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Pakistan's Groundwater Crisis: Policy Lessons and a Framework for Sustainable Resource Use

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ABSTRACT

Pakistan's groundwater crisis stems primarily from governance failures and policy distortions rather than an actual shortage of physical water resources. The unregulated expansion of tube wells over the decades, coupled with poorly designed energy and crop subsidies, has led to excessive groundwater extraction. Additionally, a consistent policy bias towards surface-water planning, along with fragmented institutional responsibilities, has hindered effective groundwater management.

As a result, groundwater extraction has now surpassed natural recharge rates in many parts of the country, especially in the Indus Basin and major urban centers. Pakistan has become the world's fourth-largest user of groundwater and is home to the second most stressed aquifer globally. This quantitative strain is exacerbated by severe degradation of water quality, which includes widespread salinity, pollution, and arsenic contamination. This has critical risks to food security, public health, and climate resilience.

Drawing on secondary data and institutional analysis, this paper presents a comprehensive framework for groundwater sustainability. The framework involves immediate regulation of abstraction, medium-term reforms in efficiency and pricing, and long-term transformations in institutional and legal arrangements. The findings emphasise that without decisive governance reforms, ongoing groundwater depletion will increasingly threaten Pakistan's economic stability and its capacity to adapt to climate change.

Keywords: Groundwater Governance, Aquifer Depletion, Indus Basin, Climate Vulnerability, Agricultural Water Use, Groundwater Recharge.

1. INTRODUCTION

Pakistan, an arid to semi-arid country, is experiencing a significant groundwater crisis that threatens food security, urban water supply, and long-term economic stability. Although climate variability and decreased surface water availability exacerbate the situation, this paper argues that the crisis primarily stems from governance and policy failures rather than unavoidable physical scarcity.

Groundwater serves as the backbone of Pakistan's water economy, supplying nearly 60 percent of irrigation, over 70 percent of drinking water, and almost all industrial usage. However, extraction remains largely unregulated, driven by harmful subsidies, incentives for water-intensive crops, and unchecked expansion of tubewells. Institutional fragmentation complicates the issue: irrigation departments focus on canals, urban agencies prioritise short-term supply, and environmental regulators lack authority over aquifers. As a result, no single institution ensures sustainability.

The consequences are alarming. Water tables in Lahore, Quetta, and Karachi decline by 1 to 3 feet annually, salinity and contamination are spreading, and the Indus Basin aquifer is ranked among the most stressed globally. These trends pose serious long-term risks to Pakistan's development, particularly in the face of rapid population growth and climate uncertainty.

This paper looks at Pakistan's groundwater crisis through a governance and policy perspective. It presents three main arguments.

- First, policy distortions, such as subsidies and pricing failures, lead to over-extraction of groundwater and shift costs onto society.
- Second, fragmented responsibilities among various agencies create regulatory gaps that contribute to resource depletion.
- Third, without timely and prioritised reforms, groundwater depletion will continue to threaten food security, urban resilience, and climate adaptation.

The analysis draws on empirical evidence, institutional reviews, and international lessons to propose a phased framework for reform. This framework includes immediate high-impact actions, medium-term efficiency measures, and long-term structural changes. The central message is clear: Pakistan's groundwater crisis is a failure of governance, and only governance reform can reverse this issue.

Key Statistics

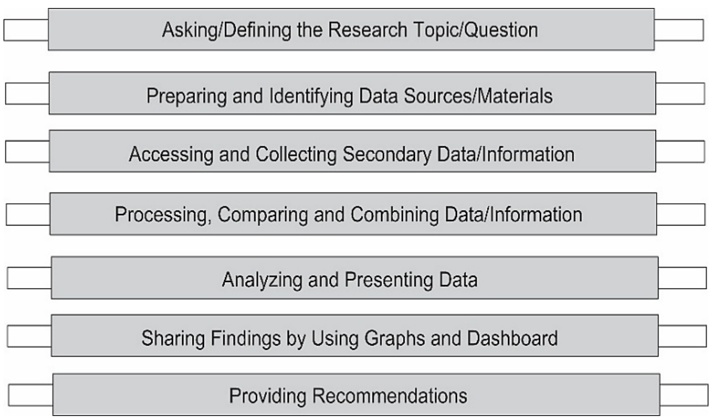
- Pakistan has the fourth-largest groundwater aquifer in the world, with a storage capacity equivalent to around 50 large dams. However, available groundwater is insufficient to meet the rising demand due to chronic over-extraction. The country is also the fourth-largest user of groundwater globally.
- Pakistan is the largest exporter of depleted groundwater embedded in agricultural products, such as rice, leather, and textiles, accounting for 29 percent of the global trade in agricultural goods resulting from groundwater over-extraction. This places Pakistan ahead of the United States (27 percent) and India (12 percent).
- The country is home to the 2^{nd} most overstressed aquifer in the world.
- The contribution of groundwater to irrigation in Pakistan has increased significantly, from just 8 percent in 1960 to over 60 percent today. This growth

is largely linked to agricultural expansion driven by high water-use crops, which have been incentivised by policy.

- Annual groundwater extraction is estimated at 65 cubic kilometers, while recharge is only about 55 cubic kilometers, revealing a growing deficit. Over 1.5 million mostly unregulated tube wells operate across the nation, contributing to approximately 6.6 percent of global groundwater withdrawals and supporting irrigation for 4.6 percent of the world's groundwater-fed cropland.
- Currently, surface water can irrigate only 27 percent of Pakistan's land, while the remaining 73 percent relies on groundwater, either directly or indirectly. The Punjab province uses around 90 percent of the country's total extracted groundwater, making it the country's food basket (Zakir-Hassan, et al. 2023).
- Water tables are declining by 1–3 feet per year in major cities such as Lahore, Quetta, and Karachi, as well as in southern Punjab.
- The quality of groundwater is deteriorating due to salinity, industrial and agricultural pollution, and seawater intrusion in coastal areas. Issues like arsenic, nitrates, fluoride, and bacterial contamination are particularly common near agricultural and urban centers.
- Climate change worsens Pakistan's groundwater vulnerability. Rising temperatures, altered precipitation patterns, early snowmelt, and increasingly erratic floods and droughts have disrupted the natural recharge cycles.

2. RESEARCH METHODOLOGY

Fig. 2.1. Research Methodology



This research follows a mixed-methods design that involves reviewing literature, secondary data analysis, and comparing institutional frameworks. Secondary data on abstraction and recharge was obtained from national databases, FAO, NASA-GRACE, and provinces. The qualitative data analysis involved an examination of policy and legislation, institutional roles and responsibilities, and other related literature. The results were evaluated using international standards for policy reform.

The methodology allows for a holistic view of groundwater depletion as a physical and governance problem, which makes sure that any policy suggestions made are based on facts and are feasible from an operational perspective.

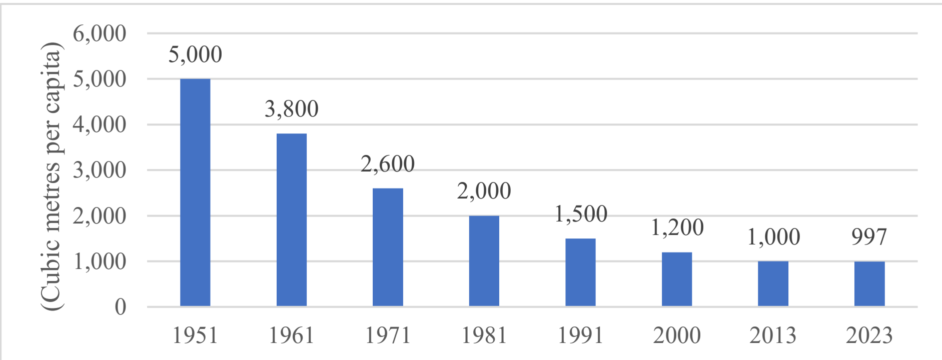
3. PAKISTAN'S WATER RESOURCE PROFILE

Pakistan is one of the most arid countries in the world, with an average annual rainfall of less than 240 mm. The country's population and economy heavily rely on an annual influx of about 180 billion cubic meters of water into the Indus river system, (World Bank, 2005) which includes the Indus, Jhelum, Chenab, Ravi, Beas, and Sutlej rivers. This water primarily originates from neighboring regions.

Pakistan is currently facing a significant water crisis driven by a combination of geographic limitations, over-extraction of water resources, inefficiencies in infrastructure, and the impacts of climate change. As one of the most water-stressed countries globally, Pakistan's per capita water availability has plummeted from over 5,000 cubic meters in 1947 to less than 1,000 cubic meters today, falling below the threshold of absolute scarcity (Figures 3.1 and 3.2).

Neil Buhne, the UN humanitarian coordinator for Pakistan, states, *"No person in Pakistan, whether from the north with its more than 5,000 glaciers or from the south with its hyper-arid deserts, will be immune to this scarcity."* (Baloch, 2018).

Fig. 3.1. Per Capita Water Availability in Pakistan, 1951-2025



Source: SBP (2017) and FAO (2025).

Pakistan's water availability per person is just 1,013 cubic metres, which is more than seven times lower than the global average of 7,101 cubic metres in 2022 (see Table 3.1). This limited availability, coupled with insufficient river flows, groundwater depletion, and rapid population growth, has made the country highly vulnerable to water stress. The gap between demand and supply is expected to worsen due to climate change, which is likely to affect weather patterns. Changes in precipitation may lead to erratic and unpredictable rainfall, further influencing river flow. The challenge for South Asia is to increase food production for its growing population while also ensuring sufficient water for domestic users and meeting industrial and energy demands.

Pakistan's water system, developed over thousands of years through human activity, relies almost entirely on the Indus River system. This river system originates in the Himalayas and is sustained by glacier melt, snowmelt, and monsoon rains. The Indus River basin spans a drainage area of approximately 1,137,819 km², lying between the Tibetan Plateau and the Arabian Sea. The largest portion of this basin (60 percent) is in Pakistan, while substantial upstream areas are found in India and smaller portions in Afghanistan and China.

Of the total basin area, about 228,694 km² (21 percent) is irrigated land, with 60.9 percent of this located in Pakistan and 37.2 percent in India. The river system includes the main stem of the Indus River and several key tributaries, including the Kabul, Jhelum, Chenab, Ravi, Beas, and Sutlej Rivers. The glaciers, seasonal snowmelt, and rainfall contribute to the rivers, which collectively have an annual water flow of approximately 207 km³, allowing for habitation and agriculture in large areas of this predominantly arid and semiarid region.

Precipitation in the basin varies significantly, ranging from 392 to 461 mm per year, and is distributed unevenly both spatially and temporally. Notably, around 80 percent of the rainfall occurs during the summer monsoon season, which spans from July to September (Mustafa, et al., 2017).

The Indus Basin Irrigation System (IBIS) is the largest contiguous irrigation system in the world, covering an area of 60,800 km and irrigating 43 million acres of land across Khyber Pakhtunkhwa (KPK), Punjab, Sindh, and Balochistan. This extensive system includes three major reservoirs—Tarbela, Mangla, and Chashma—along with 23 barrages, 12 inter-link river channels, and 45 primary canals. According to Pakistan's Water Accord of 1991, water is allocated among the four provinces as follows: Punjab receives 49 percent, Sindh 43 percent, KPK 5 percent, and Balochistan 3 percent (PBC, 2023).

Outside the Indus Basin, particularly in Balochistan, water sources include spate irrigation and groundwater-dependent systems such as the Pishin-Lora aquifer and traditional karez networks. These systems, once sustainable, are now under stress due to deep tube well extraction, reduced recharge, urbanisation, and weakening of customary water-sharing arrangements.

Pakistan's climate is heavily influenced by two main precipitation patterns: the summer monsoon and the winter western disturbances. The monsoon brings significant rainfall from July to September, with averages around 200 mm, primarily affecting the eastern regions of the country. In contrast, winter precipitation is largely due to western disturbances. Rainfall varies widely across different areas, with arid regions like Baluchistan and Sindh receiving less than 100 mm annually, while moist highland areas can exceed 1,500 mm. The Gilgit-Baltistan region, known for its glaciated terrain, can experience snowfall of over 5,000 mm annually at altitudes above 5,000 meters, highlighting the significant spatial variability in precipitation throughout Pakistan (UNDP, 2016).

In parallel, groundwater has become the informal lifeline of Pakistan's water economy—especially in the face of unreliable surface water supplies. The alluvial aquifer system under the Indus Plain spans over 16 million hectares. Around 64 percent of the irrigated land in the basin lies over fresh groundwater zones, mainly in Punjab, where groundwater now meets 80–100 percent of agricultural water needs in many areas. Conversely, in Sindh, over 80 percent of groundwater is saline, making the province heavily dependent on surface water. Groundwater withdrawals now account for nearly one-third of Pakistan's total water use—an estimated 62.6 billion cubic meters annually—yet remain largely unregulated and poorly monitored (Mustafa, et al., 2017).

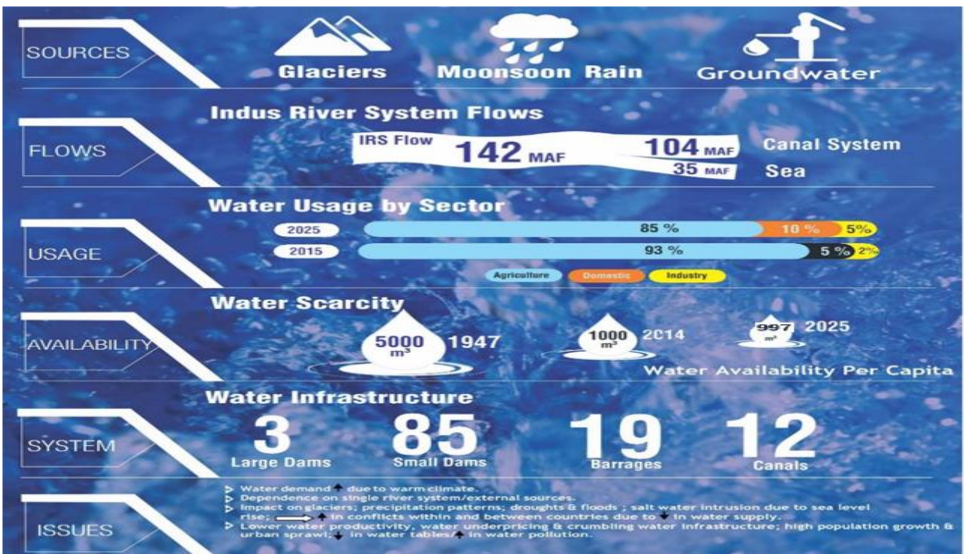
Compounding these challenges is climate change, which is already disrupting the hydrology of the Indus system. Nearly 80 percent of the basin's flows are fed by glacier and snowmelt in the Hindu Kush–Karakoram–Himalayan ranges. Warming temperatures, changing snowfall patterns, and altered monsoon dynamics are expected to create more erratic river flows, reduce storage capacity due to increased sediment loads, and intensify seasonal imbalances in water supply. This will have far-reaching implications for agriculture, hydropower, drinking water, and disaster risk management.

Table 3.1
Water Resources in Pakistan and other South Asian Countries

	India	Pakistan	Bangla-desh	Afghanis-tan
Total renewable water resources (10^9 m3/year)	1,910.9	246.8	1,227.0	65.3
Total renewable groundwater (10^9 m3/year)	432.0	55.0	21.1	10.7
Dependency ratio – water originating from outside the border (percent of total water)	30.5	77.7	91.4	28.7
Precipitation (mm/year)	1,083	494	2,666	327
SDG 6.4.1. Water Use Efficiency (US$/m3)	3.4	6.2	9.5	0.6
SDG 6.4.1. Irrigated Agriculture Water Use Efficiency (US$/m3)	0.5	0.3	1.0	0.1
Total water withdrawal (10^9 m3/year)	761.0	183.5	35.9	20.4
Total groundwater withdrawal (10^9 m3/year)	251.0	65.4	28.5	3.1
Agricultural water withdrawal as percent of total water withdrawal	90.4	94.0	87.8	98.2
Industrial water withdrawal as percent of total water withdrawal	2.2	0.8	2.1	0.8
Municipal water withdrawal as percent of total withdrawal	7.4	5.3	10.0	1.0
Total renewable water resources per capita (m3/inhab/year)	1,341	997	7,244	1,610
Total water withdrawal per capita (m3/inhab/year)	534	753	212	502

Source: FAO 2025.

Fig. 3.2. Pakistan's Water Sector Overview



Sources: Author's computations, FAO 2025 and LEAD, Pakistan 2016.

Despite the complexity of Pakistan's water systems, current governance remains fragmented, with outdated institutional mandates, limited integration between groundwater and surface water management, weak data systems, and underinvestment in climate adaptation. Addressing the looming water crisis will require a paradigm shift—from supply-side expansion and unregulated extraction toward sustainable, integrated, and climate-resilient water governance.

Conclusion: This section shows that Pakistan's water scarcity is mostly due to governance issues instead of being an unavoidable physical reality. Chronic over-extraction, poor regulation of groundwater, scattered institutional responsibilities, and harmful agricultural and energy policies have turned a water system that is variable but manageable into a crisis. Therefore, reforming governance is the main policy priority, rather than simply increasing supply.

4. GROUNDWATER RESOURCES AND USE IN PAKISTAN

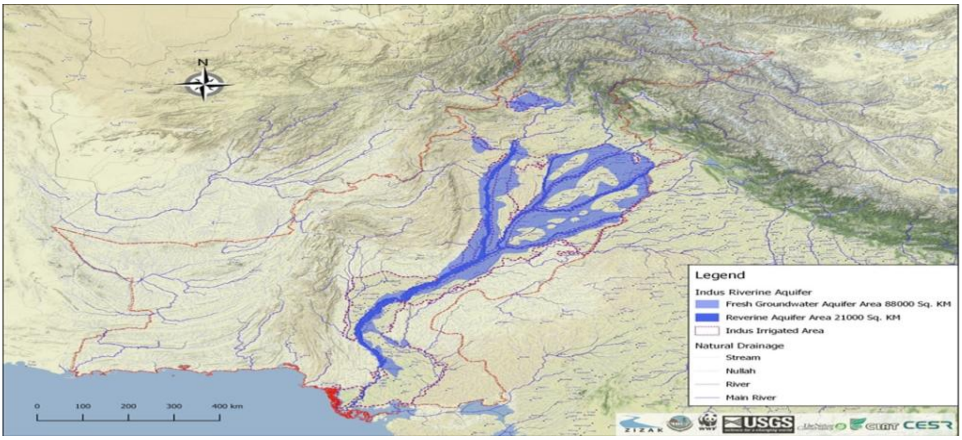
Pakistan's groundwater resources—once considered an abundant buffer—are now under severe stress due to unregulated extraction, quality degradation, and poor governance. Of the 200,000 square kilometres that make up the Indus Plain, around 88,000 square kilometres contain fresh groundwater, with an estimated storage capacity of 400 million acre-feet (MAF), or 4,800 billion cubic metres (BCM) (against current total demand of 104 MAF), equivalent to 1,000 days of storage compared to current storage of 30 days (after excluding polluted areas). This is roughly 80 times the combined storage capacity of Pakistan's three major dams—Tarbela, Mangla, and Chashma (Figure 4.1). Despite this vast reserve, the country faces chronic water stress due to rapid depletion and contamination of its aquifers (Hussain & Abbas, 2019).

Pakistan is the fourth-largest user of groundwater globally, accounting for over 7 percent of total global withdrawals. It has the second-most overstressed aquifer system in the world, with annual abstraction (65 BCM) exceeding recharge (55 BCM). A staggering 94 percent of abstracted groundwater is used for irrigation—more than any other top groundwater-using country (see Table 4.1). Groundwater meets over 60 percent of agricultural water needs, 90 percent of domestic drinking water demand, and nearly all industrial usage (Iqbal, et al., 2020). Punjab is the largest user, accounting for about 90 percent of national groundwater extraction, supporting the province's dominant agricultural economy. However, reliance has intensified with rapid urbanisation and industrialisation, even as water quality deteriorates. Only 23 percent of Punjab's groundwater is of poor quality, compared to 78 percent in Sindh (Salam, et al., 2023).

In Sindh, groundwater use is limited due to high salinity. A thin freshwater lens overlying saline aquifers is tapped using skimming wells, particularly in areas like Hyderabad and Nawabshah. Safe annual yield is estimated at 5–10 BCM, yet most of the province (95 percent) remains reliant on canal water (Soomro, et al., 2023).

In Balochistan, groundwater is the main source of irrigation due to the absence of perennial surface flows. However, excessive tube well development—from 5,000 in the 1970s to over 40,000 today—has caused critical aquifer decline. Regions like Quetta, Pishin, and Mangochar are experiencing annual groundwater level drops exceeding five meters (Ashraf & Hasan, 2021). Karez systems, once central to the province's agro-economy, have dried up or become non-functional, and further extraction risks irreversible depletion. *"The extreme discharge can lead to water table depletion at alarming levels and may lead to a point of 'no return' as in the case of Cape Town in South Africa"*, says Dr Muhibullah Kakar, assistant professor in the Geology Department at the University of Balochistan (Mandokhel, 2024). It is estimated that, out of a total available potential of about 0.9 MAF, 0.5 MAF is already being utilised, thereby leaving a balance of 0.4 MAF that can still be utilized (Kahlown & Majeed, 2003).

Fig.4.1. Freshwater Aquifers in the Indus Plains and Riverine Corridors in Pakistan



Source: Hussain & Abbas (2019).

Pakistan is also the world's largest exporter of depleted groundwater—accounting for 29 percent of the global trade in agricultural commodities grown using over-abstracted aquifers, ahead of the United States (27 percent) and India (12 percent) (Mustafa, 2017). This groundwater embedded in exports represents a hidden depletion of national resources that undermines long-term food and water security.

Unregulated pumping, weak institutional oversight, lack of metering and monitoring, and absence of groundwater rights or pricing mechanisms have contributed to an unsustainable extraction regime. Without urgent reforms—including aquifer zoning, water accounting, licensing systems, and investments in recharge and reuse—Pakistan risks turning large parts of its agricultural heartland into water-stressed or barren regions. The groundwater crisis is no longer just an environmental issue—it is a direct threat to national security, economic resilience, and intergenerational equity.

Table 4.1

Groundwater Withdrawal and the Percentage for Irrigation for Selected Countries

Country	Estimated Total Groundwater Withdrawal (km3)	Percentage for Irrigation	Estimated Groundwater Withdrawal for Irrigation (km3)
India	251	89%	223
China	112	54%	61
USA	112	71%	80
Pakistan	65	94%	61
Iran	64	87%	56
Bangladesh	30	86%	26
Mexico	29	72%	21
Saudi Arabia	24	92%	22

Source: UNESCO (2022).

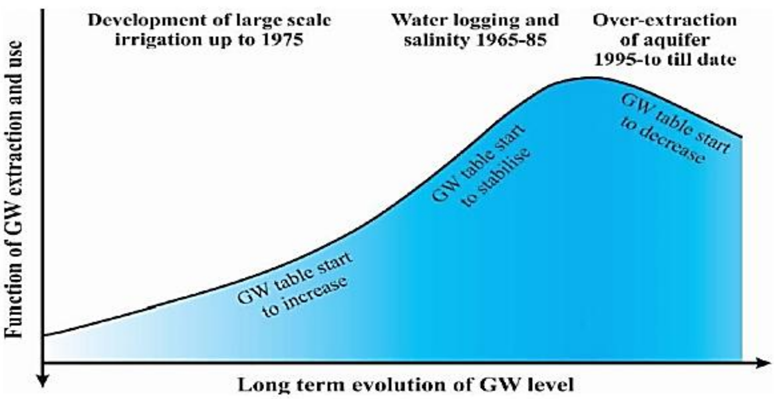
4.1. Historical Development of Groundwater in Pakistan

Pakistan's transition from a surface water-dependent to a groundwater-reliant economy has been shaped by the evolution of its irrigation infrastructure and state policies. The development of the Indus Basin canal system between 1870 and 1930 raised groundwater tables significantly, contributing to widespread waterlogging. By the early 1950s, the Colombo Plan Survey estimated over 5 million hectares affected by high water tables (Prathapar, et al., 2021).

Following the 1960 Indus Waters Treaty, Pakistan expanded irrigated agriculture across more than 16 million hectares. However, increased seepage from the expanded canal network led to a rise in shallow groundwater tables, causing salinity and waterlogging. In response, the government launched the Salinity Control and Reclamation Project (SCARP), installing around 16,700 deep tubewells to lower water tables and improve crop productivity. Initially managed by the government, these tubewells were later transferred to farmers, marking the onset of unregulated private groundwater use.

In the 1970s and 1980s, public policies—such as subsidised electricity, free pump sets, and cheap loans—further accelerated tubewell adoption. A 227 percent increase in electric tubewells eventually prompted the removal of subsidies and the imposition of flat-rate tariffs (Schmid, et al., 2017). Yet, during the 1996–2001 drought, subsidies were reintroduced to mitigate surface water shortages, entrenching groundwater as a primary irrigation source (Shah & Akbar, 2021). These subsidies aimed to manage waterlogging and salinity, ultimately shaping the norms for groundwater development in Pakistan. Neither customary law nor government policy has provided the impetus for finding a balance between recharge and groundwater extraction as shown in Figure 4.2.

Fig. 4.2. Trend in Groundwater Usage in Pakistan

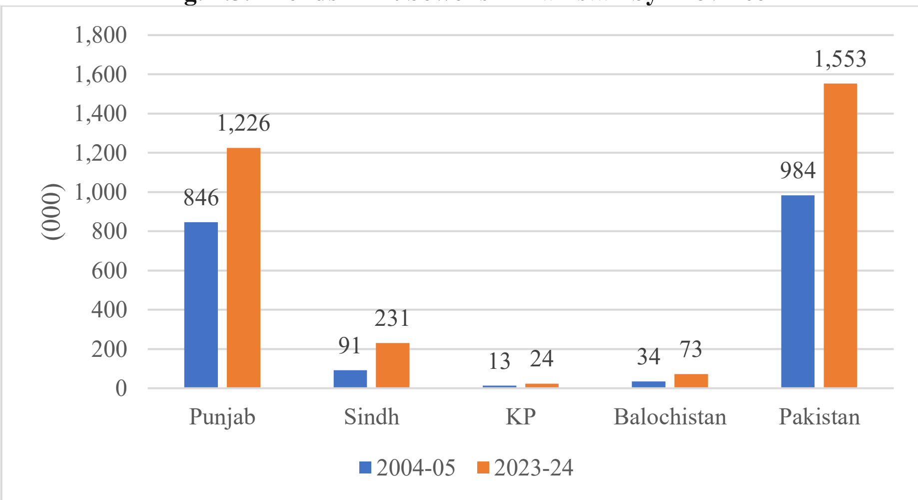


Source: Watto (2015).

By 2024, Pakistan had over 1.5 million tubewells—79 percent in Punjab, followed by Sindh (15 percent), Khyber Pakhtunkhwa (1 percent), and Balochistan (5 percent) up from 30,000 in the late 1960s (Figures 4.3 – 4.5) (Salam, et al., 2023). While Punjab benefits from relatively good groundwater quality (only 23 percent of its area affected by poor quality), Sindh faces 78 percent groundwater quality degradation, limiting its usability. Today, Pakistan meets around 60 percent of its irrigation needs through groundwater and is the world's fourth-largest groundwater extractor (Salam, et al., 2023).

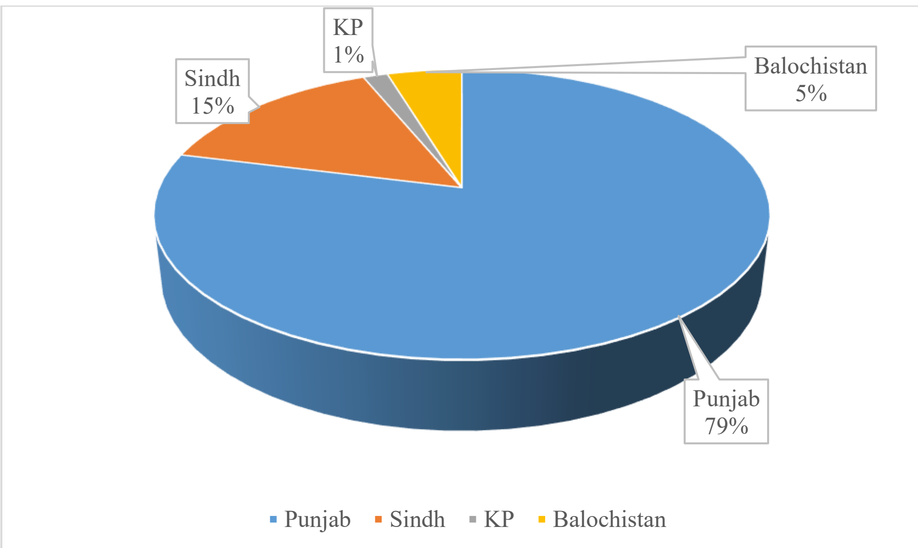
This largely unregulated expansion has led to over-extraction, falling water tables, and deteriorating water quality, particularly in urban areas like Lahore and water-stressed regions such as Balochistan. Climate change, reduced recharge, and weak institutional oversight have worsened the situation. While frameworks such as the Punjab Water Act 2019 exist, enforcement and coordination remain limited. Without urgent regulatory and institutional reforms, Pakistan's groundwater crisis could seriously undermine its water and food security.

Fig. 4.3. Trends in Tubewells in Pakistan by Province



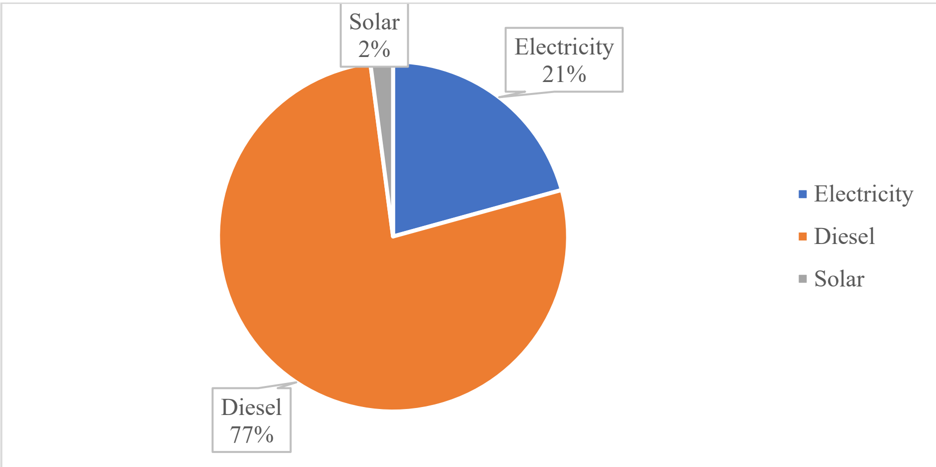
Source: GOP (2023 and 2025).

Fig.4.4. Tubewells in Pakistan by Province, 2023-24



Source: GOP (2025).

Fig. 4.5. Tubewells in Pakistan by Fuel, 2023-24



Source: GOP (2025).

4.2. Groundwater Over-extraction in Pakistan

Since the 1960s, Pakistan has transitioned from a country dependent on surface water to one reliant on groundwater. It has also shifted from having a groundwater surplus to facing significant challenges related to groundwater overdraft, compounded by increasing salinity issues due to the use of poor-quality groundwater for irrigation. Approximately 21 percent of the irrigated area is affected by salinity (UN Water, 2022).

The use of groundwater varies across the provinces. In Sindh, groundwater exploitation is minimal due to its poor quality. Khyber Pakhtunkhwa and Balochistan face higher costs associated with groundwater access because of greater depths and aquifer characteristics. In contrast, Punjab has shallow groundwater with relatively good quality, leading to its widespread use. Punjab possesses 50 million acre-feet of ground water and accounts for 90 percent of total groundwater pumping in Pakistan (Kamal, 2023).

Decades of unregulated abstraction—particularly in response to the limitations of the Indus Basin Irrigation System (IBIS)—have led to severe and accelerating groundwater depletion. While IBIS follows a rotational schedule (warabandi) designed for a 75 percent cropping intensity, farmers with access to groundwater have more than doubled that, achieving cropping intensities over 150 percent, mostly through uncontrolled tubewell use (Baocheng, et al., 2024).

Pakistan hosts more than 1.5 million tubewells to irrigate over 5 million hectares. Yet groundwater governance remains fragmented and weak, lacking enforceable regulation, metering, or licensing systems. Five major crops—rice, wheat, cotton, sugarcane, and maize—consume 85 percent of total water while contributing less than 5 percent to GDP, reflecting highly inefficient water use (Hasan & Fatima, 2025).

NASA classifies the Indus Basin aquifer as the world's second-most stressed (Fig. 4.6) (LaFond, 2015). Arabian Aquifer System is the most overstressed in the world, while Murzuk-Djado Basin in northern Africa is third. A study with data from April 2002 to May 2023 over the Indus basin in Pakistan shows annual groundwater loss rates increasing from –0.65 cm/year (before 2015) to -2.16 cm/year (after 2015). Declining precipitation, surface runoff, and increasing evapotranspiration and vegetation growth are major contributors to groundwater loss (Dharpure, et al. , 2025). Areas most affected include the Panjnad sub-basin, canal tail-ends in Punjab and Sindh, and nearly all major cities and valleys in Balochistan. In Quetta, groundwater tables are declining at over 6 meters annually, with wells now exceeding depths of 350 meters. Pishin's aquifers have dropped below 1,000 feet. Similar trends are observed in Hyderabad, Kohat, and Benazirabad.

In urban centers, groundwater is overextracted to bridge the supply-demand gap. Lahore, with over 1,800 tubewells, extracts 4.32 MCM per day and has seen a consistent 1-meter annual decline in water tables (see Table 4.2). Islamabad and Rawalpindi extract 127 and 58 MCM annually, respectively, with declining aquifers and deteriorating quality due to saline intrusion (Arshad, et al. , 2023). In Punjab alone, 15 percent of irrigated areas are already facing critical water table declines—a figure projected to rise sharply if current practices continue (Habib &Wahaj, 2021).

Compounding the crisis are poor wastewater management, saline water intrusion, and contamination of deeper aquifers. According to journalist Zofeen T. Ebrahim, *"Weak implementation of environmental laws, low investment in wastewater treatment, and unmanaged, unlicensed expansion of pumping infrastructure have turned pristine water toxic."* (Ebrahim, 2021).

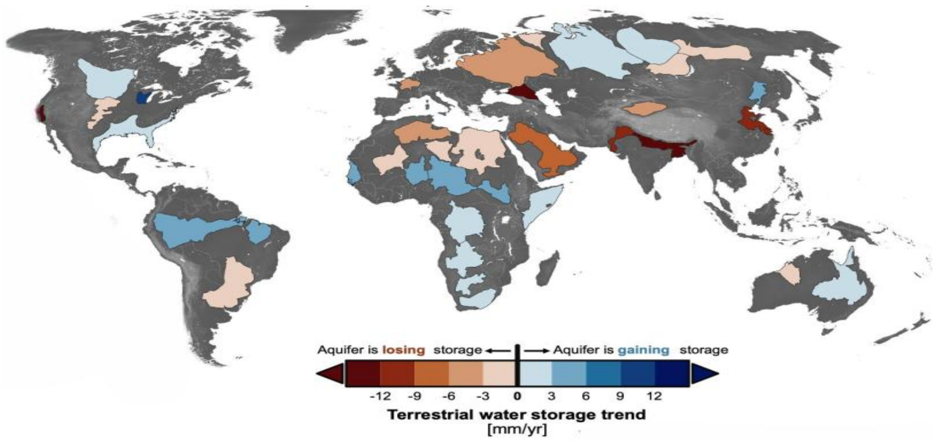
Table 4.2

Average Annual Rate of Groundwater Decline in Lahore

	Rate of Decline (feet/year)	Rate of Decline (meter/year)
1960-1967	1.0	0.30
1967-1973	1.8	0.55
1973-1980	2.0	0.60
1980-2000	2.1	0.65
2007-2011	2.6	0.79
2011-2013	3.0	0.91

Source: SBP (2017).

Fig. 4.6. Trend in Water Storage in the World's Large Aquifer Systems (2002-23).



Source: Famiglietti (2023).

Conclusion: The section shows that depletion of groundwater in Pakistan is not merely due to increased demands or environmental stresses. In fact, it is quite obvious that poor enforcement of rules regarding extraction levels, misalignment between agriculture, energy, and water policies is bound to lead to over-extraction of groundwater, resulting in a number of socioeconomic challenges in the future.

5. PAKISTAN'S GROUNDWATER CHALLENGES

Groundwater is the lifeblood of Pakistan's water economy. Despite its vital role, governance remains weak and fragmented, leading to over-extraction, contamination, and declining aquifer resilience. Current policies prioritise surface water and treat groundwater as an open-access resource with little regulation. To tackle Pakistan's groundwater crisis, we must address the structural barriers to sustainable management, including policy inconsistencies, regulatory inertia, administrative fragmentation, financial misalignments, and infrastructure gaps.

5.1. Policy Gaps

Groundwater governance in Pakistan faces significant challenges due to entrenched policy barriers and a longstanding neglect of aquifers in national water planning.

- No binding national groundwater law; provincial acts exist but weakly enforced.
- Policies remain surface water–centric, while groundwater absent in planning and climate adaptation.
- Crop subsidies encourage water-intensive crops (rice, sugarcane), accelerating depletion.

Pakistan's groundwater governance suffers from major policy deficiencies. Provincial laws such as the Punjab Water Act (2019) and the Khyber Pakhtunkhwa Water Act (2020) provide a legal foundation, but their enforcement is inconsistent and poorly resourced. The National Water Policy (2018) highlights the urgent need for sustainable groundwater management, emphasising aquifer recharge and institutional reform. However, without a binding national groundwater law, regulation remains decentralised and uneven across provinces following the 18th Amendment (GOP, 2018).

"Water governance is only implemented to a certain extent in Punjab. The groundwater level in Multan has plummeted to 600 feet while in Lahore it is decreasing by three feet each year. Despite the existence of the Punjab Water Act and Water Policy, WASA pumps 350 million gallons of water daily in Lahore. It is challenging to prevent private individuals from pumping water, but solar pumping can be supported as a solution. However, it should not be allowed without any law in place", says Syed Ali Murtaza, Federal Secretary Ministry of Water Resources (*Dawn*, 2024).

Agricultural policies continue to incentivise water-intensive crops like sugarcane and rice, worsening aquifer depletion, while groundwater is insufficiently integrated into climate adaptation strategies despite being the country's primary buffer against drought. In contrast to groundwater, the governance of surface water benefits from strong institutional frameworks. Provincial irrigation departments possess the authority and expertise to manage surface water flows and allocate resources effectively. However, the growing unpredictability of these flows—driven by climate variability, upstream withdrawals, and escalating demand—has compelled both agriculture and industry to shift towards unregulated groundwater extraction, further jeopardising our already depleting aquifers. The National Water Policy lays out an inspiring roadmap for a transition to Integrated Water Resource Management (IWRM), urging provinces to craft holistic water resource plans that seamlessly address both surface and groundwater needs. Yet, a significant barrier to achieving this vital integration remains: the scarcity of detailed data on groundwater availability and usage. This challenge must be overcome to secure a sustainable water future.

Hassan Abbas, a hydrogeologist in Punjab, highlights that many farmers use up to ten times more water than necessary, which underscores the urgent need to reevaluate current practices. He advocates for a transformation that uses climate change as a catalyst to shift towards solar-powered irrigation, advanced technologies, and the restoration of wetlands and forests in the Indus Basin. These changes aim to improve groundwater recharge and enhance flood resilience (Novo, 2020).

5.2. Weak Regulation

Pakistan's groundwater crisis is significantly impacted by regulatory weaknesses.

- Unlicensed, unmetered pumping (without pricing) from 1.5 million tubewells.
- 70–80 percent groundwater unsafe with serious impacts on human health.

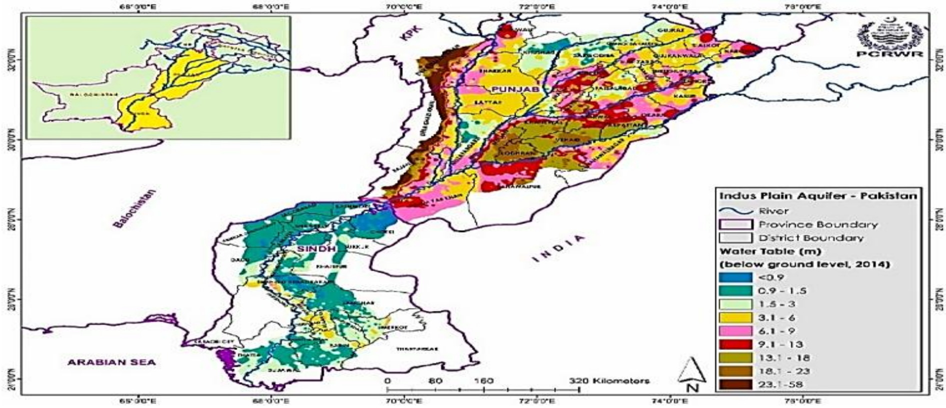
Groundwater extraction is almost entirely unregulated. Pakistan hosts more than 1.5 million tubewells to irrigate over 5 million hectares. Yet groundwater governance remains fragmented and weak, lacking enforceable regulation, metering, or licensing systems. Five major crops—rice, wheat, cotton, sugarcane, and maize—consume 85 percent of total water while contributing less than 5 percent to GDP, reflecting highly inefficient water use (Hasan & Fatima, 2025).

Generally, the Indus Plain Aquifer is in equilibrium (Iqbal, et al. , 2020). However, there are specific regions within the aquifer, where groundwater depletion is a major concern. More specifically, the groundwater depletion is taking place at tail-ends of canal command areas of Punjab and Sindh provinces (see Figure 5.1), Balochistan province and almost all urban centers (Arshad, et al. , 2023).

NASA classifies the Indus Basin aquifer as the world's second-most stressed (LaFond, 2015). Arabian Aquifer System is the most overstressed in the world, while Murzuk-Djado Basin in northern Africa is third. A study with data from April 2002 to May 2023 over the Indus basin in Pakistan shows annual groundwater loss rates increasing from -0.65 cm/year (before 2015) to -2.16 cm/year (after 2015). Declining precipitation, surface runoff, and increasing evapotranspiration and vegetation growth are major contributors to groundwater loss (Dharpure, et al. , 2025). Areas most affected include the Panjnad sub-basin, canal tail-ends in Punjab and Sindh, and nearly all major cities and valleys in Balochistan. In Quetta, groundwater tables are declining at over 6 meters annually, with wells now exceeding depths of 350 meters. Pishin's aquifers have dropped below 1,000 feet. Similar trends are observed in Hyderabad, Kohat, and Benazirabad.

In urban centers, groundwater is overextracted to bridge the supply-demand gap. Lahore, with over 1,800 tubewells, extracts 4.32 MCM per day and has seen a consistent 1-meter annual decline in water tables. Islamabad and Rawalpindi extract 127 and 58 MCM annually, respectively, with declining aquifers and deteriorating quality due to saline intrusion (Arshad, et al. , 2023). In Punjab alone, 15 percent of irrigated areas are already facing critical water table declines—a figure projected to rise sharply if current practices continue (Habib &Wahaj, 2021).

Fig. 5.1. Spatial Variation in Water Table Depth in Indus Plain



Source: Hasan & Fatima (2025).

Quality regulation is equally weak with serious implications for health (Table 5.1). Over 70 percent of urban groundwater sources and more than 80 percent of rural sources are unsafe for human consumption due to chemical and bacteriological contamination. This contamination results from groundwater resource development carried out without prior surveys to locate fresh water, as well as improperly designed water supply systems and treatment technologies, intermittent water supply, and issues with infrastructure maintenance (Rasheed, et al., 2022). *"On Lahore–Sheikhupura Road, for instance, 700 industrial units discharge effluents directly into unlined pits, contaminating the underlying aquifer"*, says Dr Fazilda Nabeel (Tabadlab, 2024).. Pakistan also has one of the world's highest rates of childhood malnutrition—at least a third of all children suffer from it. *"The country's highest rates of all, are in the irrigated districts"* says Daanish Mustafa, a Pakistani geographer at King's College London (Albinia, 2020).

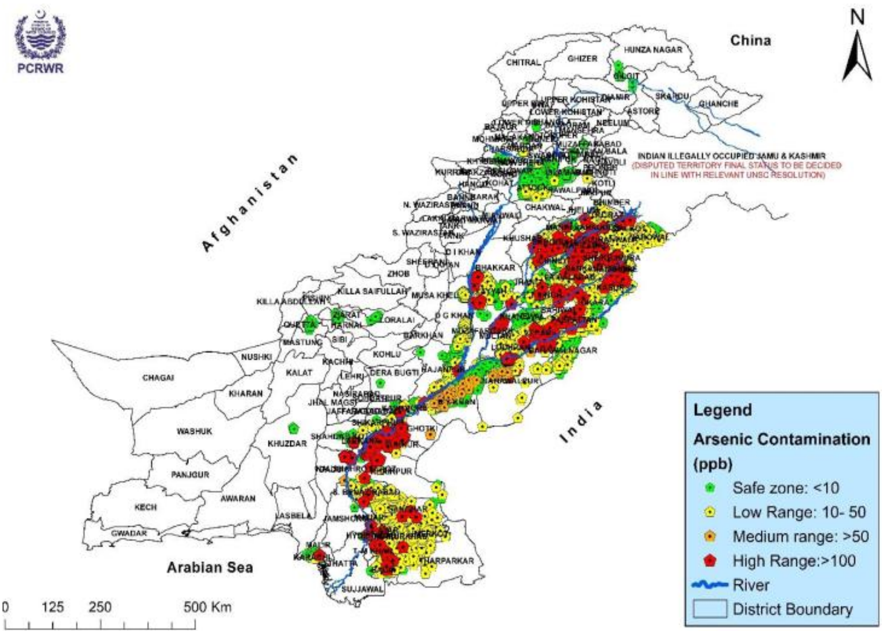
Table 5.1
Key Groundwater Contaminants and Impacts in Pakistan

Contaminant	Source	Health/Environmental Impact	Affected Areas	Risk Level
Arsenic	Natural deposits, industrial waste	Cancer of lung & bladder, skin lesions, neurological effects	Punjab, Sindh	High
Nitrates	Fertilizers, sewage	Blue baby syndrome, cancer	Punjab, KP	High
Salinity	Overpumping, seawater intrusion	Kidney stones due to poor hydration, soil infertility, yield decline	Sindh, South Punjab	Medium
Fluoride	Geogenic	Skeletal/dental fluorosis	Balochistan, KP, Punjab	Medium
Pathogens	Untreated sewage, pit latrines	Gastrointestinal disease, child mortality	Rural areas nationwide	High
Heavy Metals	Industrial waste	Kidney, liver damage; developmental disorders	Lahore, Karachi, urban Punjab	High

Source: Author's computations.

- Pakistan ranks fourth globally among the arsenic-affected countries globally (Masood, et al. , 2021). Research in Science Advances journal finds that, based on about 1,200 groundwater samples, up to 60 million people, more than a quarter of the population, are at risk of consuming arsenic (Kugelman, 2018). Sindh and Punjab provinces are the worst arsenic-affected areas of Pakistan. Arsenic levels above WHO's 10 µg/L threshold are found in 14 percent, 13 percent and 10 percent of water sources in Punjab, KP and Sindh respectively Highly contaminated districts are Multan, Bahawalpur, Rahim Yar Khan in Punjab, Khairpur and Dadu in Sindh province (see figure 5.2) (Hifza, et al., 2023).
- Fluoride contamination is prevalent in Quetta, Umerkot, Kasur, and Swabi, contributing to skeletal deformities and joint pain. about 13 million people may be at risk of fluorosis due to consuming groundwater with fluoride concentrations >1.5 mg/L in Pakistan, which corresponds to ~6 percent of the total population (Ling, et al., 2022).
- Heavy metals like lead, chromium, nickel, and cadmium are frequently found in groundwater from Lahore, Karachi, and Faisalabad, far exceeding WHO permissible limits (Kumar, et al., 2023).

Fig. 5.2. Arsenic Distribution in Groundwater of Pakistan

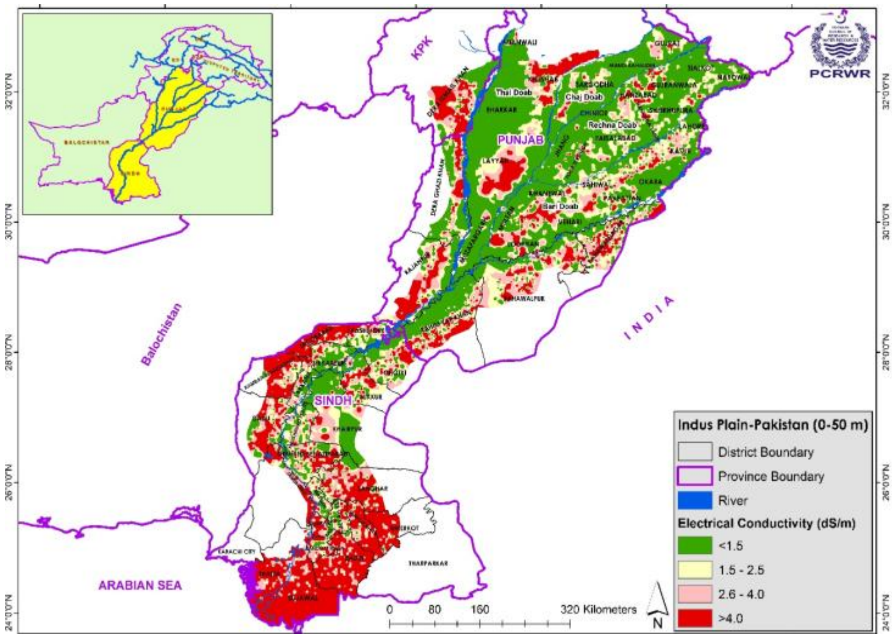


Source: Hifza et al. (2023).

- In Punjab, saline groundwater is dominant in the Thal, Chaj, Bari, and Rechna doabs, with 33 percent of Thal and 28 percent of Bari affected. In Sindh, only 20 percent of groundwater is of usable quality (≤2.5 dS/m), mostly along the Indus River. Elsewhere, groundwater is often saline and deteriorates further with depth (see Figure 5.3). Currently, more than 4.5 million hectares of land are affected by salinity, half of which lies in the irrigated Indus Basin. An additional one million hectares suffer from waterlogging caused by canal seepage and poor drainage infrastructure. The impacts are most acute in Sindh, where thin freshwater layers, saline upflow, and limited drainage capacity have compounded land degradation (Janjua, et al., 2021). Despite various technical interventions, such as SCARP drainage schemes, salinity and waterlogging remain largely unresolved due to fragmented governance, lack of enforcement, and inadequate maintenance.

- Nitrate pollution—from fertilizer use and sewage leaching—is acute in Punjab and Balochistan, posing a serious threat to maternal and child health (Masood, et al., 2021).
- Pakistan's vulnerability is exacerbated by Article IV of the Indus Waters Treaty, which obligates the country to receive untreated effluents from Indian Punjab via the Hudiara, Kasur, Salimshah, and Fazilka drains. These flows further degrade Pakistan's aquifers, especially in eastern Punjab (Mustafa, 2025).

Fig. 5.3. Spatial Variations in Groundwater Quality (Salinity Levels) in the Indus Basin of Pakistan



Source: Iqbal, et al. (2020).

5.3. Administrative Fragmentation

Groundwater management in Pakistan faces significant challenges due to administration fragmentation.

- Overlapping mandates (WASAs, irrigation, PCRWR, environment).
- Rural groundwater use (bulk of withdrawals) is unmonitored; urban monitoring patchy.
- Poor federal–provincial coordination.

The lack of coordination among key institutions further exacerbates the issue. Multiple agencies—such as provincial irrigation departments, Water and Sanitation Agencies (WASAs), the Pakistan Council of Research in Water Resources (PCRWR), and environmental authorities—often operate in isolation, with overlapping mandates and minimal collaboration. Groundwater extraction in rural and agricultural areas, which constitutes the majority of usage, is largely unmonitored. Urban groundwater is partially tracked by WASAs, and organisations like PCRWR and the Geological Survey of Pakistan conduct limited assessments. However, the absence of well-licensing systems, weak data infrastructure, and inadequate hydrogeological mapping severely undermine effective regulation and evidence-based planning.

Data systems are weak, with little hydrogeological mapping or aquifer modeling. In contrast, surface water benefits from established institutions such as IRSA, highlighting the governance vacuum around groundwater.

The situation has worsened since the 18th Constitutional Amendment, which devolved water management responsibilities but failed to establish the necessary mechanisms for coordination, cohesive legislation, and integrated data systems. As a result, groundwater—especially in agriculture, which is the largest and least efficient user—is being overexploited.

5.4. Fiscal and Budgetary Challenges in Groundwater Management

Pakistan's groundwater management faces significant fiscal and budgetary challenges that jeopardize this crucial resource.

- Only 24 percent O&M and 60 percent abiana charges recovered.
- Utilities underfunded; tariffs low and collections weak.
- Electricity subsidies (for tubewells) promote over-pumping.

Urban water tariffs encounter several challenges, including low rates, poor cost recovery, and weak incentives for conservation. Many household tariff rates have not been updated in years, and the efficiency of collections varies significantly, ranging from 20 percent to 80 percent across different cities. This inconsistency creates fiscal stress for utilities. On a national level, only 24 percent of the operating and maintenance costs for irrigation systems are recovered, and just 60 percent of billed water charges, known as abiana, are actually collected. As a result, infrastructure is deteriorating, and the irrigation system has become financially unsustainable (IMF, 2015).

The *abiana* (irrigation water tariffs) are set significantly below the actual costs of water delivery, while electricity subsidies for tube wells promote excessive and unsustainable groundwater extraction—particularly in agriculture, where overuse is most severe. *"Although the 'abiana' rate has been revised in 2022-23 yet we need adequate water pricing for sustainability of water resources infrastructures"* says Dr. Javed Iqbal, Director Strategic Planning and Reform Unit, Government of Punjab *(Business Recorder*, 2023).

At the same time, limited fiscal space constrains investment in aquifer recharge schemes, drainage infrastructure, monitoring networks, and wastewater treatment facilities. Pakistan also underutilizes international climate finance opportunities that could fund groundwater adaptation projects. Table 5.2 shows climate risks for Pakistan along with other countries of South Asia.

Table 5.2

Summary of Climate Risks for South Asian Countries

Risk level	India	Pakistan	Bangladesh	Afghanistan	Nepal	Sri Lanka
High	Drought Riverine flood Flash flood Groundwater depletion	Drought Groundwater depletion Landslide	Riverine Cyclone Coastal flood Siltation	Flash flood Land slide Riverine flood	GLOF Flash flood Landslide	Cyclone Riverine flood Coastal flood
Medium	Landslide Cyclone Coastal aquifer salinization	Riverine flood GLOF Flash flood Erosion/ siltation Groundwater salinization	Erosion Drought Groundwater depletion Coastal aquifer salinization	Drought Siltation Groundwater depletion	Drought Erosion/ Siltation Groundwater depletion	Flash flood Landslide Erosion/Siltation Drought Coastal aquifer salinization
Low	GLOF Erosion/ Siltation	Coastal flood Cyclone	Flash flood Landslide	GLOF Cyclone	Riverine flood Cyclone	Groundwater depletion

Source: Allspring Global Investments (2021).

Rationalising tariffs for both rural and urban sectors can promote more responsible water use and generate essential revenue. A pricing structure linked to income or consumption levels could help ensure affordability while improving equity. The revenue from these pricing reforms would be used to invest in necessary repairs, water-saving technologies, and programmes that promote access for low-income communities. Water expert Simi Kamal highlights that rehabilitating Pakistan's canal system alone could potentially release around 75 million acre-feet of water, which is equivalent to the entire annual flow of the Indus River (Kugelman, 2015).

5.5. Infrastructure Gaps

Groundwater management in Pakistan faces significant challenges due to critical infrastructure deficiencies.

- Sparse monitoring networks, digital data, and recharge systems.
- Inadequate drainage causes salinity and waterlogging on >4.5 million ha.
- Lack of wastewater treatment, rainwater harvesting, and coastal protection against seawater intrusion.

Pakistan lacks the physical infrastructure needed for sustainable groundwater management. Monitoring networks of observation wells, real-time meters, and digital data platforms are sparse, hampering evidence-based planning. Drainage infrastructure is inadequate, causing widespread salinity and waterlogging in the Indus Basin, particularly in Sindh and South Punjab. Past schemes like SCARP drainage projects collapsed due to poor maintenance and fragmented governance. Urban areas also lack facilities for wastewater treatment and rainwater harvesting, while massive volumes of floodwater are lost each year instead of being harnessed for managed aquifer recharge. Coastal regions face worsening seawater intrusion, but protective infrastructure is absent. Without substantial investments in recharge systems, treatment plants, and modern monitoring tools, Pakistan's aquifers will continue to deteriorate.

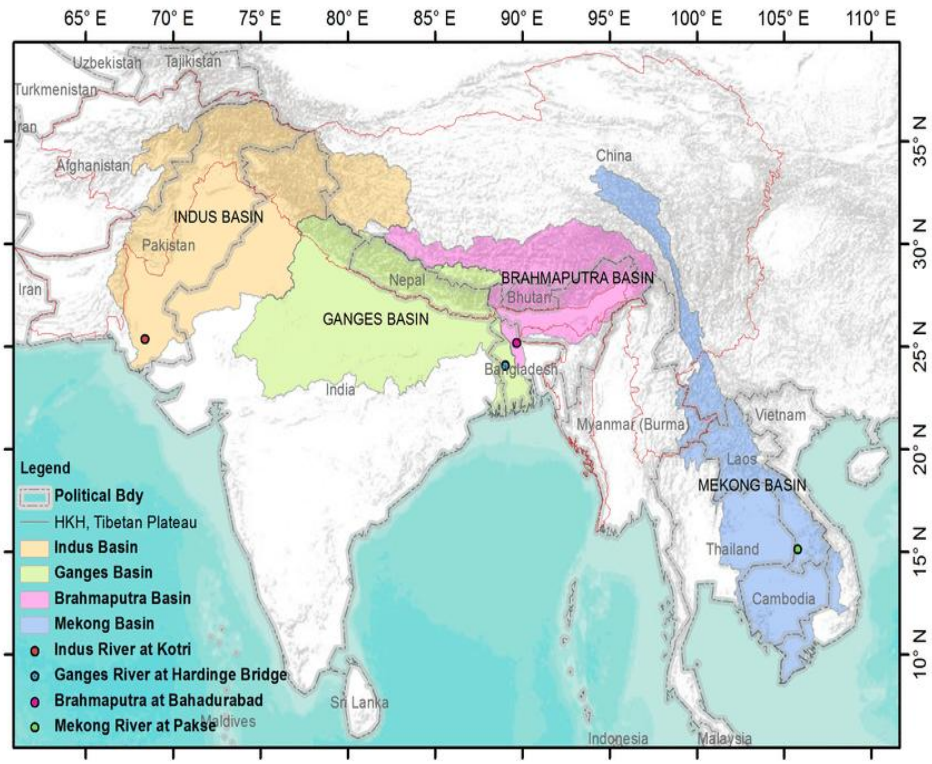
Rising sea levels and the excessive extraction of groundwater in coastal regions, particularly in Sindh and Balochistan, are accelerating the intrusion of seawater into freshwater aquifers (Young, et al., 2019).

5.6 Transboundary Groundwater

Six of the eight South Asian countries India, Pakistan, Bangladesh, Afghanistan, Nepal, and Bhutan are connected by transboundary river basins. Of the 20 rivers in the region, more than half of South Asia's surface area is drained by three major river basins: the Ganges-Brahmaputra-Meghna (GBM) river system, the Indus River Basin, and the Helmand River Basin. These basins are fed by glacial melt and annual precipitation, providing abundant freshwater resources for South Asia (see Fig. 5.4 and Table 5.3).

The remaining areas include various watersheds in peninsular India, the river basins of Sri Lanka, rivers in northern and western Afghanistan, smaller rivers in Balochistan, and coastal rivers in Bangladesh. The proportion of total renewable water resources that originates from outside each country varies significantly. It ranges from 0 percent in Bhutan, the Maldives, and Sri Lanka to between 6 and 91 percent in India, Pakistan, Bangladesh, Afghanistan, and Nepal (see Fig. 5.4).

Fig. 5.4. Major River Basins in South Asia



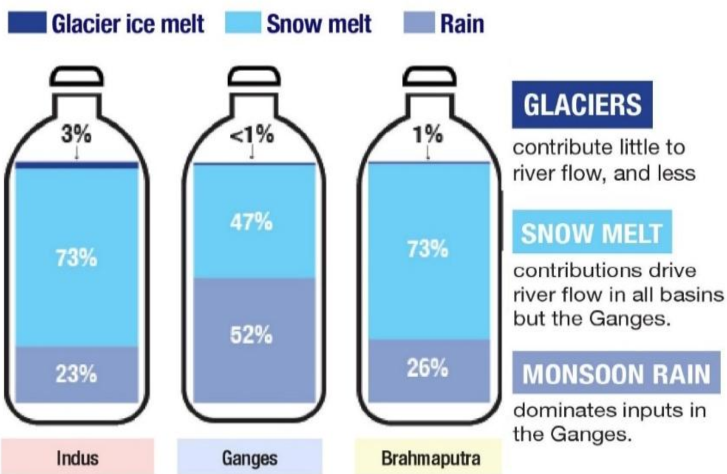
Source: Hasson (2016).

Table 5.3
Major River Basins in South Asia

	Ganges	Brahmaputra	Mehgna	Ganges-Brahmaputra-Mehgna (GBM)	Indus	Helmand
Surface area (km2)	1,087,000	552,000	82,000	1,721,000	1,165,000	306,500
Mean flow (km3/year)	525.4	624.8	160.9	1,311	207	15
Mean runoff mm/year)	483	1,132	1,963	762	178	45
% of the Basin in the Country						
Afghanistan	…	…	…	…	6%	85%
Bangladesh	4%	7%	43%	7%	…	…
Bhutan	…	7%	…	3%	…	…
India	79%	36%	57%	64%	39%	…
Nepal	14%	…	…	8%	…	…
Pakistan	…	…	…	…	47%	4%
China	3%	50%	…	18%	8%	…
Iran	…	…	…	…	…	11%

Source: Lacombe, et al. (2019).

Fig. 5.5. Indus, Ganges and Brahmaputra River Basins by Source in South Asia



Source: CHARIS Project (2018).

Conclusion: The section indicates that the problem of Pakistan's groundwater is a result of policies and governance, not the hydrological nature of the resource itself. In other words, poor governance structures, perverse incentives, inadequate regulations, and chronic underinvestment have made the issue worse, making reforms a much more important solution than expansion.

6. A FRAMEWORK FOR GROUNDWATER SUSTAINABILITY IN PAKISTAN

This section outlines a structured and actionable framework for achieving groundwater sustainability in Pakistan. Instead of simply listing policy ideas, it translates diagnosis into action by organising reforms into three timeframes: immediate high-impact actions (0–2 years), medium-term efficiency-enhancing reforms (2–5 years), and long-term structural transformations (beyond 5 years). This approach takes into account Pakistan's political, fiscal, and institutional constraints, recognising that not all reforms can—or should—be pursued at once.

The logic behind the framework is clear. The first step is to slow down depletion by establishing control over water extraction and addressing the most harmful incentives. Once these control mechanisms are in place, the focus should shift to improving efficiency, aligning pricing with scarcity, and enhancing data collection and monitoring systems. Finally, achieving long-term sustainability requires significant institutional, legal, and regional reforms that will reshape water rights, governance structures, and cooperative arrangements. By framing groundwater reform as a series of decision pathways—rather than a one-time overhaul—policymakers are provided with a realistic and politically feasible roadmap.

6.1. Immediate Actions with High Impact (0-2 Years)

To mitigate groundwater depletion, it is crucial to implement early, high-impact reforms that specifically target uncontrolled extraction, distorted incentives, and fragmented governance. Without these immediate reforms, future investments in efficiency, recharge, or technology will produce limited outcomes.

6.1.1. Licensing & Metering of Groundwater Extraction

Legal reforms are also essential. Key tools such as well licensing, metering, and innovative pricing mechanisms should be employed to conserve water and ensure its efficient use. It is critical to establish a singular, empowered apex institution with clear mandates, authority, and accountability to address the existing institutional fragmentation. Lessons can be learned from Australia's Murray-Darling Basin Authority and Andhra Pradesh's participatory groundwater initiatives, which demonstrate the benefits of integrated, transparent, and community-focused water governance.

6.1.2. Phasing Out Distortionary Electricity Subsidies

A key factor in this crisis is the political economy of subsidies. Water and electricity subsidies mainly benefit larger farmers, who are responsible for the majority of groundwater extraction, while smallholders receive minimal benefits. This imbalance leads to excessive pumping and undermines equity. To address this issue, we need to implement targeted subsidies, set extraction caps, and impose limits on solar-powered tubewells. These measures will ensure that efficiency gains and fiscal support reach the intended beneficiaries instead of encouraging overuse.

However, these reforms necessitate inclusive stakeholder participation, transparent data systems, and strong political will. *"Pakistan's leaders and stakeholders need to take ownership of this challenge and declare their intention to tackle it. Simply blaming previous governments, or blaming India, for the crisis won't solve anything. Next, the* *government needs to institute a major paradigm shift that promotes more judicious use of water"*, says Michael Kugelman, South Asia expert at the Washington-based Woodrow Wilson Center (Domínguez, 2015).

6.1.3. Establishing a National Groundwater Council

Groundwater governance in Pakistan is currently facing a crisis due to institutional fragmentation, inadequate regulations, and unchecked over-extraction. The situation has worsened since the 18th Constitutional Amendment, which devolved water management responsibilities but failed to establish the necessary mechanisms for coordination, cohesive legislation, and integrated data systems. As a result, groundwater—especially in agriculture, which is the largest and least efficient user—is being overexploited.

Institutional reforms should include the establishment of a National Groundwater Council to align sub-national actions with national plans. This council could be modeled after India's Central Ground Water Authority (CGWA) and California's Sustainable Groundwater Management Act (SGMA). By collaborating with the Indus River System Authority (IRSA), provincial irrigation departments, and various stakeholders, this council would promote integrated strategies and the implementation of uniform standards.

6.2. Medium-Terms Actions and Reforms with Efficiency Gains (2-5 Years)

Once extraction is under control, reform efforts should focus on reshaping incentives, improving efficiency, and grounding decisions in scientific evidence. This phase highlights pricing reform, agricultural demand management, and robust data systems to support sustainable governance.

6.2.1. Water Pricing Reform

Water pricing is a crucial policy tool for addressing inefficiencies, encouraging conservation, and enhancing the financial sustainability of water systems in Pakistan. However, current practices hinder these objectives. The *abiana* (irrigation water tariffs) are set significantly below the actual costs of water delivery, while electricity subsidies for tube wells promote excessive and unsustainable groundwater extraction—particularly in agriculture, where overuse is most severe. *"Although the 'abiana' rate has been revised in 2022-23 yet we need adequate water pricing for sustainability of water resources infrastructures"* says Dr. Javed Iqbal, Director Strategic Planning and Reform Unit, Government of Punjab (*Business Recorder*, 2023).

To resolve these issues, a regionally differentiated approach to water pricing is essential. In areas with abundant freshwater, *abiana* should be increased and linked to the farmers' canal locations to accurately reflect their volumetric access to water. In contrast, regions with saline groundwater should focus on investing in infrastructure to improve delivery efficiency and reduce losses, rather than merely raising tariffs.

Water pricing reform must take into account the varying water needs of different crops. Uniform pricing structures do not adequately reflect the significant differences in water requirements among crops such as rice, sugarcane, and cotton. This lack of differentiation can discourage the adoption of water-efficient and higher-value alternatives. To address this, provincial revenue boards should implement tiered pricing systems that align with canal deliveries and local aquifer conditions. This approach would create incentives for responsible water use and encourage better crop choices.

Irrigation departments should be allowed to retain collected revenues for reinvestment in system maintenance and service delivery. At the federal level, the government could advocate for politically sensitive reforms through performance-based transfers under the National Finance Commission (NFC), drawing inspiration from international models such as Morocco's decentralisation strategy.

Urban water tariffs encounter several challenges, including low rates, poor cost recovery, and weak incentives for conservation. Many household tariff rates have not been updated in years, and the efficiency of collections varies significantly, ranging from 20 percent to 80 percent across different cities. This inconsistency creates fiscal stress for utilities. On a national level, only 24 percent of the operating and maintenance costs for irrigation systems are recovered, and just 60 percent of billed water charges, known as abiana, are actually collected. As a result, infrastructure is deteriorating, and the irrigation system has become financially unsustainable (IMF, 2015).

Rationalising tariffs for both rural and urban sectors can promote more responsible water use and generate essential revenue. A pricing structure linked to income or consumption levels could help ensure affordability while improving equity. The revenue from these pricing reforms would be used to invest in necessary repairs, water-saving technologies, and programmes that promote access for low-income communities. Water expert Simi Kamal highlights that rehabilitating Pakistan's canal system alone could potentially release around 75 million acre-feet of water, which is equivalent to the entire annual flow of the Indus River (Kugelman, 2015).

Moreover, Pakistan should actively seek climate finance to support these reforms and enhance resilience. By submitting proposals to the Green Climate Fund (GCF), the Global Environment Facility (GEF), and other international financial institutions—following the successful examples of countries like Mexico and South Africa—Pakistan can secure funding for groundwater adaptation and sustainability initiatives.

Israel's success highlights the importance of strong political commitment, institutional autonomy, and evidence-based decision-making. Water experts were empowered to operate without political interference, which allowed for significant investments in desalination and wastewater reuse. As a result, Israel now recycles nearly 90 percent of its wastewater. The key takeaway is clear: accurately measure water usage, implement rational pricing, and provide targeted assistance where needed. This approach demonstrates that a combination of rational pricing, innovation, and governance reforms can effectively transform water scarcity into resilience.

6.2.2. Agricultural Demand Management and Irrigation Reform

Agriculture is the largest consumer of groundwater in Pakistan, but it faces inefficiencies and policy distortions that jeopardize the long-term sustainability of the country's water resources. Among the most pressing issues are subsidized electricity for tube wells and the widespread cultivation of water-intensive crops like sugarcane and rice, practices that are particularly harmful in already water-stressed regions.

Farmers' behaviour regarding groundwater extraction is primarily rational, influenced by distorted incentives that promote excessive extraction with low or no marginal costs. To effectively tackle agricultural groundwater depletion, it is essential to encourage behavioral change through reforms that align with these incentives, rather than implementing sudden or punitive restrictions. A key reform priority is to gradually remove electricity subsidies, replacing them with performance-based incentives that reward water productivity. This approach draws on successful experiences from countries like Israel and Morocco.

At the same time, the government needs to increase financial and technical support for efficient irrigation technologies, such as drip and sprinkler systems, especially in Punjab, where water use is excessive. According to Pervez Amir, former country director of the Pakistan Water Partnership, regulating uncontrolled groundwater extraction through designated protection zones and introducing water-saving technologies is essential for ensuring food and water security (Saeed, 2015).

Equally important is shifting cropping patterns to promote the cultivation of less water-intensive crops—such as pulses, oilseeds, and vegetables—based on localised assessments of groundwater availability, salinity, and recharge potential. Qureshi (2015) stresses the need for regionally differentiated groundwater management in the Indus Basin to prevent aquifer degradation and the mixing of fresh and saline water.

Moreover, international best practices, including community-based initiatives in Andhra Pradesh and policy reforms in Tunisia, provide valuable lessons for Pakistan's transition to sustainable agriculture.

Hassan Abbas, a hydrogeologist in Punjab, highlights that many farmers use up to ten times more water than necessary, which underscores the urgent need to reevaluate current practices. He advocates for a transformation that uses climate change as a catalyst to shift towards solar-powered irrigation, advanced technologies, and the restoration of wetlands and forests in the Indus Basin. These changes aim to improve groundwater recharge and enhance flood resilience (Novo, 2020).

6.2.3. Investing in Science, Monitoring, and Data Systems

To ensure the long-term sustainability of groundwater in Pakistan, a coordinated, data-driven strategy is essential, focusing on investment in research, monitoring, and predictive modeling. A key priority is the launch of a National Aquifer Mapping Programme, led by the Pakistan Council of Research in Water Resources (PCRWR), SUPARCO, and the Survey of Pakistan. This programme will utilize satellite imagery, field data, and hydrogeological surveys to generate reliable baseline information. *"We need to map all our underground water resources for future policies and utilisation instead of just hovering around the Indus basin"* , says Dr. Pervez Amir, former country director for the Pakistan Water Partnership (Saeed, 2016).

Pakistan currently has access to satellite-based remote sensing and global datasets, including initiatives supported by NASA, which could greatly improve groundwater assessment and monitoring. However, these resources are still underutilised. To maximise their potential, it is important to institutionalise their use through formal international partnerships and integrate them into national data platforms. Accurate aquifer mapping and real-time monitoring systems are essential for evidence-based groundwater governance. This will enable policy-makers to transition from reactive responses to proactive planning.

At the same time, it's crucial to develop real-time monitoring systems and a centralised, interoperable data platform. Such a platform would enhance transparency, create early warning systems, and support evidence-based decision-making across agriculture, urban planning, and disaster preparedness. Lessons can be learned from successful international examples, such as Spain, the Netherlands, and the EU's INSPIRE framework.

Given the current fragmentation and inconsistency of groundwater data across provinces, establishing an Interagency Working Group on Groundwater Security is necessary. This group would harmonize protocols, coordinate institutional efforts, and ensure public accessibility to information. Strengthening institutional capacity—through inter-agency collaboration, technical training, and community engagement—is equally important.

Additionally, regulatory frameworks, targeted incentives, and groundwater pricing reforms, particularly in agriculture, are vital for promoting more efficient and sustainable abstraction. By aligning scientific research, policy, and local knowledge, Pakistan can shift from a reactive approach to groundwater depletion to a proactive, resilient, and sustainable groundwater future.

6.3. Actions and Reforms for Long-term Impact (Beyond 5 Years)

Achieving long-term sustainability requires reforms that tackle deep-rooted legal, institutional, and regional challenges. These changes may be politically complex, but they are essential for enduring results.

6.3.1. Delinking Water Rights from Land Ownership

A significant obstacle to reform in Pakistan is its colonial legacy, which ties groundwater rights to land ownership. This connection grants landowners unrestricted rights over groundwater. Additionally, the electoral political system makes it difficult to implement reforms such as irrigation fees (abiana). Pakistan could learn from Australia, which restructured its water sector by separating water rights from land ownership. This change empowered farmer cooperatives to manage irrigation effectively and created a framework that prioritized domestic and environmental uses over agricultural and commercial ones. Water trading allowed users to buy and sell water rights. The Australian government assessed aquifer conditions and set limits on groundwater extraction and the installation of tube wells. By improving management systems, establishing institutions, and creating economic incentives through water markets, Pakistan can move towards a sustainable and equitable groundwater management system. This approach would facilitate effective regulation of groundwater extraction.

6.3.2. Integrated Water Resource Management and Recharge

Groundwater management in Pakistan needs to be fully integrated into basin-level planning using Integrated Water Resources Management (IWRM) approaches. This integration should align surface and groundwater usage based on the regional hydrological conditions.

Groundwater systems in Pakistan vary significantly across different regions. In Punjab and canal-command areas, aquifers are generally renewable due to recharge from rainfall and the canal system. In these areas, efforts should prioritize promoting recharge through methods such as check dams, recharge wells, and rainwater harvesting. Additionally, reducing canal seepage and improving conveyance efficiency are essential. Evidence from irrigation programmes in Punjab indicates that combining infrastructure upgrades with local recharge initiatives can greatly enhance the health of aquifers.

In contrast, much of Balochistan depends on non-renewable aquifers, where depletion is irreversible. As a result, uniform policies are not suitable for this region. Balochistan requires strict regulation, the revival of traditional systems like karez, and pricing controls to prevent irreversible loss of water resources. Furthermore, Managed Aquifer Recharge (MAR) projects utilising floodwater and treated wastewater should be prioritised in water-stressed provinces such as Khyber Pakhtunkhwa (KP) and Balochistan.

Urban areas offer valuable opportunities for groundwater recharge by requiring rainwater harvesting in public infrastructure, including schools, hospitals, and government buildings. Redesigning urban bylaws to promote vertical construction while discouraging urban sprawl can help protect forests, green spaces, and soil, which contributes to groundwater recharge. This approach has been shown to be cost-effective and scalable in regions such as Tamil Nadu and Mexico City.

"The rainwater storage solutions like artificial lakes at housing societies or artificial recharge wells would help manage rainwater", says Dr. Muhammad Ashraf, Chairman of the Pakistan Council of Research in Water Resources (PCRWR) (*Express Tribune*, 2022).

In canal command areas, pilot projects on conjunctive management—coordinating the use of surface and groundwater—should be launched, taking inspiration from successful models in Gujarat.

However, the widespread adoption of these measures will require legal reforms, incentives for farmers, and sustained public investment to ensure equitable and sustainable groundwater recharge across various agro-ecological zones.

6.3.3. Building Human Capital and Public Awareness

The future of groundwater management in Pakistan depends on having a workforce that is knowledgeable and empowered. But there is now a severe lack of experts in the fields of hydrogeology, groundwater modeling, geospatial analysis, and community involvement in the nation. A national human capital development programme that promotes collaborations between academic institutions, technical institutes, governmental organisations, and the commercial sector must be started in order to close this gap. In order to give professionals the skills they need for efficient groundwater governance, this initiative should involve modernising curricula, increasing vocational training, and encouraging applied research.

A National Groundwater Fellowship Programme should be created concurrently to assist aspiring engineers, scientists, and planners, taking inspiration from the Water Research Commission in South Africa. Building grassroots capacity, which entails giving farmers, local governments, and community-based groups the tools they need to take part in governance and responsible water stewardship, is equally crucial.

Sustainable water management should involve working in harmony with nature rather than in opposition to it. Prioritising localised, nature-based solutions—such as rainwater harvesting, groundwater recharge, improved drainage, and watershed management—is essential. These strategies are cost-effective, scalable, and resilient to environmental changes. Community participation is crucial; without local ownership, solutions imposed from the outside often fail. By combining traditional knowledge with modern practices, Pakistan can enhance its resilience while also protecting ecosystems.

To guarantee that future generations comprehend the importance and fragility of this essential resource, groundwater literacy must also be incorporated into school and college curricula. Following successful models like Ethiopia's "My Water, My Life" campaign, widespread public awareness campaigns in local languages should be carried out via radio, television, and mobile platforms to support these initiatives.

When combined, these investments will create the institutional, sociological, and technological framework required for Pakistan's groundwater management to be sustainable.

6.3.4. Transboundary Groundwater Governance

Pakistan's transboundary groundwater resources are shared with neighboring countries of India and Afghanistan but are largely unregulated, understudied, and excluded from formal water agreements.

The Indus Water Treaty (IWT) is recognised as a successful agreement for cooperation on shared water resources between India and Pakistan. However, it does not adequately address the impacts of climate change on groundwater and water pollution, nor does it propose effective monitoring and surveillance mechanisms. Abandoning the IWT in search of a new, more comprehensive framework is not a viable solution. Instead, both countries need to reaffirm their commitment to the letter and spirit of the IWT as a necessary first step. Additionally, it is essential to enhance the role of institutions like the Permanent Indus Water Commission in resolving issues related to water quality monitoring, the effects of climate change, and improved watershed management. Pakistan can learn from the Guarani Aquifer Agreement in South America. To better understand and manage the aquifers near the western border, the nation should also work with Afghanistan to perform cooperative groundwater evaluations.

Groundwater can also be discussed diplomatically and included in environmental accords through regional organisations like SAARC and ECO. Equitable and collaborative transboundary water management can also be emphasised through international legal tools, including the UN Watercourses Convention and SDG target 6.5.

A coordinated regional-level solution has the potential to transform the fate of the region by turning climate change from a challenge into an opportunity, ensuring that the growth process is both inclusive and sustainable. Given that climate change will impact water availability and increase transboundary water issues across the region, it is essential to move beyond bilateral solutions and develop regional strategies for the optimal use of available water resources.

A regional institution dedicated to managing shared water resources should establish mechanisms and processes for:

- Exchanging data and information;
- Facilitating more robust water-sharing treaties, particularly in light of hydrological variability and climate change; and
- Addressing pollution issues and promoting better flood management.

These efforts will help South Asia in achieving holistic river basin management, transforming water from a source of conflict into one of cooperation. This approach will involve all stakeholders in the Indus and Ganges-Brahmaputra-Meghna basins, including Afghanistan and China. Notably, China is the largest source of transboundary river flows into much of South Asia, and its plans to harness the vast water resources of the Tibetan region are crucial to the hydro-politics of the area. See Maqbool (2023) for more details.

Conclusion: This framework presents Pakistan’s groundwater issue as a problem of order, motivation, and authority instead of just a lack of technical knowledge. The analysis shows that small or separate reforms will not stop depletion unless key distortions are fixed in the right sequence. Without universal licensing and metering, the state cannot manage what it cannot measure, and over-extraction of groundwater will continue. If electricity subsidies and water pricing are not reformed, agricultural demand will keep exceeding aquifer recharge, no matter how efficient or advanced the infrastructure is. Without reorganising disconnected institutions and clarifying groundwater rights, long-term investments in recharge, data systems, and climate resilience will yield limited benefits. The main policy takeaway is clear: groundwater sustainability in Pakistan will remain out of reach unless political support is first gained for controlling extraction, then for reshaping incentives, and finally for implementing structural and institutional changes.

7. CONCLUSION

Pakistan's groundwater crisis is not inevitable—it is the product of policy distortions, weak regulation, and fragmented institutions. Aquifers remain a vast but mismanaged resource, capable of buffering climate variability and sustaining agriculture if governed properly.

The evidence presented shows that:

- Unregulated extraction has pushed withdrawals beyond recharge, creating a growing deficit.
- Subsidies and crop incentives drive inefficient water use, locking farmers into unsustainable practices.
- Institutional fragmentation leaves no authority accountable for aquifer sustainability.
- Climate change magnifies vulnerabilities, disrupting recharge cycles and intensifying stress.

To move from depletion to resilience, reforms must be sequenced and prioritised:

- Immediate (0–2 years): Universal licensing and metering, phasing out distortionary subsidies, and establishing a National Groundwater Council.
- Medium term (2–5 years): Water pricing reform, crop policy alignment, irrigation efficiency, and investment in monitoring and data systems.
- Long term (5+ years): Institutional restructuring, delinking water rights from land ownership, recharge infrastructure, and transboundary cooperation.

This paper demonstrates that Pakistan's groundwater crisis is fundamentally a governance challenge. Addressing it demands political will, institutional clarity, and policy coherence. Only then can Pakistan safeguard its aquifers, secure its food systems, and build resilience against climate change.

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