aquatic ecosystems [16,17])); and (3) population projections for 2030.

3.2. Surface Water Distribution

Unlike some arid regions where water rights can be bought and sold separately from the land, such as in the western United States and Australia, access to irrigation water in the Indus basin is directly linked to land [18]. The Indus basin irrigation system was initially designed to distribute limited quantities of water over large areas to provide drought protection, rather than for intensive production over a smaller area. The original design for seasonal irrigation intensity was around 40%. The operating system is supply-based, with the main and distributary canals operating either at a full supply or closed

in a pattern designed to meet the approximate water demands of the dominant crop in an area. Irrigation canals have a typical design capacity of about 2.0 mm/d (more in the non-perennial canals and areas designed for rice). The distribution of water from the canal outlets to farmers is performed on a fixed rotational system called “warabandi”, which generally occurs on a seven-day cycle. Under this system, each farmer can take the entire flow of the outlet once in seven days for a time proportional to their landholding size. Given the meager duties, the water delivered in one turn is insufficient to irrigate the whole farm. A farmer must therefore decide whether to underirrigate all land or leave a fraction unirrigated [18]. Since the water is scarce, this automatically encourages farmers to seek the most productive allocation of limited water.

While this system of distributing water is crude, it should be noted that the system serves almost 60,000 outlets, each of which provides water to a group of 30–50 farmers. Given the severe scarcity of surface water, a simple approach to management, with transparent rules that invoked peer pressure among farmers to oversee local distribution, was the only way of ensuring a degree of equity in the allocation of water [18].

In recent decades, the discipline and equity that this system was designed to achieve have deteriorated. Good maintenance was essential to ensure proportional allocations at all levels in the system, but maintenance budgets have been inadequate for decades. As the service provided declined, farmers interfered with outlets, installed illegal “direct” outlets, and officials were influenced to make ad hoc reallocations of water to favored areas. The result is inequitable water distribution, poor technical performance, a pervasive environment of mistrust, and conflict between the water managers and the farmers [19]. Furthermore, because no allowance is made for seepage along a watercourse, the “turn” assigned to head-enders delivers a lot more water per hectare than an identical turn to a tail-end, with the difference usually exceeding 25%. This is reflected in the crop productivity levels of the head-, middle-, and tail-enders of the same canal [20]. Therefore, equitable water distribution remains a challenge.

3.3. Low Crop Yields and Low Water Productivity

Increasing demand for food and favorable marketing conditions has provided the incentive to increase annual cropping intensities from the original design of 70–80% to more than 150%, primarily based on groundwater development. Moreover, many canals can no longer convey their actual design capacity due to siltation and inadequate maintenance [20,21].

The productivity of water in Pakistan is among the lowest in the world. For wheat, it is 0.5 kgm^{-3} , compared with 1.0 kgm^{-3} in India and 1.5 kgm^{-3} in California [22]. This reveals that there is a substantial scope for increasing water productivity which needs to be harnessed. The average wheat yield in the Indian Punjab is 4.2 tha^{-1} , compared with 3.2 tha^{-1} in the Pakistani Punjab. Similarly, rice, maize, and sugarcane yields are much higher in the Indian Punjab than in the Pakistani Punjab. A recent analysis of India’s and Pakistan’s irrigation practices showed that the primary reason for higher crop yields and water productivity in India is their higher nitrogen use. The nitrogen use in India for wheat and rice crops is almost double that of Pakistan [23]. This is due to the non-availability of nitrogen fertilizers at affordable prices to farmers. Therefore, Pakistan needs to focus on all inputs (not only water) to increase irrigated crop yields.

3.4. Increasing Soil Salinity Problems

As irrigation has spread in the Indus basin, so has the prevalence of soil salinity, affecting crop productivity. In addition to saline soils, waterlogged soils also occur in the basin due to a lack of drainage systems. These pose a significant impediment to the optimal utilization of agricultural production systems [20]. Salt-affected soils adversely affect the socioeconomic conditions of the people living in these areas, causing low living standards and health problems for humans and animals.

The basin faces a substantial salt balance problem. The salts brought in by the rivers and their tributaries are estimated at 23 million tons (Mt) annually. The extensive groundwater pumping adds another 45 Mt of salt annually to the irrigated lands. Most of it is in Punjab (41.5 Mt), and 3.5 Mt is in Sindh. Most salts are fossil salts deposited in the deeper strata and aquifers during the Indus plain's formation. The outflow to the sea is 10 Mt, while 2.2 Mt are captured in a series of evaporation ponds [20]. The remaining 49 Mt of salts is retained in the irrigated lands and its underlying strata and aquifer [20,24]. This implies that, annually, an average of 3.5 tons of salts is added to each hectare of irrigated land. Currently, about 4.5 Mha are affected by various levels of salinity [24]. The highest concentration of saline area is in the Sindh province, where nearly half of the land is affected by soil salinity. The efforts have reduced the saline area from 35% of the total area in 1980 to 28% in 2007 (Figure 3). Due to deeper groundwater depths and leaching through monsoonal rains, much of the salt added by the groundwater in Punjab is washed away. This is the reason that the saline area in Punjab is low compared with Sind. In the Sind province, groundwater is shallow and of inferior quality, restricting leaching even in monsoon months [20].

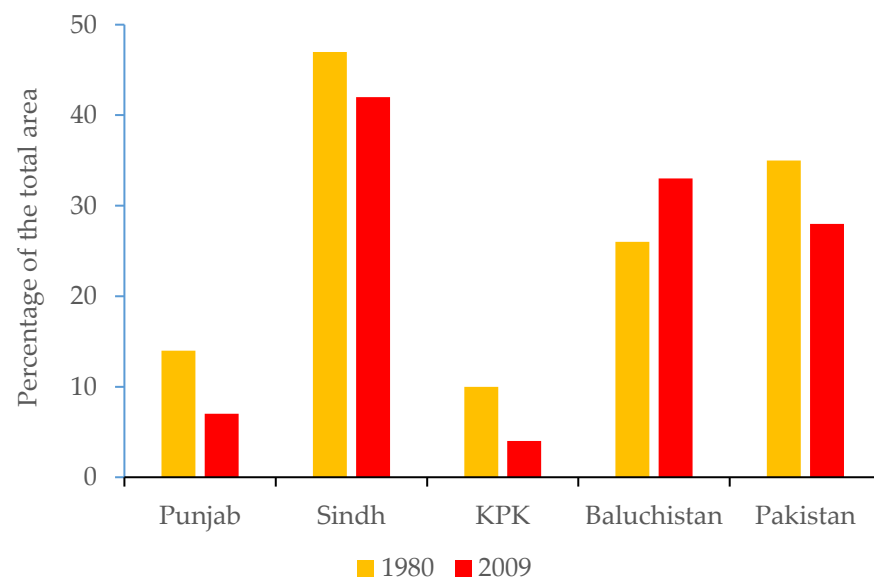


Figure 3. Salt-affected area (%) in different provinces of Pakistan (Source: WAPDA, 2007).

The cost of inaction in underperforming degraded lands, such as salt-affected soils, is estimated to be a 15–69% loss in revenues, depending on variables such as the crops grown, the intensity of land degradation, and the level of water quality deterioration, among other factors [25]. These estimates do not account for additional costs, such as loss of employment, increased human and animal health problems, reduced land values, and associated environmental costs. Therefore, along with water shortages, equal attention is needed for salinity management in the irrigated areas.

Over the last four decades, the government and farmers have tried various options for salinity management. These include engineering, reclamation, and biological interventions. Under engineering options, public sector tube wells were installed to lower the groundwater levels, and the pumped groundwater was discharged into canals to increase the water supply for irrigation. For the reclamation of salt-affected soils, gypsum was provided to farmers at the subsidized rates along with technical training. In the highly saline areas, farmers were encouraged to plant salt-tolerant food and feed crops to improve the productivity of salt-affected lands [20,25]. These interventions help in reducing the extent of salt-affected lands, although success has been limited.

3.5. Funding

Annual irrigation service fees are about USD 2/ha, and no government over the last 50 years has sought to raise irrigation charges to cover the costs of repairs and maintenance, due to political reasons. Currently, the annual operations of the surface system for farmers cost the government roughly USD 14/ha [3]. Young et al. [3] estimated the total cost of system operation and annual maintenance at USD 102/ha. The gap between revenue collection and the amount spent on operation and maintenance (O&M) for the Punjab province widens continuously (Figure 4).

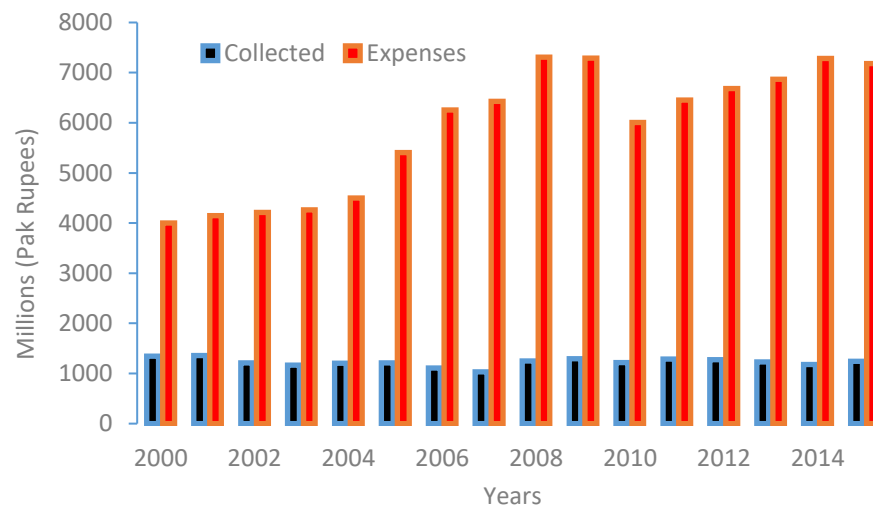


Figure 4. Comparison of expenses and collected water charges in the Punjab province.

The large gap between the collected irrigation fees and actual (let alone required) expenses stresses the need to revisit the irrigation service fee mechanism needed to provide farmers with adequate services. Furthermore, an intersectoral approach is also required for charging water use by different subsectors. It is evident from the global experiences that raising water tariffs, levying effluent charges, and encouraging water markets can significantly improve economic efficiency and environmental sustainability [26]. Therefore, a holistic approach is needed to estimate the total cost of the provision of irrigation services. However, the practicality of full cost recovery requires building the financial capacity of farming communities. This can only be achieved through proper service delivery, provision of the right quality inputs, and favorable production marketing [27].

4. Response Options

4.1. What Is Feasible?

Irrigation management in Pakistan is based on the Northern India Canal and Drainage Act of 1873 (as amended following partition). The act defines the rules and responsibilities of all involved, from senior engineers to individual farmers, associated with a complex infrastructure system designed to support the uniform sharing of scarce water over a vast area with minimum active management levels. Access to groundwater is governed by the Act of Easement (1882, as amended), which allows the operator of the land unrestricted access to underlying groundwater.

Unsurprisingly, almost 150 years after the framing of these acts, many factors have changed. Cropping patterns have changed, and cropping intensity has increased. Groundwater has developed into a major source of irrigation water, and salinity and waterlogging have evolved in many irrigated areas. The progressive deterioration in system performance has provided the excuse for individual farmer interventions that have undermined system managers' effectiveness [27].

A typical response to this situation is to recommend “reform.” The recent World Bank report [3] has many recommendations, including the following related to water service delivery:

- Replace warabandi with new water-sharing rules based on economic efficiency and farmer equity;
- Reform irrigation tariffs to reflect realistic operations and maintenance (O&M) costs;
- Strengthen water user associations for improved system operation and improved collection of water charges;
- Reform the governance of water user associations and farmer organizations to prevent elite capture;
- Modernize irrigation systems, including new hydraulic control structures and the lining of canals in waterlogged and saline areas;
- Automate the control of hydraulic structures using real-time data acquisition systems.

These recommendations are no doubt desirable, but are they feasible? “Replacing warabandi in pursuit of farmer equity and economic efficiency” poses at least three major difficulties. First, it would require total reformulation of both the laws governing water allocation and access. Second, “farmer equity” suggests that more water should be provided to less productive areas to improve low farm incomes, while “economic efficiency” requires reallocation of water in the opposite direction to improve average productivity. Third, since the entire system consists of 170,000 km of channels, all the associated control structures (and 58,000 outlets serving farmer groups) would need to be rebuilt to new standards to support the flexible delivery of water to individual farms, all of which is required to support individualised service delivery and water trading. Once built at a potential cost of USD 5000–10,000/ha, the operational costs would vastly exceed the current needs of USD 102/ha [3], the actual expenditure of USD 12/ha, and the current service charges of USD 2. Regarding the need to strengthen and reform farmer organizations, the 1873 act created effective farmer organizations for each watercourse, defining their obligations in operating and maintaining all the infrastructure at that level. These functions have declined in parallel with the drop in service standards.

Paradoxically, of course, the need to reform water laws after more than a century is offset by the entrenched interests in place after such a long period. Any substantial reform of the system management and water allocation would be resisted by those benefiting from current inequities in distribution. All these factors constrain a realistic reform program, which should prioritize interventions that do not require amendment of the Acts and reconstruction of the entire system and are relatively inexpensive. If successful, such interventions may provide the basis for further, more substantial reform toward the objectives set out by the World Bank.

4.2. What Are the Priorities?

Three issues stand out. First, inequitable water distribution along the irrigation channels allows excessive use by the head-end farmers, contributing to waterlogging. This, in turn, causes erratic supplies and low productivity at the tail tends, increasing soil salinity. Second, interventions should minimize the extent to which salt is mobilized from saline aquifers (and the deeper levels of currently “fresh” groundwater areas). Third, funding for maintenance (and remedial works) that restores the functionality of the rules under which the system is supposed to operate must be provided. This is a fundamental component of “governance” that only the government can address, either through increased user charges or direct government subsidies. It may seem defeatist to prioritize rehabilitation and reassert the management approaches of the nineteenth century. However, these objectives can be pursued within the existing rules and infrastructure to improve productivity while minimizing saline water mobilization.

4.3. What Should Government Agencies Do?

In areas where the groundwater is saline, the distributary canals' rotational priorities should be reorganized to match delivery schedules as closely as possible to current crop water demand, limiting the quantity of water delivered while increasing the reliability of the schedules. In other words, the quality of service should be prioritized over the quantity. This would have the dual benefits of reducing the incentives to pump and mix saline water with fresh water and minimizing untimely excess deliveries that contribute to waterlogging. Untimely deliveries (for example, when there has been rainfall and irrigation is not needed) should be allocated to fresh groundwater areas, where the excess can contribute to reusable recharge. Additionally, wherever possible, the government should pump fresh groundwater into distributaries to improve availability at the tail ends. Both these interventions would serve to enhance the productivity of water in the system, reduce inequities, and minimize, if not reduce, the mobilization of salt. At the watercourse level, warabandi would continue, with investments (to the extent possible and supported by cost recovery) focusing on lining channels to ensure equitable distribution and reduce waterlogging at the head ends. The recommendations to replace the existing warabandi system with water-sharing rules based on economic efficiency and equity [3] are practically impossible without a complete restructuring of the system. These changes also require analysis of the trade-off between efficiency and equity, especially in a system where millions of smallholders rely on the canal water for their livelihoods.

Changing water allocation laws would also require a political understanding of the issue, government-level interventions for changing the policies, and realignment of public sector organizations to improve their capacity to handle complex land and water management issues. The approach outlined is consistent with the primary objectives of the recently adopted National Water Policy. This policy stresses the need to adopt a more integrated approach to protect all upstream and downstream stakeholders' interests concerning quantity and quality and empowers the federal government to develop a regulatory framework to ensure efficient and sustainable groundwater resource utilization [28].

4.4. Improving Water Productivity

Water productivity can be improved in several ways. First, reducing excess deliveries during periods of low demand reduces evaporative losses (estimated at one-third of the water applied and infiltration into saline aquifers). Secondly, a more reliable irrigation service encourages more intensive use of inputs and hence higher yields. All these outcomes would be supported by the interventions proposed above. Improved agronomic and on-farm water management practices, such as land leveling, ridge and furrow, zero tillage, and mulching also enhance water productivity. Studies have shown that irrigation deliveries to wheat and cotton can be reduced up to 40% without reducing yields or rising soil salinity [29–32]. Qureshi and Bastiaanssen (2001) [33] recommended that in Pakistan, wheat and cotton crops can produce optimal yields by applying 300 mm of irrigation water instead of the current practice of 420 mm.

Drip irrigation techniques are also widely used to improve irrigation efficiency by reducing soil evaporation and deep percolation losses. These micro-irrigation systems can be economically more attractive if used to grow high-value crops, as the productions and income will be many times higher than traditional crops. However, in the absence of a lucrative market and affordable access to these systems, their large-scale adoption for small farmers will remain a challenge. The water-saving techniques for rice, such as direct seeding and alternate wet and dry (AWD) methods, can reduce water use by 15–20% [34,35]. However, fixed rotational irrigation systems and a lack of farmer training would be serious constraints in the large-scale adoption of the AWD method in Pakistan.

4.5. Reusing Saline Drainage Water

Saline drainage water is being extensively used for growing a range of salt-tolerant crops. These include (1) fiber and grain crops; (2) forage grass and shrub species; (3) medic-

inal and aromatic plant species; (4) biofuel and multipurpose species; (5) fruit trees; and (6) agroforestry systems. Several studies in the Indus basin have shown emerging examples of crop diversification and management for optimal drainage water use for irrigation [36,37]. Among grain crops, barley—at soil salinity levels around 12 dS/m—can produce 80% of the yield potential anticipated from non-saline conditions [38]. Quinoa is a salt-tolerant crop of high nutritional value. It is now recognized as a potential alternative crop for salt-affected areas and is expected to play an essential role in ensuring future food security [39]. The quinoa crop is now being cultivated in many (semi-) arid regions, especially where soils are salt-affected and freshwater availability is limited. Forages produced by irrigation with saline water provide additional income sources for farmers in marginal lands. Several promising forage species that can be successfully grown on salt-affected soils using saline drainage water have been identified. The selection of suitable plants for saline lands depends on the cost of the inputs and the subsequent economic or on-farm benefits [40].

4.6. Improving Water Governance

The Irrigation and Drainage Act of 1873 gives extensive powers to irrigation officers to control the irrigation infrastructure and financial resources. Provincial irrigation departments (PIDs) were responsible for irrigation water distribution to farmers, collecting water charges, and repairing and maintaining irrigation infrastructure down to the outlet, with farmers responsible below that point. In addition to the top-down and rigid supply-driven irrigation managers' approach, poor service delivery has increased farmers' dissatisfaction and resulted in poor maintenance of the system and low collection of water charges. The situation was further exacerbated by inequitable water distribution, unauthorized outlets, and illegal pumping from canals [41].

It was generally argued that the IBIS's efficiency is low because it is being managed without farmers' involvement [42]. In the late 1990s, the government of Pakistan also restructured the Provincial Irrigation Department (PID) by establishing the Provincial Irrigation and Drainage Authorities (PIDAs) at the provincial level with three broad objectives in mind: (1) decentralization and autonomy; (2) empowering farmers; and (3) improving efficiency and sustainability. The management tiers of the PIDAs included commercially oriented area water boards (AWBs) at the canal level to operate the main and branch canals and participatory farmer organizations (FOs) for operation and maintenance at distributaries and minor canals. As part of this reform process, the irrigation canals at distributaries and minor levels were transferred to FOs [24]. The PIDAs act also defined groundwater extraction rights and empowered water user associations (WUAs) to monitor groundwater extraction in the canal command areas.

However, farmers' focus remained on the canal water distribution and collecting water fees, while groundwater monitoring was entirely ignored. The weak enforcement of the PIDA laws and regulations disappointed local water users. The main lesson learned was that ordinances and laws are irrelevant if not correctly implemented [42]. However, the main question remains: Who should organize farmers? Even the establishment of FOs in many countries could not solve this issue. Limited success has been achieved in areas where smaller numbers of farmers are involved. However, this has not been the case in India and Pakistan, where the numbers of farmers are large. It is argued that PIDAs have transferred the government's financial burden to farmers, but it has not improved the O&M and productivity of irrigated lands [24,42].

Hassan et al. (2004) [24] noted that farmers are willing to pay an irrigation service fee only if they are assured of the benefit of the service they pay for. The above discussion does not mean that rules are not necessary. However, they must be backed by a public awareness campaign about resource depletion and degradation [43]. There is a need to review the performance of PIDAs and take necessary measures to address the issues hindering its proper implementation.

4.7. Strengthening Institutions to Improve Water Management

There is a need to rethink the political and public policy fronts in Pakistan by prioritizing water conservation, ensuring water recycling and reuse, and supporting productivity enhancement of underperforming land and water resources [42]. Such policy actions should be accompanied by a call for sustainable intensification of agricultural production systems [43]. Skilled professionals, supportive institutions, and strengthening institutional collaborations would be key to supporting such policy actions. The key challenge would be supporting subsistence farmers by providing new knowledge about improved irrigation management and soil reclamation approaches.

The capacity at the provincial and federal levels for improving water and associated natural resource management remains heavily eroded. This requires building an engineering, social, and scientific cadre capable of working with all users in defining the problem and developing solutions. Adoption of a multidisciplinary and participatory approach is the way to go. This would require bringing together concerned government departments, farmers, the private sector, the civil society, knowledge institutions, local political leadership, and other serious stakeholders [44]. Using an integrated approach that combines the role of technology, research and extension services, and best management practices at the farm level as described by Mpanga and Idowu [45] will complement the proper governance of water allocation.

The roles and responsibilities of public organizations should be clearly defined to ensure efficient management at all levels. Effective water management requires integrating institutions, policies, skills, and technologies to promote water saving and improve water use efficiency and disaster management. A concerted approach that incorporates all stakeholders is needed to make necessary changes in water supplies and allocations. This discussion reveals that Pakistan's water stress is not related solely to supply and demand problems, but it is linked more to unsustainable practices and gross mismanagement. The irrigation department has failed—in the absence of adequate funding—to maintain the physical infrastructure that is intrinsic to its successful operation. Unless profound changes are made to address institutional inadequacies, weak governance, and political deadlock, Pakistan may witness further complications in managing its water resources.

5. Conclusions

This paper suggests several options to improve—or more precisely, to reinstate—water governance and water and salt management to support sustainable, large-scale irrigation in Pakistan. Three governance issues need the immediate attention of government agencies. First, inequitable water distribution along the irrigation canals stimulates excessive use by the head-end farmers, contributing to waterlogging while causing low, erratic, and poor productive use at the tails (increasing soil salinity). Second, interventions should minimize the extent to which salt is mobilized from saline aquifers (and the deeper levels of current fresh groundwater areas). Third, funding for maintenance (and works) that restores the functionality of the rules under which the system is supposed to operate must be provided. Changing the basic process of allocating water among farmers would require both a change in the law and system-wide upgrades to infrastructure.

In areas where the groundwater is saline, the distributary canals' rotational priorities should match the crop water demand to the greatest extent possible. This would have the dual benefits of reducing the incentives to pump and mix saline water with fresh water and minimizing untimely excess deliveries that contribute to waterlogging. In fresh groundwater areas, the government should pump groundwater into distributaries to improve availability at the tail ends. At the watercourse level, warabandi would continue, with investments focused on lining channels to ensure equitable distribution and reduce waterlogging at the head ends [41]. Within Pakistan's current political economy, changing the current water allocation and distribution laws without modernizing the infrastructure seems complicated. Therefore, operating the system in its current form

while appropriately maintaining the infrastructure is the best route to improved Pakistan's irrigation productivity.

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