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Water management in Pakistan's Indus Basin: challenges and opportunities

Shahmir Janjua [a,*], Ishtiaq Hassan[a], Shoaib Muhammad [b], Saira Ahmed[c] and Afzal Ahmed[d]

[a] Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan
[b] Department of Civil Engineering, Wah Engineering College, University of Wah, Wah Cantt 47040, Pakistan
[c] Directorate of Sustainability and Environment, Capital University of Science and Technology, Islamabad, Pakistan
[d] Department of Civil Engineering, University of Engineering and Technology, Taxila, Pakistan
*Corresponding author. E-mail: shahmir.janjua88@gmail.com

SJ, 0000-0001-6384-4655; SM, 0000-0002-5235-2812

ABSTRACT

The Indus River System is a major source of life in Pakistan. A vast array of Pakistan's agricultural and domestic consumption needs are critically dependent on the Indus River System. The Indus River contributes towards 25% of the country's gross domestic product, providing water for almost 90% of the food production in Pakistan. Linked to the water security issues, Pakistan is potentially at risk of facing a severe food shortage in the near future. The World Bank report of 2020–2021 estimates that the water shortage will increase to 32% by 2025, which will result in a food shortage of almost 70 million tons. Water shortage could also result in confrontation between the provinces as river sharing has always been a source of problem for Pakistan. According to recent estimates, siltation and climate change will reduce the water storage capacity by 2025 to almost 30%. As for the per capita water storage capacity in Pakistan, it is about 150 m^3, which is quite meagre in comparison with that in other countries. Irrigated agriculture will soon be adversely affected due to the reduced surface water supplies and the consequent increase in groundwater abstraction. To make matters worse, over the past decades, a great deal of distrust has developed among the provinces of Pakistan regarding the water distribution issue, and the successive federal governments have failed to formulate a cohesive inter-provincial National Water Policy. Along with the shortages and increasing demand for water, administrative corruption also plagues the water sector and is quite common. The beneficiaries of this water reallocation system are not only the rural elite, for example the large and politically influential landlords, but also the small and medium capitalist farmers. If not properly addressed, these complications of decreasing water resources could result in serious political and economic hostility among the provinces. If it wants to harness its potential to increase storage capacity, Pakistan must improve its water-use efficiency and manage its groundwater and surface water resources in a sustainable way. Strengthening the institutions and removing mistrust among the provinces are the key elements for maintaining a sustainable irrigated agriculture in the Indus Basin.

Key words: Groundwater abstraction, Indus River, National water policy, Pakistan, Sustainable

HIGHLIGHTS

- Indus River, a major source of life in Pakistan.
- River sharing has always been a source of problem and confrontation between the provinces of Pakistan.
- The paper highlights various problems in Pakistan's Indus Basin.
- It also gives several recommendations for improving sustainability in Pakistan's Indus Basin.

1. INTRODUCTION

Being the sixth most populous country in the world, the population of Pakistan is predicted to reach 220 million by the year 2025. The Indus Basin occupies a total area of 566,000 km^2 and 80% of Pakistan's total population lives within the Indus Basin. Over the last 10 years, Pakistan has become a water-stressed country. The United Nations (UN) has estimated that the per capita water availability of Pakistan has reached 1,090 m^3 (Condon *et al.*, 2014). The economic development of Pakistan has always been dependent on irrigated agriculture, and consequently, water. Seventy-five percent of Pakistan's total population is dependent on agriculture, and this sector accounts for 60% of the foreign exchange earnings, employs 44% of the labour force and accounts for almost 20% of the country's GDP (Qureshi, 2011).

However, Pakistan's water resources are under immense pressure due to the rapidly growing population. An increase in population means that there is a requirement for more food, but no new resources of water are there for its production. Water shortage has been identified as the most challenging of all problems by the Government of Pakistan because the water required for agriculture is vital for the growth of the agriculture sector and consequently for poverty reduction (Syed *et al.*, 2021).

Due to the deficiency in surface water supplies, farmers are meeting their growing needs through overexploitation of groundwater which is unregulated in Pakistan. The simultaneous use of both groundwater and surface water is taking place on almost 70% of the irrigated lands (Qureshi *et al.*, 2004). However, the poor quality of groundwater has resulted in salinization, which is a significant threat to sustainable irrigated agriculture in Pakistan. Today, Pakistan is one of those countries that are the worst affected by salinity (Syed *et al.*, 2021). Successful conjunctive management of both groundwater and surface water is essential for successful irrigation in the country (Qureshi & Mccornick, 2010). With the passage of time, contract farming in the country is increasing rapidly resulting in more advanced and commercial farmers, foodgrains being displaced by high-value crops and more people being attracted to agriculture because of the increasing prices of agriculture commodities. A paradigm shift in the water management strategies and water-resource development is required to find a solution to these problems.

Irrigation is the leading consumer of both groundwater and surface water in Pakistan. With the passage of time, as the population and the economy of the country grow, the management and distribution of water resources will become a serious issue. Currently, water usage for industrial and municipal supplies in the urban sector is about 5.3 km^3, which is expected to increase to 14 km^3 by 2025 (Condon *et al.*, 2014). The irrigation sector will, therefore, face a tough competition from the industrial and municipal sectors for the use of water. The current per capita water availability of 1,090 m^3 will be decreased considerably by the year 2025, which would mean that the shortfall in water requirement will be around 32%, which will result in 70 million tons of food shortage (Arshad & Shafqat, 2012). In order to cover the large areas in the canal commands, the Indus Basin was designed to provide low-intensity irrigation. However, the increased cropping intensities and the demand for more water have put more pressure on the surface irrigation systems (Bhutta & Smedema, 2007). The overexploitation of groundwater and reduction in the surface water supplies are having a deleterious effect on the agriculture sector in Pakistan, which accounts for almost 20% of the country's GDP and is consequently affecting the food security of the people (Habib, 2021).

Pakistan's water disputes with Afghanistan and India are always in the limelight and take precedence over other matters, but in an already fragile nation like Pakistan, it is the intra-state or inter-provincial water disputes that are posing a threat to environmental, domestic and political security. Intra-state or inter-provincial water disputes can cause more violence and damage than intra-state or international conflicts. However, mostly, the level of attention attracted by international water disputes is much more than that of intrastate water disputes (Mustafa *et al*., 2013). The growing demand–supply gap as a result of climate change and the growing population is making water resource a source of conflict among Pakistan's provinces. Pakistan, being an agrarian economy, has deep regional and ethnic fissures that have led to disputes among the four provinces (Ranjan, 2012). The management of both surface water and groundwater is very important for the future of Pakistan. Hopefully, there exist various opportunities for improving the management of water in the country. However, the supply–demand gap is increasing rapidly and is creating incessant unrest among the provinces. The increase in droughts especially in Sindh province has made problems worse. Therefore, there is an urgent need for adopting and implementing water conservation measures, building new water reservoirs and managing and allocating water resources in a better way. This paper presents an in-depth review of the water resource situation in Pakistan, the challenges being confronted by the water sector and the likely remedial measures to overcome these challenges and ensure sustainable irrigated agriculture in Pakistan's Indus Basin. In this paper, Section 2 presents the main features of the Indus Basin, Section 3 discusses the problems faced by the country's water sector, Sections 4 and 5 provide various recommendations for improving sustainability in the water sector and Section 6 concludes the paper.

2. FEATURES OF THE INDUS BASIN

About 566,000 km^2 of the area, which is about 70% of the country, is drained by the Indus Basin. It spreads over parts of four provinces, namely Punjab, Sindh, Baluchistan and Khyber Pakhtunkhwa (KPK) (Yu *et al*., 2013). As shown in Figure 1, the Indus Basin is fed by the eastern rivers (Ravi and Sutlej) and the western rivers (Jhelum, Chenab and Kabul). The total length of the basin is about 2,900 km and an altitude of 18,000 ft (5486.4 m) from the top of Himalayas to the low-lying areas of Sindh, where it flows into the Arabian Sea.

The Indus Basin has the largest contiguous irrigation system in the world. About 150,000 km^2 of cropland out of 190,000 km^2 are irrigated by the Indus Basin Irrigation System (Ahmad, 2005). The Indus Basin is home to the seventh largest mangrove system and the fifth largest delta in the world. However, there has been a deterioration of the delta's ecosystem in recent years due to a lack of a sustained minimum river flow. The average precipitation in the basin is around 230 mm/year, which is very low. A sub-tropical climate exists in the basin with transpiration rates of 2,112 mm/year (Ullah *et al*., 2001). Most of the flow in the Indus River (around 40–70%) is from glacier melt and snow off the Himalayas. Most of the flow (about 85%) in the basin's catchment occurs from the months of May to September (National Research Council, 2012). The Indus Basin in Pakistan has a mean annual flow of 176 billion m^3, of which almost 90% is supplied for irrigation purposes. Despite this, there are high variations in demand and supply: for example, during the droughts of 2000 and 2002, the difference between supply and demand was 20% (Briscoe, 2006). Due to factors such as urbanization and high population growth aggravated by evapotranspiration, canal and water course seepage, field application losses and field-level irrigation inefficiency, deficits are expected to be around 20% by 2025 (Briscoe, 2006; Ranjan, 2012).

The underlying unconfined aquifer in the Indus Basin covers 0.16 million square kilometres of the surface area. A total of 63 billion m^3 is considered as a safe groundwater yield for the aquifer, whereas extractions from the industrial, domestic and agriculture sectors amount to 52 billion m^3. However, the increase in salinity due to the decline in the groundwater levels and redistribution of salts in the aquifer, further exploitation of groundwater is highly unlikely. In Pakistan, the challenge of uncertain and low crop yields has been transformed into more assured crop production due to the availability of groundwater. Due to the on-demand groundwater availability in this Indus Basin, crop yields have increased, which has resulted in improved rural livelihoods and increased food security. However, this growth has led to various other problems like degradation of groundwater quality, falling water tables and groundwater overdraft (Qureshi & Mccornick, 2010).

Fig. 1. | Irrigation and river network of Pakistan's Indus Basin (FAO, 2013).

3. WATER MANAGEMENT CHALLENGES IN PAKISTAN'S INDUS BASIN

3.1. Availability, variability and future water demand in Pakistan

Pakistan is the fifth most populous country in the world and its population is increasing at the rate of 2.8%. Currently, the country's population is around 220 million, which is expected to reach 250 million by 2025 (Yaqoob *et al.*, 2021). The percentage increase in urban population will be from 35% in 2017 to 52% by 2025 (UNDP, 2019). Due to this increase in population, the water demand for industrial, domestic and other non-agricultural uses will increase by 8% in 2025 (Parry, 2016). In 1951, Pakistan had a per capita water availability of 5,000 m^3, which fell to 1,100 m^3 in 2005, and by 2025, it is expected to fall to 800 m^3 (Khemka & Kumar, 2019; Qureshi & Ashraf, 2019).

The UN' estimates that Pakistan's water demand is increasing at the rate of 10% every year (Connor, 2015). The estimates suggest that water demand will increase to 338 km^3 in terms of area by 2025, but the total water availability will remain in the same range from 240 to 258 km^3 (Shaheen, 2010).

The total current water withdrawals in Pakistan area-wise are calculated as 175 km^3. Out of this, almost 29% of the withdrawals (about 50.75 km^3) are from groundwater and about 71% (124.25 km^3) are from surface water. Out of the overall surface water available, 74% is extracted, while 83% of the total available groundwater is extracted, which is extremely high (Laghari *et al*., 2012). The demand–supply gap is also increasing due to an increase in population (Figure 2), and since there is no proper mechanism for water allocation, disputes among the provinces are also increasing (Bakhsh *et al*., 2011).

3.2. Vulnerability due to climate change

The effect of climate change on water supply in the Indus Basin is still difficult to assess. There are many uncertainties associated with respect to the local impacts of glacial melt, snowmelt, glacial retreat and precipitation patterns (National Research Council, 2012). Glacial melt and snow from the Himalayas contribute about 45% of the flow to the basin, which suggests that the vulnerability to climate change and glacial melt is very high. The Hindu Kush Himalaya (HKH) range stretches 2,000 km across the Asian continent, spanning Pakistan, Nepal, India, China, Bhutan and Bangladesh. This region comprises large rivers that include the Indus, Brahmaputra and Ganges. These rivers provide water source to almost 1 billion people in these regions. According to the latest research, the rate of glacial retreat in the local glaciers is comparable to those in other parts of the world, confirming that glacial retreat has accelerated in the past century (National Research Council, 2012).

Some recent estimates indicate that in the coming years, the rate of glacial melt due to the rise in global temperature will increase. This shall cause a 40% surge in river flow. However, the average flows in the Indus River in the long run would be lowered by almost 60% (Briscoe, 2006). Moreover, with global warming, the evapotranspiration rates across the irrigated Indus Basin are likely to increase, which will result in increased irrigation water demands resulting in an increased competition of surface and groundwater among the provinces (National Research Council, 2012).

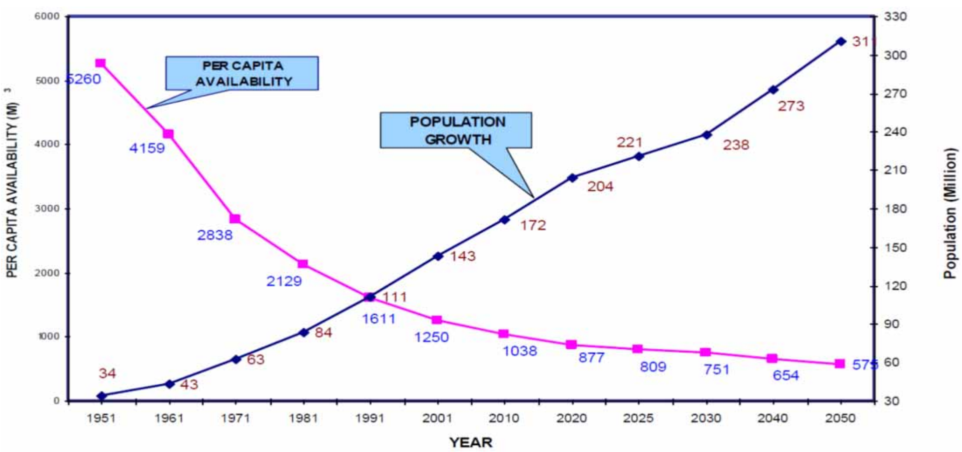

Fig. 2. | Water availability per capita (Ministry of Planning, 2017).

Almost 85% of the annual discharge in the Indus Basin occurs between the months of May and September and is from monsoon rainfall, glacier and snowmelt. During the next decade or two, the entire hydrological system is expected to undergo a big change due to the change in the intensity, location and timing of monsoon activity (National Research Council, 2012). The 2010 flood in Pakistan is an example of this change in the hydrological system (Lau & Kim, 2011). Glacial melting played no role in this case.

3.3. Groundwater overdraft

In Pakistan, surface water has always been the main focus, which is related to subnational hydro-politics, but groundwater in the Indus Basin and the problems associated with it, such as groundwater overdraft, salinity and waterlogging, are expected to have more serious effects on the efficiency of agriculture, water use and, hence, the hydro-politics in the long run. The surface water scarcity has forced the farmers to abstract and even overdraw groundwater. According to a survey, 0.8 million water pumps are operating in Pakistan, most of them in Punjab, and almost 50% of the agricultural water requirements are met by them (Qureshi *et al.*, 2008).

The increasing number of water pumps and overextraction of groundwater has led to the salinization of almost 4.5 million ha of land, half of which lies in the irrigated lands of the Indus Basin. Due to inappropriate practices of irrigation and waterlogging from canal seepage, nearly 1 million ha of irrigated land is also affected. In Sindh, the problem of salinity is more serious. The remedial measures taken to counter the problems of waterlogging and salinity have proved to be futile and the degradation of land is fast having a damaging effect on the agricultural productivity of Pakistan (Qureshi *et al.*, 2008). In view of the above-mentioned groundwater problems, surface water conflicts between the two large provinces, that is, Sindh and Punjab, also arise. Land degradation and salinity in Sindh is more than that in the other provinces, and, therefore, it is obvious that Sindh has a greater requirement for surface water supplies. In the canal command areas of both Sindh and Punjab, there is a severe decline in the water table due to the overexploitation of groundwater (Bhutta & Smedema, 2007).

3.4. The lack of storage capacity

Pakistan has very less storage capacity relative to other arid countries in the world, which is only 15% of the annual river flow. Pakistan has a per capita water storage capacity of only 150 m^3, which is very less considering that the United States and Australia have a storage capacity of above 5,000 m^3 and China has 2,200 m^3. The river flows are highly uneven all around the year, and, therefore, the agricultural requirements depend on storage capacity. However, Pakistan has a storage capacity for only 30 days in a year. If we compare this capacity with that of the other countries, it is extremely low, given that Egypt has a storage capacity for about 700 days, the United States for about 900 days and India for about 120–220 days (Monheit, 2011).

Currently, Pakistan has only two major reservoirs, Tarbela and Mangla, which are plagued with siltation problems. Due to sediment deposition, both reservoirs have lost between 32 and 20% of their storage capacities, respectively (Sattar *et al.*, 2017). Agriculture was recognized as the centre of the long-term development plan of Pakistan according to the Lieftinck Report of 1968. In this report, it was stated that insufficient irrigation development was the main cause for the limited growth of the agriculture sector between 1950 and 1960. In this report, it was concluded that in order to meet the increasing demands of agriculture, at least one reservoir, of the size of Tarbela, should be constructed once every 10 years. The report also stated that a yield of a million acre-feet (1.233 billion cubic meters) would be created by million acre-feet of storage available for agriculture. The storage yield curve also shows that the Indus River has significant remaining storage potential (Figure 3). It was also stated that due to the high silt load of rivers, the storage capacity of the existing reservoirs would decrease (Hassan, 2016).

If no new storage capacities are built soon, 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

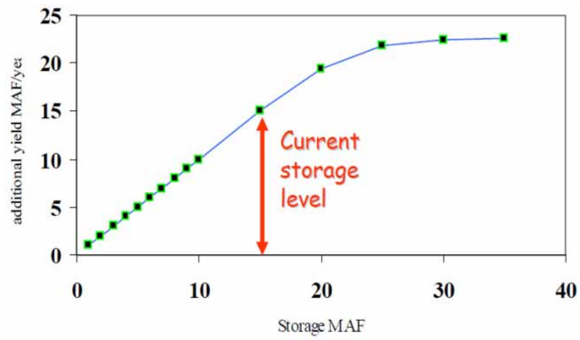

Fig. 3. | Additional storage yield curve for the River Indus (Ministry of Planning, 2017).

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 the completion of Tarbela Dam in 1976, no decision could be taken on the construction of new storage capacities (Azeem *et al.*, 2017; Janjua & Hassan, 2020a; Hussain *et al.*, 2020).

Another reason for the need for new reservoirs is that with the growing industry and population, the electricity demand in Pakistan is increasing by almost 7% annually, and the supply of electricity is falling short of demand by 2,000–4,000 MW (Trimble *et al.*, 2011). Due to poor transmission capability, generation deficits and increasing electricity demand, the country is facing extreme power shortages in the form of daily power rationing, also known as load shedding. Blackouts are frequent in the cities, which last about 8–10 h a day during the summer season. In rural areas, these power outages are often double the frequency (Dhaubanjar *et al.*, 2021).

3.5. Lack of environmental flows

The signing of the Water Apportionment Accord in 1991 recognized the need for environmental flows in the Indus Basin for the first time. Flow necessary for the environment was not agreed upon by the provinces at that time and further studies were planned to determine the environmental flows. It was decided in a report by international experts in 2005 that in order to maintain the flows that were required to sustain coastal fisheries, prevent salt accumulation and to check seawater intrusion, a flow of 5,000 ft^3/s (141.584 cubic meters per second) is necessary from the Kotri Barrage to the sea (González *et al.*, 2005). Due to the extensive Indus Basin Irrigation System canal network which diverted most of the water of Indus River for irrigation, sediment supply to the delta was also reduced considerably. Therefore, in order to meet the sediment demands, it was decided to ensure a cumulative flow of 30 km^3 over a 5-year period (González *et al.*, 2005).

Despite the recognition of environmental flows by the Water Apportionment Accord of 1991, these flows were not allocated separately. Although while making calculations for allocation to provinces in each 10-day period, these environmental flows are included, they are the first ones to be compromised whenever the system's supply is insufficient. With the increasing claims of provinces for water allocations, the federal government must take a strong stance to make the environmental flows necessary, which will be very beneficial for the long-term sustainability of the basin.

3.6. Transboundary water issues (international)

The Indus Basin Treaty was signed between Pakistan and India in 1960, which entitled the three eastern rivers (Beas, Sutlej and Ravi) to India and the use of three western rivers (Indus, Chenab and Jhelum) was exclusively given to Pakistan. The construction of dams, link canals and barrages on the Indus River and its two tributaries was also a part of this treaty. Being the largest contiguous irrigation system in the world, the IRBS consists of 4 storage reservoirs (Tarbela, Chashma, Mangla and Warsak), 16 barrages, 12 inter-river link canals, 2 siphons, 44 command canals (23 in Punjab, 14 in Sindh, 5 in KPK and 2 in Baluchistan), 59,000-km-long irrigation canals and 107,000-km-long watercourses. The last few years have witnessed serious differences between Pakistan and India over the issue of water sharing. The alleged construction of a series of dams on rivers by India has created serious concerns for Pakistan. These issues and differences need to be resolved to avoid any damage to the irrigated agriculture in Pakistan (Qureshi, 2011).

Apart from the rivers flowing from India, the Kabul River from Afghanistan is also a major contributor to the flows of the River Indus. It contributes 25 billion m^3 to the River Indus annually (Ahmed, 2010; Azam, 2015; Yousaf, 2017). Afghanistan's short-term water usage is around 10 billion m^3. Much of the water contribution from the Kabul River can be lost once Afghanistan begins to establish water storage projects on the River Kabul. Feasibility studies are already being conducted by Afghanistan to build new dams. Therefore, it is important that Pakistan should reach an agreement with Afghanistan on the sharing of water before differences turn into serious disputes (Qureshi *et al.*, 2010a).

3.7. Transboundary water issues (national)

In order to resolve the chronic issue of water disputes among the provinces, the then (1990) government of Pakistan took a positive step in the form of the Water Apportionment Accord. The Water Apportionment Accord 1991 was signed by all the four provinces of Pakistan, but serious differences among the provinces arose shortly after the signing of the accord, especially between Punjab and Sindh and between Sindh and Baluchistan. The Indus River System Authority (IRSA), an independent body, was established according to the provisions of the Water Accord by an act of parliament in 1991. The member board of the IRSA comprised of five members, one from the federal government and one from each province. The chairman was to be chosen from these five members in alphabetical order for a period of 1 year in rotation. The term of office of the members was 3 years. The implementation of the accord was the main agenda of the IRSA. Sharing of the available water supplies for each season was determined by the IRSA for each province. These supplies were released by the Water and Power Development Authority (WAPDA) from the reservoirs accordingly (Bhatti & Farooq, 2014).

The operation of the IRSA was smooth and satisfactory for about a decade, but due to the problem of sedimentation in Mangla and Tarbela and the drought conditions, the water fell short of the requirements. The IRSA faced severe criticism, as it failed to satisfy all the provinces due to the shortage of water. The provinces, mainly Sindh and Baluchistan, objected to the accord, and with this, the sub-national hydro-politics also came into play. The Indus Water Accord 1991 also became controversial as Punjab was blamed by the then Sindh government for not releasing its agreed quantity of water. The Baluchistan government also alleged that Sindh was not releasing water to Baluchistan (Kanwal, 2014).

The reservoirs of Mangla and Tarbela were the main causes of dispute among the provincial governments of KPK, Punjab and Sindh. Irrigation water for agriculture was mainly used by these three provinces. The Sindh government accused Punjab of stealing its share of water from these reservoirs. Punjab's provincial government was of the view that in order to accommodate the provincial governments of KPK and Sindh, it had been using less water than its requirements. Table 1 shows the water distribution for the four provinces of Pakistan as per the Indus Water Accord of 1991.

4. LIMITATIONS OF THE INTERPROVINCIAL WATER ACCORD

A minimum flow of water was allowed by the Indus Water Accord to be let into the sea and the remaining water was to be shared among the provinces (Table 1). So, the accord could only ensure an erratic flow of water.

Table 1. | Water allocation among provinces.

Province	Rabi season (km^3)	Kharif season (km^3)	Yearly share (km^3)	Balance supply shares[a] (%)
Punjab	23.30	45.76	69.03	37
Sindh[b]	18.29	42.00	60.17	37
Baluchistan	1.25	3.51	4.78	12
KPK	2.83	4.29	7.13	14
Ungauged Canals[c]	1.48	2.22	3.7	
Total	45.70	95.4	144.87	100

Source: Indus Water Accord 1991.
[a]Including flood flows and future storages.
[b]Including urban and industrial uses for Karachi.
[c]Ungauged Civil Canals above the Rim Stations.

However, the accord attempted to ensure a kind of equality among all provinces in that the provinces either lost in the form of shortages or gained from surpluses. The share of water for the provinces in terms of area were: (a) Punjab 69.03 km^3; (b) Sindh 60.17 km^3; (c) NWFP 7.13 km^3 and (d) Baluchistan 4.78 km^3. The future storages and floodwaters were to be distributed as: (a) Punjab and Sindh 37% each; (b) NWFP 14% and (c) Baluchistan 12%. 141.11 km^3 was the total surface water that was distributed among the provinces (+3.70 km^3 above the Rim Stations).

Until 1999, the distribution of water was done on an *ad hoc* basis. As ample water was available, there was no controversy over its distribution and all four provinces received their due share as defined in the Water Apportionment Accord of 1991. However, the declining availability of water after 1999 led to the implementation of a ministerial decision that led to water allocation as per the historical uses of 1977–1982 (Condon *et al.*, 2014). The proportional sharing of shortages and surpluses among the provinces is accounted for by the accord. However, the two small provinces, Baluchistan and KPK, were exempted from the proportional sharing of shortages by an act of 2003. Thus, whenever the total volume falls, the deficiencies are shared only by Sindh and Punjab (Condon *et al.*, 2014). This implies that there is no proper mechanism of water distribution when the total volume falls short or when the demands of the provinces exceed the total available water. Also, KPK and Baluchistan have not yet developed their irrigation systems properly, and, therefore, they always get more water than they can use. The flows of the western rivers varied from 112.5 to 231.6 km^3 annually during the period 1937–2007. The mean annual river flows at 50% probability came out to be 168 km^3. When the river flows are less than the allocated water based on canal diversions, as given in the accord, of 141.11 km^3 by about 17% of probability of exceedance, it creates disputes among the provinces (Janjua & Hassan, 2020b).

4.1. Problem of improper distribution and non-utilization

Out of the total water available in the country, only 3% is used for domestic and industrial purposes. Therefore, water sharing is related to environmental flows and agricultural requirements. The origins of the water conflicts in the country lie between the province of Sindh (lower riparian (agent)) and Punjab (upper riparian (agent)) and between Sindh (upper riparian (agent)) and Baluchistan (lower riparian (agent)). Punjab has certain grievances regarding water sharing (Hassan, 2016) such as the following: Punjab has more than double-cropped areas than Sindh, but the water allocation for Punjab is only slightly higher than that for Sindh (Table 1). Almost 66% of the total wheat, 73% of the total cotton and 68% of the total rice in Pakistan are produced in Punjab, while Sindh produces only 17% of wheat, 27% of cotton and 26% of rice. So, the crop productivity of Punjab is higher than that of Sindh. On the other hand, Baluchistan also accuses Sindh of stealing the water that it is not able to utilize. The Baluchistan government had filed a case against the Sindh government for payment of Pakistani Rupees (PKR) 7 billion. The Baluchistan government was of the view that Sindh had used its share of water which it could not utilize because of the lack of carrying capacity (Laghari *et al.*, 2012).

5. THE WAY FORWARD: RECOMMENDATIONS FOR IMPROVING SUSTAINABILITY IN PAKISTAN'S INDUS BASIN

The IRBS is beset by several problems that include improper management of groundwater, increasing waterlogging and salinity, seepage from unlined canals, poor irrigation practices, improper water distribution, transboundary water issues (national and international) and insufficient surface water supplies (Bisht, 2013). Studies suggest that 40% additional food would be required by 2025 to feed the increasing population. Ecological and environmental threats, along with decreased investments in the water sector, can further aggravate the problem of water management in Pakistan (Tariq *et al.*, 2020). The development of new storage reservoirs, the development of new water-sharing mechanisms among the provinces, improvement in existing irrigation structures and removal of mistrust among the provinces are some of the ways forward. To boost the sustainability and productivity of the irrigation system in Pakistan and to avoid conflicts among the provinces, the following potential solutions are suggested.

5.1. Improvement in water infrastructure and the development of new storage reservoirs

In a latest move, the government of Pakistan has successfully raised $8.32 million financing for water resources management projects in the fertile province of Punjab from the Asian Development Bank. This loan shall be targeted at financing the detailed designs and safeguard documents, feasibility studies and other due diligence assignments ahead of the execution of five priority irrigation infrastructure projects identified by the Punjab government (Habib, 2021).

Pakistan has invested heavily on water infrastructure and is extraordinarily dependent on it. Much of the irrigation infrastructure in the country is in decay due to negligence and mismanagement. No fund allocation or asset management plan exists for the existing irrigation infrastructure. The funds allocated by the government for irrigation infrastructure are somewhat less. More fund allocation and investments are needed in the irrigation sector to ensure food security for more than 20 million people of Pakistan (Janjua & Hassan, 2020a). Therefore, the above allocation of $8.32 shall go a long way in addressing the pressing needs.

Apart from these, a policy should be formulated by the federal government for the development of hydropower and water storage projects on an urgent basis. No major water project could have been started in Pakistan since the construction of the Tarbela Dam in 1976 as a result of famine conditions, particularly in Sindh. For today's conditions, major reservoirs should be constructed by developing consensus among all the provinces (Khan *et al.*, 2014).

Pakistan is dependent on the import of expensive oil to generate electricity despite its access to hydropower. Oil purchase places a huge strain on the economy, as it increases the external current account deficit and aggravates the country's balance of payment position (Trimble *et al.*, 2011). The construction of hydropower dams would not only help in flood control and irrigation storage, but also lessen the burden of importing oil, which puts a considerable strain on our economy.

5.2. Developing mathematical models for water allocation among the provinces

A serious problem with the Water Apportionment Accord is that the water allocations are fixed, which creates a quantified entitlement. Fixed water allocation mechanisms can lead to water allocations that are unacceptable for the provinces, especially during times of uncertainty and droughts and due to the stochastic nature of river flows. The Water Apportionment Accord among the provinces of Pakistan was signed almost 28 years ago. Since then, the pattern of the water demands of the provinces has changed due to the increase in population and the irrigated area. Therefore, in Pakistan, the gap between water supply and water demand has considerably increased (Hassan *et al.*, 2019). As the provincial water entitlements stated in the water apportionment are fixed, mathematical models (Bankruptcy Methods and Nash Bargaining Solution), as proposed by various authors such as (Safari *et al.* (2014); Degefu *et al.* (2016); Fu *et al.* (2018); Qin *et al.* (2019) and Janjua *et al.*, (2020)), are needed for water allocation among the provinces in order to cope with the changing supply and demand.

5.3. Addressing inequitable distribution and inefficient water use

Inefficient use and inequitable distribution of water lead to wastage and socio-political disorder. This is particularly relevant in the case of the irrigation sector and provincial water distribution where unjust distribution creates a feeling of dissatisfaction and deprivation in particular segments of society and leads to inefficient use of water. Pakistan has one of the lowest agricultural productivities in the world (Hussain *et al.*, 2004). For wheat, agricultural productivity is 1 kg/m^3 in India and 1.5 kg/m^3 in California, whereas it is only 0.5 kg/m^3 in Pakistan. However, Pakistan has enormous potential for increasing crop water productivity and improving low system efficiency, which shall ensure more income and jobs – per drop of water.

Equitable distribution of water should be ensured among all water users to overcome the problem of unequal distribution. Farmers should be educated and encouraged to use efficient technology for irrigation like sprinkler and drip irrigation, which would help to save large amounts of water. Out of all the modern irrigation technologies that are available at present, drip irrigation remains the most efficient. Water can be conserved, and yield can be expanded for farmers with the help of this technology, specifically for those who are cultivating their crops in semi-arid regions. It has exceptionally attractive characteristics among all the alternatives considered by experts and policy-makers to address the issue of water availability (Reid Bell *et al.*, 2020). Water-use efficiency is greatly increased by this method (when compared with the conventional irrigation methods where the yield increase is from 20 to 100%, while water savings range from 40 to 70%). The introduction of other water conservation technologies such as bed and furrow planting, precision land levelling and zero tillage can also help in improving water productivity (Tariq *et al.*, 2020).

5.4. Ensuring controlled pumpage of groundwater

In order to ensure a sustained supply of water in areas where the water level is going down due to increased and unchecked pumping of groundwater, controlled pumpage is essential. There is no particular check or regulation for the installation of tube wells or for groundwater extraction at present (Qureshi *et al.*, 2010b). The overextraction of groundwater has resulted in scarcity of water in certain areas of Punjab. Groundwater consumers with better technology are digging deeper for the extraction of groundwater, but with depleting groundwater, it will not be possible in the future to get more water even with powerful pumps. In order to maintain a certain level of groundwater, restrictions need to be imposed on the pumping of groundwater to allow groundwater recharge. Also, instead of individual water extraction, community-based water supply should be encouraged to conserve the fast-depleting groundwater resources (Watto & Mugera, 2016).

5.5. Mass public awareness about water management

It is essential that cohesive public awareness campaigns about water management be organized and stakeholders targeted at the institutional level, including at the levels of the government, academia, community and non-profit organizations. In general, radio and television are the most effective instruments for comparatively less-educated people, and print media should focus on the educated segments of the society. One aspect of the issue is the motivation and awareness at the national level, and the other segment of the campaign is also very important, which pertains to making the people realize through their payment/contribution for the services that they utilize (Ahmad & Salam, 2018). People generally become careful when they know that whatever they are consuming requires payment, however small the amount may be. The severity of the issue is sometimes not conveyed through free services and mere motivation is not enough (Sahibzada, 2002).

5.6. Improve water availability predictions and establish independent monitoring

The federal water agencies of the country, the WAPDA and IRSA, should work along with the provincial departments to set up a modern, reliable and independent methodology of water prediction (Khan, 2020). Some large multi-state basins around the world should be consulted and the technology best suited for the Indus River should be adopted along with investments in existing infrastructure (Bhatti *et al*., 2019). Along with the improvement in the water availability prediction, a reliable method of flow monitoring should be implemented by the federal government through an audit of conveyance losses. The provincial irrigation departments should be involved and asked in which area the conveyance losses have increased, and compensation should be given to those who have suffered from these losses (Bhatti *et al*., 2019). To achieve this, an appropriate compensatory mechanism should also be implemented.

5.7. Marketing of unutilized water share

Presently, the smaller provinces, KPK and Baluchistan, are not able to utilize their due share of water. As per the functional decision of the IRSA, their unutilized share is used by the provinces of Sindh and Punjab. The provinces of Baluchistan and KPK have sought compensation from Sindh and Punjab on several occasions for using their unutilized share (Laghari *et al*., 2012).

The functional decision of the IRSA to exempt these provinces from the sharing of shortages means that their 'unused' water is used by the larger provinces of Punjab and Sindh. Baluchistan, for example, is presently not able to fully exploit its allocated water share, and, therefore, as stated in the Water Apportionment Accord of 1991, the provinces should be allowed to market their unutilized water share to the other provinces.

5.8. Rationalize cropping patterns

The misuse and overuse of groundwater in the past was the main reason for the survival of Pakistan's agricultural economy as unmanaged groundwater was used by millions of farmers. This era of misuse and overuse of groundwater is now coming to an end, as the water table is now falling in many areas (Qureshi, 2020). A policy should be formulated to develop a balance between water withdrawals and groundwater recharge. There is a need to formulate an appropriate policy to replace water-intensive crops such as sugarcane and rice with high-value crops like pulses, vegetables and sunflowers, which can also help increase farm incomes. Pakistan is currently importing US$1 billion worth of edible oil (Qureshi & Mccornick, 2010). Restricting rice and sugarcane production to domestic needs could help reduce considerable pressure on both surface and groundwater.

5.9. Separate allocation for environmental flows

Pakistan's agriculture primarily relies on the Indus River, and in the long term, the cost of ignoring environmental flows will be very high. These environmental flows must be allocated separately and should be a part of Pakistan's national water strategy. With the construction of new dams, there is an opportunity to recognize the environmental flows, revise the allocations and make separate allocation for them (Lohano & Marri, 2020). It must be recognized that the window of opportunity for allocating and recognizing these flows will be very narrow, as with the passage of time, the provinces will also claim their increase in shares. The federal government must take a strong stance to recognize and prioritize environmental flows for the long-term benefit of the Indus Basin.

6. CONCLUSIONS

The water sector of Pakistan plays an important role in the development of the nation. With the increase in population, the gap between water supply and demand is increasing, leading to water insecurity among the provinces of Pakistan. At present, the country is facing severe water shortage, which will become more severe due to increase in population, climate change and poor management of water resources. The lack of trust among the provinces, inadequate technical policies and lack of storage capacity are the main causes of disputes among the provinces of Pakistan. Addressing intra-provincial disputes, particularly between the provinces of Sindh and Punjab, is a big challenge for the federal government. It is important that the government introduce innovative water policies for the water sector that help in addressing environmental sustainability, economic efficiency, equity and storage issues. Regulating and altering water-use behaviour, along with adopting modern irrigation technologies like drip irrigation, can curtail water shortages and pave the way for improved economic growth and development. It will be a long incremental process, but one that needs to be initiated earnestly through appropriate institutional reforms in the water sector and a healthy dose of democracy in the water resource decision-making structures.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories (https://cust.edu.pk/static/uploads/2021/04/PhD-Thesis-Shahmir-Janjua.pdf).

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