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Pakistan's water resource management: Ensuring water security for sustainable development

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Pakistan is blessed with abundant water resources but facing a critical water shortage due to a lack of storage facilities, poor water governance, and the adverse impacts of climate change. The burgeoning population at present 225 million, which is expected to cross 250 million by 2025 is creating an additional burden on water resources, as per capita availability is depleting sharply from 5,000 m3 in 1951 to 1,100 m3 in 2005, which is expected to fall to 800 m3 by 2025. Pakistan's water demand is increasing at an average yearly rate of 10% which in terms of the area will increase to 338 km3 by 2025, against the availability of 240–258 km3. Out of the available surface water, approximately 74% is extracted, while 83% of the groundwater is used for agricultural and other uses, which is an exceptionally high ratio for a water-scarce country like Pakistan. The adverse impacts of climate change are also causing extreme weather conditions, resulting in drought and floods almost every year. Inadequate water reservoirs, water wastage in agriculture and households, negligible wastewater recycling, and contamination of drinking water are causing health risks that have turned serious national security challenges for Pakistan. This research article argues that surface and subsurface water in Pakistan is depleting sharply, and if not addressed in time, has the potential of becoming the biggest national security problem. The article investigates the available water status in Pakistan covering surface and subsurface resources in detail, including reservoirs for storage, and sectoral utilization, to draw conclusions on water availability and usage requirement. The policy recommendations highlight the effective integration of smart technology in addressing multidimensional water issues and efficient water governance for ensuring water security for the sustainable development of Pakistan.

KEYWORDS

water scarcity, water management, sustainable development, human security, national security

1 Introduction

Pakistan is the world's fifth most populous country with an estimated population of 225 million and an average growth rate of 1.75% every year (World Bank, 2022b), it is 33rd country by area with 650 miles of coastline along the Gulf of Oman and the Arabian Sea and 340,590 square miles land area (UN, 2022). The geography, topography, and climate of Pakistan are diverse ranging from the high and glaciated mountains of Hindukush, Himalayan to the plains and deserts of Punjab and Sindh, mountain and semi-mountains of Baluchistan and Khyber Pakhtunkhwa (KPK) provinces. Starting from the north, Pakistan has three distinct geographical zones: The Northern highland containing Kashmir and Gilgit -Baltistan regions. The northern regions have famous

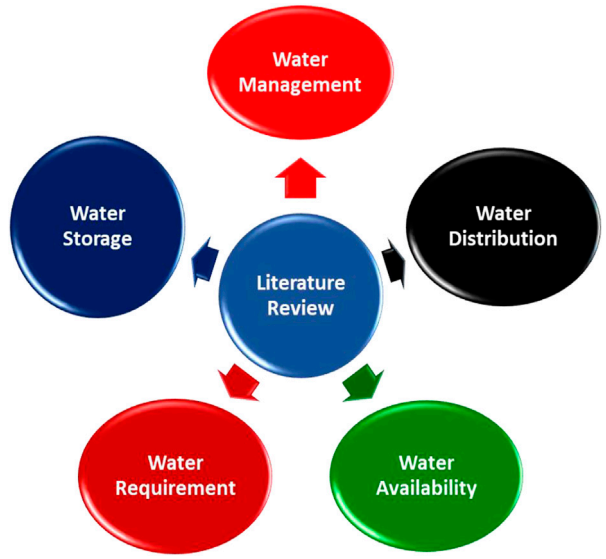

FIGURE 1
Literature review dimensions.

ranges of Hindukush, Karakoram, and the Pamir Mountains, where K2 and Nanga Parabt are also located. The Indus plain contains tributaries of the Indus River starting from Kashmir to the Arabian Sea. Baluchistan Plateau is in the west and the Thar Desert lies in the east of the country, which is contiguous to the Cholistan Desert of Punjab Province and the Rajasthan Desert of India. Pakistan is blessed with all four seasons, where climate varies from tropical to temperate and arid conditions in the coastal South. The northern and glaciated regions receive extreme cold and snowfall during winters, while the monsoon season is from July to September every year in the rest of the country, with some variations in the plains of Punjab and Sindh. Two extreme conditions of drought and flood are also common occurrences witnessed in a year as seen in the ongoing year 2022. Indus River System (IRS) is the major source of water supply for Pakistan (Pappas, 2011). However, the increase in demand for water due to increasing population, agriculture, and other household requirements has pushed Pakistan towards water scarcity (Khalid, 2017). There is also an asymmetry in the availability of water for drinking, irrigation, and other usages (Taimur, 2022). Pakistan is fortunate to be geographically located in rain favourable areas and varied temperature zones, ranging from four different climates to receiving rainfall throughout the year. As per the World Bank survey, Pakistan receives an average of 200 mm of rainfall from July to September (World Bank, 2021). Unfortunately, most of the rainwater ends up in the Arabian Sea, due to flooding and improper water storage and drainage channels (Briscoe et al., 2005). The research article has been developed considering the United Nations Sustainable Development Goals (SDGs) and the Millennium Development Goals (MDGs) on the provision of fresh drinking water across Pakistan, water storage, management, judicious distribution, and use of technology for recycling wastewater. As a policy input to the relevant government ministries in Pakistan, this research article provides a comprehensive set of recommendations to achieve SDGs by 2030.

2 Literature review

For a comprehensive literature review, the dimensions as shown in Figure 1 have been discussed in this part.

2.1 Pakistan's population and water requirements

Water being a necessity for life has always been a source of the establishment of great civilizations as can be witnessed since the dawn of civilization, e.g., by observing the ancient Egyptian and Mesopotamian Civilizations in the Middle East and the Indus Civilization in South Asia (Water From the Dawn of Civilization | Earth Sciences—UNESCO Multimedia Archives, n.d.). The water demand has been exponentially increasing with the increase in the global population. Approximately six times more water is needed worldwide due to the increasing world population as compared to the last century (Tehsin et al., 2019). Water availability has been gradually strained due to increasing demand and consumption of natural resources coupled with water mismanagement, particularly in the case of developing nations, where Pakistan is no exception. Pakistan has the Indus River System (IRS) as the principal source for irrigation that 'irrigates 80 percent of the 21.5 million hectors of agricultural land in Pakistan (Ministry of Finance, 2007) Pakistan Economic Survey 2006–07 Chapter 16 Environment. PDF, n.d.). Being the only major river system coupled with increasing population and decreasing snowfall over the Himalayas and Karakorum Mountain ranges puts increasing stress on the surface water resources in Pakistan. Underground water sources are also depleting at a fast pace due to unusually high withdrawals. The alarming decline in per capita availability of freshwater resources, i.e., from 5,300 cubic meters (m^3) at the time of inception of Pakistan in 1947 to about 1,000 cubic meters (m^3) in 2011 indicates many challenges, most significant one are the water resources management in Pakistan (World Bank, 2013). Pakistan is blessed with a unique mix of water resources in the form of glaciated mountains, the Indus Basin River Water System (IRS), and a network of canals and distributaries. However, with the rising population, lack of appropriate water resource management, and water distribution, and less emphasis to sensitize the public on water discipline, Pakistan is fast transiting from a water-stressed to a water-scarce country. It is highlighted that Pakistan is the fifth populous country in the world with an annual increase rate of 1.75%. At present, the population of Pakistan is estimated at approximately 225 million, which is likely to reach 250 million by 2025 (Yaqoob et al., 2021), where urban population alone is likely to increase by 52% by 2025 (Janjua et al., 2021). Due to this exponential increase in population, the water demand for agriculture and non-agriculture usage like; industrial and domestic will also increase by 8% in 2025 (Parry, 2016). It has been revealed through a literature review that 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 (Qureshi and Ashraf, 2019). The UN estimates that Pakistan's water demand is increasing at an average yearly rate of 10% (Connor, 2015), which means that the water demand in terms of the area will increase to 338 km^3 by 2025, but the total water availability will remain in the same range from 240 to 258 km^3 (Shaheen, 2010). Out of the available surface water, approximately 74% is extracted, while 83% of the groundwater is extracted for agricultural and other uses, which is an exceptionally high ratio for a water-scarce country like Pakistan (Laghari et al., 2012). The inadequate water resources management system is causing a demand and supply gap in the judicious utilization of

available water due to the increase in population, and wastage of surface and groundwater. Water scarcity is emerging as a serious national security challenge for Pakistan. Apart from water-related disputes with India (Riaz et al., 2020), it is also causing inter-provincial disharmony and societal conflicts (Bhatti et al., 2019).

2.2 Water resources of Pakistan

Pakistan's water resources, like most of the South Asian nations, comprise surface water sources i.e., rivers, lakes, coastal basins, large and small water reservoirs, and underground water resources. Primary sources include rainfalls and falls leading to the formation of glaciers. Pakistan has 143 large and small water storage reservoirs, among which the Tarbela, Mangla, and Chashma are major ones with a collective storage capacity of 18.92 Million Acre Feet (MAF) (Tehsin et al., 2019). Over some time, a serious decline in the existing water resources of Pakistan has been witnessed, which can be attributed to several factors. The increased demand for freshwater supply can be related to the increasing population. The population growth has resulted in rendering more than 12% population without fresh drinking water as per the Human Development Report 2001 of the United Nations Development Program (UNDP) (UNDP and United Nations, 2001). Furthermore, a reduction in average annual rainfall has also contributed to stress on water resources due to less recharge on yearly basis (Naheed and Rasul, 2010). The phenomena of global warming have also affected Pakistan, with rising temperatures every year (Chaudhry et al., 2009), which results in the melting of glaciers at a rapid pace. The unregulated use of tubewells has also contributed to the water scarcity and depletion of subsurface water sources (Tehsin et al., 2019).

2.3 Water resources management in Pakistan

The institutional arrangements to manage and regulate the water resources in Pakistan are devolved to the provincial and further to the local governments since 2001 (Cooper, 2018). Some of the key challenges in water management in Pakistan emanate from the unequal per capita water consumption in urban and rural areas. Water supply and sanitation are underinvested by the public sector (Water and Sanitation, n.d.). In April 2018, the Ministry of Water Resources published the National Water Policy to address the water resources management issues prevailing in Pakistan and projected the key targets to be achieved by 2030. It emphasized more sustainable utilization of water resources and proposed the concept of "producing more crop per drop" (National Water Policy of Pakistan, 2018). Water expert and former diplomat Shafqat Kakakhel contends that Pakistan's new National Water Policy, despite significant gaps, represents a breakthrough moment (Opinion: Pakistan's new National Water Policy is historic, 2018). The water resource distribution between Pakistan and India is also managed through a bilateral water distribution accord called the "Indus Water Treaty (IWT)". The details are covered in the relevant part on water resources and distribution in subsequent paragraphs. The summary of literature review is given at Table 1.

3 Data and methodology

The study has been completed over the last 7 months covering a wide-ranging examination of Pakistan's topography, from the northern Himalayan areas of Gilgit and Skardu to the plains and deserts of Punjab and Sindh. The framework of Data and Methodology is given in Figure 2 below, which is explained in detail in the ensuing paragraphs.

FIGURE 2
Framework of data and methodology.

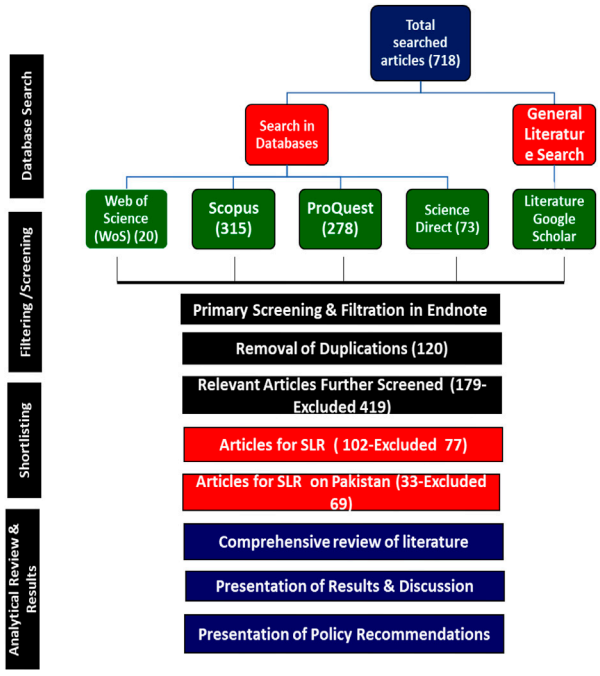

FIGURE 3
Process of systematic literature review (SLR).

3.1 Methodology of systematic literature review (SLR)

This SLR methodology is designed to systematically review the required literature to draw relevant conclusions from available data. More specifically, SLR helps to review the climate and water governance-related literature for the classification of key governance elements; enabling dynamics; significant gaps and challenges; and possibly an effective governance approach for the management of water resources of Pakistan. SLR is a preferred mode for researchers in reviewing various attributes of water governance and management. Based on the SLR strategies devised by prominent researchers, a five-step approach has been observed for undertaking the SLR, which broadly covers; scoping, planning for SLR, searching, screening, and presenting a literature review. The Systematic Literature Review (SLR) Methodology was adopted for the critical examination of available literature on Pakistan's water resources, utilization, and constraints. The excerpts of literature have been incorporated in Literature Review part above, however, details of the SLR methodology are given in Figure 3 below.

3.2 Implications drawn from literature review

The available literature mostly focuses on Pakistan's available water resources, distribution among the provinces and sectors of water utilization, that too in a compartmented fashion. Therefore, the current study has been designed in a way to cover the holistic investigation of water management in Pakistan which should take into account all forms of surface and sub surface water, its recharging, storage, distribution, and future vision for achieving water related SDGs by 2030. The implications of climate changes on water management in Pakistan have also been examined in detail and relevant conclusions have been incorporated in the policy recommendations.

TABLE 1 Summary of literature review.

References	Name of journal/Book	Context
Yaqoob et al. (2021)	Processes	Pakistan's population
Janjua et al. (2021)	Water Policy	Pakistan's urban Population
Parry, (2016)	International Institute of Sustainable Development (IISD)	Water demand and consumption in Pakistan
Khemka and Kumar, (2019)	Social Development and Sustainable Development Goals in South Asia	Pakistan's water availability and demand
Qureshi and Ashraf, (2019)	Water Resources Management	Pakistan's water availability and demand
Connor, (2015)	UN World Water Report 2015	Pakistan's water demand
Shaheen, (2010)	Institute of Regional Studies Islamabad	Pakistan's water availability and demand
Laghari et al. (2012)	Hydrology and Earth Sciences	Groundwater sources in Pakistan
Riaz et al. (2020)	NDU Journal	India -Pakistan water distribution
Bhatti et al. (2019)	Water	Water conflicts and Pakistani society
Water From the Dawn of Civilization (2010)	UNESCO Documentary Archives	Timeless significance of Water Resources
Tehsin et al. (2019)	Margalla Papers	Increased Water Requirements over the past century
Pakistan Economic Survey (2007)	Pakistan Economic Survey - Chapter 16: Environment	Indus River and irrigation of agricultural lands in Pakistan
Pakistan Water Supply and Sanitation Sector: Urban Water Supply and Sanitation (2013)	International Bank for Reconstruction and Development/The World Bank. (2013). (report). Pakistan Water Supply and Sanitation Sector: Urban Water Supply and Sanitation	The decline in *per capita* freshwater resource availability
UNDP and United Nations, (2001)	UNDP Human Development Report	2001 Stats for Pakistanis with no access to drinkable water
Naheed and Rasul (2010)	Pakistan Journal of Meteorology	Reduced annual rainfall is a contributory factor to the scarcity of freshwater resources
Chaudhry et al. (2009)	Climate Change Indicators of Pakistan. Pakistan Meteorological Department report	Global warming and scarcity of water resources
Cooper (2018)	Water management/governance systems in Pakistan. K4D Helpdesk Report. Brighton, United Kingdom: Institute of Development Studies	Hierarchy of Water Resource Management in Pakistan
Water and Sanitation (2018)	Ministry of Planning and Development, Government of Pakistan. Water and Sanitation. MTDF	Sector-specific challenges in Water Resource Management in Pakistan
National Water Policy of Pakistan, (2018)	National Water Policy 2018, Ministry of Water Resources, Government of Pakistan	Government of Pakistan's efforts in Water Resource Management in the upcoming decade
Opinion: Pakistan's new National Water Policy is historic (2018)	Opinion: Pakistan's new National Water Policy is historic. The Third Pole	A critical review of the National Water Policy of Pakistan2018

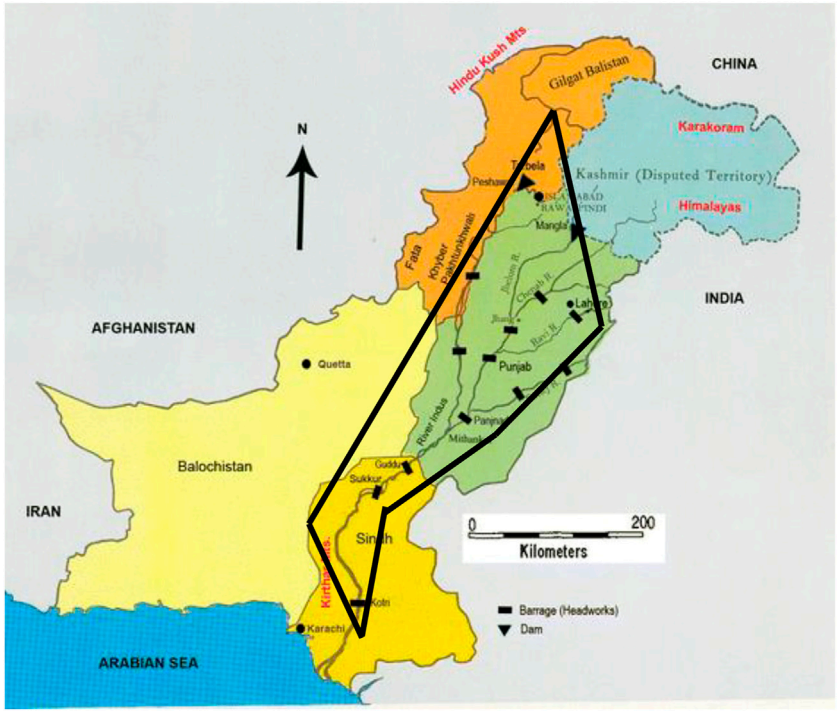

FIGURE 4
Field visits to the indus basin area.

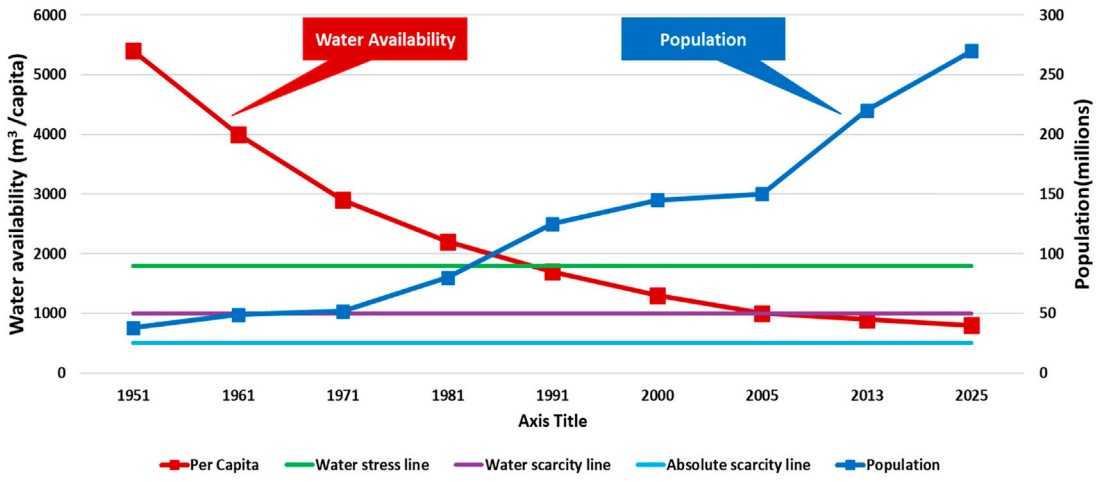

FIGURE 5
Pakistan's water availability and demand by 2025.

3.3 Model setting

Pakistan's available water resources, population, and water requirement for human consumption, agriculture, and non-agriculture consumption have been analyzed using primary data available from the Ministry of Energy Pakistan, Water and Power Development Authority (WAPDA), Indus River System Authority (IRSA), field visits to major dams of Mangla, Tarbela and Chashma, and review of different studies and findings conducted by national and international organizations on Pakistan. For the tangible outcome of the study, a comprehensive approach was adopted covering all regions of Pakistan for examination of the water situation. All headworks and barrages were physically visited for analyzing the water governance issues. Interviews were also conducted with regulatory staff, who agreed to respond based on anonymity and incorporating their views in the study without referring to them. Their privacy request has been given value and nowhere any identity to this effect has been divulged. Figure 4 below shows the area of field visits for examining the water situation.

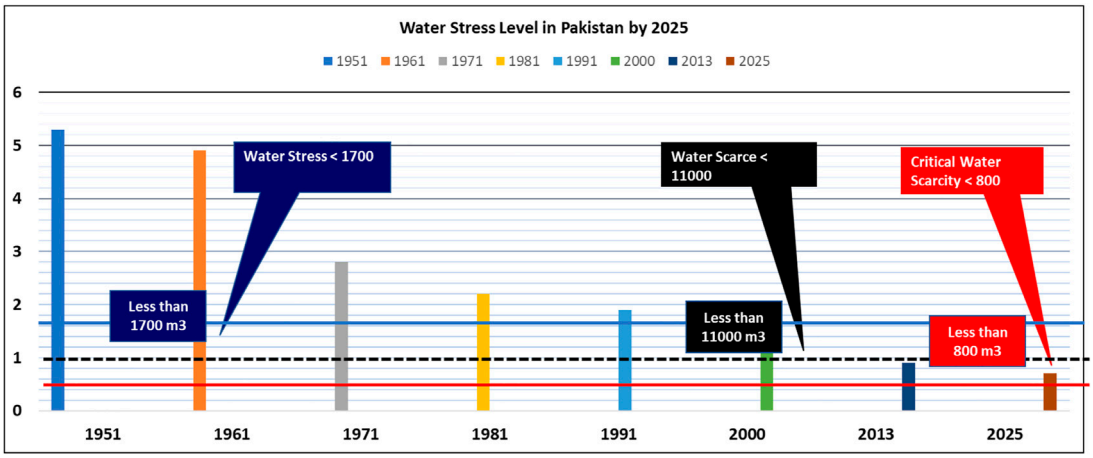

FIGURE 6
Water stress level in Pakistan by 2025.

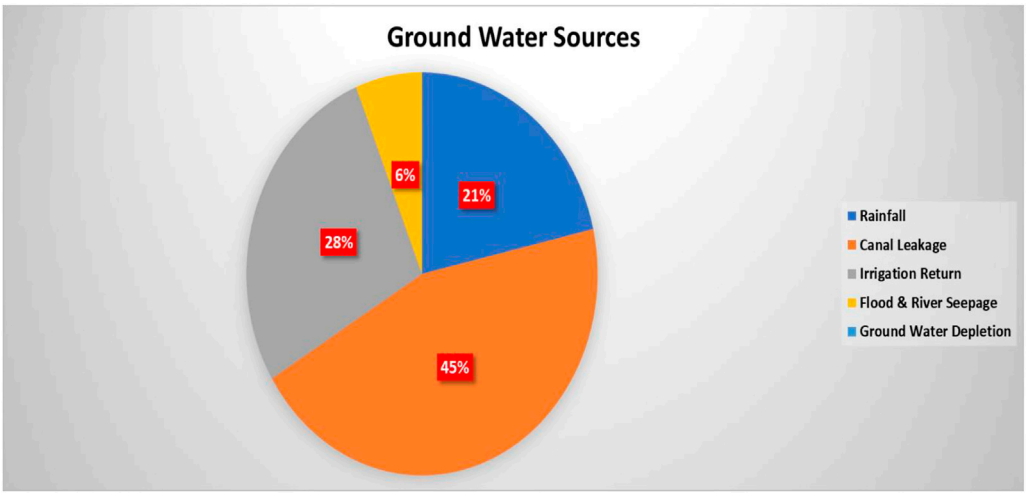

FIGURE 7
Groundwater sources in Pakistan (World Bank Report https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin).

From the northern glaciated region of Skardu along the Indus River, the field visits followed the systematic route stretching from north to south of Pakistan, passing over the entire Indus Basin Delta and Indus River System, which provided a unique mix of natural resources, the climax of engineering expertise and colossal irrigation system in the form of canals and link canals for proportionate distribution of water to the entire country. The manifestation and implications of the Indus Water Treaty on water sharing between India and Pakistan since its implementation in the last 50 years have also been examined in detail. The inter-provincial water-sharing arrangements have been analyzed with their implications on national security. Pakistan's water management policy documents have been examined and referred to in the relevant parts of the study. In the last part, viable recommendations have been offered as policy input for relevant government ministries for optimization and conservation of available water resources, developing national consensus on the construction of additional water reservoirs for sustainable development of Pakistan and achieving water-related Sustainable Development Goals (SDGs) and Millennium Development Goals (MDGs) by 2030.

3.4 Data analysis

The study focuses on ensuring efficient water governance for sustainable development of Pakistan, therefore, the data collected from literature review, field visits, interviews and on-sight briefings have been analyzed using qualitative and quantitative research methods. The findings have been explained in results and discussion part, while policy recommendations have been proffered in the last part of the study.

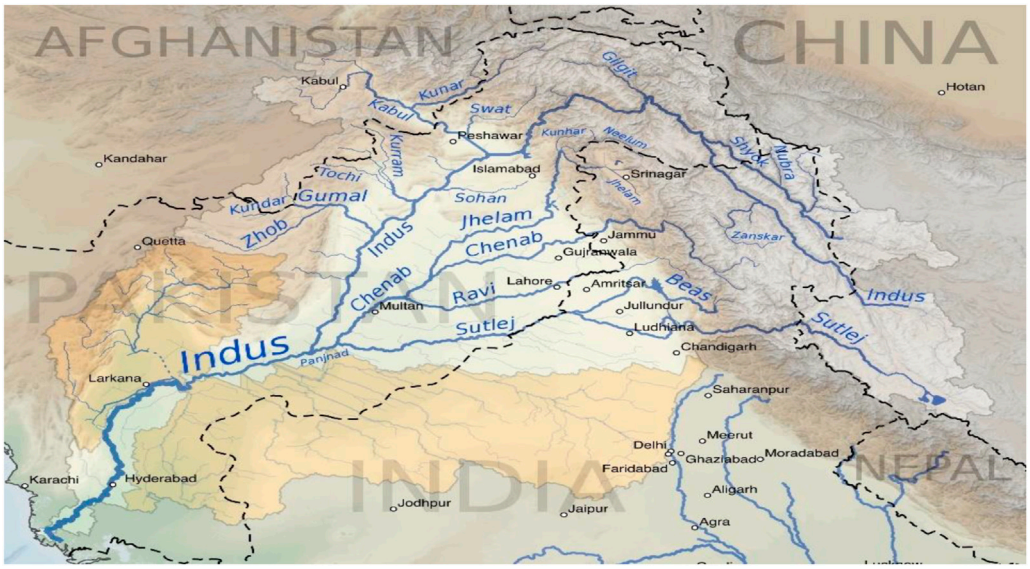

FIGURE 8
Indus rivers system in Pakistan.

4 Empirical results and discussion

4.1 Pakistan's water demand and availability

Water remains one of the critical issues in Pakistan since the time of its inception in 1947. Water is a main source of sustenance not only for humans but plants and animals as well around the globe. Pakistan remains scarce in terms of clean drinkable water availability to the masses. Indus River System (IRS) is the major source of water for the people and agriculture in Pakistan (Pappas, 2011). The population of Pakistan is increasing at a rapid pace due to which the average daily demand for water is also increasing, while availability is declining sharply. Another important aspect is that Pakistan is an agrarian country, where due to inadequate alternate sources of agricultural water, more than 95% of the surface and sub-surface water is consumed by agriculture and livestock sectors (Khalid, 2017). Pakistan is ranked 80 (Mehmood et al., 2013) among 122 nations in the world regarding drinkable water (Azizullah et al., 2011). Figure 5 below shows the graphical representation of water supply and demand status in Pakistan by 2025.

Pakistan is an underdeveloped country due to which it faces issues in many domains, where water scarcity has emerged as the most pressing national security issue. Pakistan not only faces a water shortage but also lags in clean drinkable water for the population. The construction of water reservoirs for storing and then systematically distributing water remains lopsided, despite the growing demand. Figure 6 below shows the systematic path towards water scarcity as year on year basis, the gap between water availability, storage, and sectoral consumption is widening and water security is emerging as a vital national security challenge for Pakistan if remedial measures are not initiated now as the time is running out and we are only 3 years away from the water-scarce line.

There is also an asymmetry in the availability of water for drinking, irrigation, and other usages (Taimur, 2022). Pakistan receives an average of 200 mm of rainfall from July to September (World Bank, 2021), but most of the rainwater ends up in the sea due to inadequate water storage and drainage channels.

4.2 Pakistan's water resources and management

4.2.1 The supply source of water resources

Pakistan's Northern areas which include the provinces of Gilgit-Baltistan (GB) and Azad Jammu and Kashmir (AJ&K) are blessed with abundant glaciers with an approximate area of 13,680 sq km, which is approximately 3% of the mountainous region of the upper Indus River Basin (Ahmed et al., 2007a). The winter season from October to March every year receives plentiful snowfall which is the main source of icing of the glaciers. The melting process starts in the summer, roughly from late May to August, which feeds adequate water to Indus River Systems (IRS). River Kabul is another source of water to IRS as it enters Pakistan through Unai Pass in Southern Hindukush to the North of Khyber Pass in Khyber Pakhtunkhwa (KPK) Province at an elevation of 3,000 m above sea level.

Rainfall is complimentary to the melting of glaciers in the summer and monsoon seasons of Pakistan, which provide profuse water to IRS. On average, the rainfall is more than 200 mm from July to September each year. More than 70% of the rain is witnessed from the monsoon and the western disturbances. In northern parts of Pakistan, a low-level rain cycle continues at frequent intervals even during winter.

According to the World Bank report, groundwater provides 90% of domestic water in rural areas and 70% at the national level with its share of approximately 50% for agriculture (World Bank, 2022a). The main sources of recharging of groundwater are the seepage from IBIS, which sits as a freshwater layer even on saline water in desert regions of Pakistan and is considered the main source of drinking and irrigation. Similarly, rainwater also finds its way through the layers to submerge in groundwater. The percentage-wise sources of groundwater recharge are given in Figure 7 below. Due to the unpredictability of canal water supplies, farmers across Pakistan have resorted to groundwater pumping, which is going on in a highly unregulated manner. The agriculture areas in the Indus Basin Irrigation System (IBIS) have installed approximately 500,000 tube wells, which are estimated to pump water of approximately 50 Billion Cubic

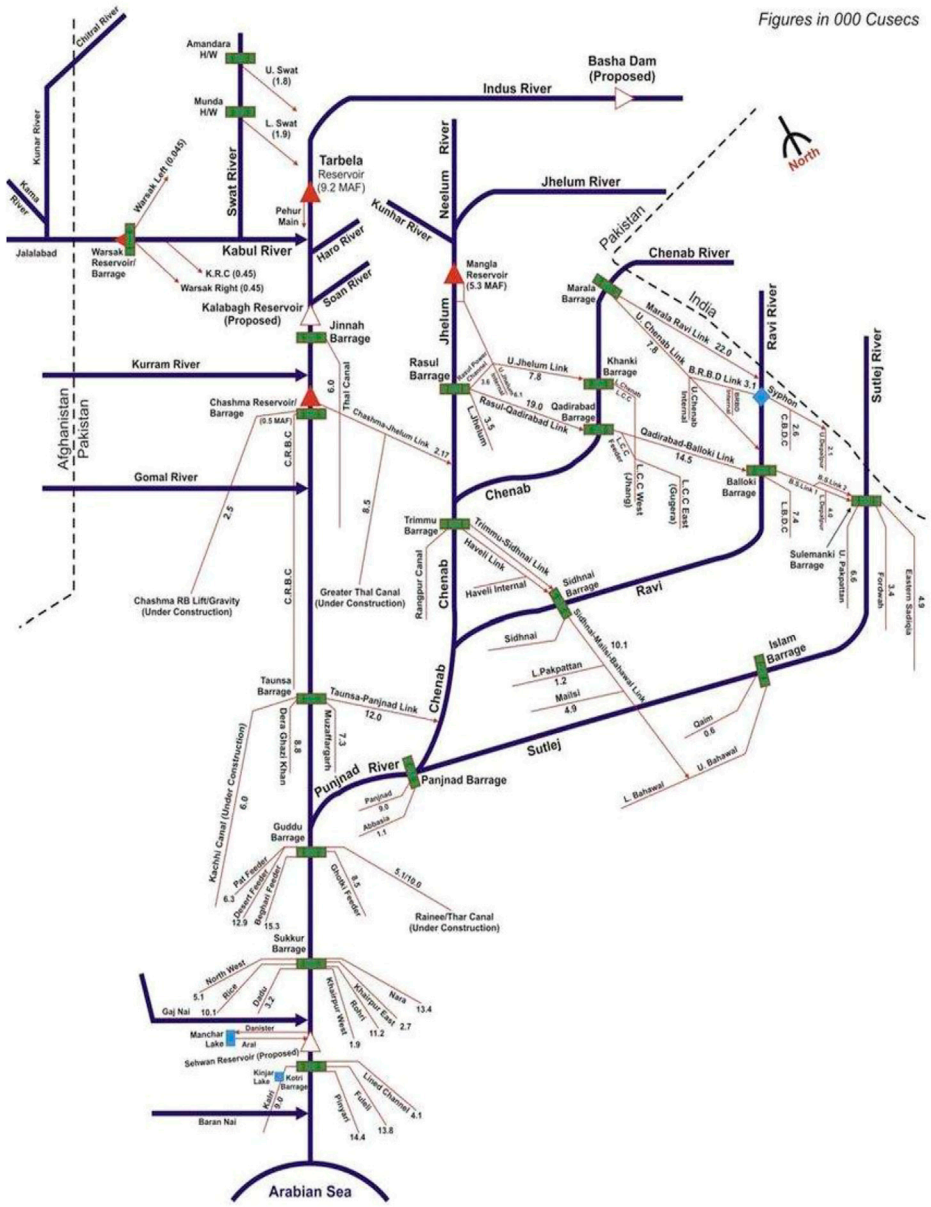

FIGURE 9
Indus basin irrigation system (IBIS) of Pakistan. Source ministry of planning and development (Iqbal, 2013) https://www.pc.gov.pk/uploads/plans/Ch20-Water1.pdf.

Meters (BCM) (Ahmed et al., 2007b), whereas, the groundwater potential in Pakistan is approximately 55 MAF (Ebrahim, 2018). Even in the domestic sector, unmonitored groundwater misuse is on the rise, which is sharply decreasing the most precious commodity of nature.

The primary source of surface water in Pakistan is through Indus River System (IRS) which is based on the river inflows and is measured at predesignated rim stations. The rim stations are control measures in the shape of dams, barrages, and other such reservoirs. The significant rim stations on Indus River System are at Mangla and Tarbela Dams, Marala at Chenab River, Marala reservoir at River Jehlum, Sulemanki Headworks at Sutlej River, and Baloki at Ravi River. Figure 8 shows the alignment of different rivers in the Indus River System.

Pakistan's 70% of the land is drained by the IRS accounting for almost 566,000 km^{2,} which is spread to all four provinces of Khyber Pakhtunkhwa (KPK), Punjab, Sindh, and Baluchistan originating from Gilgit -Baltistan and Azad Jammu and Kashmir (AJ&K) except Kabul River which enters in KPK Province at Khyber Pass (Winston et al., 2013). The stretch of IRS is approximately 2,900 km with an elevation of 18,000 ft from the Himalayas to the lower riparian areas of Sindh Province leading it to the Arabian Sea (Janjua et al., 2021). The IRS is among the leading irrigation system in the world. Around 150,000 km^2 of agricultural land out of 190,000 km^2 is irrigated by the Indus Basin Irrigation System (Ahmed et al., 2007a). The IRS contains a network of 16 barrages, three dam, three Headworks, two siphons, 44 canal systems, (23 in Punjab, 14 in Sindh, five in KPK, and two in Balochistan), while 12 link canals and more than 107,000 small water courses (Hassan and Ahmad Khan, 2002).

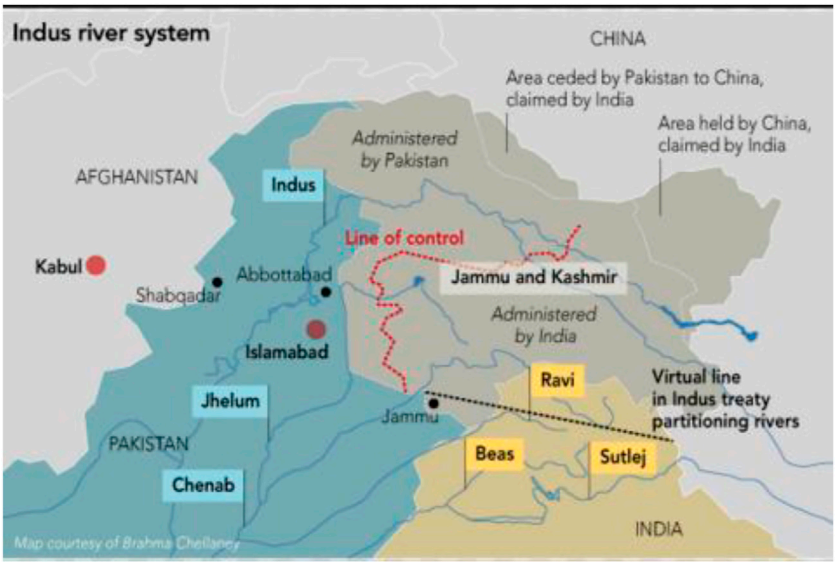

FIGURE 10
Indus water treaty and distribution of rivers between India and Pakistan.

4.2.2 Water resource management system

The IRS is a lifeline for Pakistan's survival as majority of the agricultural production is dependent on the river water. The Indus Basin contributes more than 25% of Pakistan's GDP, as it provides a critical water supply to almost 90% of the food production crops in Pakistan. The Indus Basin Irrigation System (IBIS) of Pakistan is among the world's leading contiguous irrigation systems, which contains six major rivers which are, the Sutlej, Ravi, Jhelum, Chenab, Indus, and Kabul rivers. The IBIS has an annual flow of 146-million-acre feet (MAF), while 106 MAF of water is diverted to canals. Pakistan receives about 50%–80% of average river flows from glacial melt, while the remaining is from the yearly monsoon rains. The three Western rivers, ie., Indus, Chenab, and Jhelum contain 144.91 MAF of water, and the two Eastern rivers ie., Ravi and Sutlej contain 9.14 MAF of water. From the available water, 104.73 MAF is used for irrigation purposes, 39.4 MAF usually flows to the Arabian sea due to limited storage capacities, and around 9.9 MAF is expended through the system losses like evaporation, seepage, and spill during floods. Figure 9 shows the excellent network of IBIS, which is unique in South Asia and the world at large.

The current water storage capacity is insufficient as the three main reservoirs, i.e., Mangla (1967), Tarbela (1978), and Chashma (1971), have a designed capacity of 15.75 MAF, however, sedimentation has reduced it to 13.1 MAF. Therefore, these reservoirs can hardly store water for 30 days against global standards of at least 120 days. The usual flow to the Arabian Sea during floods has also increased significantly as witnessed during the recent floods of the year 2022, which instead of storing and then reusing at the time of need has been wasted causing enormous men and material losses to the tune of 30 million people affected and financial losses of US$ 30 billion (Haidar and Dilawar, 2022). Moreover, the canals and link canals have an Earth surface which also results in the seepage of a substantial amount of irrigation water. Another important aspect is the traditional approach to farming and the use of irrigation water through flooding instead of using a drip irrigation system. Such a lavish wastage of water has created serious demand and supply gap, and depleted the limited storage capacity, especially during the critical harvesting seasons.

Pakistan is a lower riparian country and all the rivers less than Kabul flow to Pakistan from India. During the early days of partition

TABLE 2 Pakistan's water resource management organizations

MOWR	Ministry of Water Resources	PIDs	Provincial irrigation dept
WAPDA	Water and Power Development Authority	PADs	Provincial Agriculture dept
PMD	Pakistan Metrological Dept	PIDAs	Provincial Irrigation and Drainage Authority
SUPARCO	Space and Upper Atmosphere Research Commission	OFMW	On Farm Water Management
IRSA	Indus River System Authority	LG&CD	Local Govt and Community Development Dept
FFC	Federal Flood Commission	WASAs	Water and Sanitation Agencies
IWC	Indus Water Commission	AWBs/FO	Area Water Boards/Farmers Organization
PCRWR	Pakistan Council of Research on Water Resources	WUA	Water Users Association

TABLE 3 Pakistan's water resource management laws

1960	Indus water treaty between Pakistan and India
1983	Pakistan Environmental Protection Ordinance (PEPO), the first regulation regarding the protection of continuously decreasing environmental sources in Pakistan
1983	Pakistan Environmental protection agency (PEPA), a proper working body to regulate PEPO 1
1984	Pakistan Environmental Protection Council (PEPC) in 1984, more specifically working on environmental protection
1991	Water Apportionment Accord
1992	Pakistan National Conservation Strategy (NCS) with a clear enough implementation plan for sustainable development in Pakistan
1993	National Environmental Quality Standards (NEQS) to provide safe limits for municipal and liquid industrial effluents released to water bodies, industrial gaseous emissions, and motor vehicle exhaust and noise
1997	Pakistan Environmental Protection Agency (PEPA), under Section 2 the term environment was defined to include water and various forms of pollution like discharge
2000	Millennium Development Goals (MDGs), goal 7 is to ensure environmental sustainability with target 10 to Halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015
2001	National Environmental Action Plan (NEAP), a clear plan for sustainable development approved by PEPC
2005	National Environmental Policy to protect, conserve and restore Pakistan's environment to improve quality of life
2008	National Drinking Water Policy to provide access to safe and sustainable drinking water and protection of water resources and related issues
2015	Sustainable Development Goals (SDGs) goal 6 is to ensure the availability and sustainable management of water and sanitation for all, with target 6.1 to achieve universal and equitable access to safe and affordable drinking water for all by 2030 (PCWR, 2021)

on 01 April 1948, India stopped the rivers flow to Pakistan, which gave a devastating blow to the agriculture sector and a serious national security issue emerged. After hectic diplomacy by the great powers and the World Bank, Indus Water Treaty (IWT) was formalized on 19 September 1960. According to the treaty, India was granted exclusive rights to two eastern rivers (Beas/Sutlej and Ravi), while Pakistan was given the rights to three Western rivers (Jhelum, Chenab, and Indus) (Riaz et al., 2020). Despite three major wars and two standoffs with India, the IWT has proved its resilience and robustness. This is a highly successful treaty of the South Asian region. Despite some reservations over its interpretation and implementation by way of constructing dams on a run of the rivers flow by India in Indian Occupied Kashmir, it has largely prevailed (Ishaque and Shaikh, 2017). Figure 10 shows the river's distribution under IWT between India and Pakistan.

Pakistan has elaborate organizations at the federal and provincial levels for managing water resources as given at Table 2. The organizational framework, institutional capacity, and bureaucratic mindset have made the horizontal (within institutions) and vertical (among institutions) coordination, synchronization, and execution of work extremely challenging and often fragmented. The institutional responsibilities for climate and water governance are dreadfully demarcated between federal and provincial institutions, and other associated organizations (Yasin et al., 2021). This functional ambiguity often creates overlaps and conflicts of interest. As a result, mistrust prevails among and between the provinces on issues of water governance like; water availability and flows, water allocations, and data sharing.

In the recent years, the water availability and quality have become the most critical issues in Pakistan (Soomro et al., 2011). The increasing population, industrialization, and food demand have intensified these problems during the last few decades. The government of Pakistan from time to time has enacted several laws and regulations for the availability, storage, distribution, and use of water. Realizing the impact of climate change, limited storage capacity, and achieving water-related SDGs of provision of safe and clean drinking water to all by 2030, the regulations are in place which have been promulgated with the consensus of all the provinces and economic coordination council (ECC). The details of promulgated laws and regulations for governance of water in Pakistan are highlighted at Table 3. however, their implementation in the right spirit appears to be a daunting task for federal as well provincial governments.

4.2.3 Impact of climate change on water sustainability

The United Nations Secretary-General Mr. Antonio Gutters paid an official visit to Pakistan on 9–10 September 2002 to show solidarity to flood victims and assess the devastations through field visits and official briefings. He stated that "nature, has attacked Pakistan, which contributes less than 1% of global emissions" (Guterres, 2022b), while facing the consequences of developed countries' emissions and pollution of climate. He further added that "it was outrageous that action to reduce greenhouse gas emissions was being put on the back burner, today it is Pakistan, and tomorrow, it could be your country" (Guterres, 2022a), pointing toward industrialized countries. The Global Climate Index (GCI) 2021 has also vindicated Pakistan's vulnerabilities to climate risks, where Pakistan stands at number 8 (Eckstein et al., 2021) in the vulnerability Index. The analysis presented highlights the severe impacts of climate change on Pakistan ranging from extreme heat and drought to dreadful floods. Therefore, long-term water sustainability in Pakistan is highly susceptible to changes in weather patterns.

4.2.4 Recycling and management of wastewater

The sustainable use of recycled wastewater for agriculture, washing, cleaning, and other uses less drinking is on the rise in developed countries and developing countries are also catching

up. In Pakistan, neither adequate regulations nor any such public-private partnership is in place for the smart use of wastewater. The problems of wastewater disposal tend to stem from distortions due to the failure of environmental policies and the lack of institutional capacity for monitoring and management (Bashir, 2012). The biggest challenge faced by the policymakers is the efficient use of technology and the realization for the masses to recycle wastewater. The rural population is disconnected from mainstream national policies and international good practices, and hardly any mechanism exists to address this vital issue at the national and provincial levels. Therefore, as Pakistan approaches the water scarcity line in the next 3 years, the situation will be further exacerbated and complicated.

4.2.5 Water scarcity an evolving national security challenge

According to Rao Irshad Ali Khan, Chairman Indus Water River Authority (IRSA), the water availability in Pakistan has declined tremendously since 1947 (Islam, 2011). At the time of independence, the per capita water availability was 5,600 cubic meters. This percentage has decreased from over 5,260 cubic meters in 1951 to 1,038 cubic meters in 2010. If the same situation continues, then by 2022, the water availability in Pakistan will further decrease to 877 cubic meters per annum and by 2025 to 660 cubic meters, and by 2050 it will touch 575 cubic feet (Daud et al., 2017).

Another important factor is the availability of river water, viz a viz the requirement of sub-surface water to meet human consumption and agriculture needs. However, these wells due to the improper level of maintenance get dried up and people in rural area start looking for alternative sources which in most cases is full of health hazards. Rural areas lack proper infrastructure due to which there are no proper water storage areas for storing rainwater, resulting in flooding and wastage of rainwater.

5 Policy recommendations

5.1 Proposed policy framework

After critically examining Pakistan's available water resources, storage, distribution, governance and management, promulgation of laws and regulations, and future water demand and supply gap, certain recommendations are offered, which shall provide the policy input for Pakistan's relevant ministries and organizations. The thrust lines of the proposed framework given in Figure 11 involve strong policy implementations for efficient water governance, to achieve water-related SDGs and MDGs by 2030 for the sustainable development of Pakistan.

The efficient water governance model suggested in Figure 12, considers the synergistic coordination with key stakeholders, relevant institutions, policy framework, and unfathomable commitments of leadership at all levels for achieving the optimum results. The important elements of the proposed water governance model include; political commitment and leadership for policy formulation and implementation. Capacity building of relevant institutions, stakeholders' engagement, and use of technology for efficient resource management.

The terms of reference for each of the elements of the proposed water governance model are highlighted in self-explanatory Figure 13 below.

5.2 Drip water and recycling of wastewater for irrigation

Due to a lack of smart irrigation water management, each province consumes its water quota at a very early stage. While main cash crops remain deprived of water at critical stages of the year. A drip system is suggested to be encouraged in a phased manner to judiciously use available water. Sindh is often found complaining about the discriminatory distribution of water by the federal government. The Sindh Information Minister Sharjeel Memon even appealed to the federal government to take notice of the grave water shortage in Sindh province (Alvi, 2019). He even brought to the attention of the government the 1991 water accord, which ensured judicious water distribution to all provinces. The Pakistan Water Apportionment Accord 1991 was established to dispense water share to all provinces. However, the accord doesn't give an exact proportion of the amount of water being allocated to the provinces (Irsa, 1991). For this purpose, IRSA was established to address, regulate, and develop standard operating procedures regarding water allocation to the provinces. Unfortunately, each

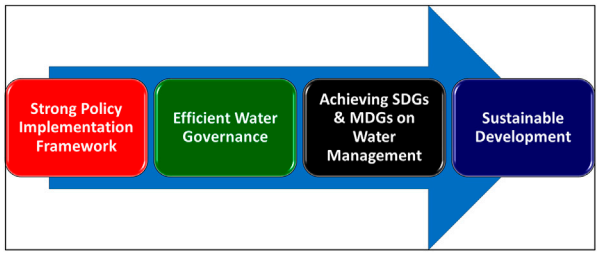

FIGURE 11
Proposed policy framework.

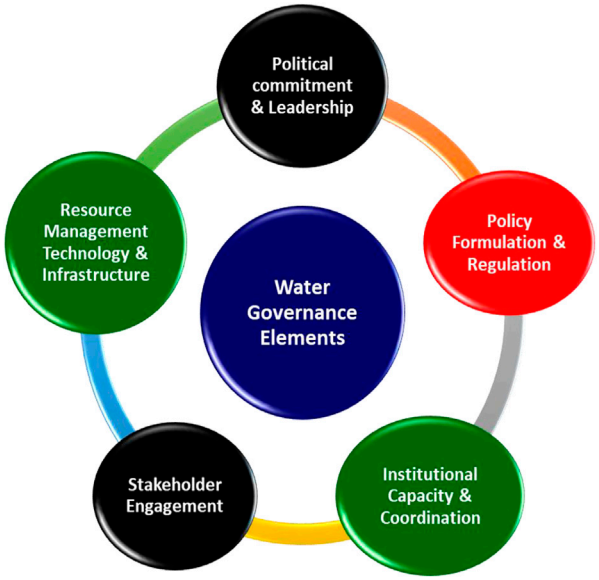

FIGURE 12
Elements of the proposed water governance model.

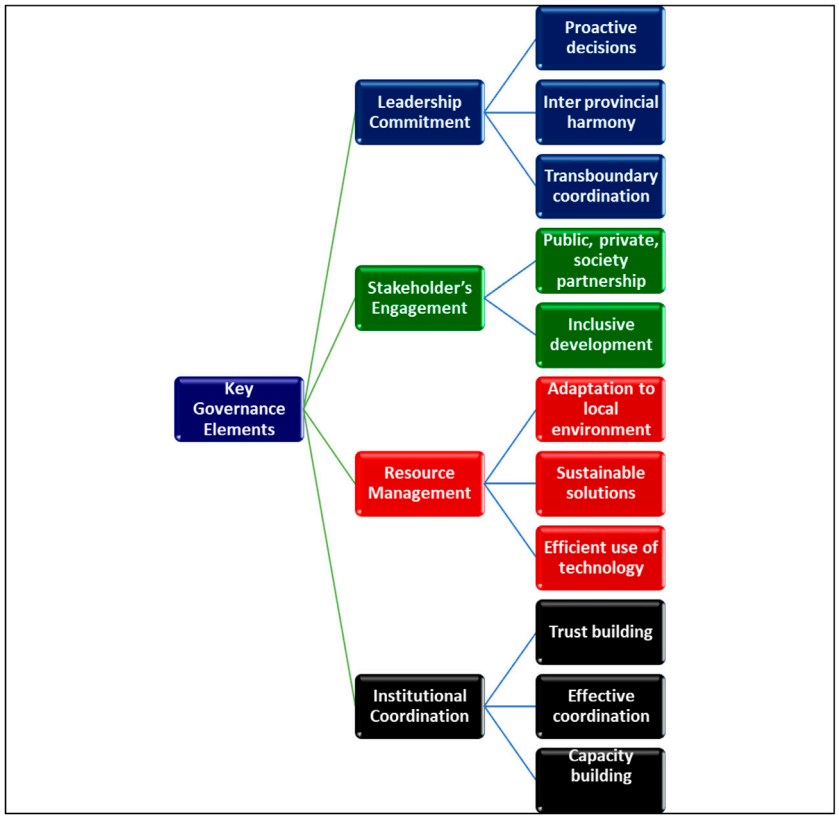

FIGURE 13
Suggested terms of reference for water governance elements.

province has its unique features in terms of agricultural needs and population, thus making the interpretation and implementation of the accord even more difficult. Therefore, it is suggested that smart irrigation systems be installed as a priority for the judicious use of agricultural water. Similarly, wastewater recycling plants should be introduced in a phased manner commencing from provincial capitals and gradually extending to all urban and rural areas. This water should be diverted for cleaning, agriculture, and other non-drinkable usage. Modern housing societies like Bahria Town Islamabad have already installed such plants, which can be replicated in other parts as well.

5.3 Enforcement of legislations

While Pakistan has promulgated multi-dimensional legislation for the storage, distribution, and use of water, however, there are several coordination and management issues at federal and provincial levels, which have been amply discussed in the analysis part. It is, therefore, suggested that appropriate dispute resolution forums be established through consensus so that the stakeholders can debate and find solutions to evolving water challenges instead of press briefings. The recent floods have also exposed Pakistan's extreme vulnerability to climate change, therefore, appropriate laws and Standard Operating Procedures (SOPs) should be revisited and re-adjusted to meet future challenges in a befitting manner.

5.4 Construction of more reservoirs on an urgent basis

The need for the construction of more dams has been realized in the last 4 decades, however, the trivial political mileages created fissures among the federating units, which provided an excuse for not constructing dams. Now that Pakistan is at a critical juncture of its survival, hardly 3 years away from being declared as water scarce country, therefore, all elements of national power (ENP) should be mobilized for building consensus, arranging resources, and fast-paced completion of more dams. The speed of the ongoing projects of Diemer and Bhasha should be expedited and while China-Pakistan Economic Corridor (CPEC) is more focused on infrastructure development, a part of it should be renegotiated for the construction of water reservoirs. A comprehensive road map for at least 15–20 years should also be prepared by the Ministry of Planning Commission in consultation with all the stakeholders for the development, conservation, and judicious use of water. The existing capacity of Mangla, Tarbela and Chashma has been eroded to a large extent due to silting, which should be restored at priority.

5.5 Rationalizing groundwater and crop patterns

The installation of tube wells should be subject to the issue of a no objection certificate (NOC) by the local government after all the

technical evaluations of water availability and sustainability, coupled with the monitoring mechanism for avoiding the wastage of groundwater. Instead of an individual-level water supply, a community-based tube well system is proposed to conserve groundwater and ensure effective monitoring. Similarly, in short term, water-intensive crops should be discouraged and replaced by high-yield crops requiring less water.

5.6 Refurbishment of canals and tributaries

To preserve the water seepage and unusual waste, it is strongly recommended that all water channels should be cemented. This practice was initiated in Punjab province some 20 years ago and has proved highly successful in the preservation of water. This should be extended across Pakistan over a phased program. This long-term investment would be beneficial for ensuring water security on a sustainable basis.

5.7 Integrated water management system (IWMS)

The "whole of government" and "whole of nation" approach is recommended for dealing with water crises holistically. The proposed approach should be able to handle the existing and evolving challenges like; the impact of climate change, surface and groundwater use, urbanization, industrialization, and pollution impacting the water quality.

6 Conclusion

Today Pakistan is confronting ever-increasing water security issues, which are likely to compound further due to the burgeoning population, negative impacts of climate change, and inefficient management of available water resources. The prevailing mistrust among the federation and federating units, inadequate implementation of policies, and lack of storage capacity attribute to ongoing friction and disputes. Addressing interprovincial disputes, predominantly between Sindh and Punjab, is a challenge for the federal government as such issues arise every cropping year. It is, therefore, imperative that the government should introduce policies that help in addressing equity, storage issues, environmental sustainability, and sustained economic development while ensuring water security. Regulating and altering water-use comportment, along with adopting modern irrigation technologies, can limit water shortages in the short term and pave the way for improved economic growth and development in the long term.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

WI designed the study, and contributed results parts. MM contributed literature review, while RT contributed policy recommendations and proof reading.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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