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Pakistan

Getting More from Water

William J. Young, Arif Anwar, Tousif Bhatti, Edoardo Borgomeo, Stephen Davies, William R. Garthwaite III, E. Michael Gilmont, Christina Leb, Lucy Lytton, Ian Makin, and Basharat Saeed

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Foreword

Water security is an important and growing challenge for Pakistan, and one that extends far beyond the traditional water sector. It influences diverse aspects of economic and social development, as well as national and regional security. This study takes a long-term view of water security—out to 2047 when Pakistan turns 100. The work has been closely coordinated with the World Bank's broader economic policy work for Pakistan@100. This work thus contributes not only to the important water sector dialogue but also to the broader conversation on Pakistan's economic and social development.

The 4,000-year-old Indus civilization has its roots in irrigated agriculture. Pakistan still relies heavily on the Indus River for water supply to all sectors of the economy as well as for energy generation. Water for irrigation across the semi-arid Indus floodplains, which underpins national food security, is the dominant use. Nonetheless, for many Pakistanis the foremost water security concern is that of inadequate domestic water supply and sanitation services, which uses a very small share of the available water.

Pakistan is home to nearly 210 million people—a near seven-fold increase since the formation of the country in 1947. In 1960, after almost a decade of negotiations, the Indus Waters Treaty formalized a partitioning of the Indus Basin water resources between Pakistan and India and defined the basic water resource envelope for Pakistan. Although blessed with a large water endowment, and with extensive glacier storage that buffers supply variations, the huge increase in population means Pakistan is now challenged by relative (per person) water scarcity, and both the population and water demands are projected to grow for several decades. The challenge of balancing supply and demand will be exacerbated by climate change, which will increase the variability in supply and, because of higher temperatures, will push water demands even higher. These challenges are further vexed by widespread pollution that is degrading the resource base and undermining both public and environmental health.

Pakistan cannot continue business as usual (BAU) water management. How Pakistan tackles these challenges, and the speed at which is does so, will have a major influence on the country's rate of economic development and the quality of life for her people. While there are major infrastructure and financing challenges to surmount, the fundamental challenges are ones of governance, in irrigation and urban water supply, at federal, provincial, and local levels. The World Bank stands ready to support Pakistan—in partnerships with governments, civil society, the private sector, and regional and international organizations—to improve all facets of water security.

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Abbreviations

ADB	Asian Development Bank
ADP	Annual Development Program
AEDB	Alternative Energy Development Board
AWB	area water board
AWS	automatic weather stations
BAU	business as usual
CGE	computable general equilibrium
CPEC	China–Pakistan Economic Corridor
DPR	delivery performance ratio
EPA	environmental protection agency
FATA	Federally Administered Tribal Areas
FEWS	flood early warning system
FFC	Federal Flood Commission
GAMS	General Algebraic Model System
GDP	gross domestic product
GLOF	glacial lake outburst floods
GoP	Government of Pakistan
HEC	Higher Education Commission
HEP	hydroelectric power
IBIS	Indus Basin Irrigation System
IBMR	Indus Basin Model Revised
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
IRSA	Indus River System Authority
IRSM	Indus River System Model
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
KMC	Karachi Metropolitan Corporation
KP	Khyber Pakhtunkhwa
KWSB	Karachi Water and Sewerage Board
LEP	lower export price
LGD	local government department
LIC	low-income country
MIC	middle-income country
MOWP	Ministry of Water and Power
NDMA	National Disaster Management Authority
NGO	nongovernmental organization
NPV	net present value
NWP	National Water Policy
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
PAMRA	Punjab Agricultural Marketing Regulatory Authority
PCIW	Pakistan Commissioner for Indus Waters

PCRWR	Pakistan Council of Research in Water Resources
PDMA	provincial disaster management authority
PHED	public health engineering department
PID	provincial irrigation department
PIDA	provincial irrigation and drainage authority
PMD	Pakistan Meteorological Department
PPP	public-private partnership
PSDP	Public-Sector Development Program
RUMI	reaching upper-middle-income
RWSM	Regional Water System Model
SAM	Social Accounting Matrix
SCARP	Salinity Control and Reclamation Projects
SRI	System of Rice Intensification
SUPARCO	Pakistan Space and Upper Atmosphere Research Commission
WAA	Water Apportionment Accord
WAPDA	Water and Power Development Authority
WASA	water and sanitation agency
WMO	World Meteorological Organization
WSTF	Water Sector Task Force
WUA	water user association

Executive Summary

Is Pakistan 'Water Secure'?

Water security describes the social, economic, and environmental outcomes—beneficial and detrimental—from how water is managed and used. Assessing these outcomes indicates that Pakistan is not water secure. Pakistan is well endowed with water—only 16 countries have more water—but because Pakistan is the world's sixth most populous country, water availability per person is comparatively low. Fewer than 10 percent of the global population lives in countries with less water per person. Water scarcity is challenging but does not define a country's economic destiny. There are 32 countries with less water per person than Pakistan; across these countries the average per capita gross domestic product (GDP) is 10 times that of Pakistan. Only six of these 32 water scarce countries are poorer than Pakistan—all African nations with little irrigation investment and a heavy reliance on traditional rainfed agriculture.

Pakistan does not make the best use of its water endowment. Water use is heavily dominated by agriculture, which contributes around one-fifth of national GDP, but less than half of this is from irrigated cropping. Irrigation contributes around US$22 billion to annual GDP. The four major crops (wheat, rice, sugarcane, and cotton) that represent nearly 80 percent of all water use generate less than 5 percent of GDP—around US$14 billion per year. Other economic contributions from water are difficult to accurately assess, but hydropower generation is economically significant, with a current market value of US$1 billion to US$2 billion.

The economic costs to Pakistan from poor water and sanitation, floods, and droughts are conservatively estimated to be 4 percent of GDP, or around US$12 billion per year. These costs are dominated by the costs of poor water supply and sanitation. The economic costs of degradation of the Indus Delta are estimated to be around US$2 billion per year, while the costs of pollution and other environmental degradation have not been assessed. These estimates of economic benefits and costs cannot be directly compared or aggregated, but they demonstrate that Pakistan gets a poor economic return from its significant water resource.

However, for many Pakistanis, poor social outcomes from water best characterize water insecurity. Water-borne diseases are a leading cause of suffering and death in Pakistan, reflecting widespread contamination of water supplies by sewage effluent. Poor water supply, sanitation, and hygiene contribute to high levels of childhood stunting, undermining human capital. Women and children are the most vulnerable, especially in rural areas where sanitation is particularly inadequate, and most water supplies are contaminated.

Up to a quarter of the population may be at risk from arsenic contamination of drinking water. Floods and droughts also have significant social impacts, again affecting women and children the most.

Scant attention is paid to the environmental outcomes from water in Pakistan, and water-dependent ecosystems—rivers, lakes, wetlands, and the Indus Delta—are in rapid decline. This decline is characterized by biodiversity loss, greatly reduced stocks of freshwater and estuarine fish stocks, and a loss of other ecosystem services, including the storm protection afforded by coastal mangrove forests. Excessive water withdrawals and widespread pollution are the main causes of decline, but river fragmentation by infrastructure and changed sediment regimes contribute.

What Undermines Water Security in Pakistan?

Water security in Pakistan is undermined by poor water resource management and poor water service delivery—including irrigation and drainage services—and domestic water supply and sanitation services. In addition, some growing, long-term water-related risks are not adequately recognized and are poorly mitigated.

Water resource management is compromised by (i) poor water data, information, and analysis; (ii) weak processes for water resources planning and allocation; (iii) environmentally unsustainable levels of water withdrawal; (iv) widespread pollution; and (v) low water productivity in agriculture. Inadequate monitoring and data management prevent robust water resource assessments and accounting to guide water planning and management and prevents reliable flood and drought forecasting. Water resources planning has historically focused on supply augmentation and has not addressed sustainable resource use or been linked adequately to broader economic planning. Although provincial water shares have been formally defined, they have been demonstrated to be economically suboptimal, and there is insufficient clarity on risk sharing during times of acute scarcity. These deficiencies are expected to become starker with increasing water demands and climate change. Water resources management in Pakistan does little to protect water-dependent ecosystems either by way of environmental flows or pollution control.

No formal mechanisms exist within provinces for reallocating water between sectors to match shifting demands or to cope with extreme drought. Irrigation water allocation is suboptimal in terms of efficiency, equity, and transparency, contributing to the low productivity of irrigated agriculture and causing a lack of trust between farmers and service providers. Improvements in water productivity in agriculture in recent decades have been achieved through increased fertilizer use, additional labor, and a huge increase in groundwater pumping. But there has been little improvement in water use efficiency and very little intensification or transition toward higher-value crops. Agricultural water productivity lags well behind that of most other countries.

Irrigation service delivery is poor and contributes to low productivity. Hydraulic efficiency of water distribution is very low, and water delivery across command areas is inequitable. Irrigation services are not financially sustainable and financial performance is declining. Service tariffs are set too low and are decoupled from service quality, and the operational costs of service providers are far too high. Poor operational performance in irrigation continues to exacerbate waterlogging and salinization, especially in Sindh. Despite large-scale reclamation efforts, high water withdrawals and poor drainage mean salt continues to accumulate in soils and groundwater in the lower Indus Basin, affecting agricultural productivity.

Domestic water supply coverage is high—especially for urban households, but coverage is declining because of rapid urbanization. And although coverage is high, the quality of supply services is poor—especially in terms of water quality and reliability. Sanitation services are variable: open defecation is increasingly uncommon even in rural areas, but collection, treatment, and disposal of sewage effluent are all grossly inadequate. Most water supplies are therefore contaminated.

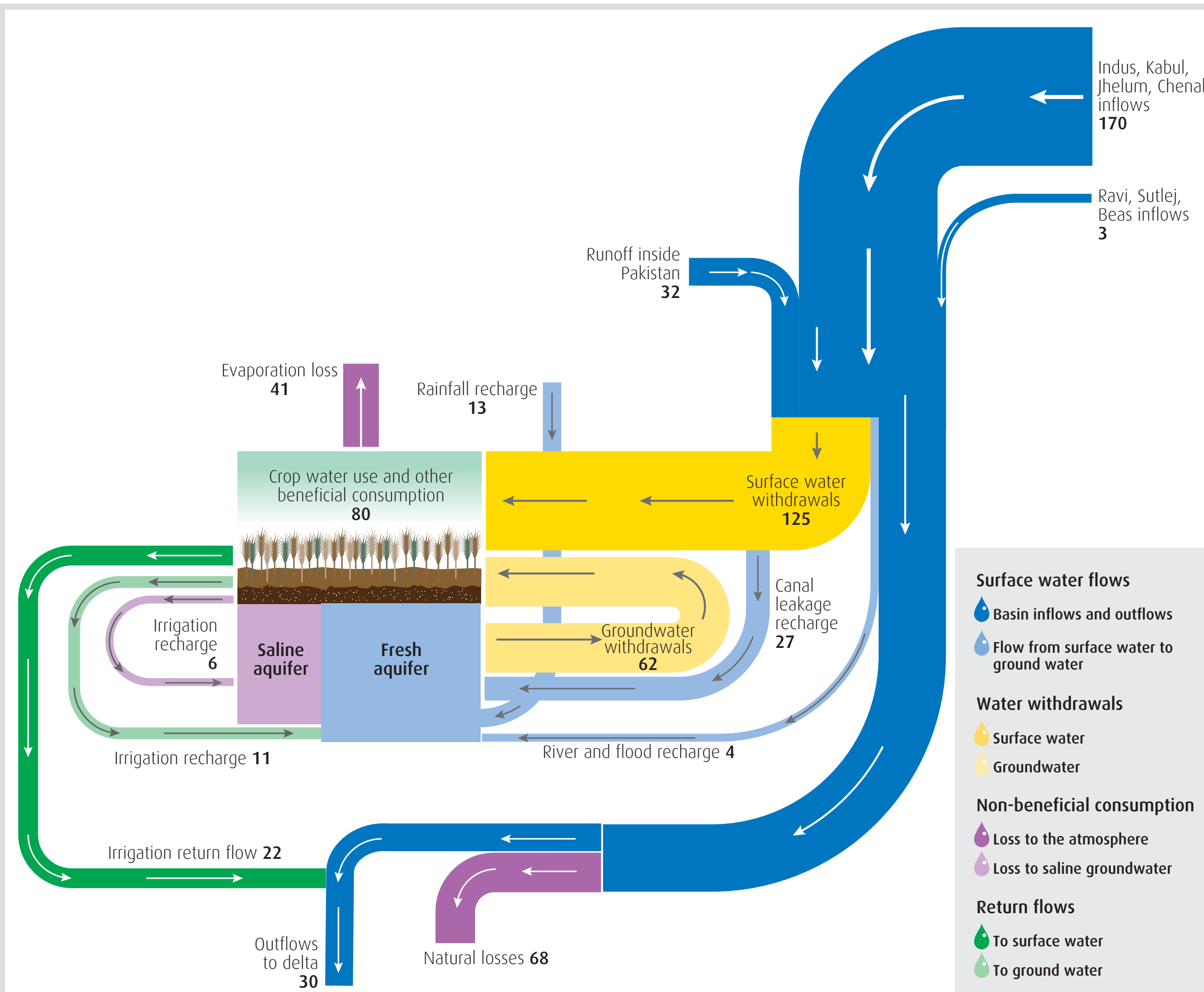
Climate change is the biggest longer-term and currently unmitigated external risk to Pakistan's water sector. Climate change is not expected to greatly alter average water availability over coming decades, but inflows will become more variable between and within years, increasing the severity of floods and droughts. Climate warming is expected to drive water demands up by 5 percent to 15 percent by 2047, in addition to the demand increases from population and economic growth. In the upper Indus Basin, accelerated glacial melting will increase the risks of dangerous glacial lake outburst floods. In the lower Indus Basin, sea level rise and increases in the frequency and severity of coastal storms will exacerbate seawater intrusion into the delta and into coastal groundwater. In coastal Sindh, this will further degrade groundwater quality, groundwater-dependent ecosystems, and irrigation productivity. A second overlooked risk is change in basin-scale river sediment dynamics. Sediment dynamics in the Indus—sourcing, transport, and deposition—have been significantly altered by water resources development. Without greater attention, these changes will increasingly threaten the safety and operational performance of water infrastructure—and the health of river and delta ecosystems.

How Well Are Water Resources Understood?

Some of Pakistan's water resources are well qualified, while others are poorly assessed or simply overlooked in most resource assessments. The surface water inflows to Pakistan from the Indus and its tributaries are measured sufficiently well to give high confidence to average annual flows (see figure ES.1). However, runoff generated within Pakistan—including in Balochistan outside the Indus Basin—is not well measured and is often ignored in resource assessments. Groundwater has usually been quantified in terms of withdrawals, but this leads to a significant double counting in resource estimates: much of the groundwater is simply surface water withdrawals that seep from canals, distributaries, and fields into the aquifers. A careful assessment of all water resources, drawing on a range of data and past studies, suggests that Pakistan's current total average annual renewable resource is 229 billion cubic meters (BCM). Only 4 percent of this is outside of the Indus Basin.

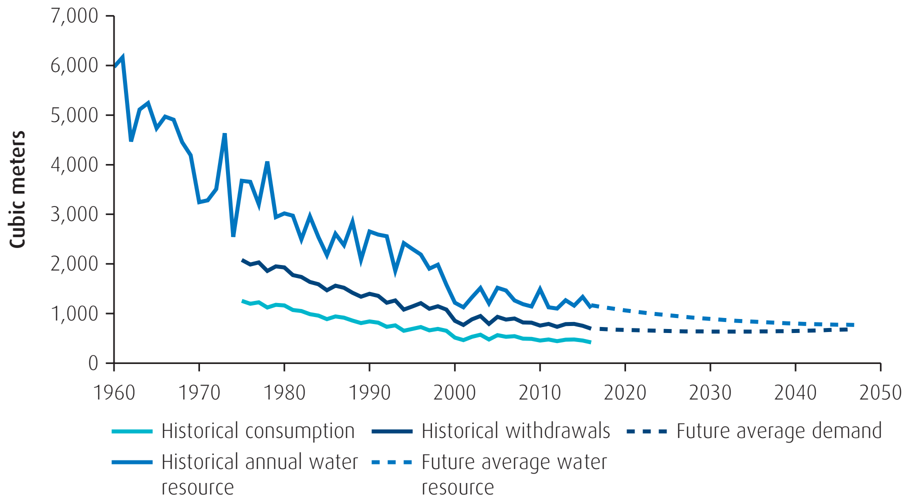
Water availability per capita varies between years because of climate fluctuations, but in recent decades has declined because of population growth (see figure ES.2). There has also been a small but important reduction in inflow from the eastern tributaries of the Indus because of development in India, which is permitted under the Indus Waters Treaty. Currently, average water availability is estimated to be around 1,100 cubic meters per capita, considering all renewable water resources. Withdrawals per capita have declined with rising population, while actual consumption has remained a fairly constant proportion of withdrawals, given little improvement in water use efficiency. Water demand is projected to rise, driven mostly by economic

Figure ES.1 Indus Basin Average Annual Water Balance



Sources: Ahmad and Rashida 2001; FAO 2011; Karimi et al. 2013; Laghari, Vanham, and Rauch 2012; MacDonald et al. 2016; van Steenbergen and Gohar 2005. Details are in appendix A, table A.1.
Note: Flows are in billion cubic meters.

Figure ES.2 Historical Water Availability, Withdrawals and Consumption per Capita; and Projected per Capita Availability and Demand



Sources: WAPDA unpublished data and author calculations.

and population growth, but also by climate warming. Demand management will be critical to stay within the available resource envelope, as will efficiency improvements that can allow consumption to increase. The converging supply and demand projections highlight a key aspect of the water security challenge for Pakistan.

Water withdrawal in Pakistan—as a fraction of the available resource—is high compared to that of most other countries. However, adjusting for the double counting of surface and groundwater withdrawals reveals that water stress is less extreme than commonly quoted, although the stress on water ecosystems is still high. Severe groundwater depletion is evident in Lahore, Quetta, and parts of southern Punjab. But depletion is a very small fraction of the overall groundwater balance, and in any case, it follows decades of water-level rise caused by excessive irrigation. Waterlogging remains a bigger problem, especially in Sindh, yet the greatest threat to long-term groundwater sustainability is contamination—both salinization and other pollutants.

What Interventions Can Improve Water Security in Pakistan?

There is no single simple solution to address water security in Pakistan. It will take concerted effort on many fronts by all governments and water users over many years. Large infrastructure gaps must be addressed, which require significant financial resources. Provincial-level water sector financing has increased in recent years, but federal financing has declined significantly in proportional terms. Collectively, sector financing is well below recommended levels. This is the case for major infrastructure, reforms, and institutional strengthening; urban services; flood mitigation; and environmental management.

The biggest challenges, however, are ones of governance, especially regarding irrigation and urban water. The governance challenges relate to inadequate legal frameworks for water at federal and provincial levels, and the incompleteness of policy frameworks and the inadequacy of policy implementation. The policy deficiencies stem from institutional problems including unclear, incomplete, or overlapping institutional mandates, and a lack of capacity in water institutions at all levels. Behind these multiple challenges in the formal governance arrangements are deeply embedded vested interests in the status quo that have proved resistant to reform.

The most important infrastructure gaps are associated with water supply and sanitation services and irrigation and drainage services. Wastewater treatment infrastructure is woefully inadequate for both urban and rural communities. Treatment capacity is inadequate, and existing infrastructure is poorly maintained and operated. Sewerage network coverage is very limited, and the current partial network is poorly maintained. Water distribution networks are often similarly inadequate. Many rural areas lack both public water and sanitation infrastructure. While irrigation infrastructure is very extensive following more than a century of incremental investment, the distribution network is outdated and poorly maintained. Despite considerable investment in drainage infrastructure, waterlogging continues to worsen. Modernization of irrigation and drainage infrastructure is required on a massive scale, including upgrading flow control structures and installing real-time data acquisition systems for improved operations.

Pakistan needs continued investment in flood protection infrastructure. The country has made moderate progress in flood mitigation, given the significant damage and disruptions from floods over the last 50 years; however, climate change will increase the risk of flood damage, meaning greater investment is required. Flood infrastructure should be complemented with "soft" measures such as floodplain zoning, improved flood forecasting, and early warnings.

Large storage reservoirs can help improve some aspects of water security but do not address the most pressing water security issues. New reservoirs would deliver relatively modest additional yield, and the water supply benefits would not justify the significant financial costs. It is only the benefits from hydropower—either from storage or run-of-river facilities—that justify new dams in economic terms. New reservoirs will help mitigate floods and seasonal flow variations, both of which are expected to increase with climate change. Additional storage upstream of Tarbela Dam will help to slow its incremental loss of live storage caused by rapid sedimentation.

The legal frameworks for water management need to be far more comprehensive. Out of 48 legal elements identified as important for sound water resources management, only 16 to 19 are in the legal frameworks among the provinces. The 2018 National Water Policy provides strong support for improving water resource management, echoing other policy documents (e.g., the National Climate Change Policy). However, significant policy work is required at the provincial level, because policy frameworks for irrigation and water resources management are partial, fragmented, or nonexistent, and implementation has been inadequate. Provincial policy frameworks for urban water services should be clarified and aligned with relevant legislation, including that of local government. Institutional responsibilities for several aspects of water resource management need to be better delineated both national and provincial levels and between entities at these levels. The institutional responsibilities for urban water need to be clarified and overlaps resolved.

Is Water Scarcity a Constraint to Reaching Upper-Middle-Income Status by 2047?

Because of sustained and rapid population growth, relative water availability has shrunk to less than a quarter of what of it was half a century ago. Municipal and industrial water demands are increasing, and environmental water allocations need to be agreed and implemented. attention. Economic modeling suggests however, that despite projected population increase and climate change, water scarcity will not prevent Pakistan from reaching upper-middle-income status by 2047.

Although population growth is slowing, projections suggest Pakistan's population will exceed 300 million by 2047, driving water demands much higher. Without serious demand management and reform, and if the climate warms rapidly, water demand could increase by nearly 60 percent by 2047. This would exceed water availability, even if no environmental limits were placed on withdrawals. The largest increases in demand will be for irrigation. Population and economic growth are the main drivers, but climate warming will contribute significantly. The fastest rates of demand growth will be for domestic and industrial supply. These changes require a major focus on demand management to improve water use efficiency and water productivity.

For many years, adequate water availability and modest urban demands have resulted in little urgency and few incentives to improve water use efficiency or to seriously tackle demand management. Food production increased to keep pace with population growth, although food security was compromised by problems of affordability, access, and dietary diversity. Water planning and investment was dominated by large supply-side projects that did not improve water productivity.

Water resource constraints mean a far stronger focus on demand management is required. Water losses must be reduced, and water productivity growth must be accelerated. It is commonly believed that Pakistan has inadequate water storage, and that new reservoirs will dramatically enhance water supply. Planned new reservoirs will provide limited additional supply—and of lower reliability. Reservoirs buffer inflow variations to stabilize supply. Existing reservoirs adequately buffer inflow variations between years, although supply shortfalls in Rabi are common. New reservoirs would improve the reliability of Rabi supply. But given the severe environmental degradation of the lower river and delta, partly caused by high water withdrawals, any increase in withdrawals, especially in drier years, must be carefully assessed in terms of additional environmental degradation.

Changes in water allocation and use will be critical to driving economic growth. First, demand growth and changing demand patterns mean that meeting the increasing and higher-value water demands outside of agriculture, will, within a few decades, limit the growth in agricultural consumption of water. Until then, water consumption in agriculture can increase without increasing water withdrawals. This will require reforms and investments that dramatically reduce water losses. Second, water will need to be secured and managed to protect water-related environmental services and benefits, especially those associated with the Indus Delta. With additional storage this may be possible without reducing withdrawals but confirming this requires more detailed modeling. Third, the use of water for irrigation needs to be dramatically improved. To ensure continued food security and to contribute to accelerated economic growth, the productivity of water in agriculture must be greatly increased. Reforming distorting agricultural policies that support wheat and sugarcane will help move water toward higher-value crops.

Changes in diet—already apparent as incomes rise—will further change patterns of food demand. If production of low-value cereals declines in response to falling demand, more water may shift to growing cotton for export. Cotton—and the associated textile industry—generate considerable export income for Pakistan, and should remain economically attractive over the long term, especially if greater value-addition postharvest is achieved. These benefits can only accrue, however, if major reductions in water losses can be achieved.

Assuming optimistic rates of economic growth, modeling suggests Pakistan can reach upper-middle-income status (GDP of US$6,000 per capita) by 2047, ensure adequate food supply, improve environmental sustainability, and deliver better municipal and industrial water security, even in the context of a rapidly warming climate. However, this will not be easy, and will require action on many fronts.

Conversely, without major reforms, Pakistan would see only minor improvements in water productivity and continued slow economic growth to reach only US$2,200 GDP per capita by 2047. Urban water security would likely decline, and environmental degradation would worsen. A lack of resilience, especially to increasing drought severity, could lead increased conflict over water between provinces and sectors.

Twelve Recommendations for Improving Water Security

Twelve high-level recommendations emerge from the analysis in this report: six for improved water resource management, three for improved service delivery, and three for improved risk mitigation (see table ES.1). These address the major areas of poor sector performance and would ensure water security is not a constraint to Pakistan's economic development ambitions. The recommendations are qualitatively assessed in terms of complexity, urgency, and scale of water security impact (bubble size) (see figure ES.3). For each recommendation, more actions are provided for reforming water governance (laws, policies, and institutions) and infrastructure investments.

Table ES.1 Twelve Recommendations for Improving Water Security in Pakistan, Indicating the Required Legal, Policy, and Institutional Reforms and Necessary Infrastructure Investments

Legal reforms | Policy reforms | Institutional reforms | Infrastructure investments

Water Resources Management
Strengthen Water Data, Information, Mapping, Modeling, and Forecasting
Clarify federal legal mandates for water information collation and sharing.
Strengthen provincial legal frameworks for land-use planning that consider flood risks.
Establish an implementation framework for the National Water Policy, with clear roles and responsibilities for water data and information.
Develop standards and guidelines for flood risk mapping and a policy framework for floodplain zoning.
Strengthen federal capacity for water data management, modeling, and forecasting, including the use of Earth Observations.
Strengthen provincial capacity for monitoring and reporting water distribution and use.
Strengthen federal capacity for flood risk mapping and flood forecasting.
Build provincial capacity for floodplain zoning.
Expand national and provincial hydromet networks, including for cryosphere and groundwater monitoring.
Establish interoperable national and provincial water information systems.
Establish a Multistakeholder Process of Basin-Scale Water Resources Planning
Establish a sound legal mandate for federally led cooperative basin planning.
Strengthen provincial legal frameworks for water resource planning.
Establish an implementation framework for the National Water Policy that articulates roles, responsibilities, time frames, and processes for basin planning.
Establish a National Water Council, as proposed in the National Water Policy, to provide strategic framing for cross-jurisdictional basin planning.
Strengthen the federal government capacity for river basin management (either within the Indus River System Authority (IRSA), the Pakistan Water and Power Development Authority (WAPDA), or by establishing a new authority), in cooperation with provincial governments.
Establish consultative processes for effective and broad stakeholder input.
Establish Provincial Water Planning and Intersectoral Water Allocation Mechanisms
Establish clear legal property rights (licenses) for water—separate from land—and the legal requirement to maintain public register of water licenses.
Develop and implement provincial water policies to establish sectoral priorities and to define allocation processes.

table continues next page

Table ES.1 continued

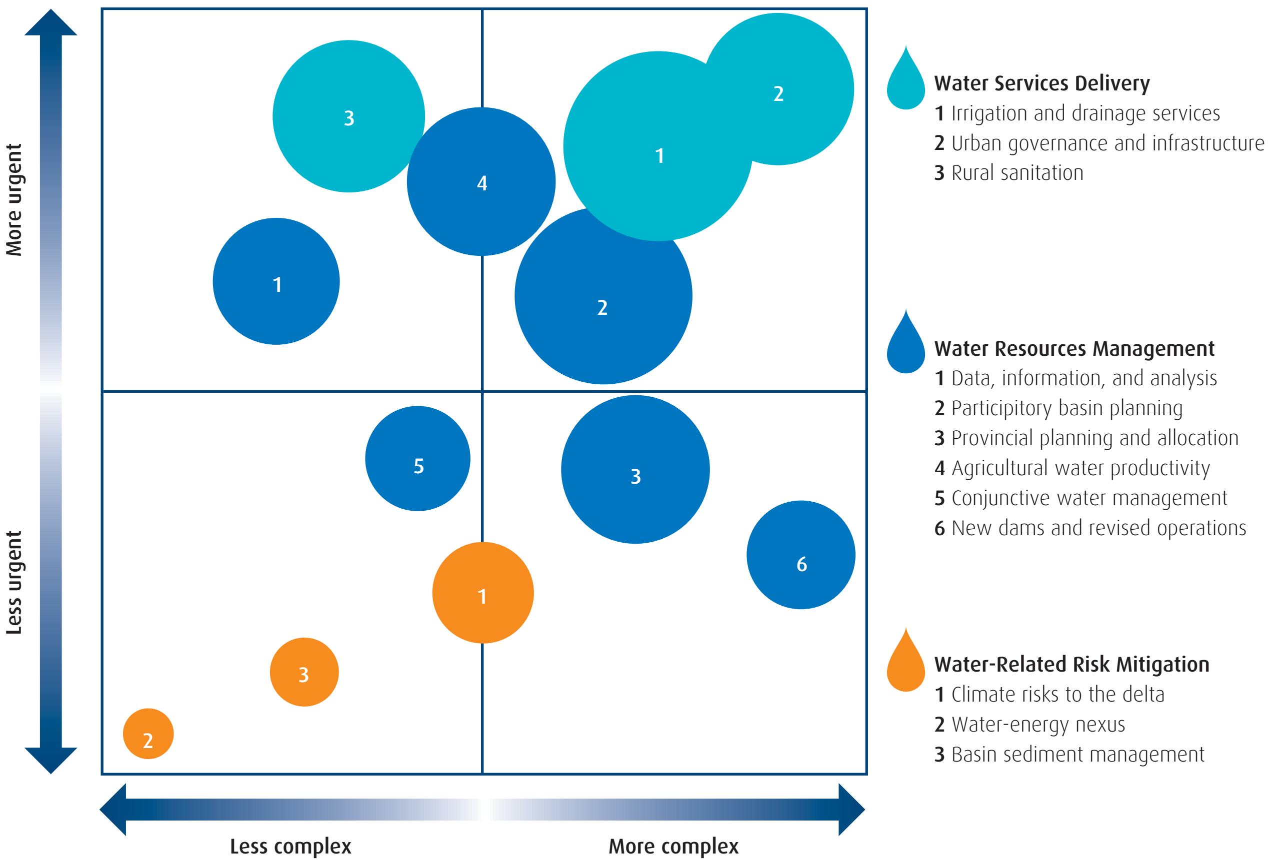
Incrementally transform provincial irrigation departments into water resources management agencies with broad responsibilities, including environmental management.
Establish robust participatory processes to guide water allocation planning.
Accelerate Agricultural Water Productivity Increases
Scope legal provisions to support pricing and trading of water rights.
Phase out subsidies for wheat and sugarcane.
Liberalize agricultural commodity markets.
Support adoption of water efficiency technologies and diversification to higher-value crops.
Strengthen capacity for economic modeling within federal and provincial governments.
Improve on-farm water management through farmer training and awareness raising.
Introduce methods of rice cultivation that require less water.
Increase investment in agricultural research.
Adopt Conjunctive Planning and Management of Surface and Groundwater
Establish provincial-level regulatory frameworks for groundwater access and for management and regulation.
Develop district-level conjunctive water management plans that focus on building drought resilience.
Strengthen the capacity of provincial water resource management departments for groundwater management and conjunctive planning.
Strengthen water user associations for local monitoring and management of groundwater resources in line with agreed conjunctive water management plans.
Build federal capacity for basin-scale modeling and analysis of surface–groundwater interactions.
Construct Limited New Storage and Review Reservoir Operations
Review and revise reservoir standard operating procedures, based on detailed modeling and analysis.
Strengthen federal capacity to enable periodic reviews of operating procedures and to support a multiobjective approach to operations.
Secure finance for construction of Diamer Bhasha Dam and associated power generation and distribution infrastructure (if HEP justifies the expense).
Water Services Delivery
Modernize Irrigation and Drainage and Improve Operations
Revise the Provincial Irrigation and Drainage Authorities Act to clarify roles and responsibilities in irrigation management between irrigation and drainage authorities and provincial government departments.
Replace *warabandi* with new water sharing rules based on economic efficiency and farmer equity.
Reform irrigation tariffs to reflect realistic operations and maintenance (O&M) costs.
Strengthen the capacity with provincial government water resources management departments to oversee irrigation and drainage authorities and performance of water user associations and farmer organizations.
Strengthen water user associations for improved system operation and improved *abiana* collection.
Reform governance of water user associations and farmer organizations to prevent elite capture.
Modernize irrigation systems, including new hydraulic control structures and lining of canals in waterlogged and saline areas.
Automate control of hydraulic structures using real-time data acquisition systems.
Systematically improve drainage infrastructure.
Reform Urban Water Governance and Close the Infrastructure Gap
Establish legal mandate for regulatory oversight of urban water service provider performance.
Strengthen the regulatory framework for pollution discharges.
Rationalize overlaps in the provincial policy frameworks and align with local government legislation.
Develop and disseminate standards for urban water service delivery, and link service tariff increases to service quality.
Strengthen and empower urban water service providers.
Establish independent regulator to oversee service provider performance and to help reduce political interference.
Establish an enabling environment for increasing private sector participation in urban water sector.
Greatly increase the capacity and performance of wastewater treatment.
Improve O&M of existing major distribution infrastructure.
Increase the coverage and reliability of urban water meters.
Improve Rural Sanitation
Establish clear legal mandate for the provision of rural sanitation services.
Establish provincial standards and targets for rural sanitation services.
Strengthen the capacity and increase the financing of provincial government departments responsible for rural sanitation.
Establish appropriate district-level institutional arrangements to engage with communities in infrastructure improvement.
Establish appropriate mechanisms to ensure sustainable revenue base for O&M costs.
Monitor and report progress toward rural sanitation targets.
Invest in public infrastructure for rural sanitation services including wastewater collection and basic treatment and disposal at village level.

table continues next page

Table ES.1 continued

Water-Related Risk Mitigation
Improve Understanding and Management of Climate Risks to the Lower Indus and Delta
Develop long-term plans for sustainable management of the Indus Delta.
Strengthen the technical capacity of water and environmental management agencies in Sindh for climate change impact assessments and mitigation planning.
Resource relevant agencies for effective implementation of management plans.
Assess the feasibility of barrier groundwater wells to slow sea water intrusion.
Strengthen Planning and Management of Water-Energy Interactions
Establish provincial-level regulatory frameworks for groundwater access and management.
Analyze the synergies and antagonisms between current national energy and water policy frameworks to inform policy implementation.
Increase coordination between government departments at federal and provincial levels.
Strengthen capacity for joint energy–water analysis that considers economic and environmental outcomes.
Expand solar and wind power investment where sensible.
Explore feasibility for small-scale hydro on irrigation canals.
Continue major HEP investment with run-of-river focus.
Improve Understanding and Management of Basin-Scale Sediment Dynamics
Develop a management plan to guide long-term, basin-scale sediment management.
Strengthen capacity in relevant technical institutions for multiple aspects of sediment monitoring, modeling, and analysis.
Ensure that new reservoir designs and barrage rehabilitation projects consider sediment-related risks to structural safety and operational performance.

Figure ES.3 Complexity, Urgency, and Scale of Impact of Key Recommendations



Note: Relative scale of impact is indicated by bubble sizes.

Next Steps

Pakistan's National Water Policy (2018) outlines many of required reforms and investments to improve water security. It can provide a platform for increased sector dialog, especially between the provinces, but also among diverse stakeholders within the provinces. Establishing an implementation plan for the National Water Policy that identifies agreed priority actions with clear responsibilities is critical. Implementation will require realistic assessment and commitment to increased sector financing and a robust and transparent process for tracking and reporting implementation progress to demonstrate political commitment and to ensure accountability. Given the long history of significant interprovincial tensions around water sharing, the establishment of a National Water Council as proposed in the National Water Policy is fundamental. The National Water Council should establish long-term social, environmental, and economic objectives for the management of the Indus Basin water resources in the national interest that guide cooperative basin planning as well as provincial water management.

CHAPTER 1

Setting the Scene

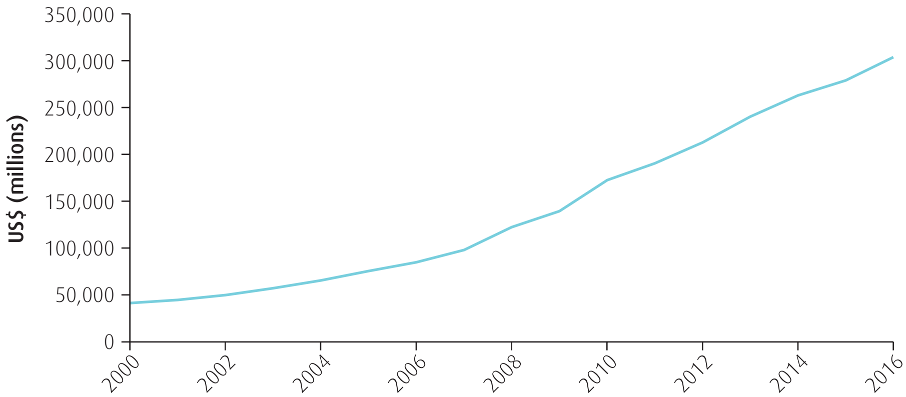
Economic, Demographic, and Geographic Context

Pakistan has experienced two decades of steady economic growth (figure 1.1). By 2017, gross domestic product (GDP) exceeded US$300 billion (around US$1,500 per person) with an annual growth rate of 5.4 percent and strong performance in the agriculture, services, and industry sectors (GoP 2017). This growth has delivered significant reductions in poverty, with the headcount poverty rate falling from 64.3 percent in 2001/02 to 24.3 percent in 2015/16. Demand-side growth has been dominated by domestic consumption, and an increase in foreign investment from China for China–Pakistan Economic Corridor projects has contributed to growth.

The structure of Pakistan's economy changed significantly between 1960 and 1990: the relative contribution from agriculture to GDP fell from around 45 percent to around 25 percent between (figure 1.2). In the last decade structural change was very gradual. The agricultural share in the economy declined slowly to be around 20 percent, similar to that of industry, while the services sector grew to be around 60 percent (figure 1.3, panel a). The decline in the relative contribution of agriculture to the economy (and in the employment share in agriculture) has been slower than in other Asian countries (Briones and Felipe 2013; Felipe 2007). This slower structural transformation and slower movement of labor and resources from low to high productivity sectors have constrained economic growth (Sanchez-Triana et al. 2014). The relative decline of the industry sector can be partly attributed to severe power shortages and weak international competitiveness. Within agriculture over the last decade, cropping has had much slower productivity growth compared to that of livestock, such that Pakistan's major crops—that use most of the water—now contribute less than 5 percent of GDP (figure 1.3, panel b).

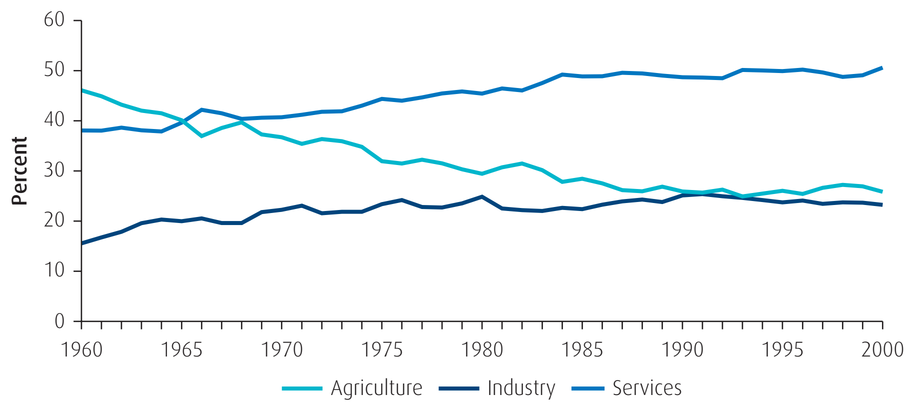
Pakistan covers more than 880,000 square kilometers and comprises four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Balochistan, the Federally Administered Tribal Areas (FATA), the Islamabad Capital Territory, and the Jammu and Kashmir region. The current population of Pakistan is estimated to be nearly 208 million (table 1.1), making it the sixth most populous country in the world. Punjab and Sindh are home to more than three-quarters of the national population. Population growth is high (currently over 2 percent); however, the fertility rate has fallen from 6.5 percent to 3.5 percent over the last three decades. Further fertility decline is expected, and a medium population projection for 2050 is 307

Figure 1.1 GDP of Pakistan, 2000–16



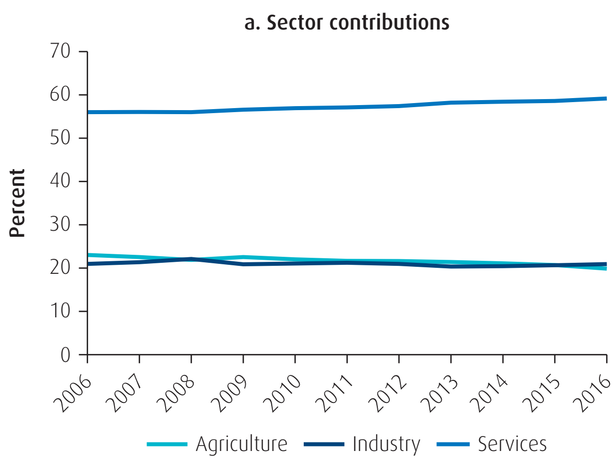
Source: GoP 2017.
Note: GDP = gross domestic product.

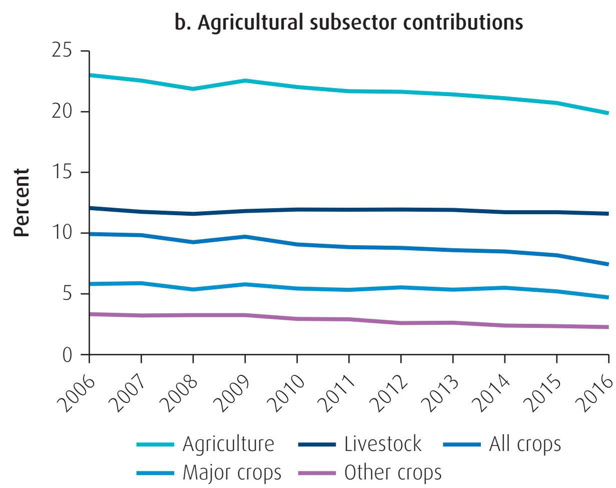
Figure 1.2 Sector Contributions to GDP in Pakistan, 1960–2000



Source: WDI https://datacatalog.worldbank.org/dataset/world-development-indicators.

Figure 1.3 Sector and Agricultural Subsector Contributions to GDP in Pakistan, 2006–16





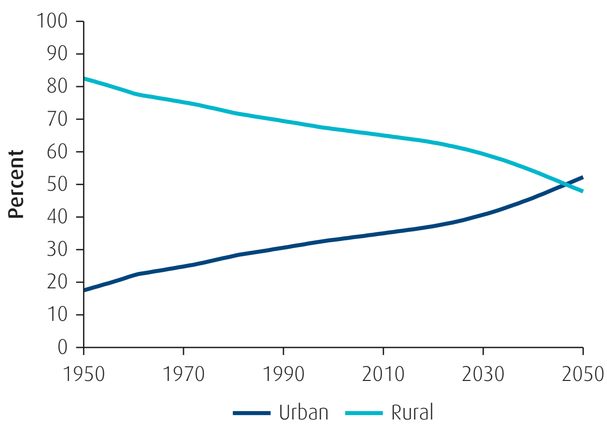
Source: GoP 2017.
Note: GDP = gross domestic product.

Table 1.1 Population Growth across Provinces in Pakistan
millions

	1981	1998	2017
Punjab	47.3	73.6	110.0
Sindh	19.0	30.4	47.9
Khyber Pakhtunkhwa	11.1	17.7	30.5
Balochistan	4.3	6.6	12.3
FATA	2.2	3.2	5.0
Islamabad Capital Territory	0.3	0.8	2.0
Pakistan	**84.3**	**132.4**	**207.8**

Source: GoP 2018.
Note: FATA = Federally Administered Tribal Areas.

Figure 1.4 Share of Urban and Rural Population in Pakistan, 1950–2050



Source: UN 2018.

million (UN 2017). Pakistan is rapidly urbanizing and is the most urbanized country in South Asia. By 2035 around half the population is expected to be urban (figure 1.4).

Except for sparsely populated, semi-arid Balochistan, Pakistan is geographically and hydrologically defined by the Indus Basin, which encompasses all of Punjab and Khyber Pakhtunkhwa (KP), and most of Sindh (map 1.1). The Indus Basin extends across four countries: Afghanistan (6 percent of the basin), China (7 percent), India (34 percent), and Pakistan (53 percent). The Upper Indus has its headwaters in China; it then flows northwest through Jammu and Kashmir before turning sharply to exit the mountains through KP. Moving east, the Jhelum, Chenab, Ravi, and Sutlej (and its tributary the Beas) all flow from India into the Pakistan province of Punjab. The headwaters of the Sutlej are at high elevation in China, close to the source of the Indus mainstream. To the west, the Kabul, Kurram, and Gumal rivers all largely originate from Afghanistan, although key tributaries of the Kabul—the Kunar and Swat—rise in Pakistan, with the former tributary only then flowing into Afghanistan. The extensive Indus floodplain is closely connected to alluvial aquifers extending across 16 million hectares, of which 6 million hectares are fresh (mostly in Punjab) and remainder saline (mostly in Sindh). The Indus exits through an extensive delta system to the Arabian Sea. The Balochistan Plateau, to the west of Pakistan, is a rugged, arid landscape characterized by several rivers, some flowing to the Arabian Sea, others into Afghanistan or the Islamic Republic of Iran. Only the Zhob and Kundar (tributaries of the Gumal) and the Nari are within the Indus Basin.

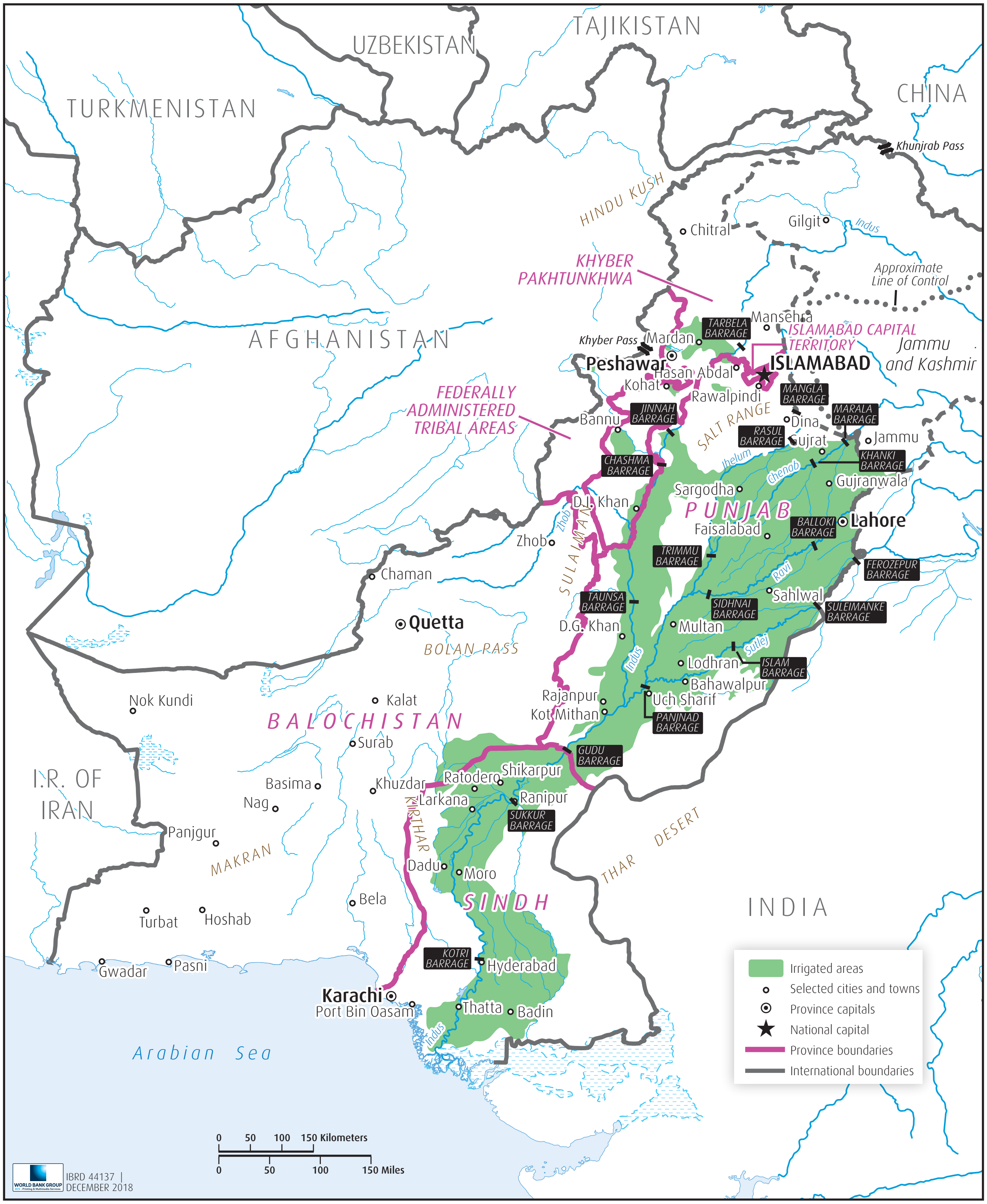
Pakistan has a semi-arid monsoonal climate, although physiographic diversity gives rise to very different climates. Annual precipitation varies across Pakistan from as much as 2,000 millimeters in the mountainous headwaters (mostly occurring as winter snowfall) to less than 200 millimeters across most of the low-lying and semi-arid expanse of the Indus plains and western Balochistan. Across most of the country, around 60 percent of the precipitation falls between July and September. The relative flow contributions from snowmelt, ice melt, and rainfall runoff vary among the tributaries, reflecting catchment elevation. These flow fractions have different seasonal patterns: snowmelt peaks in June, and rainfall runoff and glacier melt peak in August (Lutz et al. 2016).

Water Resources Overview

Pakistan comprises three hydrologic units: the Indus Basin, the Kharan Desert system, and the Makran coastal drainage. Most surface and the groundwater resources are in the Indus Basin. Pakistan's geography means that few interbasin transfers are economically or technically feasible. Desalination of seawater or saline groundwater can help augment supply for high-value uses.

Pakistan's total water resource is somewhat uncertain, as data are limited (especially for Balochistan where the hydrology is highly variable), and a lack of robust water accounting means only approximate resource estimates are available. Additionally, surface groundwater exchanges are not well quantified. The current total renewable water resource is estimated to be 229 billion cubic meters or around 1,100 cubic meters per capita (table 1.2). This estimate includes the water resources outside of the Indus Basin, as well as the water within the Indus that is generated within Pakistan. This estimate reflects the current level of flow to Pakistan from the eastern tributaries of the

Map 1.1 Pakistan



Indus (the Ravi, Sutlej, and Beas) allocated to India under the Indus Waters Treaty (1960). This estimate is higher than other widely quoted estimates that consider only the major surface water inflows to the Indus Basin irrigation system (measured at so-called "rim stations"). The estimated fraction of the resource sourced from outside the country is high, at 74 percent (table 1.2), and yet the internally generated resource, although poorly quantified, is important, and indeed critical for Balochistan.

Water withdrawals in Pakistan are high. The sum of annual surface water and groundwater withdrawals is around 184 billion cubic meters, or 78 percent of the total average annual resource (table 1.3). However, this total embodies a significant double counting error because much of the groundwater withdrawal is water that was first withdrawn as surface water (diversions into irrigation canals) and then leaked to groundwater from the canal system. Of the groundwater withdrawals, around 70 percent is supported by canal leakage and irrigation drainage, the remainder being rainfall recharge and river recharge (Laghari, Vanhamm, and Rauch 2012). Adjusting for this double counting error suggests a net annual withdrawal of around 136 billion cubic meters, or 59 percent of the total renewable water resource. An estimated 94 percent of withdrawals are for agriculture, 5 percent for municipal use, and 1 percent for industry (FAO 2011).

Table 1.2 Estimated Contributions to Total Average Annual Renewable Water Resource, Pakistan

	BCM
Indus Basin	
External	
Indus (including Kabul), Jhelum, Chenab	170.5
Ravi, Beas, Sutlej	3.3
Internal	
Surface runoff	32.6
Groundwater rainfall recharge	12.7
Total	**219.1**
Kharan Desert	
Surface runoff	5.5
Groundwater rainfall recharge	0.7
Total	**6.2**
Makran Coast	
Surface runoff	2.9
Groundwater rainfall recharge	0.6
Total	**3.5**
Grand total	**228.8**

Sources: FAO 2011; Halcrow 2007; Laghari, Vanhamm, and Rauch 2012; van Steenbergen et al. 2015; WAPDA unpublished data.
Note: This resource estimate is based on data for different time periods, for different parts of the total resource, and quoted by different sources using differing assumptions. There is no complete, consistent published total national resource estimate. BCM = billion cubic meters.

Table 1.3 Average Annual Water Withdrawal and Consumption Volumes, Pakistan
billion cubic meters

	Water withdrawal		Water consumption
Canals	122	Irrigation	80
Groundwater	62	Livestock	1
Total	**184**	Municipal	1
Double counting	48	Industrial	<1
Net withdrawal	**136**	**Total**	**82**

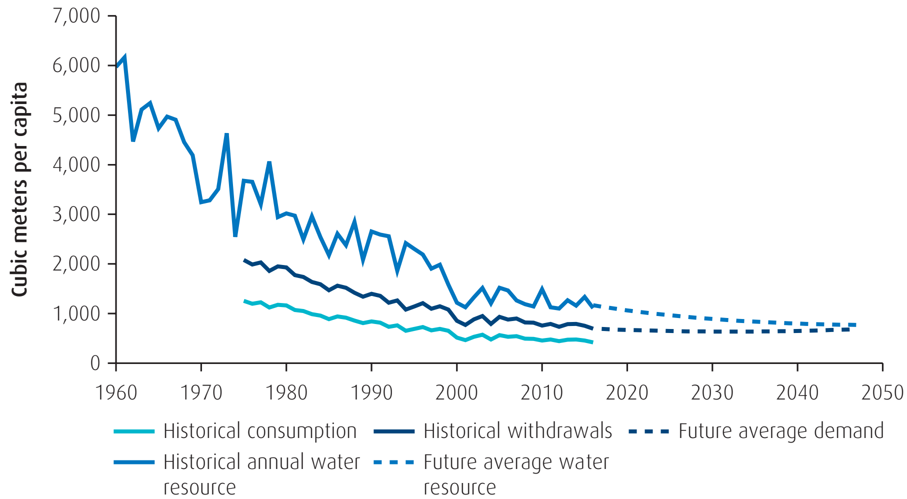
Sources: Amir and Habib 2015; FAO 2011; IFPRI CGE-W baseline model; Laghari, Vanhamm, and Rauch 2012.

Actual water consumption is difficult to assess because it is not directly measured, and even indirect measurement is complex and rare. An estimated 90 percent of municipal and industrial withdrawals are not "consumed" but flow back to the rivers or to groundwater, albeit with much poorer quality. Of the water diverted into the major irrigation canals (122 billion cubic meters on average), a large fraction leaks from the distribution system (canals and distributaries) to groundwater. Of the water applied to fields, a considerable fraction is lost to evaporation, or drains back to groundwater, rivers, or surface drains. Modeling suggests that actual water consumption by crops is around 80 billion cubic meters (table 1.3), or a little over 60 percent of the adjusted withdrawal volume. However, even this estimate includes some field-level evaporation. While some evaporation, especially from paddy rice, is unavoidable, improved agronomic practices can reduce field-level evaporation. Nearly 98 percent of total consumptive use is by irrigated crops.

The difference between water withdrawals and water consumption in irrigation reflects both the high internal leakage to groundwater and the high level of water lost to evaporation in irrigated areas. Water accounting studies confirm that over half the water applied to fields for irrigation is lost to evaporation, with over 40 percent of this being associated with crop rotations involving paddy rice (Karimi et al. 2013). Total actual beneficial consumption is only around 36 percent of the total average available resource.

Pakistan is commonly considered to be both water scarce (low water availability per capita) and water stressed (high water withdrawals high relative to water availability). However, in each case, important aspects of Pakistan's water situation are commonly overlooked. Most water scarcity assessments ignore the 24 percent of the total resource that is internally generated (including rainfall recharge to groundwater) (table 1.2). Average availability has been declining with the rising population for many decades, but also varies annually with climate fluctuations (figure 1.5). Water stress is typically

Figure 1.5 Historical Water Availability (1960–2016), Withdrawals (1975–2016), and Consumption (1975–2016); and Projected Availability and Demand to 2047



Sources: GoP 2017 and author calculations.

noted as being very high. FAO (2011) indicates withdrawals are 74 percent of the total renewable resource. The resource estimate in table 1.2 and total withdrawal estimate in table 1.3 suggest a stress level of 80 percent. Adjusting for the double counting inherent in the withdrawal total, however, indicates a less alarming stress level of 59 percent. Pakistan is indeed "water stressed," but perhaps less so than typically assumed. This highlights the importance of understanding the internal recycling of water between the rivers, canals, and groundwater system. During drought years, withdrawals are kept high despite low system inflows, and thus the level of water stress—and environmental impact—rises considerably. Only during the worst drought years (e.g., 2001/02) is water availability seen to significantly constrain water withdrawal (figure 1.5).

Average annual water withdrawal per capita is currently around 885 cubic meters, compared to around 600 cubic meters in India, 420 cubic meters in China, and 560 cubic meters in Turkey. For Pakistan, this value includes a significant double counting error between surface and groundwater. Adjusting for this indicates net withdrawal per capita is around 655 cubic meters. (Potential double counting in other national estimates has not been assessed). As noted previously, only around 60 percent of water withdrawal is actually consumed by crops.

Simple per capita projections of water resource and withdrawals highlight the macro water resource challenge facing Pakistan (figure 1.5). The water resource projection assumes that the ungauged internal water resource varies between years in proportion to the variation in measured inflows, and that future average annual inflows will be unchanged from the recent past. The demand projection assumes a 1.3 percent annual growth in demand based on the projection of Amir and Habib (2015) for 3 degrees Celsius of global warming by 2050 (see chapters 5 and 6). Adjustments to account for the double counting of surface and groundwater withdrawals are made for both historical withdrawals and future demand. The resource and demand projections assume the population will grow to more than 300 million by 2047. Consumption is not projected, because this will depend on water management—especially improvements in water use efficiency. The water resource as assessed is not completely available to meet consumptive demands: a fraction is unregulated peak monsoon flows. With current available storage, and without improved demand management, future water demand would exceed supply, even in the absence of a reasonable allowance for environmental water.

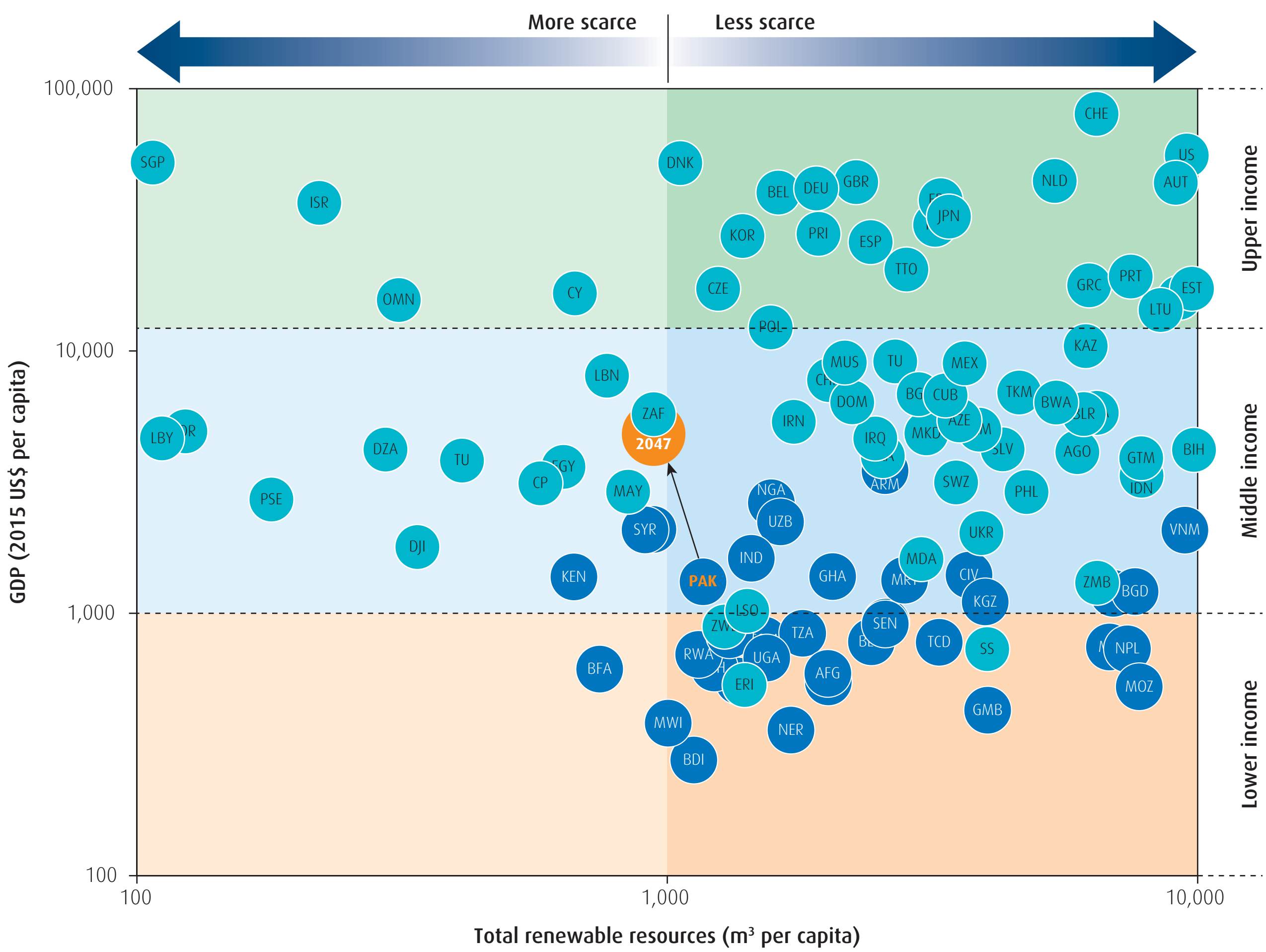
These simple projections of steady total supply and increasing demand imply a gradual increase in the average level of water stress. In addition, because interannual variability of water availability is expected to increase, supply limits will more frequently constrain withdrawals and cause more frequent and severe instances of high environmental stress. As discussed in chapter 3, active management of water storage—reservoirs and groundwater—can help buffer these variations. Other aspects of the future supply-demand challenge are explored in chapter 6, both from water resource management and economic perspectives. This includes more granularity on demand projections by sector and considering the role of climate warming on demand increase. It also includes consideration of the crucial issues of water use efficiency and productivity. As highlighted in figure 1.5, actual consumption is far lower than withdrawal; therefore, there is considerable opportunity to increase water consumption for greater production through enhanced efficiency.

Pakistan's Water Economy in the Global Context

It is useful to briefly locate Pakistan's water economy in the global context. Using World Bank economic data and FAO agricultural and water resources data, metrics of economic productivity, water availability, water productivity, and water stress are calculated and compared. Water scarcity does not preclude reaching upper- or middle-income status, and although water is important in many economies, no upper-income countries and few middle-income economies rely heavily on irrigated agriculture (figure 1.6). Pakistan is a lower-middle income agricultural economy—most of the lower economies are rainfed agriculture dominated—but it needs to transition away from its reliance on agriculture as the engine of economic growth.

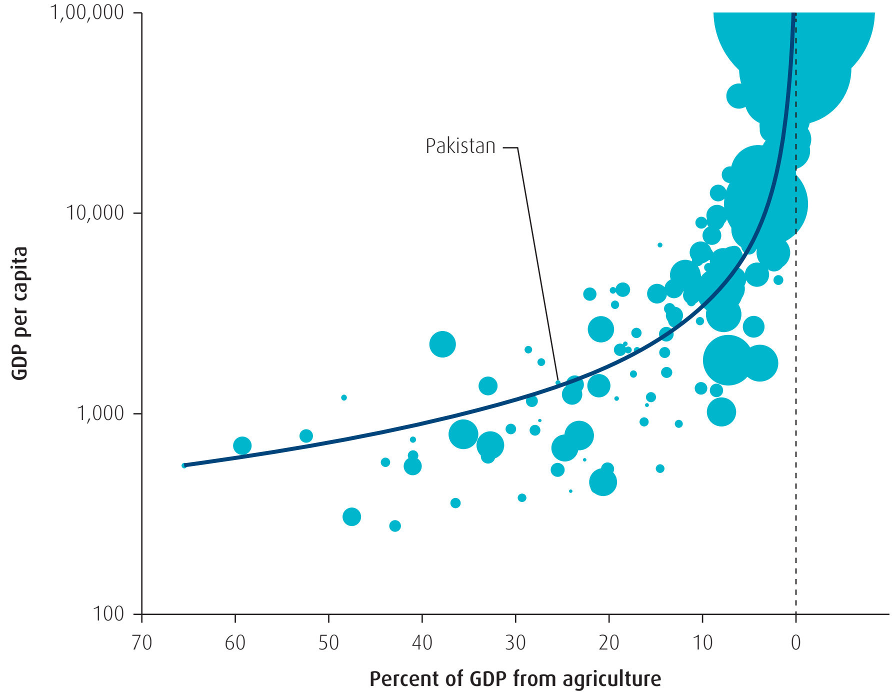
This report explores the ability of Pakistan to transition to an upper-middle-income country by 2047 in the context of increasing relative water scarcity given a growing population. The trajectory of this transition is indicated on figure 1.6, with Pakistan needing to move to the approximate current position of South Africa. Pakistan's position on a trajectory of structural economic transformation suggests that to

Figure 1.6 Global GDP per Capita and Total Renewable Water Resources per Capita



Source: http://www.fao.org/nr/water/aquastat/main/index.stm.
Note: Countries in blue have more than 15 percent of GDP in agriculture. Many countries—not shown—have more than 10,000 m³ per capita and a few have less than 100 m³ per capita. Country codes at http://www.fao.org/countryprofiles/iso3list/en/.

Figure 1.7 Global Structural Transformation Trajectory



Source: http://www.fao.org/nr/water/aquastat/main/index.stm.
Note: Bubbles represent countries, with size scaled for water productivity (GDP per cubic meter of withdrawal). GDP = gross domestic product.

reach middle-income status, it will have to reduce the share of agriculture in the economy, as others in that status have done (figure 1.7). The latter stages of this transformation see a consequential increase in the overall economic productivity of water. Pakistan's water productivity is currently very low even considering its current position on the structural transformation curve.

Water productivity is an indicator of the economic output per unit of water withdrawn from the environment. Countries with high levels of water productivity ensure there is secure water for high-value sectors of the economy. Countries managing their water resources sustainably ensure water stress does not creep too high (figure 1.8). Countries withdrawing or using more than the renewable resources—that is, with water stress exceeding 100 percent—are either mining groundwater, significantly supplementing supply with desalination, or as in the case of the Arab Republic of Egypt, withdrawing the same water multiple times given internal recycling within the irrigation system. Pakistan is in the lowest 5 percent of countries in terms of water productivity, indicating water is comparative far less productive in economic terms and in most countries. Even considering productivity of water only in the agricultural sector, Pakistan is still in the lowest decile.

Pakistan is in the highest decile of countries in terms of water stress. Adjusting for the double counting error gives a lower and more accurate assessment of water stress but does not greatly shift Pakistan's position on figure 1.8. This level of water stress is typically associated with considerable environmental degradation and makes managing water supply fluctuations difficult. An indicative trajectory for Pakistan (assuming GDP growth to reach upper-middle-income status by 2047) is shown on figure 1.8. This trajectory reflects a reduction in overall water use through efficiency improvements to enable reallocation of water to meet priority environmental needs. Dimensions of this trajectory, primarily relating to irrigated agriculture, are explored using modeling in chapter 6.

Water scarcity and water productivity are just two aspects of the much broader concept of water security that is explored and evaluated in this diagnostic. Assessing water security and identifying water sector priorities require going beyond single-issue indicators of water or economic performance to consider the social and environmental outcomes from water management, service delivery, and risk mitigation, and how these in turn are enabled or constrained by water governance, infrastructure, and financing.

Figure 1.8 Water Productivity and Surface Water Stress by Country

Source: http://www.fao.org/nr/water/aquastat/main/index.stm.
Note: Countries more than 15 percent of GDP in agriculture in green. Country codes at http://www.fao.org/countryprofiles/iso3list/en/.

Purpose and Structure of Report

Pakistan has seen steady economic growth and reductions in poverty levels over recent decades, but these will be difficult to sustain without greatly improved water security. There are many economic growth trajectories Pakistan could follow, but these differ in the degree to which they improve water security. Population growth, limited water resource, and increasing climate change suggest that without careful attention, water issues could disrupt development progress—economically, socially, environmentally, and politically.

In 2018, Pakistan's federal and provincial governments jointly adopted a National Water Policy, acknowledging the criticality of water to Pakistan's economic prospects and stability. It provides the first comprehensive policy framework to guide coordinated water reform and investment across Pakistan. To facilitate faster growth, Pakistan should leverage the approval of the 2018 National Water Policy to act decisively on water. Long-standing issues that have made water security elusive need to be addressed—as well as emerging issues. Slower or incomplete reform may lead to more frequent or more significant water-related disruptions to economic growth—or disruptions to social and political stability—together with ever greater environmental degradation.

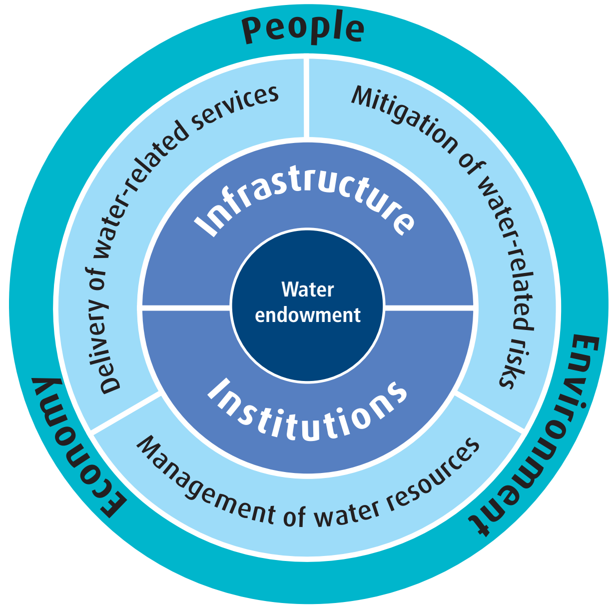
Much has been said and written about water in Pakistan over the last few decades. The federal government, international organizations, and civil society have all provided assessments of Pakistan's water sector. Two particularly influential reports are *Pakistan's Water Economy: Running Dry* (Briscoe and Qamar 2005) and *A Productive and Water-Secure Pakistan* (FoDP 2012). Briscoe and Qamar (2005) identify 14 sobering facts and five hopeful facts to highlight critical water sector issues for Pakistan to address while working toward water security. FoDP (2012) identifies five priority areas and key actions to address water sector challenges: (i) major infrastructure and associated institutions, (ii) raising agricultural productivity, (iii) living with floods, (iv) sustainable urban services, and (v) knowledge management. Many findings of these and other studies remain valid; however, changing demographics and economics, new information on climate change, emerging energy and agricultural technologies, and greater attention to the political economy are reframing the challenges and opportunities.

This report builds on prior work to provide a new, comprehensive, and balanced view of water security, stressing the importance of the diverse social, environmental, and economic outcomes from water. The report highlights the complex water issues that Pakistan must tackle to improve water security and sheds new light on conventional assumptions around water. It seeks to elevate water security as an issue critical for national development—not solely a challenge for the water sector.

The report assesses current water security and identifies important water-related challenges that may hinder progress in economic and human development. It identifies unmitigated water-related risks, as well as opportunities in which water can contribute to economic growth and poverty reduction. While some are well-known risks and opportunities, others are emerging. Some are the result of rapidly growing environmental and demographic pressures, and others have simply been overlooked. The report analyzes how the *performance* and *architecture* of the water sector relate to broader economic, social, and environmental *outcomes*. It models alternative economic trajectories to identify how intervention can lead to a more water secure future.

The report adopts a conceptual framework of water security (figure 1.9) that highlights the balance of economic, social, and environmental outcomes (costs and benefits) from water and the appropriateness of this balance. A consideration of water sector

Figure 1.9 Water Security Diagnostic Framework



architecture and performance—and how these determine outcome—lead to recommendations for improving aspects of sector performance and adjusting sector architecture for better outcomes. The analysis of sector performance considers: (i) management of the water resource, (ii) delivery of water services, and (iii) mitigation of water-related risks. The description of sector architecture considers water governance, infrastructure, and financing.

The remaining chapters of the report are as follows:

- Chapter 2 describes the positive and negative outcomes of water for Pakistan's economy, people and society, and the environment.
- Chapter 3 describes the extent, distribution, variability, and quality of Pakistan's surface and groundwater resources.
- Chapter 4 describes Pakistan's water sector architecture—infrastructure, water governance (legal framework, policy, and institutions), and financing.
- Chapter 5 assesses Pakistan's water sector performance in terms of managing water resources, delivering water services, and mitigating water-related risks, and highlights where sector performance or architecture must improve to deliver better outcomes.
- Chapter 6 considers the extent to which water may enable or constrain Pakistan reaching upper-middle-income status by 2047 and describes potential trajectories for social and environmental outcomes from water.
- Chapter 7 summarizes the report's key findings and recommends priority areas for reform and investment.

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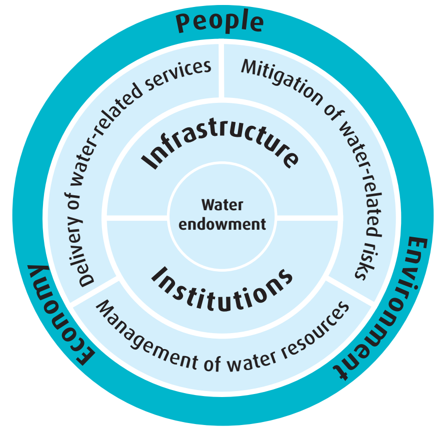
CHAPTER 2

What Pakistan Gets from Its Water

Key Messages

- Irrigation, predominantly in Punjab, contributes around US$22 billion to the economy annually. The four major crops (wheat, rice, sugarcane, and cotton) contribute US$14 billion (less than 5 percent of GDP) but are responsible for 80 percent of all water use. The full agricultural sector (including cropping, livestock, forestry, and fisheries) employs 43 percent of the labor force.
- Despite improvements in recent decades, both land and water productivity are low. Given rapid population growth, food security remains a major challenge. Food production is sufficient, but deficiencies in food procurement, storage, and distribution undermine food security.
- The potential to increase agricultural productivity by increasing inputs is now limited because groundwater is overexploited, land is nearly fully used, mechanized ploughing is widespread, and fertilizer use is high. Productivity improvements will require better control of water delivery, better on-farm water management, increased input quality (e.g., seeds), crop diversification, and better pest control.
- Hydropower represents around 30 percent of national power generation, a much smaller share than in past decades, but a major contribution to the economy nonetheless. Pakistan has considerable untapped hydropower potential, but there are many complexities and challenges associated with exploiting this potential.
- Inadequate water supply and sanitation, flood damage to property, and water scarcity for agriculture cost Pakistan an estimated 4 percent of GDP annually, with three-quarters of this associated with inadequate water supply and sanitation services.
- Water-related diseases are a leading cause of suffering and death in Pakistan, and poor water supply, sanitation, and hygiene contribute to very high levels of childhood stunting. Domestic water supplies are generally unsafe, with contamination by sewage effluent, industrial effluent, and geogenic arsenic common, but poorly assessed, especially in rural areas.
- Pakistan's water-dependent ecosystems are under increasing stress from high levels of water withdrawal, widespread pollution, rapid urbanization, and agricultural expansion. Biodiversity loss, declining fish stocks, and degradation of the ecosystems of the Indus Delta, which offer valuable ecosystem services, are increasing, with little effort to monitor or mitigate this damage.

This chapter assesses the economic, social, and environmental outcomes from water in Pakistan. Economic outcomes are considered in terms of the productive (benefit) and destructive (cost) outcomes from water. The major economic benefits are from irrigation and hydropower. The economic benefits of improved domestic water supply and sanitation are unquantified but are likely to be very significant. This chapter treats them as social outcomes. Major economic costs are associated with inadequate water supply and sanitation, floods, droughts, poor water quality, and the loss of ecosystem services. Many economic outcomes from water are closely linked to social outcomes, given strong connections between the agricultural economy and social transformation—including rural to urban migration. Human health and well-being and social dynamics and conflict are the main social outcomes. Environmental outcomes include freshwater ecosystems and their biodiversity, pollution, eutrophication, and other water quality problems.



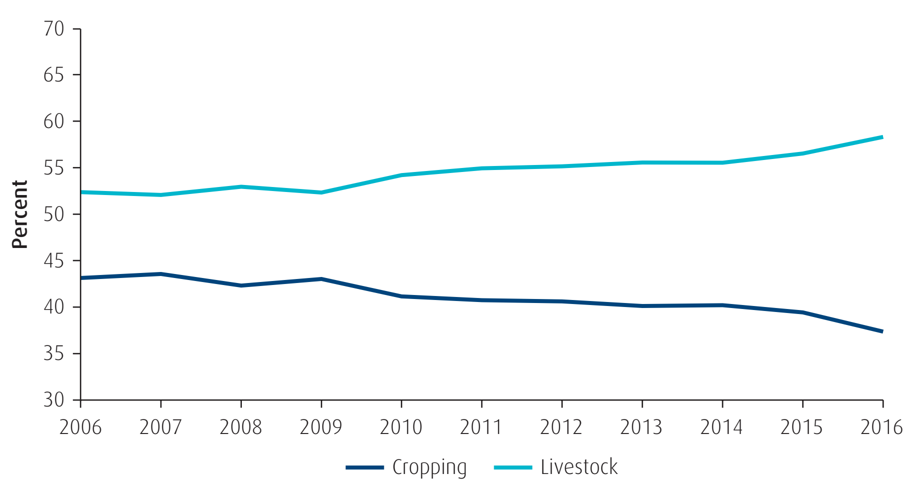
Economic Outcomes

Economic Benefits

Agriculture has an important, although declining role, in the Pakistan economy. It currently contributes a little under one-quarter of GDP. On an area basis, cropping is by far the dominant agricultural activity, but from an economic perspective, livestock production dominates. Livestock currently represents 58 percent of the agricultural GDP contribution, and cropping represents 37 percent (figure 2.2). The remaining value comes from cotton ginning, fisheries, and forestry. Livestock production uses very little water compared to irrigated cropping. The relative economic contribution from livestock is steadily increasing as the relative contribution from cropping declines (figure 2.1). While a diverse mix of crops is grown in Pakistan, around three-quarters of the area and two-thirds of the value comes from two food crops (wheat and rice) and two cash crops (sugarcane and cotton). The direct benefits to the economy from irrigation are the order of US$22 billion per year.

The four major crops, which are responsible for around 80 percent of agricultural water consumption, currently contribute less than 5 percent of total GDP, and this share is in decline. Figure 2.2 shows the fractions of water use and water-dependent agricultural GDP

Figure 2.1 Share of Cropping and Livestock Contributions to Agricultural GDP in Pakistan, 2006–16

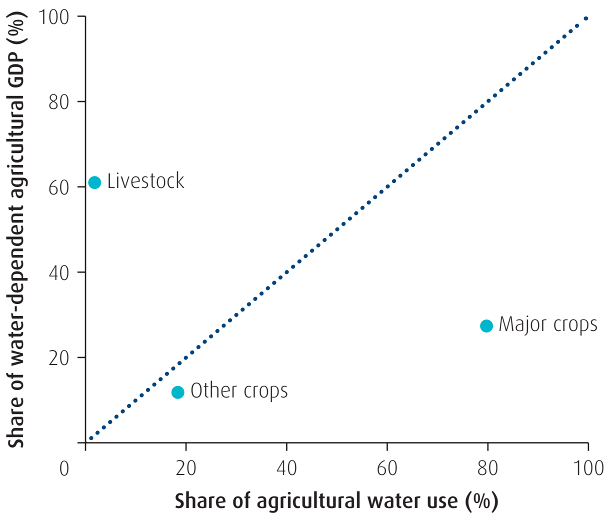


Source: GoP 2017.
Note: GDP = gross domestic product.

of the main agricultural subsectors, indicating major differences in water productivity: livestock is well above the 1:1 line while major crops are well below this line.

The agricultural sector employs around 43 percent of the labor force; but the fraction directly involved in irrigated cropping is uncertain. However, most irrigation is still undertaken by with small farming households that also own livestock.

Figure 2.2 Share of Agricultural Water Use and Water-Dependent Agricultural to GDP in Pakistan, 2016



Source: PBS 2016.

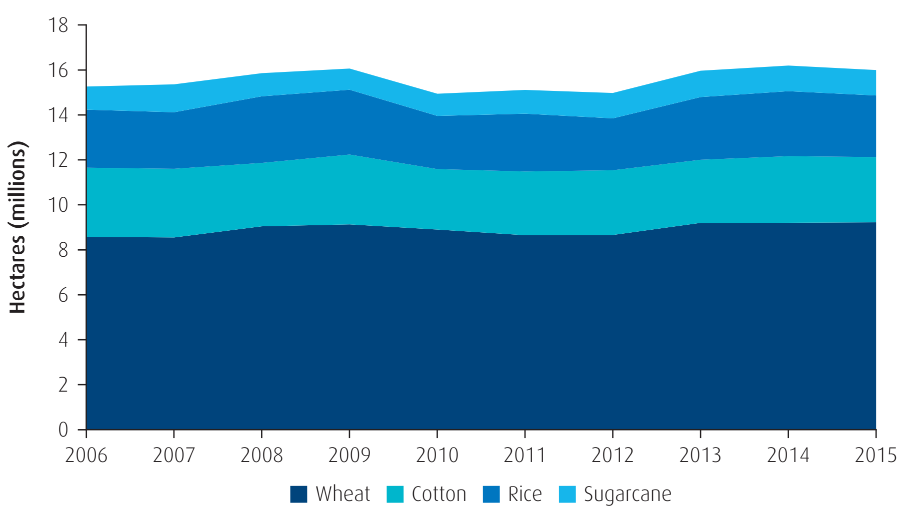
For the thirsty four major crops, the areas have remained reasonably stable over the last decade, with over half the area dedicated to wheat (figure 2.3). This contrasts with other Asian countries in which the composition of output has shifted toward higher-value crops driven by growing demand for fruits and vegetables, contributing to raising the economic returns from water in agriculture; this has not been observed in Pakistan.

Irrigation in Pakistan is dominated by Punjab (73 percent of the total irrigated area), but with significant areas of all crops also grown in Sindh (table 2.1). Punjab produces significantly more than required to meet the provincial food demand and thus dominates exports, both to other provinces and overseas. Khyber Pakhtunkhwa (KP) has a greater reliance on rainfed agriculture, but it imports from Punjab to meet the provincial demand for food.

The nature of irrigation also differs between the provinces. In addition to the largest share of the canal water, Punjab has access to very significant groundwater resources, with 80 percent of the irrigated area being at least partially dependent on groundwater (often in the rabi season) (figure 2.2). In Sindh, much of the groundwater resource is saline—either naturally or because of poor irrigation management—and is thus not a useful agricultural resource.

Yields per hectare are very low by global standards. Average yields for the major food crops (table 2.2) are 1.5 to 4.2 times below field potential and 2.1 to

Figure 2.3 Irrigated Areas for the Four Major Irrigated Crops in Pakistan, Fiscal Years 2007–16



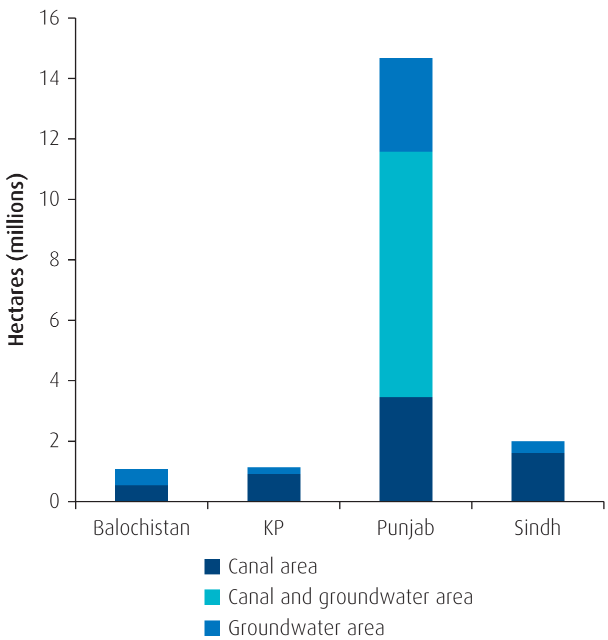
Source: PBS 2016.

Table 2.1 Distribution by Irrigated Area across Provinces of Four Major Crops in Pakistan, 2016

	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan
Wheat	75.2	12.0	8.4	4.3
Rice	67.7	24.0	2.1	6.2
Maize	55.1	0.3	44.2	0.5
Sugarcane	66.2	24.1	9.7	0.1
Cotton	80.2	18.6	0	1.2

Source: PBS 2016.

Figure 2.4 Average of Irrigated Areas by Province and Water Source in Pakistan, 2006–16



Source: PBS 2016.
Note: KP = Khyber Pakhtunkhwa.

5.6 times below international best practice (Aslam 2016). Although Punjab dominates production, yields of the four major crops are considerably higher in Sindh. Yields in KP and Balochistan are well below national averages for all crops, other than rice in Balochistan (table 2.2). If the current wheat and rice yields in Sindh could be achieved across Pakistan, total production would increase 28 percent and 46 percent, respectively.

Yields have improved over the last three decades but yield growth has been slow for the four major irrigated crops (figure 2.5). Annual yield growth has been highest for wheat, averaging 2.6 percent (just above the population growth rate).

While yield per unit area is an important metric for benchmarking performance, production per unit of irrigation water (or water productivity) is also a critically important metric when water is scarce. Over the decade following the 2000–02 drought, water withdrawals for irrigation (combining surface and groundwater) have not increased, and thus the small gains in yield reflect small improvements in water productivity. These improvements have been largely achieved by increasing inputs such as fertilizer and mechanization.

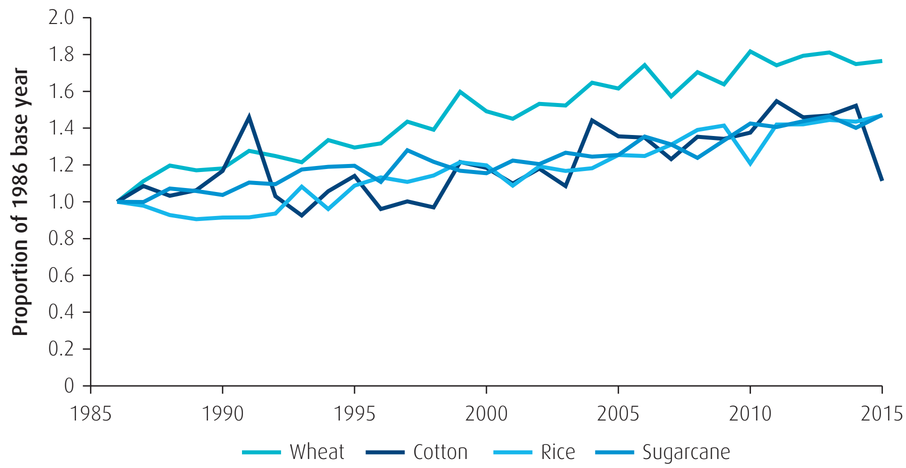
Water productivity can also be considered in the economic value generated per unit volume of water withdrawn. The economic return per unit of total water withdrawn (surface and groundwater) is significantly higher in Punjab than in Sindh (table 2.3), even though yields per hectare are generally much lower. The far lower economic productivity of water in Sindh is because (a) in Sindh, the impacts of water logging and drainage are greater; (b) in Punjab, groundwater provides greater irrigation control (especially during rabi season); (3) in Sindh, water losses are a greater fraction of withdrawals given higher temperatures and lower humidity; and (d) in Sindh, a greater proportion of the irrigated area is devoted to rice, which has higher evaporative losses compared to other crops.

Table 2.2 Average Yields of Major Irrigated Crops Nationally and by Province, 2006–16
tonnes per hectare

	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan	Pakistan
Wheat	2.7	3.5	1.6	2.1	2.7
Rice	1.9	3.4	2.0	2.8	2.3
Sugarcane	54.5	57.9	45.7	48.2	54.3
Cotton	0.7	1.0	0.4	0.4	0.7

Source: PBS 2016.

Figure 2.5 Yield Index for Major Irrigated Crops in Pakistan, 1987–2015



Source: Federal and provincial statistics bureaus.

Table 2.3 Average Land and Water Productivity in Punjab and Sindh at 1980 Prices, 2009–13

	Irrigated area (Mha)	Annual water withdrawn (bcm)	Mean annual irrigation depth (mm)	Annual revenue (US$, millions)	Land productivity (US$/ha)	Water productivity (US$/m³)
Punjab	12.2	119	975	9,931	817	0.08
Sindh	2.5	50	2,000	2,944	1,169	0.06

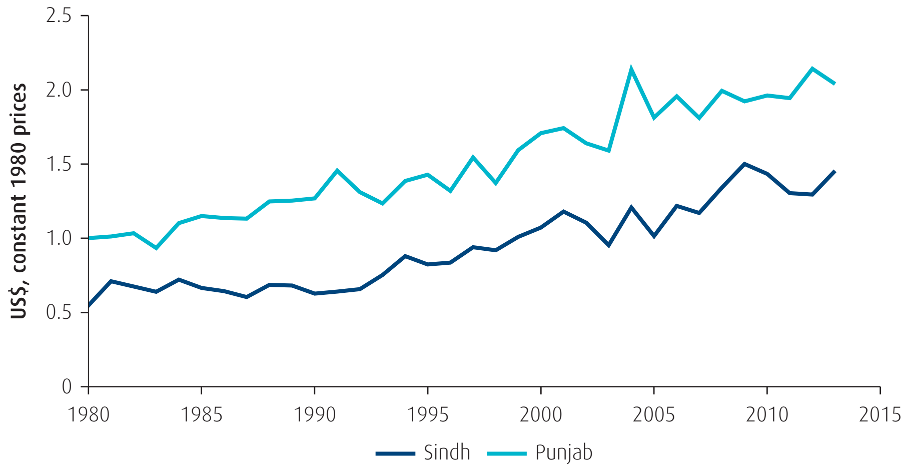
Source: Federal and provincial statistics bureaus.

These factors can be partly inferred from the average values for area-based water withdrawals (table 2.3), which indicate average annual total irrigation depths of 0.96 meters in Punjab and 2.20 meters in Sindh (values are based on withdrawals). Given the high losses in the distribution system, actual water application at field level is much lower (estimated average crop water requirements for Pakistan are around 0.4 meters for wheat and around 1.0 meters for rice (Linstead, Sayed, and Naqvi 2015).

The economic return from irrigation water has doubled over the last three decades from around US$0.03 to US$0.06 in Sindh and from around US$0.04 to US$0.08 in Punjab (figure 2.6). This has been achieved through expansion of the irrigated area, increased groundwater use in Punjab, increased use of fertilizer and mechanization, and some improvements in water management. The potential to increase yields through additional inputs is now limited: groundwater is overexploited, arable land is nearly fully used, 90 percent of ploughing is mechanized, and fertilizer use is often (although not uniformly) high. Water productivity needs to improve markedly if Pakistan is to revitalize economic growth, and should come from better water delivery control, better on-farm water management, higher input quality (e.g., seeds), and better pest control. Technology thus has a key role to play.

Irrigated agriculture, especially wheat, is the foundation of food security for Pakistan. Per capita wheat consumption is among the highest in the world (USDA 2017) and represents 72 percent of the daily caloric intake. Pakistan has significantly increased food supply, more than keeping pace with population growth, thus improving food security (Kirby et al. 2017). Increases in rice production, however, have not mirrored wheat, with a slowdown in production and yield growth in the decade around 1980. Given significant rice exports and rapid population growth, per capita availability of rice has declined significantly in recent decades (Kirby et al. 2017). Despite expansion of the irrigated area and increases in yield, food security remains a serious challenge. Food production exceeds demand, but deficiencies in the food procurement, storage, and distribution systems undermine food security (Hussain and Routray 2012). Food access is thus uneven, malnutrition is high among certain groups, and there are widespread micronutrient deficiencies (Davies et al. 2018). In 2014, 47 percent of the population were assessed as being food insecure (WFP 2014), and Pakistan ranks among the bottom third of countries surveyed by

Figure 2.6 Value of Water in Irrigation for Punjab and Sindh Relative to 1980 Value for Punjab, 1980–2013



Source: Federal and provincial statistics bureaus.

the Global Food Security Index. By 2030, annual grain demand may exceed 36 million tonnes (Hayat, Hussain, and Yousaf 2016)—more than 5 million tonnes above current production levels. To avoid a supply shortfall, grain production needs to increase by 16 percent, assuming no changes in foods imports and exports. Production increases and diversification will require a portfolio of options, many centered on water, supported by greatly improved postharvest food management systems.

Freshwater aquaculture—mostly for export—plays a minor (less than 1 percent of GDP) role in the national economy (FAO 2016). Freshwater aquaculture production has increased threefold over the last 20 years but is sensitive to drought. Increased production has helped to improve food security and increase farmer incomes.

In 2016, hydropower generation was 35 terawatt hours (IHA 2017); equivalent fossil fuel-based power generation would have cost several billion U.S. dollars. The exact value is difficult to assess given the opportunity costs of prioritizing water releases for energy generation and the cost differential of building hydropower dams instead of thermal power plants, which are partly offset by the value of reservoir storage to manage grid variability. Hydropower once underpinned the country's power sector, accounting for 60 percent of power generation in the late 1970s. This share has dropped to around 30 percent because short-term planning has favored thermal power. Given volatility in fossil fuel prices and an increasing energy supply-demand gap, low-cost and indigenous energy sources (such as hydropower) are becoming increasingly important. The proportion of hydropower in the total electricity generation mix could increase to more than 40 percent by 2030. Despite considerable unexploited hydropower potential in the upper Indus Basin, the complexities of extreme weather, difficult terrain, high sediment loads, territorial disputes, and considerable social and environmental impacts mean expanding the portfolio of large hydropower facilities is difficult, slow, and expensive (see chapter 3).

Beyond irrigation supply and hydropower, Pakistan's major dams offer some flood control benefits that are economically important. Tarbela Dam has had an active role in flood control, although dam management is prioritized heavily toward irrigation and then hydropower, limiting the ability to mitigate flood peaks. During the 2010 flood, early reservoir releases informed by forecasts mitigated damage and associated economic loss downstream.

Economic Costs

The economic losses associated with water cost Pakistan billions of U.S. dollars every year. Conservative estimates suggest average annual losses of about 4 percent of GDP (Sadoff et al. 2015), considering inadequate water supply and sanitation, flood damage to property, and water scarcity in agriculture. Other water-related economic impacts, such as loss of ecosystem services and the indirect costs of water-related disasters, are additional, suggesting the total economic costs of water insecurity are much higher.

More detailed assessments of the economic costs of water insecurity aspects have been made. These, however, are based on different methods and assumptions and cannot be simply aggregated. Inadequate water supply and sanitation services have been estimated to cost the equivalent of 3.9 percent of GDP annually (World Bank 2012a). The costs are associated with healthcare, lost work time due to water-related illnesses, lost work time due to a lack of improved water supply and sanitation close to the home, and premature mortality. These losses are about three times higher than the estimated economic costs of water scarcity for agriculture, salinity, and flood damage combined, suggesting that inadequate water services are the biggest water-related drag on the Pakistan economy.

Flooding causes direct financial loss because of infrastructure damage and temporary reductions in agricultural and business productivity. The 2010 flood caused losses estimated at US$10.5 billion, or 6 percent of the year's GDP. Post-flood reconstruction and recovery can, however, stimulate economic growth, and estimates of the average annual economic losses associated with floods range from US$800 million (Sadoff et al. 2015) to US$1.8 billion (World Bank 2015), or considerably less than 1 percent of GDP. While floods cause short-term GDP impact, GDP growth reduces the impact of floods, because stronger growth allows greater investment in protection infrastructure, mitigation systems, and response mechanisms (Sardar, Javed, and Amir-ud-Din 2016).

The economic costs of water scarcity to agriculture are significant—estimated to be at least US$600 million annually, considering only the impact on irrigation production and not rainfed production and ignoring the likely significant indirect economic losses (Sadoff et al. 2015). The cost of soil salinity to agriculture is significant; estimates for 2004 alone suggest losses of US$250 million to US$700 million (World Bank 2006). Soil salinity is worsening and poses a serious long-term threat to agriculture.

Degradation of the Indus Delta has been estimated to cost over US$2 billion annually because of foregone ecosystem services. Environmental degradation in Sindh alone costs an estimated 4 percent to 6 percent of provincial GDP. Around half is agricultural loss caused by waterlogging and salinity, and half is loss of delta ecosystem services (including from mangrove forests and fisheries) (Sánchez-Triana et al. 2015). The national costs of water-related environmental degradation are likely to be of a similar magnitude, given the economic costs of groundwater depletion, land subsidence, widespread water pollution, and inadequate environment water allocations for rivers and lakes.

The economic benefits Pakistan derives from water and water-dependent ecosystems clearly far outweigh the costs. The benefits are in the order of 10s of billions of U.S. dollars, while the economic losses are in the order of a few billions of U.S. dollars annually. However, this equation depends on the economic value placed on environmental and social outcomes, including the many foregone nonmarket benefits. In addition, the indirect, unquantified economic impacts of water-related disasters, especially drought, are likely to be significant. At the household level, these indirect impacts include costs related to healthcare, lack of economic and labor opportunities, and migration. At the business and industry level, these indirect costs include reductions in inputs and labor productivity, as well as changes in consumption patterns that affect business revenue. The value placed on social and environmental outcomes from water typically increases with economic development, improvements in living standards, and greater education; thus, the perceived balance of benefits and costs associated with how water is used and managed in Pakistan can be expected to change significantly into the future.

Social Outcomes

Human Health and Well-Being

Water-borne diseases (cholera, typhoid, hepatitis, and diarrhea) are a leading cause of suffering and death in Pakistan and reflect widespread contamination of water supplies by sewage effluent. The total health burden from water-related diseases is difficult to assess because of a lack of hospital records and limited reporting; however, the burden is disproportionally borne by poorer children and other vulnerable groups. An estimated 20 percent to 40 percent of hospital admissions and a large proportion of infant deaths have been linked to water-related diseases (Azizullah et al. 2011). It is estimated that, on average, 110 children die each day in Pakistan because of water-related diseases, poor sanitation, and hygiene (UNICEF 2016), which equates to 39,000 every year. The mortality rate attributable to poor water supply, sanitation, and hygiene is 20 deaths per 100,000 individuals—well above that of the global average of 15 (WHO 2012).

Poor water supply, sanitation, and hygiene contribute to childhood stunting. The main determinants of stunting are food insecurity, inadequate personal care and feeding, an unhealthy environment, and inadequate health care. Poor water services influence all of these factors. Despite significant reduction in poverty across Pakistan, stunting rates remain high at 44 percent nationally and over 50 percent in Balochistan and Federally Administered Tribal Areas (FATA). Each U.S. dollar spent on nutrition-specific interventions to reduce stunting in Pakistan generates an estimated US$30 return (Hoddinott et al. 2013). Water and sanitation investments can strengthen nutritional outcomes by reducing food contamination and diarrhea (Shekar, Dayton Eberwein, and Kakietek 2016).

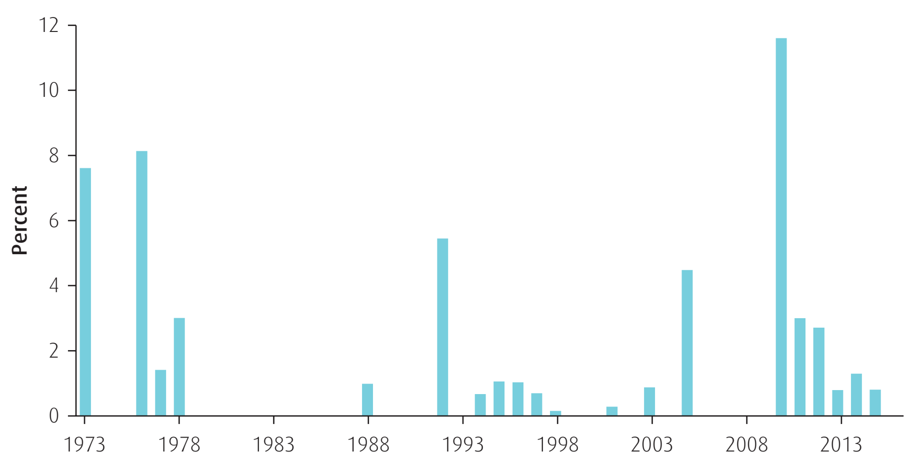
Many drinking water supplies across Pakistan are contaminated by geogenic pollutants and industrial effluents. High arsenic concentration in groundwater is widespread, and highest in Punjab and Sindh where 50–60 million people are at risk (Podgorski et al. 2017). Arsenic is primarily geogenic in origin, although anthropogenic sources contribute in some areas (Sanjrani et al. 2017). Prolonged exposure to elevated arsenic concentration in drinking water can cause skin lesions, cancer, and cardiovascular disease (Azizullah et al. 2011; Fatmi et al. 2009). Although several local assessments have been made, the number of people using arsenic-contaminated drinking water nationally has not been verified. Heavy metal contamination of drinking water supplies (especially cadmium and chromium) has been reported in many areas (e.g., Waseem et al. 2014). Although the health impacts of this contamination have not been systematically quantified, they are known to cause headaches, joint pains, hypertension, renal disease, and increased cancer and diabetes risk (Rehman et al. 2017). Effluents from marble, steel, and aluminum factories are the main sources of cadmium, and effluents from leather tanneries are the main source of chromium. Industrial leaching of lead causes lead levels in surface and groundwater across Pakistan to consistently exceed World Health Organization (WHO) guidelines (Ul-Haq et al. 2011; Waseem et al. 2014).

Women in rural Pakistan are less water secure than men, being commonly responsible for collecting water for domestic use, and more vulnerable to climate-related disasters (Parker 2016). Where public water supply infrastructure is nonexistent or unreliable, women spend 15 percent of their time on average collecting water (Ilahi and Grimard 2000). During periods of greater water scarcity, the time spent collecting water can rise by as much as 60 percent in rural Balochistan and 40 percent in rural Sindh (Hamid and Afzal 2013). Poor sanitation facilities in schools in Pakistan deter children, especially adolescent girls, from education, with up to 50 percent of girls not attending school during menstruation (Aslam 2012). Lower school enrollment and retention rates for girls mean they typically receive fewer years of schooling, with consequences for labor force participation and economic production.

Excluding women from water information perpetuates gender inequality in Pakistan. Early warning systems use a language and medium not accessible to women and other excluded groups, thus increasing their vulnerability to water-related disasters (Mustafa et al. 2015). Water–gender relationships influence social outcomes, including the limited presentation of women in formal water management institutions. Global evidence indicates gender differences in the perceptions of, and coping strategies, for drought. Women are more proactive in adapting water management strategies to drought even when excluded from formal water management arrangements (Su et al. 2017). But women are not always marginalized in small-scale irrigation, indicating water–gender relationships are complex and multifaceted (Das 2017).

Floods are the most frequent and damaging natural hazard in Pakistan. Over the past 65 years Pakistan has experienced more than 30 major floods affecting significant fractions of the population (figure 2.7). The 2010 floods affected 20 million people—about 10 percent of the country's population. From 2010 to 2015, Pakistan's population suffered a major flood at least once

Figure 2.7 Share of Population Affected by Riverine Floods in Pakistan, 1973–2016



Source: EM-DAT.

year, affecting at least 1 million people annually. From 1950 to 2016, around 15,000 fatalities were reported from riverine floods, with high numbers in the 1950, 1992, and 2010 floods (Paulikas and Rahman 2013).

Droughts have significant social impacts, especially for children. During the extended drought in Sindh of 2014–17, more than 1,000 children died and 22,000 were hospitalized with drought-related diseases in the Tharparkar District alone (ACAPS 2016). During droughts in rural Pakistan, girls are most at risk of malnutrition, because they receive less food when resources are stretched given the common preference toward sons (Mansuri 2006). Short-term migration during droughts can alleviate resource constraints, but gender gaps in development outcomes are often exacerbated by drought.

Conflict and Migration

Some instances of civil unrest and violence in Pakistan have been linked to water. Protests over water shortages can turn deadly, as in Karachi in 2001, or lead to property damage and violent encounters with the police, as in Sindh in 2012 (Mustafa et al. 2017). Evidence suggests that disputes over water allocation have led to deaths and injuries in KP and in FATA (Mustafa et al. 2017), and inequitable access to municipal water or irrigation water contributes to conflicts. In one instance, Perween Rahman, an activist working to reduce these inequities in Karachi, was murdered in 2013. Despite the interprovincial Water Apportionment Accord, interprovincial disputes over water sharing are common. These disputes have not yet turned violent, but with increasing water demand and more frequent droughts, disputes may escalate. In Pakistan and around the world, insurgent and terrorist groups use access to water and water infrastructure to pressure civilians or threaten opponents. In Pakistan, the Taliban have threatened to contaminate water sources and reservoirs (Roul 2010), fought for control of urban water supplies in Karachi (Hamid 2015), and threatened to blow up Warsak Dam that supplies Peshawar (Mustafa, Akhter, and Nasrallah 2013).

The links between water and migration are complex because migration choices reflect many economic, political, and demographic issues. Pakistan has seen short-term, temporary migration and long-term migration. The former is a common response to droughts and floods, especially in Balochistan and Sindh (e.g., Ashraf, Routray, and Saeed 2014). In Tharparkar District in Sindh, recurrent seasonal migration is exacerbated by drought. During the 2014–17 drought, 35 percent to 45 percent of families migrated to barrage areas in search of labor and grazing for livestock (Alvarez-Quinones 2015). Women are less likely than men to migrate individually in search of work or in response to water-related shocks, and women from higher socioeconomic groups don't leave their villages unless it's a drought year (Sattar 2014). Long-term migration because of water stress and climate change has received significant attention in the popular press; however, little quantitative evidence exists. Heat stress appears to be a stronger predictor of migration in rural Pakistan than rainfall shocks (Mueller, Gray, and Kosec 2014), but may partly reflect the larger relief efforts made to counteract rainfall shocks. Continued deterioration of the Indus Delta has led to drinking water shortages, seawater intrusion, and increased vulnerability to coastal storms, and these appear to influence migration (Sattar 2014).

Environmental Outcomes

Pakistan's environment resources and ecosystems are under increasing stress from high levels of water withdrawal, widespread water pollution, rapid urbanization, and agricultural expansion. Biodiversity loss, declining fish stocks, and degradation of internationally important ecosystems in the Indus Delta and other parts of the Indus Basin are key consequences.

The Indus Basin is home to more than 180 species of freshwater fish, with distributions along a longitudinal gradient from the headwaters to the delta (Mirza and Mirza 2014). Of these, 86 are of special concern, 34 are endemic to Pakistan, 11 have special International Union for Conservation of Nature (IUCN) status, 31 are commercially important, and eight are very rare (Rafique and Khan 2012). Most endemic fish species are restricted to mountainous and submountainous river reaches, which are now highly fragmented by dams and diversion structures and are characterized by modified flow regimes, such that the level of ecological alteration could lead to extinction (Regnier, Fontaine, and Bouchet 2009). The only comprehensively assessed endemic species—*Glyptothorax kashmirensis*—has been declared critically endangered (using IUCN criteria). This species inhabits the regulated and fragmented Jhelum River. The IUCN (2011) predicted an abundance decline of more than 80 percent over five to 10 years, given the species' preference for fast-flowing habitat. Detailed studies are few, but Magurran (2009) suggests that for the restricted range endemic species, overexploitation, habitat loss, and degradation of breeding grounds are likely to have led to unrecorded extinctions.

The 31 commercially important fish species are vital to rural livelihoods, providing high-quality protein and essential nutrients and minerals that are often difficult to obtain from other food (Rafique and Khan 2012). The abundance of many of these species is declining, including *Tor putitora,* which has been declared critically endangered because of overfishing, river fragmentation by water resource infrastructure, and loss of habitat (including critical breeding grounds). IUCN (2011) notes that *Tor putitora* abundance had declined by more than 50 percent, and that trends suggested declines could reach 80 percent; no more recent assessment is available. Several other commercially important species are also declining because of habitat loss and degradation, water abstraction, wetland drainage, dam construction, pollution, and eutrophication. Distributional ranges of several species have shrunk greatly since the 1980s to small, localized remnant populations; many are now on the verge of extinction (Rafique and Khan 2012). In the lower Indus, barrages block fish migration routes, and the fish ladders constructed at Muhammad and Kotri barrages have proved ineffective. The iconic Indus dolphin is recognized as one of the world's most endangered mammal species. By the early 1990s its range had been reduced by 80 percent because of major barrages that have fragmented its habitat into 17 separate reaches (Braulik et al. 2014). In most of these reaches, dolphins have disappeared within 50 years of barrage construction; dolphins are now found in only six reaches. Worsening water quality is also affecting riverine and lake ecosystems.

Pakistan has 19 Ramsar sites—wetlands of international importance—covering a total of more than 1.3 million hectares, and over 225 important perennial or ephemeral wetlands. Many of these wetlands are associated with rivers or are dependent on groundwater and thus influenced by water resource management. From a water resources management perspective, the 12 most important of the Ramsar sites are (1) the Indus Delta; (2) the Indus Dolphin Reserve—the reach between the Sukkur and Guddu barrages; (3) the Chashma and Taunsa barrages in Punjab; (4) four freshwater lakes and one costal lagoon in Sindh; (5) the Tanda Dam and the braided channels of Thanedar Wala in KP, which are important migratory bird wintering sites; and (6) the Miani Hor coastal lagoon at the terminus of the Porali River in Balochistan.

In addition to the fish fauna discussed previously, Pakistan's Ramsar sites and other wetlands support 18 threatened mammals, including the endemic Punjab urial (*Ovis vignei punjabiensis*) and the Indus river dolphin (*Plantanista minor*), 20 threatened bird species, 12 reptiles, and two endemic amphibians. Nutrients from fertilizer in agricultural drainage, untreated municipal wastewater, and industrial effluent (especially from the textiles industry) are widespread and polluting freshwater ecosystems across Pakistan. Eutrophication is affecting several water bodies, including the Manchar Lake in southern Sindh—the largest freshwater lake in Pakistan. Eutrophication leads to uncontrolled growth of algae and depleted oxygen levels in the water, killing fish and causing a major decline in biodiversity.

The Indus Delta—the fifth largest delta in the world—is characterized by rich biodiversity and valuable ecosystem services, including productive fisheries and coastal storm protection by mangrove forests. The area is estimated to be around 0.6 million hectares (Amjad, Kasawani, and Kamaruzaman 2007), with mangrove forests originally covering more than one-third of the total area. However, reduced river flows and sediment loads—and sea level rise—are driving a multifaceted environmental crisis for the delta, including sea water intrusion, soil salinization, mangrove forest loss, reduced freshwater supply, and depleted fisheries. The 17 channels that once delivered freshwater to the delta have been reduced to one (Kidwai et al. 2016), and no freshwater reaches the delta for 138 days per year on average (Renaud et al. 2013)—and for much longer periods during drought years. Given the level of water resource development upstream, flows downstream of the Kotri Barrage are now usually limited to August and September, allowing seawater to penetrate the delta for hundreds of kilometers for much of the year (Inam et al. 2007). Flow reduction is discussed in more detail in chapter 3.

Sediment delivery to the delta is just 4 percent of predevelopment level. Construction of dams and barrages has reduced sediment delivery to the delta from an estimated 270 million tonnes per year to around 13 million tonnes per year (Syvitski et al. 2013). Flow reductions have led salinity in the delta to increase significantly, leading to a reduction in plant diversity: four out of eight plant species that had thrived in the delta have disappeared in recent years (Salik et al. 2015).

Degradation of the Indus Delta has affected the lives of at least half a million people. Shrimp production and the catch of the prized *Palla fish* have fallen by 90 percent (Amanullah, Ahmed, and Ali 2014; Renaud et al. 2013). The flow, salinity, and sediment regimes are the main causes of a drastic reduction in the extent of mangrove forests from around 0.24 million hectares to 0.10 million hectares (Renaud et al. 2013). This contraction of the mangrove forests has had significant impacts on biodiversity, because they are an important wintering habitat for migratory birds on the central Asian flyway (Khan 2006). The loss of mangrove forests has also compromised their ability to act as an active barrier against tropical cyclones and storms, leaving the delta at greater risk of coastal erosion and flooding. The mangrove forests support the livelihoods of more than 100,000 people, with an estimated direct value to households of US$1,300 per hectare (Adhikari, Baig, and Iftikhar 2010); further contraction would put these livelihoods at risk.

The Miani Hor coastal lagoon in Balochistan is another productive estuarine fishery that provides important nursery habitat for the juvenile of several marine fish species. Its productivity is dependent on the freshwater flows of the Porali River. The lagoon has habitat and rich faunal diversity with more than 300 finfish species reported (Shah and Jusoff 2007). Reports of fish landing indicate as many as 350 commercially important species (Hayat 2003), with several important fish stocks now considered overfished (Lindley 2008). Water resource development in the Porali Basin is, however, comparatively limited and is not known to have significantly impacted Miani Hor.

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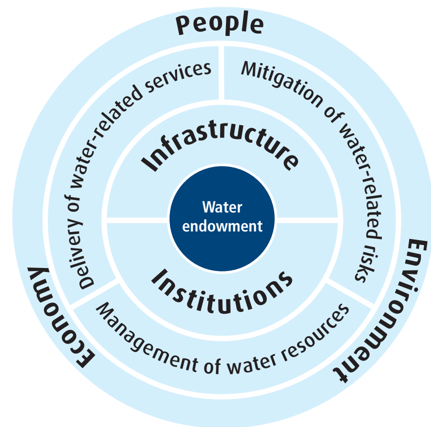
CHAPTER 3

Pakistan’s Water Endowment

Key Messages

- Most of Pakistan’s water is associated with the Indus Basin and flows into Pakistan from outside the country. The water generated within the country is an important fraction of the total water resource but is often overlooked and is less well measured.
- Average inflows to Pakistan have remained reasonably stable over many decades, although development in India permitted under the Indus Waters Treaty has recently reduced the minor inflows to Pakistan from the eastern Indus tributaries.
- Interannual variations in river flow are low compared to other large, arid zone rivers, because of comparably reliable glacier and snowmelt. Flows are strongly seasonal, reflecting the annual cycles of meltwater and monsoonal precipitation.
- While Balochistan has access to some Indus water, the province is mostly outside the basin and is largely reliant on highly variable and often flashy rainfall to recharge sedimentary aquifers and supply arid zone rivers, many of which are ephemeral.
- Groundwater is an important resource for Pakistan and in the Indus is tightly coupled to surface water. Groundwater pumping is very significant and is largely sustained by leakage from the surface water distribution system. Groundwater depletion is, however, a significant issue at some locations in Punjab and Balochistan.
- Pakistan’s irrigation command areas are characterized by high levels of internal water recycling and considerable evaporative losses. The Indus Basin also loses a considerable fraction of its water naturally because of the hot, arid nature of the lower basin. These losses are likely to increase as the climate warms.
- Given the complex, variable, and changing climate, and the history of transboundary agreements and development upstream of Pakistan, detailed river system modeling, analysis of Earth observation data, and comprehensive water accounting are required. This would improve water resources assessments and enhance the understanding of natural and induced water losses to guide irrigation efficiency investments, conjunctive water management, and drought planning for climate resilience.

This chapter reviews the extent, variability, and quality of Pakistan's water resources, considering surface water and groundwater and their interactions. Pakistan's total water endowment is poorly quantified because of limited data and a lack of robust water resource assessments. The common focus has been on the main river inflows to the Indus Basin irrigation system (at the so-called "rim stations"), which ignores all internally generated runoff and groundwater recharge, including outside of the Indus Basin in Balochistan. This chapter provides a detailed picture of the water resource based on multiple data sources and prior water accounting efforts.



Average Water Balances

Pakistan is comprised of three surface water hydrologic units: (i) the Indus Basin, (ii) the Makran Coast, and (iii) the Kharan Desert. The Indus Basin covers 65 percent of Pakistan and represents over 95 percent of its water resources (table 3.1). It includes the mountainous areas of the north and the west, the Indus Plain, the Kacchi Plain, the desert areas of Bahawalpur and Sindh, and the Rann of Kutch. Balochistan is the only province not fully within the Indus Basin. Of the 18 river basins of Balochistan, seven are part of the Indus basin; the Nari River terminates in Hamal Lake in Sindh—its waters never reaching the Indus; and the other six rivers contribute small volumes to the Indus. There are seven rivers in the Makran Coast basin of Balochistan (18 percent of the area of Pakistan) and four rivers in the endorheic Kharan Desert (17 percent of Pakistan) that flow either into the Islamic Republic of Iran or Afghanistan. These latter rivers are low-volume, intermittent rivers but of considerable value to the sparse populations that live in these basins. Although the summary resource assessment (table 3.1) suggests groundwater is of minor importance, this portrayal reflects only the direct rainfall recharge to groundwater. The major groundwater resources of Pakistan are the shallow alluvial aquifers of the Indus River plain, which are highly connected to the river. Under natural conditions the groundwater recharges from the river during high flow seasons, and groundwater discharges back to the river as baseflow during low flow seasons. Under contemporary conditions groundwater recharge is dominated by leakage and drainage from the surface irrigation distribution system. Given the internal recycling of water (from canals to groundwater) and the limited extent of groundwater monitoring and modeling, these aspects of the resource assessment are uncertain. Groundwater is an important water source, however, even if most is ultimately sourced from surface water withdrawals.

Table 3.1 Average Annual Available Water Resources of Pakistan
billion cubic meters

	Surface water	Groundwater	Total
Indus Basin	205.7	12.7	218.4
Makran Coast	6.2	0.7	6.9
Kharan Desert	2.9	0.6	3.5
Total	**214.8**	**14.0**	**228.8**

Sources: FAO 2011; Laghari, Vanham, and Rauch 2012; van Steenbergen, Basharat, and Lashari 2015.

Average annual water balances for each of Pakistan's three hydrologic units highlight the high natural water losses in these arid and semi-arid landscapes, and the high induced losses—nonbeneficial evaporation—associated with irrigation (table 3.2). In the Indus Basin the high level of withdrawals means that the average basin outflow is low, currently averaging 16 percent of the total system resource. Less than one-third of the total resource goes to beneficial consumptive use. In the Indus Basin and the Kharan Desert the sum of use and losses slightly exceeds total inflows and internal contributions, indicating groundwater depletion.

The Indus Basin dominates Pakistan's water resources, with a high level of water recycling in Indus Basin irrigation. Groundwater withdrawals are largely wsupported by leakage from irrigation canals and distributaries and irrigation drainage (figure 3.1). Two simplifications are made in figure 3.1, panels a–c: (i) canal leakage is shown separately, but watercourse leakage and field-level drainage to groundwater are combined; and (ii) irrigation returns to surface water are shown as all returning to the river, while in reality

Table 3.2 Average Annual Water Balance for Pakistan's Three Hydrologic Units
billion cubic meters

	Indus Basin	Makran Coastal Basin	Kharan Desert	Total	Percent
Inflows	*174*	*0*	*0*	*174*	*76*
Internal contributions	*45*	*6.2*	*3.5*	*55*	*24*
Beneficial consumption	80	1.2	0.7	82	36
Natural losses	68	2.0	1.2	68	31
Induced losses	41	0.7	0.5	39	18
Outflows	30	2.3	1.2	41	15

Sources: FAO 2011; Karimi et al. 2013; Laghari, Vanham, and Rauch 2012; van Steenbergen, Basharat, and Lashari 2015; WAPDA unpublished data.

a fraction is saline drainage to the sea, to saline lakes, or to evaporation basins. The split between irrigation recharge to fresh versus saline groundwater is an estimate based on the relative proportions of area covered by fresh and saline shallow groundwater (approximated as a one-third to two-thirds split). In appendix A, three separate balances are tabulated for each of these hydrologic units: (i) a river water balance, (ii) a groundwater balance, and (iii) a withdrawal balance. The withdrawal balances are dominated by irrigation but include small volumes of nonirrigation withdrawals.

The groundwater balances for the Indus Basin and the Makran Desert (figure 3.2, panels c and b, respectively, and tables A.2 and A.3) include groundwater depletion. Groundwater depletion is discussed in chapter 5, but depletion is the smallest term in these groundwater balances. The outflow value in figure 3.1a is the average gauged outflow from Kotri Barrage and so includes water used downstream, including Karachi supply. The outflow value is the average for 1975–2015; over the last 15 years of this record outflows have been about 15 billion cubic meters or half of this average.

The high natural losses of water across the Indus are inferred in the mass balance and are indicated by basin-level landscape water accounting based on remotely sensed data (Bastiaanssen, Ahmad, and Chemin 2002; Karimi et al. 2013). Natural losses include evaporation and nonagricultural plant transpiration. From a water resources management perspective, transpiration from irrigated and rainfed crops and from pasture is considered beneficial, while transpiration from forests and savannah is considered nonbeneficial. Bastiaanssen, Ahmad, and Chemin (2002) show the mangrove forest of the Indus Delta have highest levels plant water use in the basin, at around 1.3 meters of evapotranspiration annually.

Natural land uses, including the delta mangrove forests, provide important ecosystem services that should be protected. Water accounting for a single year for the entire Indus Basin (Karimi et al. 2013) indicates that irrigated crops represent 69 percent of transpiration and 39 percent of the evaporative loss. The largest share of the evaporative loss (44 percent) is associated with natural land uses (Karimi et al. 2013). It is important to better understand these natural losses, especially because they are strongly temperature-driven and so will increase with climate warming. Minimizing these losses should not be a management priority and would in any case be very difficult.

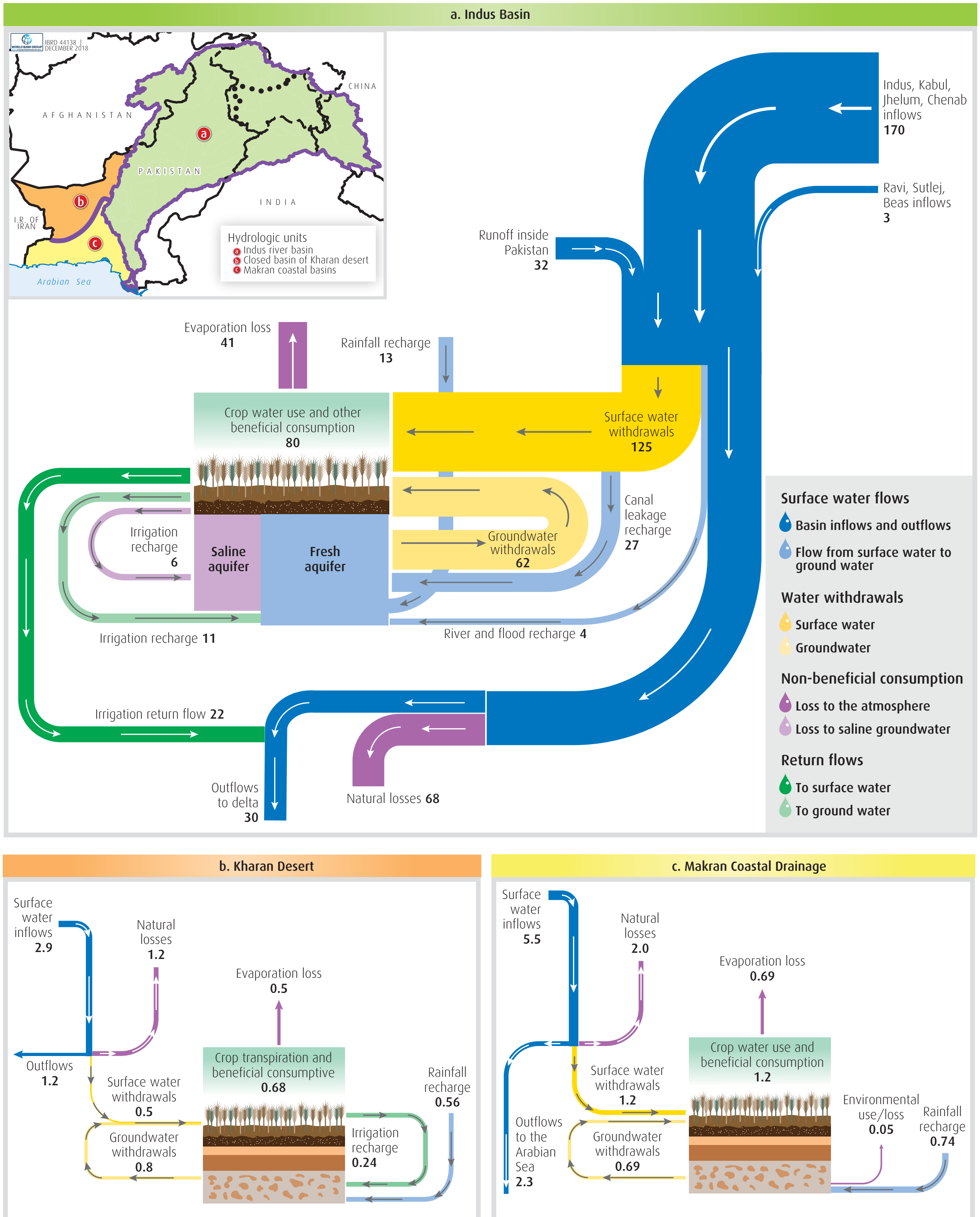
River System Gains and Losses

Managing the Indus River system requires understanding the water losses from and gains to the river. Losses include evaporation and flow from the river to groundwater. Unmeasured water withdrawals that contribute to flow differences between gauging points are sometimes treated as losses, too. Gains include unmeasured contributions from minor tributaries and drains, direct runoff to the river, and water movement from groundwater to the river.

Losses and gains vary considerably across the basin and through time, both within and between years. During kharif, high flows typically recharge groundwater, and the river is losing water overall. During rabi, as river flows start to recede, the river gains typically water from landscape and aquifer storage. The gains in September and early October are important for maturing kharif crops, while the gains from mid-October to March support rabi crops (Euroconsult 2011).

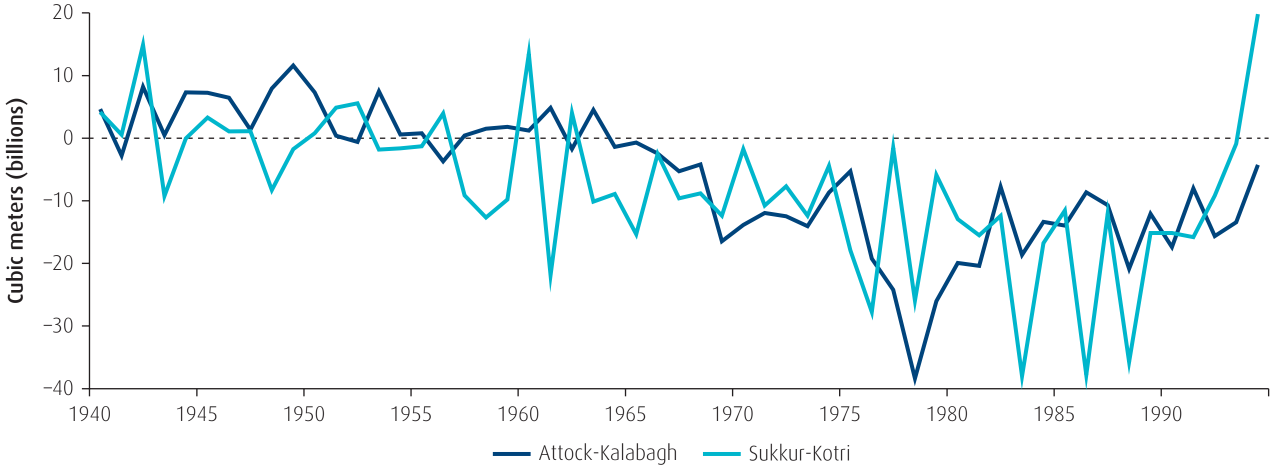
The pattern of losses and gains varies strongly across the basin. Between 1940 and 1994 there was a significant net loss in the Indus mainstem (11 billion cubic meters per year on average) and a small net gain

Figure 3.1 Average Annual Water Balance for the Three Hydrologic Units of Pakistan



Sources: Ahmad and Rashida 2001; FAO 2011; Halcrow Group 2007; Karimi et al. 2013; Laghari, Vanham, and Rauch 2012; MacDonald et al. 2016; van Steenbergen and Gohar 2005; WAPDA unpublished data. Details in appendix A, tables A.1, A.2, and A.3.
Note: Flows are in billion cubic meters.

Figure 3.2 Annual River Losses and Gains in Key Losing Reaches of Indus River, Pakistan, 1940–94



Source: WAPDA unpublished data.

in the Jhelum-Chenab zone (0.4 billion cubic meters on average). In the Indus zone, net losses are high in the Attock-Kalabagh reach downstream of Tarbela Dam, and even higher in the Sukkur-Kotri reach. These high losses are partially offset by moderate gains in the Kalabagh-Taunsa and Taunsa-Guddu reaches. A fraction of the losses between Sukkur-Kotri may be to saline groundwater; however, the high losses in this zone keep the groundwater fresh near the river. Additionally, the losses to groundwater in the Sukkur-Kotri reach support the high levels of natural evapotranspiration in the hot, dry lower parts of the basin. The losses in the reach below Tarbela are likely to be a major fraction of the groundwater recharge at least into the Thal Doab between the Indus and Jhelum rivers. In the Jhelum-Chenab zone, while there is a small net gain overall, there are significant net losses along the Jhelum in the Rasul-Trimmu and Trimmu-Panjnad reaches. These losses are likely to important groundwater recharge pathways for the lower Chaj, Rechna, and Dari doabs. They are partly offset by net gains to the Chenab and Ravi rivers. This suggests some lateral groundwater flow and significant inflows from the hill torrents in these areas.

Between 1940 and 1994, river losses and gains varied significantly, indicating complex surface-groundwater dynamics that are poorly understood (figure 3.2). The increasing losses in the Indus zone, especially in the more recent period, have previously been largely attributed to the presence and operation of Tarbela Dam and the lower barrages (e.g., Khan 1999). However, these increasing losses also mirror the increase in tube wells, especially in Punjab, and the significant depletion of groundwater in parts of Punjab. These losses may be supporting increasing groundwater use in the Thal Doab of Punjab, especially the area of significant depletion (approximately 15 meters) identified by Khan et al. (2016) in the Mianwali District. The losses below Sukkur Barrage have also been increasing, possibly reflecting the significant rate of climate warming in the lower basin (figure 3.2). During the 1980 to 1990s, losses in the reach below Tarbela averaged around 14 billion cubic meters and losses in the Sukkur-Kotri reach averaged around 12 billion cubic meters. These are very significant volumes of water—equivalent in aggregate to twice the national municipal and industrial withdrawals. River losses and gains remain poorly accounted for in water allocation and delivery operations, and the physical processes driving them are poorly understood. A detailed study of basin-scale surface-groundwater interactions is required to inform improved resource assessment, planning, and operations.

The water balance diagrams (figure 3.1, panels a–c) highlight the internal recycling of water in the irrigation system, especially for the Indus Basin. Water leaks from the canals and distributaries into the groundwater, and excess water applied to the fields flows to drains and thence to the river, or seeps to underlying aquifers. Although some data exist to describe these exchanges, full quantification would require both better measurement and detailed hydrologic modeling. Leakage and drainage to fresh groundwater supports groundwater pumping, but leakage and drainage to saline groundwater (as is the case across much of Sindh) is nonrecoverable for irrigation use. Desalination of saline groundwater could potentially augment urban supply.

Provincial Water Availability and Use

Current water availability varies between the provinces because of differences in the natural hydrology and extent of the provinces, and because of the water sharing arrangements enshrined in the 1991 Water Apportionment Accord (table 3.3). The Accord sharing largely reflects historical patterns of use. The Accord is discussed in more detail in chapters 4 and 5. The groundwater resource is solely direct rainfall recharge; river outflows are not allocated to any province but are reflected in the total resource estimate (table 3.3). The distribution across the provinces of internally generated water (runoff and recharge) is uncertain but is estimated according to climatic and hydrologic conditions.

The Accord-apportioned volume represents 61 percent of the total assessed resource. Punjab has access to over 41 percent of the national resource (excluding outflows) and has 53 percent of the national population. Water withdrawals in Punjab are 63 percent of the national total, meaning the level of resource use is highest here, with withdrawals exceeding availability by 20 percent—reflecting unsustainable groundwater abstraction and hence depletion (table 3.4).

The relative level of resource use—often called "water stress"—indicates the level of stress on the water resource and on water-dependent ecosystems, not the level of water stress experienced by communities or economic activities. Water availability per capita, while broadly indicative of resource availability, is not a meaningful indicator of water security overall. To illustrate: Balochistan and Sindh have the highest water availability per capita (table 3.4) yet are the least water secure provinces of Pakistan. Although Khyber Pakhtunkhwa (KP) has the lowest level of water availability per capita and the lowest levels of water use, rainfall is much higher in KP, meaning the reliance on streamflow and groundwater is lower. Per capita water use is highest in Sindh, probably because of few opportunities to recover the irrigation leakage and drainage water from (saline) groundwater.

Temporal Patterns

Water availability varies through time, largely driven by the temporal patterns in inflows. For users (including the environment) lower in the Indus Basin, flow variability also reflects the temporal patterns in withdrawals, consumption, and losses. These vary seasonally, especially given seasonal temperature cycles that drive water demand. The temporal pattern in Indus Basin inflows reflects the dominant inflow

Table 3.3 Average Annual Provincial Water Resource Availability in Pakistan
billion cubic meters

	Accord apportioned surface water	Internally generated runoff	Renewable fresh groundwater	Total renewable resource
Khyber Pakhtunkhwa	10.83	11	2	24
Punjab	69.00	19	9	97
Sindh	60.14	3	2	65
Balochistan	4.77	8	1	14
Pakistan	144.75	41	14	229

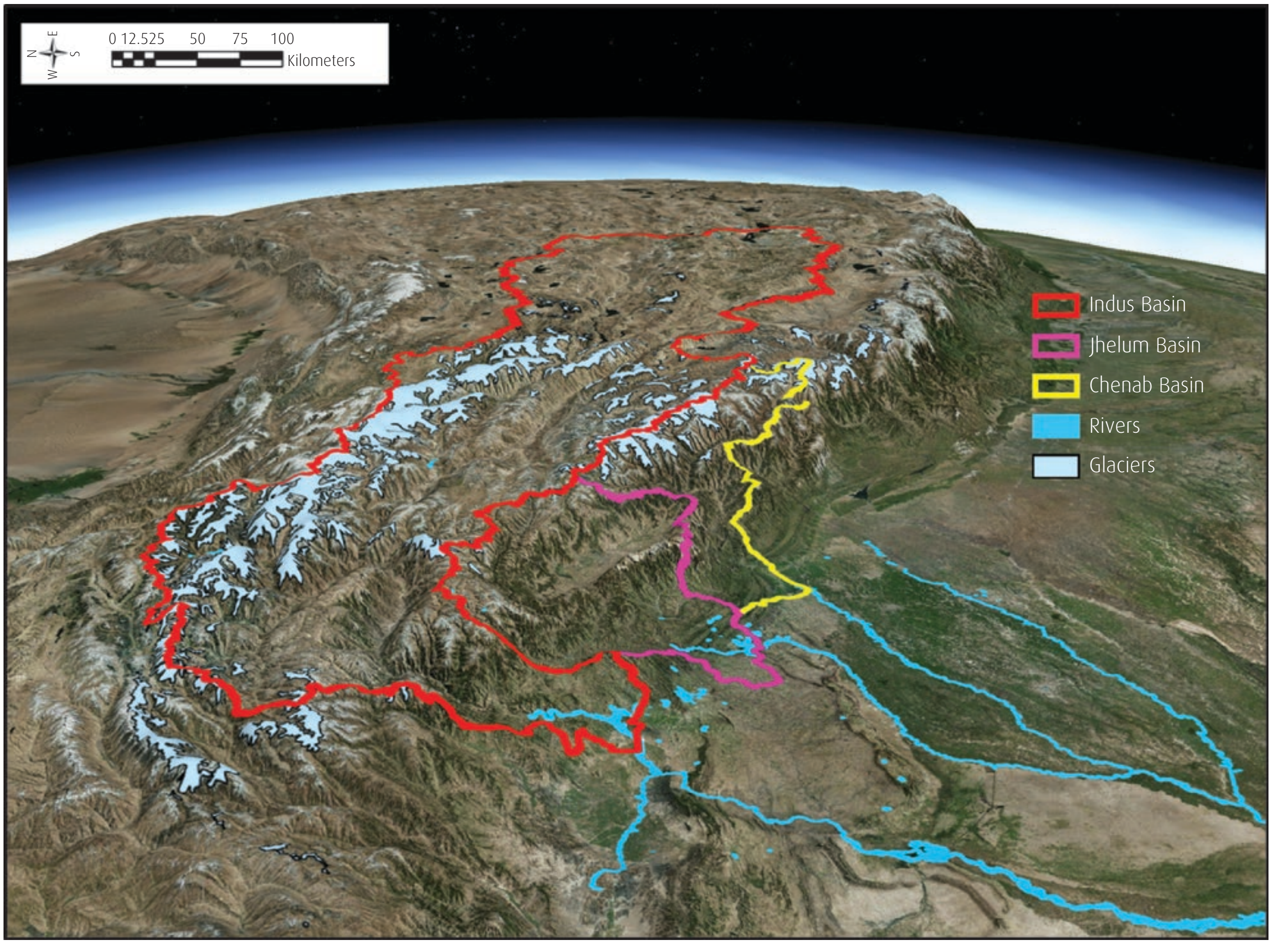
Source: Water Apportionment Accord and author calculations.

Table 3.4 Provincial Withdrawals, Level of Use, and per Capita Availability and Use in Pakistan
billion cubic meters (total withdrawals); cubic meters (per capita values)

	Total water withdrawals[a]	Relative level of resource use[a]	Water availability per capita	Water withdrawal per capita
Khyber Pakhtunkhwa	7	0.29	781	230
Punjab	118	1.21	882	1,069
Sindh	55	0.85	1,360	1,158
Balochistan	4	0.29	1,120	325
Pakistan	**184**	**0.80**	**1,102**	**885**

Source: GoP 2017 and authors' calculations.
a. Not adjusted for doubled counting of surface water and groundwater withdrawals.

Map 3.1 Oblique Aerial View of the Upper Indus Basin



Source: William Doan, USACE, *personal communication*.

sources in the major tributaries. Map 3.1 highlights the topographic differences between the main headwater catchments of the western rivers, which strongly determine their respective hydrological signatures.

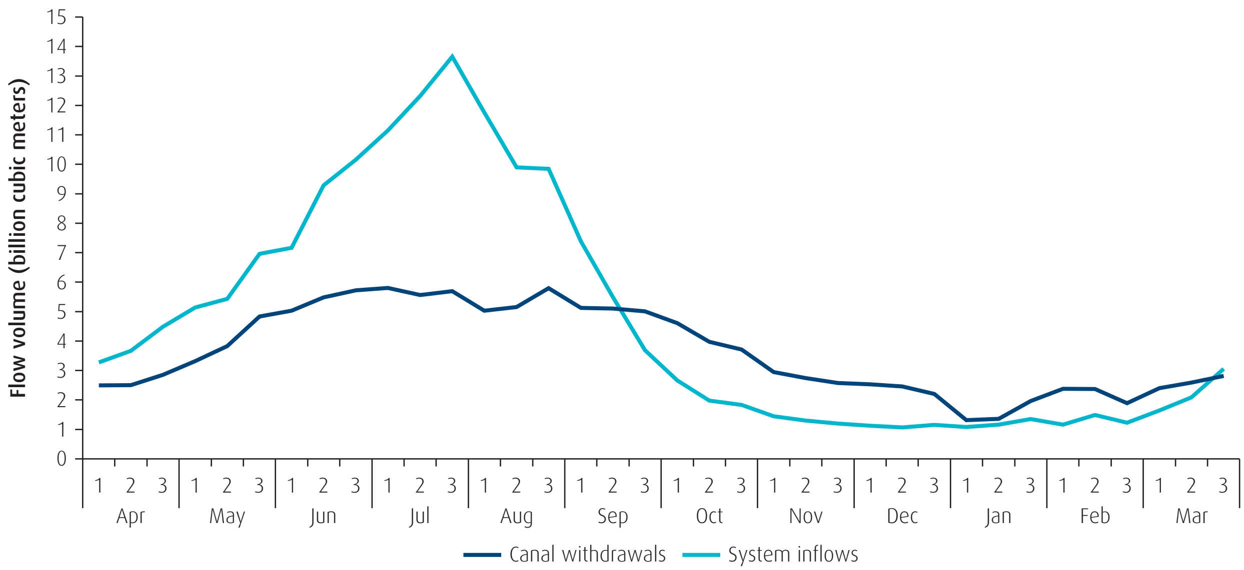
The lower altitude Sutlej, Beas, and Ravi rivers are dominated by monsoon rainfall runoff, peaking in August and September (Lutz et al. 2016). For the Indus mainstem, and hence of Tarbela Dam inflows, glacier meltwater dominates, peaking from July to September. For the Jhelum, and thus for Mangal Dam inflows, snowmelt dominates, peaking earlier from May to July. Combining these tributary signals illustrates a basin inflow pattern characterized by a wetter summer (karif) season (April to October) and a drier winter (rabi) season (October to April) (figure 3.3). Average karif inflows are four to five times that of average rabi inflows, and hence most inflows occur in the three-month period from June to August.

Kharif inflows far exceed irrigation demands; however, rabi inflows are inadequate to meet winter irrigation demand. Surplus karif inflows are therefore stored and released during rabi. The seasonal pattern of canal withdrawals reveals the temporal mismatch between supply and demand (figure 3.3). The real mismatch is starker, because rabi canal diversions are an underestimate of total demand and partially reflect the supply constraint because of limited storage. Adequacy of water storage is discussed further in chapter 4.

In Balochistan, precipitation has a less marked seasonal pattern; however, summers are very hot and dry, and potential evapotranspiration far exceeds rainfall. High natural losses mean many of the rivers are intermittent. Some are ephemeral and only flow following intense and localized storms, meaning interannual flow variability is high.

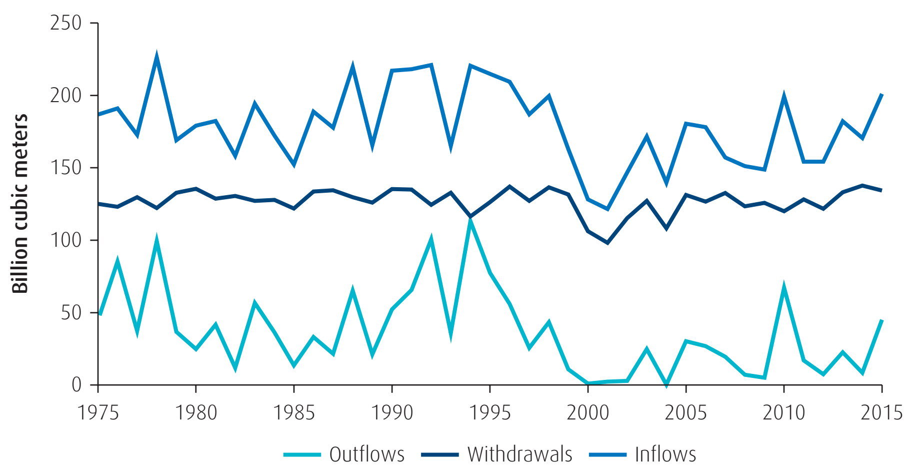
Despite a strong seasonal flow pattern, flow variability in the Indus between years is low compared to other major rivers in semi-arid regions. This is largely because the headwater glaciers (and to a lesser degree the multiyear snowpack) ensure more stable inflows, even with considerable variation in annual precipitation. Over the last

Figure 3.3 Average Annual Pattern of Average 10-Day Inflows and Canal Withdrawals, Pakistan



Source: WAPDA unpublished data.

Figure 3.4 Annual Indus Basin Inflows, Canal Withdrawals, and Outflows, Pakistan, 1975–2015



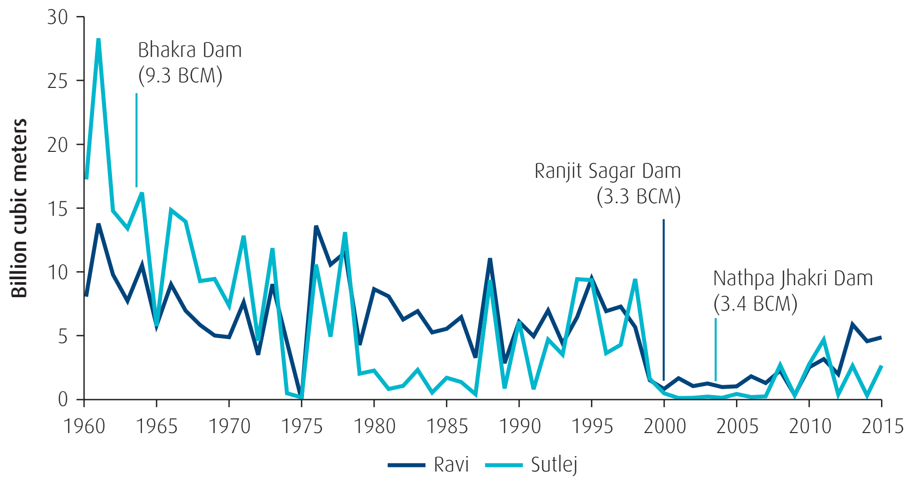
Source: WAPDA unpublished data.

40 years, annual Indus system inflows have varied from around 125 billion cubic meters to 220 billion cubic meters (figure 3.4). While inter-seasonal storage is important for irrigation in Pakistan, interannual storage is seldom required. Only during the driest years on record have inflows constrained annual canal withdrawals.

There is no statistically significant trend (at $P = 0.05$ significance level) in total Indus Basin inflows over the 55-year record from 1960 to 2015. However, the average annual inflow for the 16 years since 2000 (161.5 billion cubic meters) is significantly lower (by student t test) than the average annual inflow for the 16 years before 2000 (193.2 billion cubic meters). One factor contributing to this reduction is the significant reduction in the (albeit relatively small) inflows of the eastern tributaries (figure 3.5). Following the 1960 Indus Water agreement, which allocated the waters of the eastern tributaries to India, permitted development in India on the Ravi and Sutlej has resulted in progressing reduced inflows to Pakistan from these tributaries. This change accounts for less than one-quarter of the observed reductions in inflows between the 16-year periods before and after 2000.

There is no clear evidence of a contemporary flow reduction related to climate change. A detailed statistical analysis of long-term trends in flows in the Upper Indus Basin reveals falling trends in high-elevation glacial subcatchments balanced out by increasing trends in

Figure 3.5 Annual Inflows to Pakistan from Ravi and Sutlej Rivers, 1960–2015



Source: WAPDA unpublished data.
Note: Figure shows commencement dates and storage volumes for three major upstream reservoirs.

other subcatchments (Sharif et al. 2013). Reggiani and Rientjes (2014) find no statistically significant trends in a 50-year record of combined Upper Basin output or in 100-year records of Upper Basin precipitation. Rao et al. (2018) provide a paleohydrologic reconstruction of six centuries of flow at a number of Upper Indus Basin locations that shows greater flow variability than captured in the instrumental record, but again no long-term trend. They conclude that the observed higher flows of the 1980s and 1990s are unusual in the context of the past six centuries. They also note that the sensitivity of streamflow to summer temperatures suggests that expected future warming may increase basin inflow over coming decades, but any longer-term change will depend on long-term changes in snowfall and glacial mass balance.

Groundwater

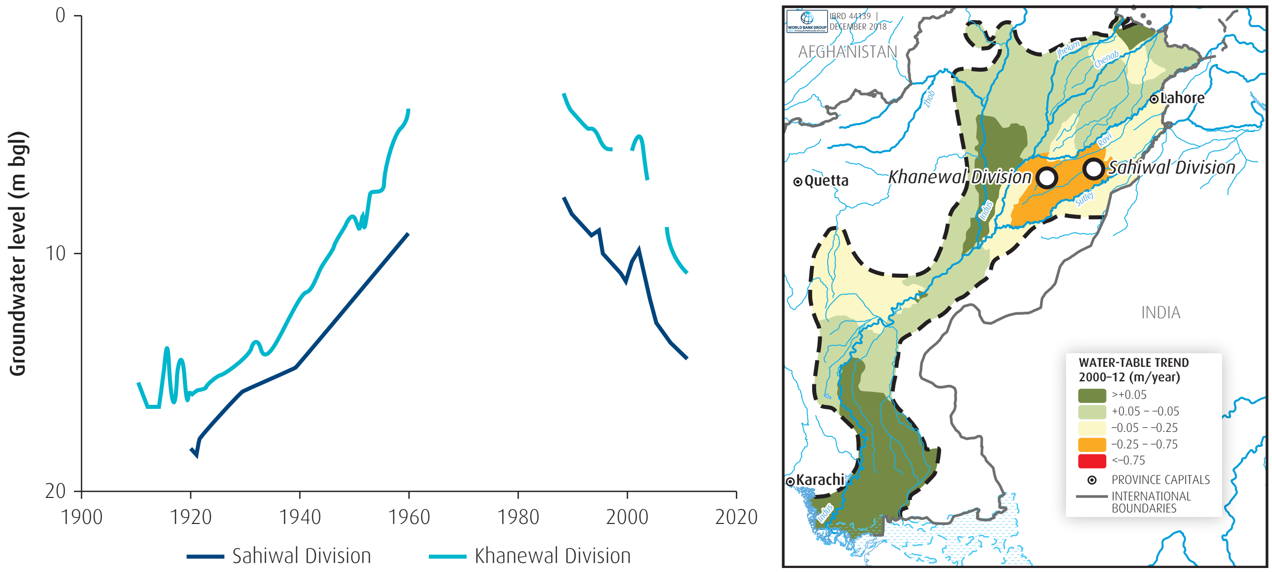
Given the seasonal variability of streamflow across Pakistan, and strong interannual variability of streamflow in Balochistan, groundwater is a critical water resource. An extensive, unconfined aquifer of unconsolidated alluvial sediment, covering 16 million hectares, lies under the Indus Basin (Qureshi et al. 2008). In Balochistan, the more limited but nonetheless important groundwater resources are found within older consolidated sedimentary landscapes. Groundwater is both accessible and plentiful across much of Pakistan. It is important for urban water supply, particularly for Lahore and Quetta, and for irrigation supply, especially in Punjab. However, this was not always the case. Easily accessible groundwater in the Indus Basin is largely a result of decades of seepage from surface water irrigation, which caused groundwater levels to rise in many areas by 10–15 meters over half a century. Thus, in the early decades of irrigation, overirrigation led to a steady rise in groundwater levels across Punjab and Sindh, leading to widespread water logging, especially in Sindh. Over the last few decades, rapid expansion of groundwater pumping in Punjab has led to significant declines in water tables, almost to predevelopment levels (figure 3.6).

Farther down the Indus Basin, the groundwater typology is influenced by natural variations in alluvial sediments and climate, and by the pattern of irrigation canals and distributaries. The changing depositional environment that led to the accumulation of the sediments of the Indus Plain has contributed to a heterogeneous sequence of sediment distribution, both vertically and laterally. These sediment characteristics directly impact the ability of the alluvium to retain, transmit, release, and store water, but in the absence of detailed surveys all groundwater assessments are approximate. In all but the marine-influenced deltaic areas, the irrigation schemes are the dominant contributors to contemporary groundwater recharge and exert a strong control on modern groundwater levels.

Renewable groundwater is defined by the recharge. However, with multiple recharge pathways—direct rainfall recharge, river recharge, flood recharge, canal leakage, and irrigation drainage (none of which are directly measured)—assessing the renewable groundwater resource is difficult. The average annual renewable groundwater resource has been estimated as 63 billion cubic meters (Briscoe and Qamar 2006). However, around three-quarters of this are sourced from surface irrigation leakage, and so cannot be simply added to the surface water resource.

FAO (2011) estimates an internally generated resource for Pakistan of 55 billion cubic meters, of which nearly 48 billion cubic meters is an overlap between surface

Figure 3.6 Groundwater Levels at Khanewal and Sahiwal Divisions, Punjab, 1910–2010



Source: Alan McDonald, British Geological Survey, *personal communication*.

water and groundwater resources. In other words, this volume is both river flow that recharge groundwater and groundwater that discharges to rivers as baseflow, implying a mere 7 billion cubic meters of direct rainfall recharge to groundwater. Van Steenbergen and Gohar (2005) estimate rainfall recharge to be around 14 billion cubic meters: this value is used in the water accounts and resource estimates in this report. Prior to groundwater development, natural recharge would have been balanced by discharge, including evapotranspiration of groundwater from floodplain wetlands and groundwater discharge to rivers and the sea.

Van Steenbergen and Gohar (2005) estimate that under contemporary conditions groundwater recharge comprises direct rainfall recharge (21 percent), canal and distributary leakage (45 percent), irrigation returns (26 percent), river recharge (6 percent), and other return flows (2 percent). This suggests that river recharge to groundwater is only 4 billion cubic meters, which is difficult to reconcile with the high river losses observed below Tarbela Dam. This reinforces the importance of better spatially distributed water accounting, especially of surface-groundwater exchanges. Despite the uncertainties, surface water and groundwater are tightly coupled in the Indus Basin, and need to be managed in a more integrated manner.

In Balochistan, groundwater is a smaller fraction of the total internal water resource. However, given the much greater interannual variability in river flows, and the very low levels of built water storage, groundwater dominates water use (Halcrow Group 2007). Indeed, groundwater use in Balochistan exceeds average recharge, and severe groundwater depletion has occurred in several parts of the province.

FoDP (2012) provides a provincewide groundwater balance indicating a combined average annual groundwater recharge of 74 billion cubic meters (table 3.5). This estimate is higher than the FAO (2011) and the Briscoe and Qamar (2005) estimates, and higher than the total groundwater flux included in figure 3.1a–c. The FoDP groundwater balance indicates 66 percent of total recharge is from irrigation recharge and 18 percent from rainfall—similar percentage values to those in van Steenbergen and Gohar (2005). The provincewide balances show recharge is dominated by irrigation seepage, especially in Punjab and Sindh. In Punjab, discharge is nearly all abstraction, while in Sindh and Balochistan, environmental evapotranspiration dominates.

FoDP (2012) suggests groundwater is in balance for all provinces except KP. This is not consistent with several other assessments that indicate significant groundwater depletion, including assessments based on GRACE satellite data. Assessments based on GRACE satellite data are at very coarse spatial scale and are typically poorly validated. However, a robust regional-scale assessment, based on in situ observations, shows that rising and falling groundwater levels exist across Pakistan (MacDonald et al. 2016).

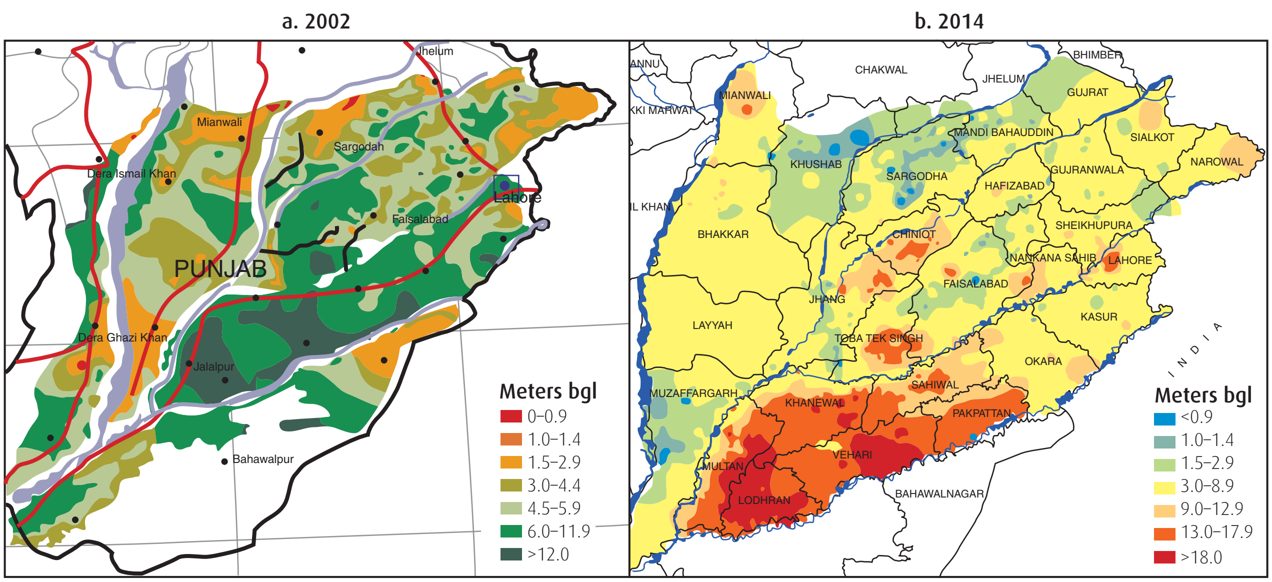
More local-scale assessments of the spatial pattern of depth to groundwater highlight the areas of Punjab where groundwater depletion is concentrated (map 3.2). Data from 2002 and 2014 reveal a similar pattern but show an increase in the extent of depletion

Table 3.5 Estimated Average Annual Groundwater Balances by Province in Pakistan
billion cubic meters

	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan	Total
Recharge					
Rainfall recharge	8.1	2.4	1.3	1.5	13.3
Recharge from irrigation system	27.0	18.9	2.3	0.8	49.0
Return flow from groundwater abstraction	8.5	1.0	0.2	0.1	9.7
Recharge from the river system	1.4	0.4	0.1	0.2	2.2
Total	**45.0**	**22.7**	**3.9**	**2.6**	**74.2**
Discharge					
Groundwater abstraction	42.5	4.3	2.2	0.6	49.6
Nonbeneficial evapotranspiration losses	2.5	17.0	0.3	1.4	21.2
Base flow from rivers and subsurface	0	1.4	1.8	0.6	3.8
Total	**45.0**	**22.7**	**4.3**	**2.6**	**74.6**
Net balance	0	0	−0.4	0	−0.4

Source: FoDP 2012.

Map 3.2 Groundwater Depth across Upper Indus Plain, 2002 and 2014

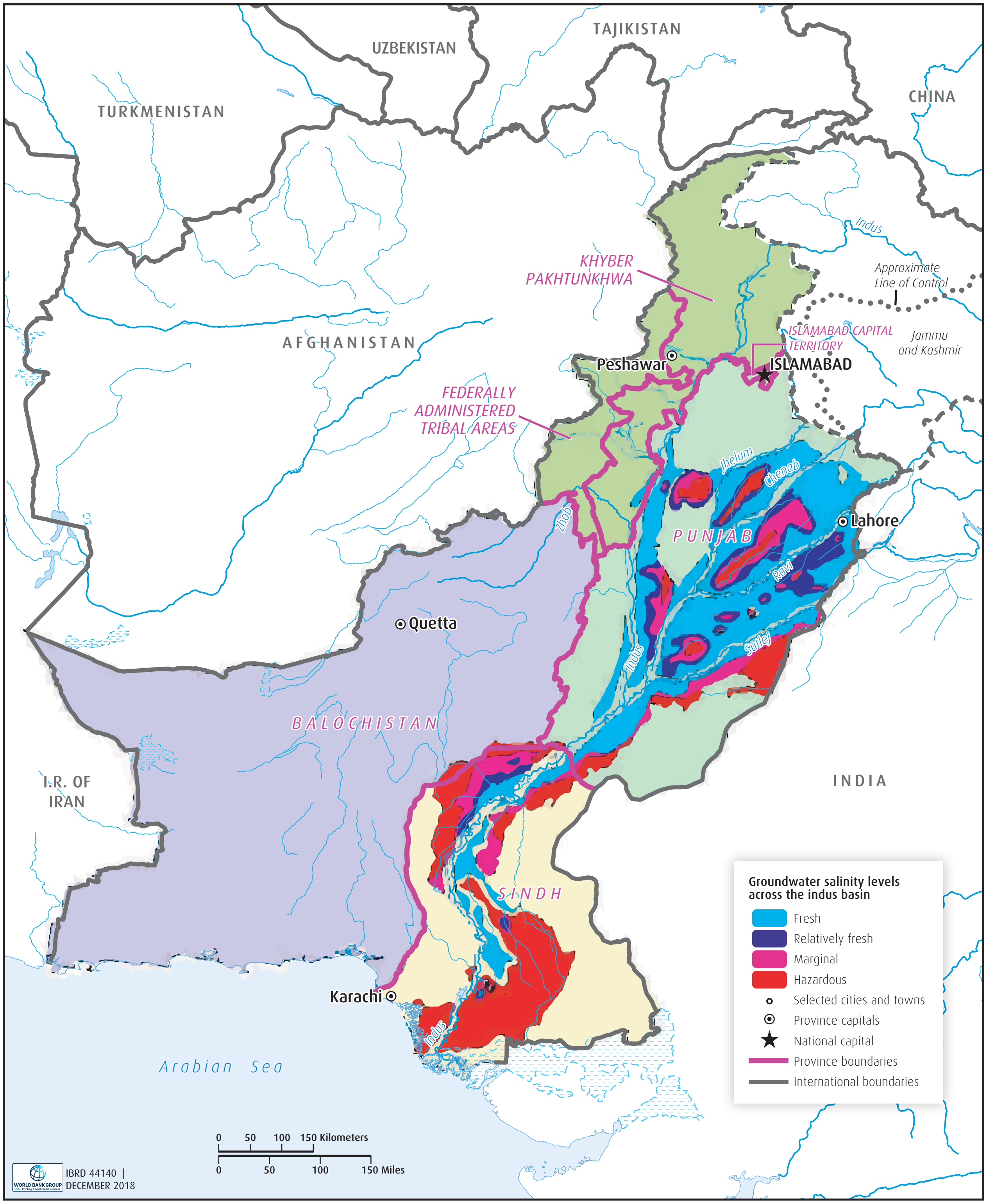


Sources: Panel a: Basharat, Umair, and Azhar 2014; panel b: Khan et al. 2016.

exceeding 12–13 meters in the lower Bari Doab. Depletion is also significant in parts of Balochistan.

The resource value of groundwater is strongly influenced by its quality. By area, well over half the alluvial aquifers of the Indus basin are saline and of limited value, especially in Sindh, although there are pockets of fresh groundwater associated with the lower river (map 3.3). Groundwater salinity patterns reflect distance from freshwater recharge, groundwater levels, and evaporation rates. In water logging areas, solute loads are typically high. Groundwater flow is slow because of naturally low gradients. Groundwater depletion can mobilize deeper (saline) groundwater, and marine incursion occurs in the southern deltaic region of Sindh. In areas distant from canal seepage recharge (parts of the Punjab and most of Sindh), groundwater use is low, groundwater levels are high, and waterlogging and high salinity are common. Groundwater dynamics and sustainability are discussed further in chapter 5 under the assessment of water resources management performance.

Map 3.3 Groundwater Salinity Levels across the Indus Basin of Pakistan



Source: Qureshi et al. 2004.

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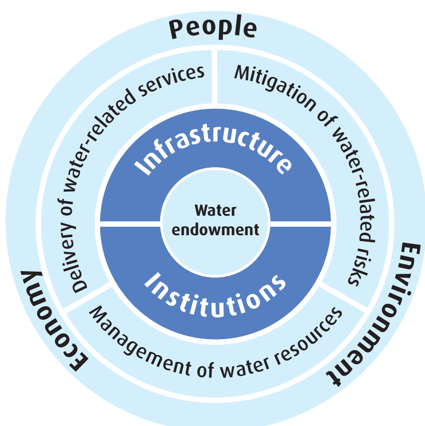
CHAPTER 4

Pakistan's Water Sector Architecture

Key Messages

- Pakistan has very extensive irrigation infrastructure, but it is poorly maintained and outdated given the level of performance now required. Extensive modernization is required to support efficient and effective irrigation and drainage services.
- It is widely believed that Pakistan has inadequate reservoir storage for reliable irrigation supply. But the low interannual flow variability of the Indus means interannual storage is not critical. In addition, new dams offer limited additional supply and comparatively low reliability. Nonetheless, Diamer Bhasha Dam can help mitigate the increases in flow variability anticipated with climate change and better match seasonal patterns of supply and demand, thus enhancing rabi supply reliability. Diamer Bhasha and proposed run-of-river dams are justified economically by hydropower, which can improve Pakistan's energy security.
- Pakistan has made major investments in flood protection infrastructure over recent decades. However, flood infrastructure needs significant additional investment because of expected increases in flood hazard (due to climate change) and increases in flood exposure (due to population growth and economic development).
- Pakistan has grossly inadequate infrastructure for the collection, storage, sharing, and analysis of hydrometeorological data and information. Significant investment is required in hydromet infrastructure to support improved water resource assessments; water accounting; and the forecasting of water availability, droughts, and floods, especially given a changing climate.
- None of Pakistan's cities have adequate water supply and sanitation infrastructure. In some cases, supply infrastructure is reasonable but poor maintenance undermines service delivery. In many cases, however, supply infrastructure is not keeping pace with rapid urbanization. In all cases, wastewater treatment infrastructure is grossly inadequate, causing widespread pollution and serious environmental and public health impacts.
- The national and provincial legal frameworks to support water policy implementation and to clearly define and assign legal mandates to relevant institutions are incomplete and require strengthening.
- The 2018 National Water Policy provides strong support for improving water resources management, echoing other policy documents, including the National Climate Change Policy. Provincial policy frameworks for irrigation and water resources management are partial, fragmented, or nonexistent, and implementation has been inadequate. The policy frameworks for urban water services lack clarity and are not well aligned with relevant legislation, including local government legislation.
- The institutional responsibilities for several aspects of water resources management are poorly delineated between national and provincial levels and between entities at these levels. Institutional responsibilities for urban water overlap or are unclear.
- Provincial water sector financing has increased in recent years; however, federal financing has declined significantly in proportional terms. Collectively, sector financing is well below recommended levels. This is assessed to be the case for financing of major infrastructure, reforms and institutional strengthening, urban services, flood mitigation, and environmental management.

This chapter describes the architecture of Pakistan's water sector as a foundation for the subsequent assessment of water sector performance. Sector architecture is the enabling environment for sector performance. Sector architecture is described here in terms of infrastructure, governance, and financing. Governance encompasses the legal frameworks, policy settings, and institutional arrangements for water management. It is impossible to entirely separate sector architecture and sector performance, and thus this chapter, while primarily descriptive, includes some critique of the adequacy of sector architecture.



Infrastructure

Water infrastructure—public and private—is necessary for all aspects of water sector performance. It is crucial for measuring water stocks and flows, storing and distributing water, generating hydropower, ensuring appropriate quality of water supply, removal and treatment of wastewater (domestic, industrial, and agricultural), and protection from floods. This section summarizes the evolution of Pakistan's water infrastructure, describes the major new infrastructure being planned, and highlights major infrastructure gaps. Chapter 5 provides additional discussion of the adequacy and performance of key infrastructure.

Indus Basin Irrigation System

The Indus Basin Irrigation System (IBIS) (figure 4.1) is a large, complex system of hydraulic infrastructure that has been developed incrementally over many decades (figure 4.2). It represents an estimated US$300 billion in investment. Some of the irrigation infrastructure predates the formation of Pakistan but following partition (when the total canal command area was around 10.4 million hectares), new irrigation systems were developed. Jinnah Barrage was completed in 1947; Kotri Barrage, 1955; Taunsa Barrage, 1959; Guddu Barrage, 1962; and Chashma Barrage, 1971, increasing the canal command area by 35 percent to 14 million hectares.

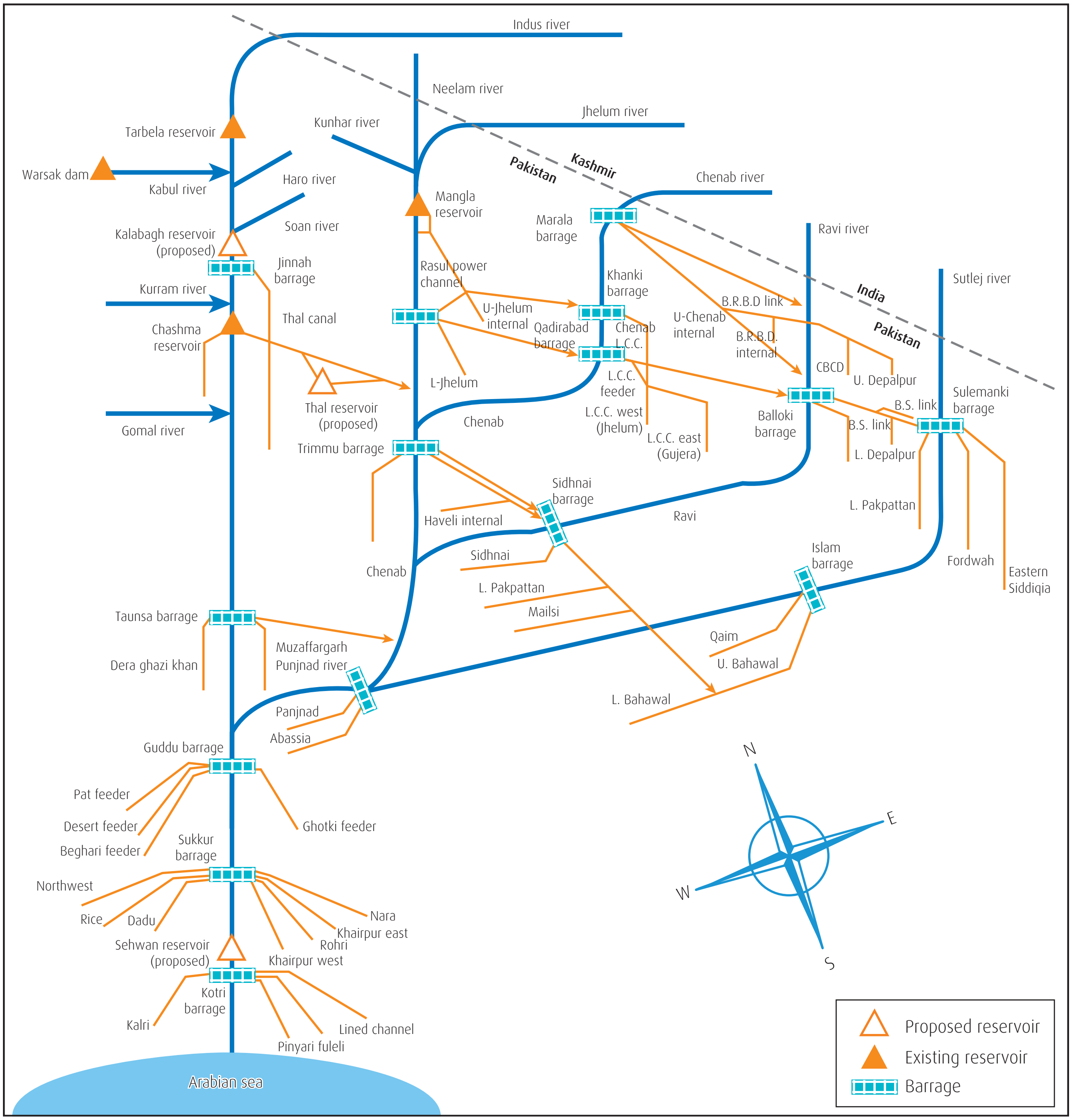
Fundamental to the design and operation of the IBIS are a series of link canals that move water eastward from the mainstem Indus and the western tributaries to the eastern tributaries. The earliest link canals—the Upper Jhelum and the Upper Chenab links—expanded irrigation on the western Rechna and Dari doabs, respectively. Following partition, further link canals were built, and with the signing of the Indus Waters Treaty in 1960 and the allocation of the waters of eastern rivers to India, the Trimmu-Sidhnai and Mailsi-Bahawal canals were constructed to supply water from the western rivers to canal systems that were previously fed from Ravi and Sutlej rivers. Some of the multiple link canals, in addition to transferring water from one river system to another, supply irrigation water to one or more irrigation channels that off-take directly from the links.

IBIS water, which services 17.2 million hectares, is regulated through three major reservoirs, 16 barrages, two headworks, two siphons across major rivers, and 12 interriver link canals. The irrigable area consists of 44 canal commands: Punjab has 23; Sindh, 14; Khyber Pakhtunkhwa (KP), five; and Balochistan, two. The upper IBIS (11.3 million hectares) comprises 28 canal commands in KP and Punjab; the lower IBIS (5.9 million hectares) comprises 16 canal commands in Sindh and Balochistan below Guddu Barrage. The distributary network that services these command areas is extensive, with an estimated 4,000 distributary channels divided into 107,000 watercourses. There is an estimated 44,000 kilometers of canals and distributary channels and close to 20,000 kilometers of drainage channels (Euroconsult 2011). Euroconsult (2011) provides detailed descriptions of the irrigation systems of each province. Figure 4.2 provides a brief summary of key infrastructure and the nature of irrigation provided by province.

The IBIS is supply-driven rather than demand-driven: demand usually exceeds supply, and available water is "pushed out" through the distribution system according to largely fixed rules. IBIS operation is almost fully manual. There is no internal reregulating storage, very rudimentary control for farm-level water delivery, and despite considerable and ongoing investment and improvement, most of the extensive distribution network is unlined and leaky.

Maintaining and operating the IBIS costs an estimated US$102 per hectare per year (FoDP 2012); the largest annual costs per hectare are for the main canals (US$38); distributaries (US$24); headwater dams (US$20); and headworks, barrages, and link

Figure 4.1 Indus Basin Irrigation System of Pakistan



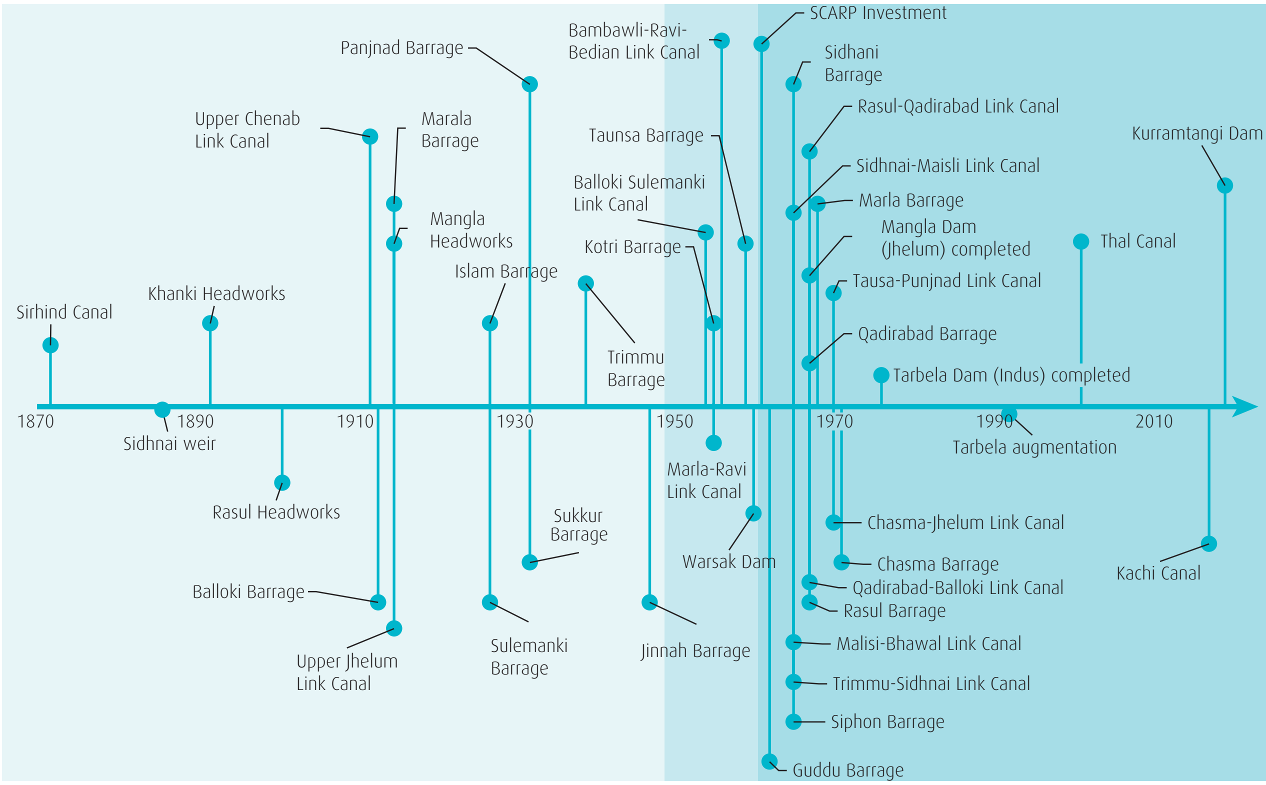
Source: FoDP 2012.

canals (US$6). These costs are not significant relative to the gross margin of wheat (approximately US$300 per hectare per year; e.g., Ishfaq et al. [2017]). IBIS's condition is generally poor, and there is no asset management plan. The poor state of the irrigation infrastructure reflects deferred maintenance, low cost-recovery and collection efficiency, and a build–neglect–rebuild cycle. The poor condition of IBIS is one cause of poor service delivery (see chapter 5). For example, many irrigation canals also supply water for urban and rural domestic needs and livestock, yet they receive untreated wastewater.

Khyber Pakhtunkhwa

Irrigation in KP is primarily in three geographic areas. The largest is a contiguous area serviced by water from the Indus River (through the Pehur canals), the Swat River (through the Swat canals), and Kabul River (through the Warsak and Kabul canals). To the

Figure 4.2 Timeline of Major Irrigation and Water Resources Infrastructure in Pakistan, 1870 to Present



Note: Shadings indicate pre-Pakistan, pre-IWT and post-IWT periods.

southeast of this contiguous area is a smaller area serviced by the Tanda Dam canals and the Marwat Canal system. The Chashma Right Bank canals service a long narrow irrigation area parallel to the Indus mainstem downstream of Chashma Barrage. In addition to government-operated and -maintained canals, there are a series of smaller private (or "civil") canals, recognized under the Water Apportionment Accord. Groundwater pumping supplements a mere 4 percent of the area irrigated by canals.

Punjab

Punjab has the largest and most complex irrigation system of Pakistan. The Indus River supplies water from the Tarbela Dam to the Jinnah and Chashma barrages and the Taunsa Headworks, which connects to two major link canals and four main canals. The Jhelum River supplies water from the Mangla Dam to the Rasul Barrage, which connects to two major link canals and two main canals. The Chenab River supplies water to four major headworks (Marala, Khanki, Qadirabad, and Trimmu), which feed five major link canals and four main canals, and a number of smaller branch canals. The Ravi River supplies water to two headworks (Ballokai and Sindhnai), which feed two major link canals and two main canals, and the Sutlej River supplies water to three headworks (Sulemanki, Islam, and Panjnad), which feed eight main canals. Across the thousands of kilometers of canals and distributaries, an estimated 58,000 outlets supply water to farms. Maintenance and upgrading is complex and problematic and has been the focus of considerable development finance in the past, including for lining thousands of kilometers of canals and distributaries.

In addition to this complex water distribution system, an estimated 800,000 private tube wells across Punjab supplement surface water supply (Qureshi 2010). Around 21 percent of the irrigated area relies solely on groundwater, and an additional 55 percent of the area relies on supplementary groundwater irrigation, especially during rabi when canal water is insufficient to meet demand. The reliance on groundwater sets Punjab apart from the other provinces; therefore, conjunctive management of surface water and groundwater is critical.

Achieving adequate irrigation drainage in Punjab is difficult. While some water drains back to the river, a fraction is too saline for safe disposal in the river. Trials of evaporation basins have not proved successful, given the risks of groundwater contamination and the large land areas required. Saline drainage from around 2 million hectares is moved from near the

Punjab–Sindh border in the Left Bank Outfall Drain either directly to the Arabian Sea or to the shallow, saline Shakoor Lake that straddles the Pakistan–India border west of the Great Rann of Kutch.

Sindh

Irrigation in Sindh dates back several thousand years. Irrigation canal systems were extended and improved during the late 1800s, and a major program of irrigation expansion began under British rule in the latter half of the 19th century. Barrage irrigation commenced in 1932 when the Sukkur Barrage became operational, followed by Kotri (1955) and Guddu (1962). Over half of the Sindh command area is supplied from Sukkur Barrage through four left-bank and three right-bank canals. Guddu supplies around one-quarter of the Sindh command area, and Kotri supplies less than one-quarter. Saline groundwater lies under at least 80 percent of the irrigated area, and groundwater irrigates less than 20 percent of the total area. Sedimentation around the lower barrages has been a major problem for effective barrage operation and barrage safety—affecting the ability of barrages to pass major floods. There has been significant recent and ongoing investment in restoring and modernizing the Guddu and Sukkur barrages.

Thirteen surface drainage systems in Sindh service half the irrigated area, and two subsurface drainage systems service 2 percent of the irrigated area. However, the Sindh drainage system is neither contiguous nor integrated, and waterlogging is widespread due to high surface water delivery (van Steenbergen et al. 2015). For more than one-third of the command area, the water table is within 1 meter of the surface, and across another third it is between 1–1.5 meters. The root zone is thus waterlogged across 70 percent of the command area for much of the time, only decreasing at the end of rabi when canal supply dwindles (van Steenbergen et al. 2015).

Balochistan

Canal irrigation in Balochistan is limited and supports just 0.3 million hectares (around one-fifth of the irrigable area). Water from the Indus is supplied by the recently completed Kacchi Canal from the Taunsa Barrage, by the Pat Feeder and Desert canals from the Guddu Barrage, and by the Khirthar Canal from the Sukkur Barrage. Small-scale irrigation from groundwater and the perennial rivers (of the Makran coastal and Indus drainage systems) support close to another 0.3 million hectares. Groundwater is accessed through traditional *karezes*, shallow dug wells, and deep tube wells. An additional 0.3 million hectares, approximately, are serviced by flood, or spate, irrigation (*sailaba*), which uses very simple diversion structures to harvest short, flashy floods into bunded basins to pond and infiltrate. Water harvesting (*khushkaba*) is a smaller version of flood irrigation that relies on capturing local unchanneled surface runoff in bunded basins; it serves around two-fifths of the irrigable area. The provincial government manages canal irrigation and, to a lesser extent, small-scale irrigation schemes. Farmer communities manage water harvesting and flood irrigation, although the government supports infrastructure construction.

Major Reservoirs and Hydropower

Three large dams constructed in the 1960s and 1970s—the Tarbela on the Indus, the Mangla on the Jhelum, and the Chashma on the Indus—account for most of the built water storage in Pakistan (WAPDA 2016). Designed primarily to supply water for irrigation, the original combined live storage capacity of these dams was 19.4 billion cubic meters (Tarbela, 12 billion cubic meters; Mangla, 7.3 billion cubic meters; and Chashma, 0.87 billion cubic meters). Ongoing sedimentation has, however, decreased capacity by around 1 percent per year to 15 billion cubic meters by 2007. Inspections of the Tarbela Dam have found it could have been designed to remove sediment using drawdown flushing, but subsequent downstream development (barrages and irrigation off-takes) would have precluded major sediment flushing.

The average annual sediment discharge into Tarbela Dam is about 181 million tons. The trap efficiency of the reservoir, that is, the percentage of incoming sediment retained by the reservoir, is greater than 95 percent in most years. The live reservoir capacity in 1974 was 11.94 billion cubic meters but declined to 8.55 billion cubic meters by 2006—a reduction of more than 28 percent in 32 years. The volume of sediment accumulated in the reservoir is now too large for practical removal. Construction of Diamer Bhasha Dam upstream of Tarbela will create a sediment trap, thus incrementally reducing Diamer Bhasha live storage but significantly slowing the sedimentation rate of Tarbela. Mangla Dam was enlarged between 2005 and 2009 (at a cost of around US$1 billion) adding an additional 3.6 billion cubic meters of live storage. Due to continued sedimentation, combined live storage is estimated to be around 16 billion cubic meters. Diamer Bhasha Dam, at preliminary construction stage and with an estimated total cost of around US$14 billion, will add 7.9 billion cubic meters of live storage. At projected completion in 2023, total system storage will be around 21 billion cubic meters. The ongoing loss of storage because of sedimentation costs tens of millions of U.S. dollars per year, which is very small relative to the total annual IBIS maintenance cost.

Table 4.1 Current and Future Reservoir Capacity and Active Groundwater Storage Capacity in Pakistan

	Current reservoir capacity	Future reservoir capacity	Active groundwater storage capacity
Days of average inflow	34	48	5,739
Days of kharif inflow	20	29	3,397
Days of rabi inflow	94	135	16,107
Days of average irrigation supply	46	66	7,863
Days of kharif irrigation supply	35	51	6,016
Days of rabi irrigation supply	68	98	11,612
Years of national urban demand	11	15	1,824
Years of Karachi demand	18	26	3,123

Source: Author calculations.

An oft-cited reason for Pakistan's lack of water security is insufficient reservoir storage. Many comparisons have been made to other major river systems based on storage volume per capita or days of storage in terms of the average flow. Table 4.1 indicates the days or years of storage in terms of average and seasonal flows, and agricultural and urban demands, both for the current and future storage volumes. Because kharif demand is largely synchronous with natural supply timing, it is storage for rabi demand that is most important. Current storage can meet 68 days of average rabi irrigation supply. Current storage is not a constraint to urban water supply reliability. Although distribution infrastructure is not in place to supply reservoir water to all major cities, Indus system storage is equivalent to 11 years of current total urban demand or 18 years of Karachi demand. Urban supply reliability is an issue of intersectoral demand prioritization and storage operation.

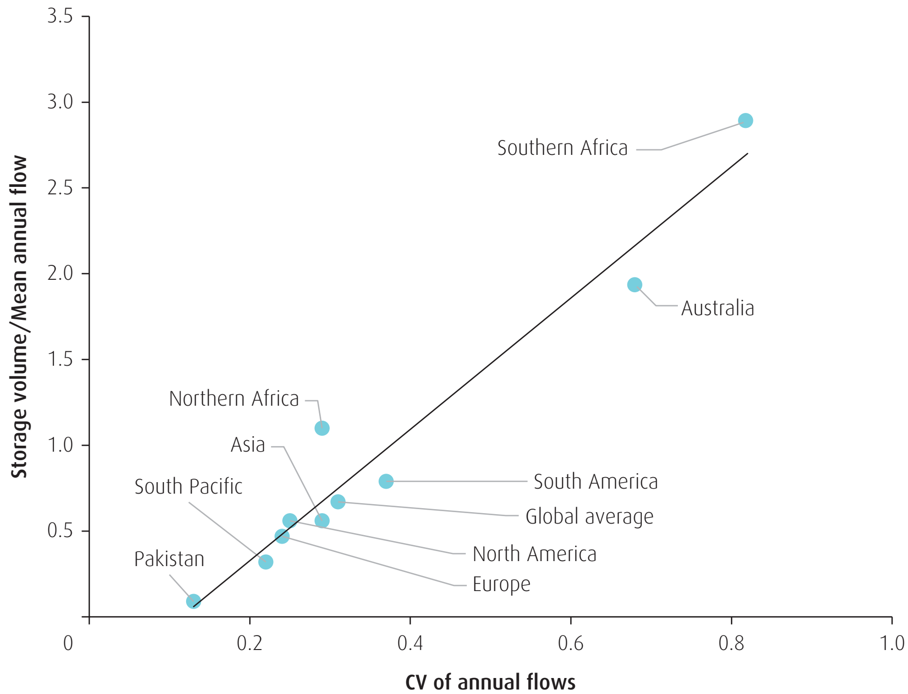
Storage comparisons can be made for active groundwater storage and glacier water storage. Khan et al. (2016) estimate Pakistan's active groundwater storage to be 2,736 billion cubic meters—170 times current reservoir storage—notionally equivalent to over 20 years of canal irrigation supply. Investigations of the pragmatism of enhanced operational management of the groundwater storage capacity are therefore warranted. Current rates of groundwater depletion that have attracted much attention may turn out to be reasonable in the context of a multiyear conjunctive water use strategy, except in the cases of severe localized depletion.

The volume of glacial ice between the entire Himalaya and Karakoram ranges is estimated to be between 3,000 billion cubic meters and 5,000 billion cubic meters. Around half the glaciated area is in the Karakoram range of the Upper Indus (Azam et al. 2018). Glacier "storage" cannot be actively managed for water supply, but discussions and planning of storage reservoirs must recognize this important natural storage in the Indus basin because it ensures a far more naturally regulated flow than in most other large river basins of semi-arid regions.

Although comparisons between river systems on such metrics as "days of average flow storage" are interesting, they can be very misleading. The level of storage required in a water supply system depends on the variability of inflows, the temporal pattern of demand, and the economically acceptable level of variation in meeting these demands. In many large arid-zone rivers, inflows are far more variable between years than in the Indus. The dominance of meltwater (glaciers and snowpack) in the Indus means inflows are far more stable between years than in most other large irrigated basins.

A global comparison of the level of system storage relative to the variability of annual flows indicates that while storage in the Indus is indeed very low (less than 10 percent of the mean annual flow), this is commensurate with the low variability of annual flows (figure 4.3). The high relative storage volumes commonly cited for other basins—two to three times the mean annual flow—are not required for the Indus for managing the low interannual flow variability. Nonetheless, although in the past system storage has enabled annual canal withdrawals to be reasonably reliable, storage is inadequate for mitigating the impacts of major drought sequences such as 1999–2001. Past modeling has indicated that the addition of Diamer Bhasha will help mitigate (but not remove) the impacts of major droughts (Robinson and Gueneau 2014). There are other options besides additional storage to manage inflow variability, including conjunctive surface water and groundwater management and water markets (see chapter 5).

Figure 4.3 Reservoir Storage Volume as Ratio of Mean Annual Flow Compared to Coefficient of Variation of Annual Flow for Selected Countries and Regions



Source: WAPDA unpublished data for Pakistan and data from McMahon et al. 2007.
Note: Relative storage value is the median of quoted ranges, assuming 75 percent draft (yield) and 95 percent reliability. CV = coefficient of variation.

Although the Indus is characterized by strong seasonal flow patterns, the timing of inflows is not entirely mismatched with the timing of water demand, unlike many basins in temperate climates in which winter inflows support summer irrigation. The performance of the IBIS is to some degree limited by available storage, but primarily because of an inability to fully meet rabi demands, for which groundwater pumping is critical. Additional storage would enhance the ability to regulate flow and store water within the year between seasons. Additional storage could increase total system yield. However, as established by Lieftinck, Sadove and Creyke (1968), once storage on the Indus reaches around 22 billion cubic meters, additional storage volume becomes increasing inefficient: for each unit of storage volume added the volume of additional yield is progressively less. The addition of Diamer Bhasha will bring storage on the mainstem Indus to around 16 billion cubic meters. Further, as shown by World Bank (1998), the additional yield from new storage would be of lower reliability, quickly dropping below the current 75 percent (proportion of years that storages fill totally). For example, the incremental additional storage from the Mangla enlargement is estimated to have a reliability of 72 percent. At 25 billion cubic meters of system storage, overall yield reliability would drop to 40 percent to 60 percent or even lower depending on environmental flow targets (World Bank 1998).

Low reliability yield is not without value but requires an irrigation sector that adapts well to yearly changes in water supply—this is not currently the case. Low reliability yield can support opportunistic irrigation that generates intermittent economic returns. Farmers with only low reliability supply need alternative sources of income in drier years.

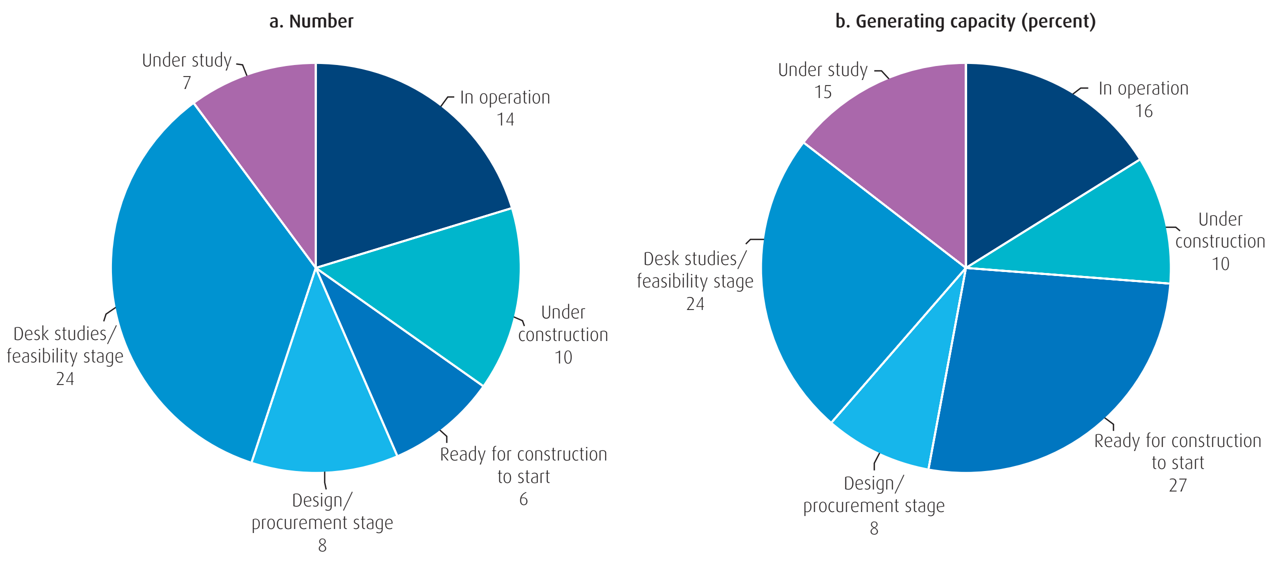
Global analyzes and modeling of the Indus support the view that additional reservoir storage alone will be of limited value for addressing water supply shortages. Gaupp, Hall, and Dadson (2015) consider the role of water storage infrastructure for managing intra- and interannual water supply variability for more than 400 important river basins around the world, based on macro hydrologic modeling. For the Indus-Pakistan, they find that while it ranks highest in the world in terms of scarcity (defined in terms of a temporal analysis of supply-demand gaps), storage dependency is among the lowest of all water scarce areas, because the scarcity index for the Indus in Pakistan is very similar with or without storage. This is because demands are similar very high relative to supply and are not compromised by interannual supply variability. A simpler analysis by Brown and Lall (2006) reaches similar conclusions. They assess demand in terms of the water required to grow sufficient food for the national population and calculate annual and intra-annual water balances by analysis of rainfall variability—which for the Indus undervalues meltwater. Their calculations enable analysis of the storage required to match supply to demand, and, consequently, the water efficiency needs ("soft" measures) to balance supply and demand when storage is not a constraint. Even considering only rainfall variability, Brown and Lall (2006) find that for the Indus, shortages should be managed entirely with "soft" measures and not with additional storage.

Hydro-economic modeling of the Indus system by Yu et al. (2013) includes a scenario with new storage equivalent to more than twice the live capacity of the Diamer Bhasha. While the additional storage would likely mitigate the economic impacts of drought, the overall economic outcome would be negative if the significant value of additional hydropower were excluded, and both agricultural gross domestic product (GDP) and household income declined. This scenario is likely because the current irrigation system does not have the capacity to benefit from increased average supply, and even improved reliability of rabi supply is of relatively minor economic value given the dominance of wheat production and the large costs of major new infrastructure. In contrast, scenarios of improved irrigation system efficiency and improving crop technologies and yield—either separately or combined—delivered significant economic benefits. These analyses did not consider scenarios of managed environmental flows or the economic benefits of environmental flows.

The hydropower benefits of existing and proposed new dams are significant. Hydropower accounts for about 35 percent of national electricity generation (see chapter 2). Total installed capacity is about 7.3 gigawatts, dominated by Tarbela (3.5 gigawatts), Ghazi Barotha (1.5 gigawatts), and Mangla (1.0 gigawatts). Pakistan has ambitious plans to increase hydropower capacity more than fivefold through 55 new projects that are at various stages of readiness, including 10 under construction (figure 4.4, panels a and b). Many of the proposed projects are run-of-the-river, with little storage. Run-of-the-river schemes rely directly on river flows, although most have a small reservoir to dampen the short-term inflow variations and manage sediment impacts on gates and turbines. They are sometimes downstream of a major storage scheme (e.g., Ghazi Barotha downstream of Tarbela). Generation by storage schemes (e.g., Tarbela and Mangla) is a function of reservoir water level (hydraulic head to turbines) and rate of flow release.

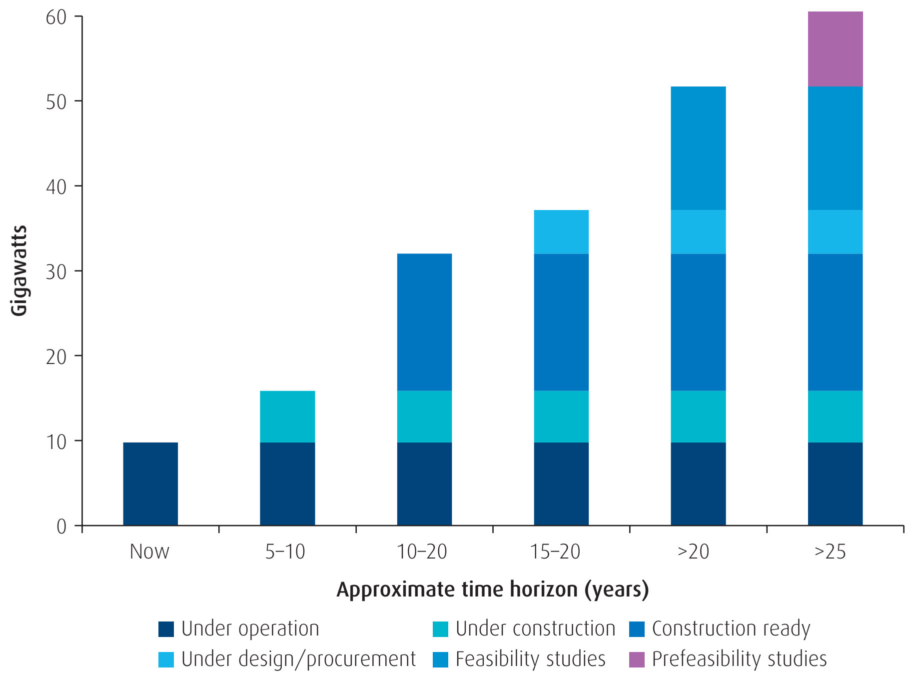
The sequence from a prefeasibility study to identify potential projects through construction and operation takes many years. Despite considerable uncertainties, including questions of financing, a timeline of increasing capacity shows Pakistan could triple its hydropower generation capacity within the next few decades (figure 4.5. The proposed expansion is predominantly in KP and Jammu and Kashmir (figure 4.6), including a string of 10 dams along the Upper Indus Basin commonly referred to as the "Indus Cascade." A small number of the total proposed projects are considered priority projects by WAPDA, and of these, only Diamer Bhasha adds significant additional storage (table 4.2). Continued development of this significant series of hydropower projects can help improve Pakistan's energy security, but the

Figure 4.4 Pakistan's Dam Readiness Stage by Number and Generating Capacity



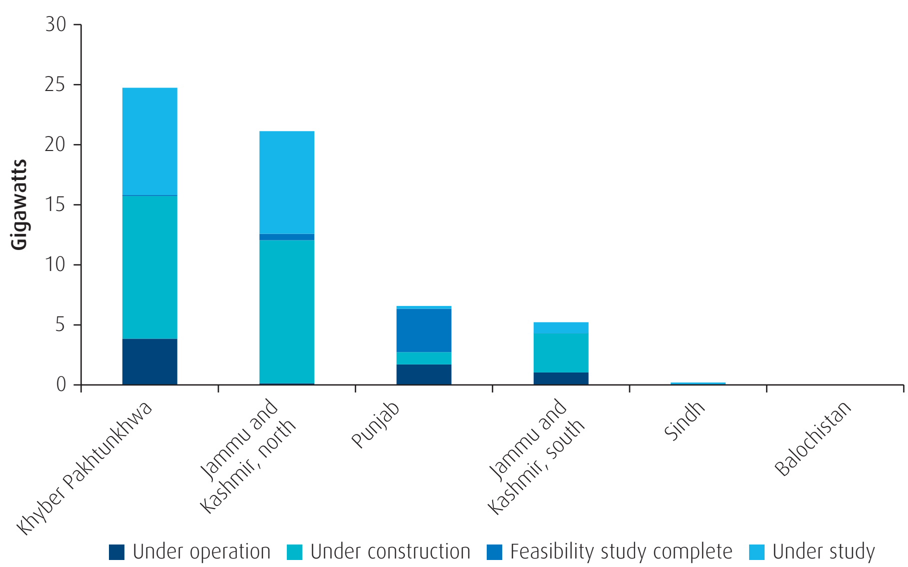
Source: WAPDA unpublished data.
Note: Tarbela is counted as "in operation," including extensions IV and V.

Figure 4.5 Projected Increases in Hydropower Capacity, Pakistan



Source: WAPDA unpublished data.
Note: Tarbela counted as "under operation," including extensions IV and V.

Figure 4.6 Capacity of New Hydropower Projects by Readiness Stage and Province or Territory, Pakistan



Source: WAPDA unpublished data.

cascade investments will have limited impact on water management further downstream (with the exception of Diamer Bhasha, which will assist with drought and flood mitigation and improve reliability of rabi supply).

Flood Protection Infrastructure

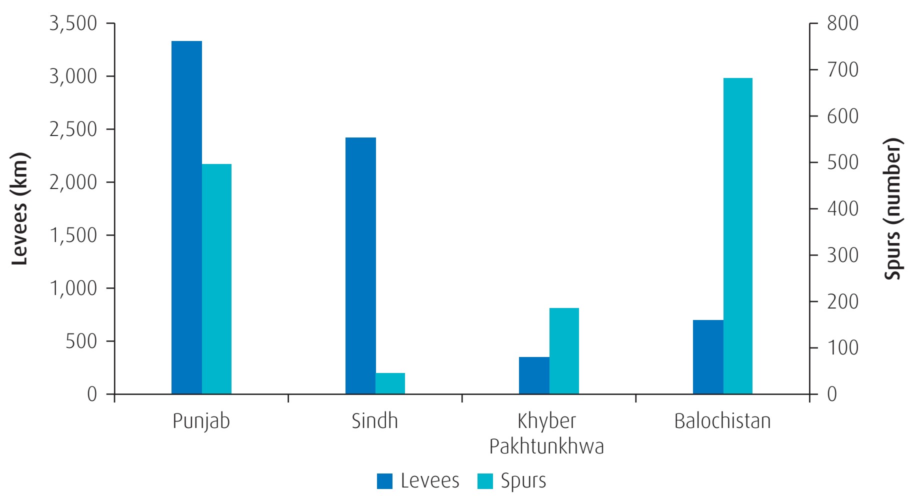
Pakistan has an extensive system of flood protection, mainly comprising levees and spurs along the Indus mainstem and its major tributaries. About 6,800 kilometers of river are embanked with levees, mostly in Punjab and Sindh (figure 4.7). In Punjab, there are levees on the left and right banks of the main stem of the Indus River between Taunsa Barrage and the confluence with the Chenab River. The Chenab is leveed on both sides between Sidhnai Barrage and Panjnad Barrage to protect the city of Multan and surrounding areas. The southern bank of the Sutlej River between

Table 4.2 Priority Dam Projects in Pakistan

Dam	River	Capacity (GW)	Live storage (BCM)	Estimated cost (US$, billions)	Status
Diamer Bhasha	Indus	4.50	7.9	11.18	Construction ready
Kurram Tangi	Kurram	0.08	1.1	0.70	Under construction
Tarbela 4th Extension	Indus	1.35	—	0.83	Ready for construction
Munda	Swat	0.74	0.9	1.40	Under study
Kohala	Jhelum	1.10	run-of-river	2.40	Design/procurement
Bunji	Indus	7.10	run-of-river	6.84	Construction ready
Dasu	Indus	4.32	0.8	5.21	Under construction
Total		**19.19**	**10.7**	**28.55**	

Sources: FoDP 2012; WAPDA 2016.
Note: — = not available.

Figure 4.7 Length of Levees and Number of Spurs by Province in Pakistan



Source: Ali 2013.

Islam Barrage and Panjnad Barrage is also protected by levees. There are few levees, however, along the Jhelum River. In Sindh, the left bank of the Indus is leveed along its full length (around 600 kilometers), and the right bank is leveed from Guddu Barrage to Manchar Lake. A total 1,410 flood spurs have been built since 1960 to protect riverbanks from erosion and direct flood flows. Nearly half of Pakistan's flood spurs are in Balochistan, where their flow-diverting function is an integral part of the many spate irrigation systems.

The 18 barrages can be operated to divert flood flows and reduce downstream flooding. Although constructed primarily for water supply, Mangla and Tarbela dams provide some flood mitigation potential. Following the 1992 flood, reservoir operating protocols were revised to incorporate flood mitigation objectives (Ali 2013). In the 2010 flood, Mangla Dam operations reduced downstream flood heights by 35 percent, and Tarbela Dam operations reduced downstream flood heights by 28 percent (Ali 2013).

Flood management infrastructure faces considerable challenges from sedimentation. In response to embankment construction, the Indus has been aggrading rapidly over the last two decades, leading to breaches upstream of barrages and inundation of large areas (Gaurav et al. 2011). In addition, climate change is increasing flood frequencies in the Indus Basin (Nepal and Shrestha 2015) suggesting flood standards should be revised. Levee heights are usually an arbitrary 1.8 meters (Ali 2013). But river morphology and climate changes suggest flood infrastructure should be upgraded and integrated with improved nonstructural flood protection (see chapter 5).

Hydrometeorological Infrastructure

Pakistan has inadequate hydrometeorological infrastructure, and much of the monitoring network is in disrepair. Development finance has supported improvements to the monitoring network, but this has been far from adequate, and the usefulness of monitoring is compromised by antiquated infrastructure for data transmission, processing, and storage.

For hydrologic monitoring, federal authorities operate primary rim stations of the Indus Basin that gauge inflows to the IBIS. These are usually defined as the Indus at Kalabagh (which includes the Kabul River), the Jhelum (at Mangla), the Chenab (at Marala), the Ravi (at Balloki), and the Sutlej (at Sulamankai). In some instances, the Indus (at Tarbela—upstream) and the Kabul (at Nowshera) are used instead of the Indus at Kalabahgh. Records began on the Jhelum in 1922; the Indus, in 1936; the Chenab, in 1940; and eastern tributaries, in Pakistan in 1960. In addition, federal authorities have gauged flows at key barrages (Taunsa, Panjnad, Guddu, Sukkur, and Kotri) since their construction, and maintain 59 other regular flow gauging stations mostly in the Upper Indus Basin as well as for various major drains and hill torrents (figure 4.8). For these stations, the earliest flow records began in 1960, and the average length of record for these stations is just 35 years (ignoring several gaps in the records). Federal authorities also maintain 59 flow gauging stations associated with specific water or hydropower development projects (Daimer Bhasha Dam, Dasu Hydroelectric Power (HEP), Neelum-Jhelum HEP, and Kachhi Canal, among many others). The project-related gauge stations have differing but mostly relatively short periods of record.

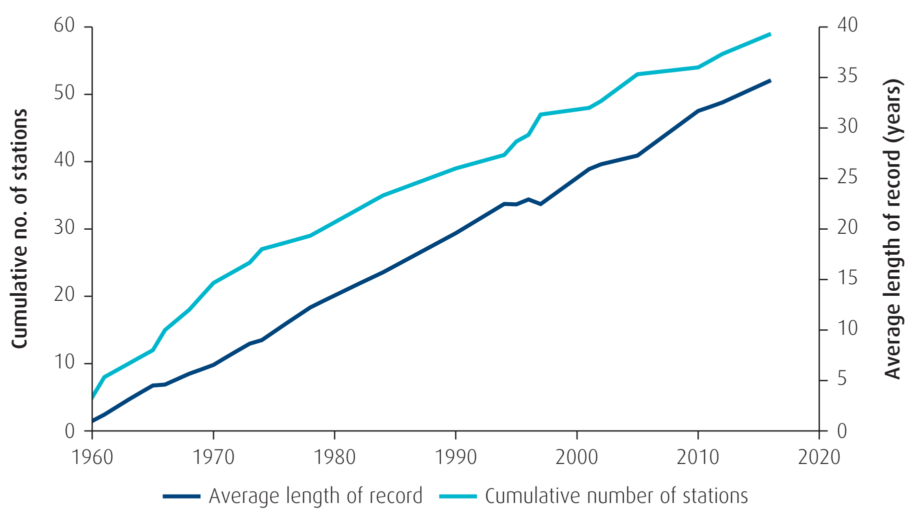
Around 35 of the regular monitoring stations take hourly measurements using automatic water level sensors—either data loggers or data transmission facilities. The remainder use manually read staff gauges. Only a small number of the gauging stations—largely the rims stations and the barrage flows—are used in volumetric water accounting or to guide operation of the reservoirs and barrages. Most of the other hydrologic stations provide data for feasibility studies to guide construction project implementation or for flood management (forecasting, early warnings, and operations). Most of these stations also measure suspended sediment loads. Actual discharge measurements for establishing and revising "ratings curves" (to convert water level measurements to flow estimates) are undertaken using a mixture of wading, cableways, bridges, and boats.

Flow gauging of irrigation withdrawals is undertaken by provincial authorities. There remains considerable uncertainty in the hydrological monitoring and a lack of trust among the governments in the flow measurements. Prior flow gauging telemetry systems have failed due to deficiencies in both design (e.g., lack of adequate power backup supplies) and operation, with opportunities for accidental or deliberate human-introduced errors. New telemetry systems are being designed to improve the accuracy and reliability of measurements, as well as to improve the transparency of real-time data sharing.

There is very limited active hydrological monitoring outside the Indus Basin in Balochistan. Several prior gauging stations have fallen into disrepair given security, access, capacity, and resourcing challenges. Lack of hydrological data compromises many aspects of water resources management and development.

There is limited operational monitoring of groundwater in Pakistan. Some municipal authorities monitor groundwater in urban centers. In Punjab, groundwater monitoring in irrigation command areas is more systematic than elsewhere due to

Figure 4.8 Federally Operated Regular Flow Gauging Stations in the Upper Indus Basin of Pakistan and Average Period of Record, 1960–2016



Source: WAPDA unpublished data.

Table 4.3 Hydrological and Meteorological Monitoring Infrastructure Maintained and Operated by Federal Authorities in Pakistan

Station type	No.	Remarks
Hydrologic monitoring		
Flow gauging stations of glacier melt	7	Data logging and intermitted discharge measurements.
Indus key sites—rim stations and barrages	24	Variable record lengths reflecting construction history. Some manual and some automatic water level sensors. New flow telemetry system planned for these key sites; hydraulic calibrations completed for seven key sites.
Regular streamflow and sediment gauge stations	59	Variable record lengths, some intermittent records
Project-related streamflow and sediment gauge stations	59	Installed as part of dam or other infrastructure project (mostly mid-1990s onward). 56 operating.
Flood forecasting telemetry stations	49	Flood forecasting, river water level, precipitation, discharge/flow measurements during floods. All operating.
Canal network flow gauge stations	—	Provincial monitoring of irrigation distribution network, including main, submain, and minor canals.
Groundwater observation wells	Multiple	Monitoring of groundwater levels in irrigation command areas, primarily in Punjab; ad hoc elsewhere.
Meteorological monitoring		
Rainfall radar	7	Two S-band and five C-band rainfall radar
Synoptic stations	97	50 automatic weather stations (35 functioning) and 33 agrometeorological stations
Upper air stations	6	None functional due to lack of consumables
Manual climate stations	12	Measuring evaporation, temperature, humidity, rainfall. All operating.
Regular climate stations	40	Variable lengths of record; none installed before 1960.
Project-related climate stations	12	Installed as part of dam or other infrastructure project (mostly last decade onward). Nine operating.
High-altitude automatic weather stations	20	Collection and transmission of hourly temperature, precipitation, relative humidity, wind, solar radiation, and snow water equivalent; 17 new stations planned.

Source: WAPDA unpublished data.
Note: — = not available.

a network of piezometric wells. Even in Punjab, however, groundwater monitoring is inadequate for sound resource management. There is very limited groundwater monitoring in Sindh, KP, and Balochistan (Bhatti et al. 2017). In Punjab there are an estimated 1.1 observation wells per 1,000 square kilometers (Government of Punjab 2012); manual readings are made twice per year on average. Data are stored in digital form for ad hoc use (Bhatti et al. 2017). There is no complete or systematic inventory of the estimated 1 million tube wells accessing groundwater.

Weather, climate, flow, and flood forecasting are informed by meteorological measurements including from a few weather radars, a limited number of automatic weather stations, and numerous manual weather stations (table 4.3). Additional meteorological monitoring, including the use of around 500 basic rainfall gauges, is undertaken across the provinces by federal and provincial governments. Overall, however, the meteorological observation network is inadequate, outdated, and poorly maintained. The systems and capacity for flood forecasting and early warnings are inadequate and in need of major upgrade.

The infrastructure for managing (archiving and accessing) hydrometeorological data is rudimentary and not standardized. Other than for basic statistics at key Indus sites, much of the hydrologic data from before the 1990s exist only in hard copy form. During the 1990s, some hydrological data began to be stored in DBHydro, a purpose-built software developed with German aid. More recently, HYSTRA software has been used (with support from Australia) to store, analyze, and report hydrometeorological data. However, these systems are not accessible online, and so outside of the custodian agencies, data access is very limited. The information technology (IT) infrastructure to support hydrometeorological data management, analysis, forecasting, and dissemination is hampered by low-speed Internet access, a lack of forecast workstations, and outdated servers. Both federal and provincial authorities share some real-time or near-real-time data online, but do not provide public access to historical data. Protocols for public data access vary, and the capacity to manage requests is low. Pakistan should move to a modern open access system for managing and sharing water data and information.

Water Supply and Sanitation

Pakistan's domestic water supply infrastructure is in poor state. Much of the existing water supply infrastructure, including pipe networks, pumping stations, groundwater wells, and water treatment facilities, are not functioning and are inadequate for a rapidly urbanizing population. Pipe networks are aging and in need of replacement with very high levels of nonrevenue water (NRW). Because of largely inadequate public supply infrastructure, alternative supplies such as private tankers and privately-owned groundwater wells are increasingly common, especially in Karachi and Quetta.

Sanitation infrastructure is grossly inadequate. None of Pakistan's major cities has adequate sewerage or wastewater treatment capacity, and in many cases existing wastewater treatment facilities are not well maintained. Wastewater treatment capacity is sufficient for only about 8 percent of the wastewater load (Murtaza and Zia 2012). Inadequate maintenance, lack of funds, and lack of human resources mean much less than 8 percent of wastewater is treated. Most urban sewage and other wastewater is discharged untreated into surface water bodies or used to irrigate crops. This pollutes waterways and contaminates food and water supplies. The extent and state of urban water supply and sanitation infrastructure for the major cities of Pakistan is summarized in the following sections by province. In rural areas, public infrastructure is very limited, other than dilapidated open drains that combine storm runoff and untreated wastewater. The rural situation is discussed in chapter 5 from a service delivery perspective.

Khyber Pakhtunkhwa

The public water supply for Peshawar is mostly groundwater, with over 700 tube wells and 33 filtration plants (sand filters), of which 24 are functional (NDC 2014). Around 23,000 cubic meters are withdrawn each day from the Bara River and treated at the Bara Water Treatment Plant. The water distribution system of approximately 1,670 kilometers of pipes—37 percent above ground and mostly of galvanized iron—has been extended haphazardly to keep up with rapid urbanization. Much of the network is well beyond its 20-year design life and needs replacing.

Sanitation infrastructure includes open and covered drains that convey domestic and industrial wastewater as well as surface runoff. Underground sewers serve only a few areas, and these are often clogged and overflow to drains and canals. A recent survey indicates that most of Peshawar's sewerage, including three pumping stations, is unused because of poor maintenance (NDC 2014). There are three wastewater treatment plants, but none are functional. Untreated effluent is discharged to rivers and canals or used to irrigate crops.

Punjab

About 35 percent of Punjab's publicly owned water supply schemes are dysfunctional (PCRWR 2011). The infrastructure is in poor condition, and its capacity is inadequate to meet quantity requirements and quality standards. Many households, therefore, rely on private tube wells, making it difficult to monitor or control the quality of the water supplied or to prevent groundwater depletion.

In Lahore, water is withdrawn from nearly 600 tube wells, of which nearly 500 are publicly managed, before being pumped directly into the 3,200-kilometer piped distribution network (AIIB 2018). Given very high levels of groundwater contamination, the lack of filtration or other treatment for this supply represents a major public health risk. The supply network is aging, with most pipes needing replacement (AIIB 2018). The Lahore sewerage system includes about 4,000 kilometers of underground sewers and 14 major drains. There are no wastewater treatment facilities, and an estimated 2.4 cubic megameters of raw sewage from the drains are discharged into the Ravi River each day (AIIB 2018; Qureshi and Sayed 2014).

Water supply and sanitation infrastructure in other large cities of Punjab is in equally poor condition as Lahore's. Nearly all of Faisalabad's water supply is groundwater pumped from tube wells along the Chenab River and the Jhang Branch Canal; public supply is augmented by private tube wells (JICA 2016). Estimates of the total available water supply suggest a daily range of about 0.3 million cubic meters to 0.33 million cubic meters (JICA 2010; WASA-F 2018). Only about 0.02 million cubic per day undergo treatment and filtration before distribution (WASA-F 2008). There is one wastewater treatment plant in western Faisalabad with a capacity of 0.076 million cubic meters per day (WASA-F 2018). An estimated 1.1 million cubic meters per day of wastewater (sewage and storm water) are discharged to rivers through drains without treatment (WASA-F 2018). In Multan, there are no water treatment facilities and only a single wastewater treatment plant (Soncini et al. 2014).

Sindh

Across Sindh, 58 percent of the publicly owned water supply infrastructure (pumps, water treatment works) are dysfunctional (PCRWR 2010). Karachi's water supply system comprises surface water storages and transfers (Hub and Haleji systems), groundwater (Dumlottee

Wellfield) and a distribution network developed as Karachi has expanded. Around 2.4 million cubic meters per day are supplied to Karachi, of which two-thirds is treated at one of seven filtration plants (KWSB 2018). The supply network is in very poor condition with extremely high leakage and other unaccounted losses; widespread cross-connections with the sewerage system contaminate the supply.

Karachi generates an estimated 1.8 million cubic meters per day of sewage (KWSB 2018). This amount indicates high system losses given that typically less than 10 percent of urban water supplied is consumed. There are three wastewater treatment plants (combined capacity of 0.6 million cubic meters per day), of which two are functional (treating 0.2 million cubic meters per day). Thus, around 1.6 million cubic meters per day of wastewater is discharged untreated into the Arabian Sea or freshwaters close to Karachi. The Karachi sewerage system is extensive, with 5,670 kilometers of sewers, six major pumping stations, and 32 minor pumping stations (KWSB 2018). However, the system is in very poor condition. Inadequate stormwater drains are clogged with solid waste and overloaded with sewage and industrial effluent, undermining their capacity to drain stormwater from flood-prone areas (World Bank 2018). Hyderabad has a major water supply and wastewater infrastructure gap; water is withdrawn directly from the Indus River and about half is treated before distribution. About a quarter of the 0.2 million cubic meters per day of sewage load is treated before discharge (PCRWR 2010).

Balochistan

Quetta's water supply relies on regulated tube wells; the groundwater source is heavily depleted and severe water shortages are common (Ahmed 2013). Sanitation infrastructure is inadequate and poorly maintained. About 100 kilometers of sewers cover a small fraction of the city, and there is a single dysfunctional wastewater treatment facility. Most of Quetta's wastewater and urban runoff is discharged into open drains, which are often clogged by solid waste and prone to overflow. There is evidence of agriculture use of untreated wastewater in urban orchards, posing significant health hazards (Khalil and Kakar 2011).

Islamabad

Most of the water for the Federal Area (Islamabad) of Pakistan is supplied from Khanpur and Simly dams and is treated before distribution at the Sangjani and Simly water treatment plants, respectively (Shabbir and Ahmad 2016). In addition, 180 groundwater tube wells augment the supply (IUCN 2015). The distribution system is in poor condition, with leaking pipes and gate valves. Asbestos cement leaches from the pipes, which contaminates the supply (IUCN 2015). The Islamabad sewerage system has not expanded as the city has grown and is now overloaded (Manarvi and Ayub 2013). There is a single wastewater treatment plant maintained and operated by the Capital Development Authority, although a recent audit indicated inadequate performance, with treated effluent not meeting national standards.

Water Governance

Many of Pakistan's water-related challenges are governance challenges. Water governance encompasses "overarching policies, strategies, plans, finances and incentive structures that concern or influence water resources; the relevant legal and regulatory frameworks and institutions; and planning, decision-making and monitoring processes" (FAO 2018). The focus here is on legal frameworks, policies, and institutional arrangements; sector financing is covered in a subsequent section. Effective water governance underpins water security by sustainably, equitably, and transparently determining "who gets what" and "who does what" in terms of water resources and services, and mitigation of water-related risks. For Pakistan, effective water governance must be tailored to the country's unique biophysical and geopolitical context and reflect its cultural and political traditions.

Federal systems for water governance often have a complex patchwork of institutions, policies, and legal provisions at provincial and national levels. This is the case in India, Malaysia, Nigeria, Argentina, the United States, and Australia (Goldface-Irokalibe 2008), as well as in Pakistan. Although constitutionally, water is largely a provincial matter in Pakistan, relevant policies, institutions, and legal provisions are distributed across the national and provincial levels. National institutions coexist with, and sometimes overlap with, provincial institutions, and the legal framework for each province includes its own laws and regulations overlain by relevant national provisions.

The formation of Pakistan in 1947 severed the majority of the Indus Basin's irrigated land (in Pakistan) from the waters that had supplied it (in India) (Briscoe and Qamar 2005), meaning existing interprovincial and state agreements, resource governance, and water supply patterns required significant reworking. This occurred over several decades to establish a formal mechanism to define Pakistan and Indian shares of the basin water resource, and to move toward reliable nationally managed irrigation systems. The former was achieved in 1960 with the signing of the Indus Waters Treaty, which allocates waters from the three eastern rivers of the Indus Basin (Ravi, Beas, and

Sutlej) to India, and waters of the western rivers (Jhelum, Chenab, and Indus) to Pakistan.

The hierarchy of water governance arrangements is summarized in the following subsections. Pakistan's legal framework is particularly complex because of the interplay between scattered early legislation with multiple amendments and a wave of mostly irrigation-focused provincial enactments over the past few decades. Appendix B provides full details and citations of the legal provisions relating to water. The description of institutional arrangements covers government and nongovernment institutions, and the processes for citizen engagement in setting water policy and holding public institutions accountable for policy implementation.

International Transboundary Water Governance

At the international level, water governance is usually determined by international arrangements (including declarations, treaties, minutes of ministerial meetings, or institutional mechanisms) between countries sharing transboundary water systems. National implementation of international arrangements is usually supported by an assigned ministry or through coordination between relevant ministries and government entities. Sometimes a dedicated national entity supports implementation.

For the waters of the Indus Basin, Pakistan's relations with India are regulated by the 1960 Indus Waters Treaty. Coordination of transboundary basin management (planning, decision making, and monitoring) with China and Afghanistan is not formally defined. The Indus Waters Treaty established the Permanent Indus Commission as a joint coordination mechanism. Its purpose and functions are to "establish and maintain co-operative arrangements for the implementation of the Treaty, to promote co-operation between the Parties in the development of the waters of the Rivers…." (Indus Waters Treaty 1960).

The Permanent Indus Commission comprises one commissioner from Pakistan and one from India. It is responsible for the exchange of information, notification of planned development projects, and responses. It is required to meet at least once per year and undertake a general tour of inspection of the rivers every five years. The treaty provides a mechanism for resolving questions, differences, and disputes. Questions are handled by the commission; differences are referred to a neutral expert, and disputes are referred to an independent court of arbitration.

Within Pakistan, the Pakistan Commissioner for Indus Waters (PCIW) is supported by a team of advisers. The data cell in the office of the PCIW is headed by a deputy commissioner, who is engaged in receiving and forwarding river flow and gauging data from India. During the monsoon, a flood cell operates in this office 24 hours per day to receive flood information and share with the Flood Forecasting Division of the Pakistan Meteorological Department (PMD). PCIW also receives data and information on Indus waters from the Pakistan Water and Power Development Authority (WAPDA) and from the provincial irrigation departments.

The office of PCIW is the only dedicated entity in Pakistan for transboundary water governance. Section 9 of the 2018 National Water Policy (NWP) recognizes the need to work out a mechanism for the sharing of "of trans-boundary aquifers and joint watershed management including sharing of composite real-time flow information especially relating to hydro-meteorological disasters/disaster-like situations endangering Pakistan's important infrastructure, communication network and economy." This mechanism should extend beyond the geography of the Indus Waters Treaty to consider other transboundary rivers and tributaries that Pakistan shares with its neighbors. It would be appropriate to consider establishing a new federal body to support both the technical and diplomatic aspects of transboundary water management with all of Pakistan's riparian neighbors, which would include the office of PCIW.

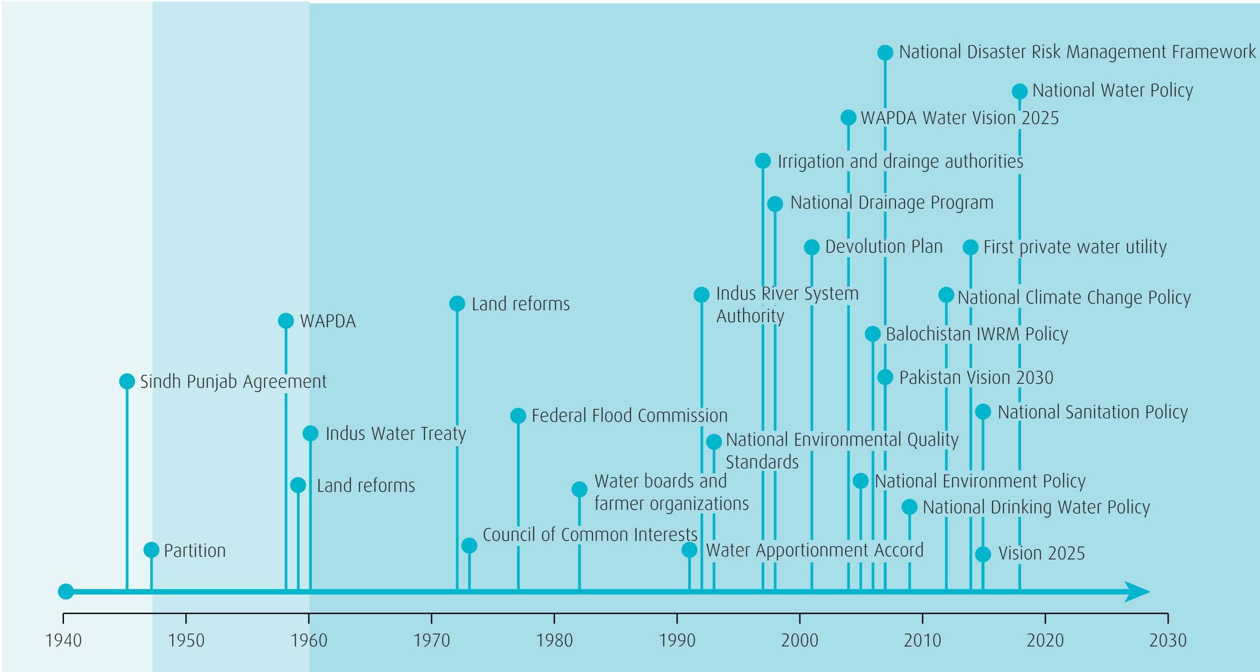
Federal Role and an Evolving Policy Framework

Water resources are not included in the enumerated federal list of the 1973 Constitution of Pakistan; water management is largely, therefore, the purview of the provinces. The 18th Amendment to the Constitution, enacted in 2010, moves issues of environmental pollution and ecology—both relevant for water management—from the list of concurrent matters (for both federal and provincial jurisdiction) to the list of solely provincial matters.

Two areas fall within federal jurisdiction: interstate water disputes and policy setting for water and power development, as originally covered by the Water and Power Development Authority Act (1958). Article 155 of the Constitution includes a dedicated procedure in case of water allocation disputes. Disputes may be referred to the Council of Common Interests for decision, and it is the legal duty of federal and provincial governments to honor the council's decision. This provision was used for the approval of the 1991 Water Apportionment Accord.

National level water policy was limited in Pakistan prior to the 1990s, although 1959 and 1970 land reforms and the 1977 creation of the Federal Flood Commission (FFC) influenced water management (figure 4.9).

Figure 4.9 Major Policy and Institutional Milestones before Partition and before and after the Indus Waters Treaty in Pakistan, 1940 to Present



Note: IWRM = Integrated Water Resources Management; WAPDA = Pakistan Water and Power Development Authority.

The land reforms were only partially completed because of political challenges and changes in government. The FFC moved responsibility for flood protection from the provincial to the federal level; however, floodplain management remained a provincial responsibility. Legal tools to support floodplain planning and development in Pakistan are limited, although the Punjab Flood Plain Regulation Act (2016) provides government with the power to declare certain areas as floodplains, and then by notification in the *Gazette*, to prohibit new construction in declared floodplain areas.

The Water Apportionment Accord was signed in 1991, and in 1992 the Indus River System Authority (IRSA) was established by federal legislation to implement the accord. Although the accord was a major step in interprovincial water sharing, little progress has been made since in resolving important ambiguities, particularly with reference to the initial conditions. For example, Punjab maintains that the volumes apportioned in clause 2 are contingent upon additional storage becoming available, whereas Sindh considers clause 2 as the baseline volume and “shortages and surpluses” are dealt with appropriately in the accord.

In 1993, Pakistan adopted the first iteration of its National Environmental Quality Standards, including standards for industrial and domestic effluent. In 1998, the National Drainage Program was established to improve saline irrigation drainage through infrastructure investments, institutional reforms, and capacity building within WAPDA; provincial authorities; and farmer organizations (World Bank 1998). In 2004, WAPDA’s Water Vision 2025 was published—Pakistan’s first long-term national plan for water resources. The Water Vision focuses on mitigating the impacts of climate change on the water sector; protecting agriculture from drought; replacing storage lost to sedimentation; and developing new hydropower, all supported by US$33 billion of investment.

In 2005, the National Environment Policy was adopted to provide a national framework for addressing all types of environmental issues, including impacts on water. It promotes action for improved drinking water and treatment provision including through low-cost technologies, improved water quality and ecosystem flow monitoring, water metering, artificial recharge, rainwater harvesting, metering, and the rehabilitation of water bodies (GoP 2005). It also calls for the development of a National Disaster Risk Management Framework, published in 2007. The framework lays out cooperation between national and provincial governments for disaster management to redress Pakistan’s reactive response to natural disasters (GoP 2007a).

Pakistan’s Vision 2030 (2007) is a general national economic policy document that highlights the country’s water insecurity. It stresses the growth of industrial and municipal water needs while recognizing the continued importance of irrigation.

It proposes changes to institutional arrangements for the ownership and pricing of water, new storages to capture peak flows, and incentivizing water saving technology in irrigation and pollution control technology in industry. It also recognizes the need to improve agricultural management to ensure food security and land sustainability (GoP 2007b). Implementation progress toward this vision over the last decade has, however, been very limited, and the more difficult reforms and larger investments have not occurred.

The 2012 National Climate Change Policy (GoP 2012) gives much attention to water in the context of multiple climate risks including increased climate extremes, glacier retreat, increasing agricultural water demands, and coastal saline intrusion. The 2013 implementation framework for the policy sets out goals, strategies, and adaptation actions for several aspects of water management and its nexus with agriculture and energy generation. It highlights rehabilitation and augmentation of storages and new options for water desalination and recycling, as well as demand management programs to reduce system losses and improve irrigation efficiency. IWRM is used to oversee intersectoral demands and the interrelationships between water sources and uses, as well as improve stakeholder engagement. It proposes legislative changes to facilitate IWRM, including for environmental protection and water management. It promotes improved hydrometeorological monitoring and information exchange to improve forecasting and water resource assessments. For irrigation, the policy focuses on water input technologies and other farm practices and mechanization. Improved forestry and land use practices are encouraged, including to reduce erosion and sedimentation and to improve groundwater recharge and protection. Hydropower expansion is encouraged to reduce greenhouse gas emissions. Although the implementation framework identifies time-bound targets and institutional responsibilities, progress over the last five years appears very limited. In the absence of robust implementation monitoring, however, it is difficult to accurately assess progress.

In 2014, the Pakistan Vision 2025 was released (GoP 2014), reiterating many of the water goals of the earlier Vision 2030, including a focus on additional storage and water harvesting, investment in technology to improve water efficiency and pricing, improvement of water allocation to reflect the economic value of water, and institutional mechanisms to manage sectoral and regional allocations. Vision 2025 stresses the need to achieve baseline levels of personal water and sanitation access and social education on water. The proposed NWP was agreed to by federal and all provincial governments in 2018.

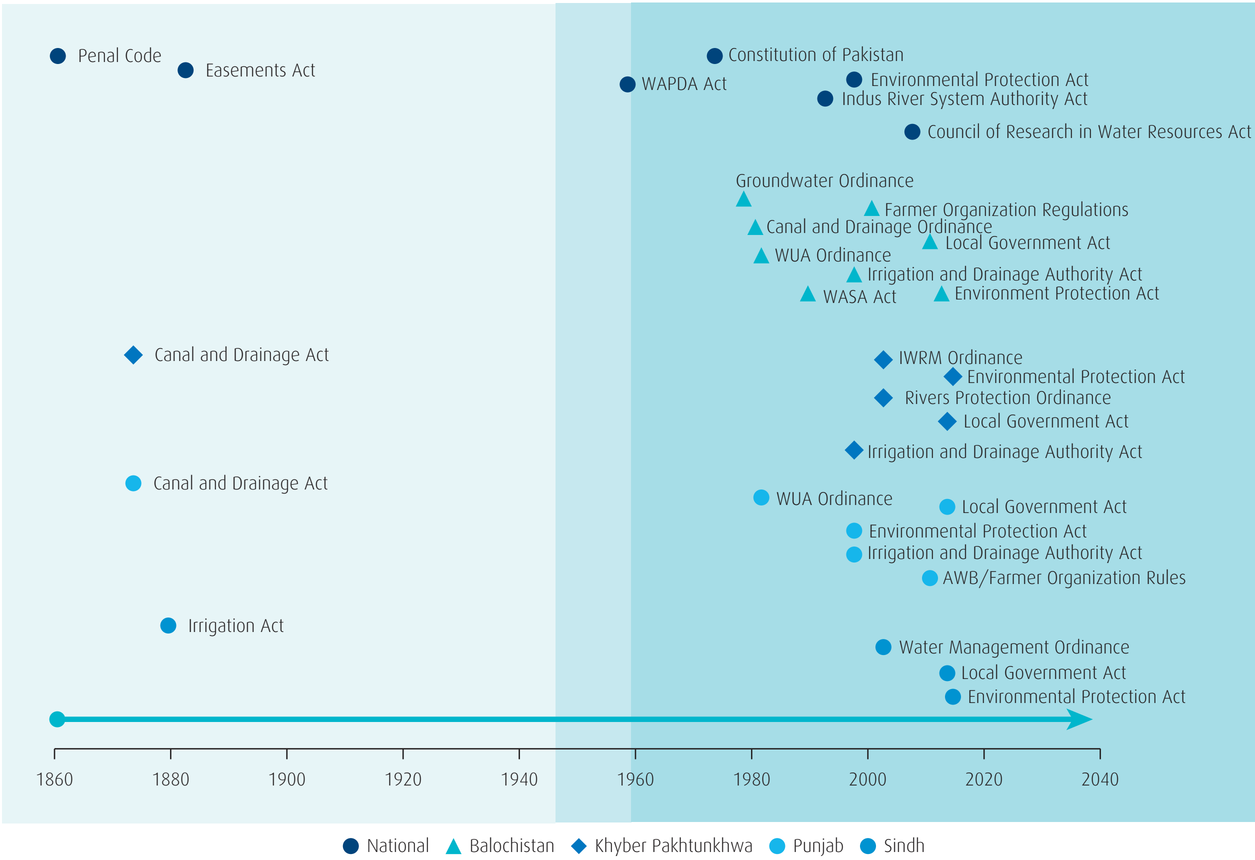
The NWP lists 33 objectives under an IWRM umbrella that span improved water allocation across competing demands, ensuring water for social and economic development, and supporting national food security objectives. The policy is wide-ranging, covering supply and demand management, regulation, and sectoral resilience. It is organized into seven strategic priority areas. Conservation and efficiency are highlighted in addition to the familiar calls for storage rehabilitation and augmentation. Technology is prioritized, including for improved irrigation management and hydrometeorological monitoring and data sharing. Renewable energy, including hydropower and solar pumping, is embraced, emphasizing the need for such developments to be planned with careful consideration of nexus issues. Pakistan's regulatory framework is highlighted for strengthening, especially coordination between federal and provincial governments and agencies, and the coordination of policy and improved implementation across government and economic sectors. Planning principles to underpin water management include sustainability, financial fairness, and knowledge and innovation. Research is needed both to drive technological innovation and for improved decision making. The inadequacy of sector financing is clear, as is the importance of financial sustainability in subsectors. There are many references to environmental sustainability, including a call to ensure environmental flows and the need for detailed action plans to improve surface and groundwater quality.

Governance for Key Aspects of Water Resources Management

This subsection describes the legal frameworks and institutional frameworks arrangements for national and provincial water resources management, with reference to the policy context outlined previously. Four key areas of water resources management are considered: data, information, and analysis; resource planning and allocation; system operations; and environmental sustainability.

The legal framework for water management combines remnant colonial legislation, the Pakistan Constitution, and a small number of federal acts focused on establishing key national institutions, and more recent but often piecemeal provincial legal instruments that affect aspects of water management (figure 4.10). Relatively minor differences are observed in the legal frameworks that apply to the different provinces. Sindh has the most comprehensive framework, and Balochistan, the least. However, many basic legal provisions for supporting water resources management found in other countries are absent in Pakistan's provinces. A fuller description and comparative analysis of the legal frameworks are provided in appendix B.

Figure 4.10 Major Federal and Provincial Legal Instruments before Partition and before and after the Indus Water Treaty in Pakistan, 1860 to Present



Note: AWB = area water board; IWRM = Integrated Water Resources Management; WUA = water user association; WASA = water and sanitation agency.

Data, Information, and Analysis

Multiple institutions have water information and analysis roles, guided by clear policy directions from recent policy documents. However, the roles lack clarity at the national level and between national and provincial levels, and there are gaps and duplication in effort. Institutions often either lack clear legal mandates for these roles, or mandates are diffuse and spread across many institutions.

The office of the PCIW is responsible for data exchange with India. Although not established by separate legislation, PMD within the Aviation Division of the Cabinet Secretariat has a leading role in water information and modeling. PMD maintains much of the national meteorological and agrometeorological monitoring network and associated data systems. PMD provides weather forecasting, flood forecasting, glacial lake outburst floods (GLOF) and early warning and drought monitoring services. The PMD Flood Forecasting Division provides flood, streamflow, and dam water level forecasts.

Hydrological monitoring is undertaken by WAPDA at the federal level and by irrigation departments at the provincial level, at least for the irrigation supply system. WAPDA operates hydrological gauging stations (for water levels and aspects of water quality) in the Upper Indus Basin, at rim stations, and at key project sites. WAPDA maintains meteorological stations in the Upper Basin, including cryosphere monitoring to support inflow forecasting. WAPDA is upgrading and expanding its network. WAPDA holds significant water data records, but its data systems and data management procedures are mostly outdated and inadequate. IRSA does not have a clear legal mandate for collecting water data, but is working to establish a modern, robust system for monitoring flows at 27 key sites across the irrigation water delivery and distribution system. These will be supported by modern data management infrastructure and procedures.

The PCRWR has an important role in national water research. Established in 1964 and reorganized as a separate corporate body under the Ministry of Science and Technology by legislation in 2007, PCRWR has a research mandate for all matters related to water, including irrigation, drainage, reclamation, navigation, flooding, drinking water, industrial water, and sewage. The establishing legislation tasks PCRWR with developing and maintaining a national water resources database for use by planning and implementing agencies and the public, as well as initiating a national water quality monitoring program and advising government on water quality and the development, management, conservation, and utilization of water. PCRWR has established a water quality testing program but has not established a national water resources database.

FFC has an expansive institutional mandate for flood information and modeling. Its functions include development of flood forecasting and warning systems, flood research, standardizing and recommending flood infrastructure designs, and evaluating progress under flood protection plans (GoP 2018).

At the provincial level, several institutions have mandates relevant to water information and analysis. Provincial government agencies collect data on irrigation water distribution with differing efficacy, and some efforts are being made in water data management. The Punjab Irrigation Department maintains a digital database of flows in each canal, and the Sindh Irrigation Department is making flow data and information for irrigation canals publicly available. The Punjab Irrigation Department is exploring automated or digital data acquisition as the next iteration of its data and information platform.

The NWP notes the need for improved water information and analysis for "improved asset management and to derive evidence- and data-driven decision making." It promotes "research on water resources issues of national importance and building capacity/delineating roles and responsibilities of federal research institutions and promoting coordination among them." The policy has detailed sections on water information management and water research, and highlights the need for a national water resources database and a national water research agenda. The Climate Change Policy also stresses improved information and analysis. It promotes improved data for irrigation water use, remote sensing of agricultural systems, and real-time meteorological information collection and exchange. It advocates for an increase in research, including of water resources and agricultural resilience, supported by enhanced monitoring, with a view to improving forecasting of seasonal water availability.

Pakistan's legal frameworks contain elements to support water information and analysis. The PCRWR Act (2007) outlines a clear national mandate for water research and analysis. The Sindh legal framework requires the creation of a publicly accessible water resource inventory and sets a mandatory timeline for periodic updating of this inventory. It requires the creation of a publicly accessible water user registry and requires the government to monitor water resources and publish monitoring results. The Punjab legal framework is less comprehensive because it does not set a timeline for a periodic update of a water resource inventory and does not require the government to publish the results of water resources monitoring. The Balochistan legal framework is weaker still, because it does not require either the water resource inventory or the water user registry to be publicly accessible, although it does require monitoring results to be published. The legal framework of KP mirrors Balochistan except it does not require water resources monitoring to be published.

Apart from the PCRWR Act, legal mandates for water information and analysis are missing at the federal level and are variable but generally weak at the provincial level. The important water data and information functions of PMD lack a clear legal mandate. In many other countries the legal frameworks for water are more comprehensive, requiring creation of a periodically updated water resource monitoring plan and the creation of a pollution discharge information system. Water conditions commonly change over time, and water information is most useful if up-to-date and accessible. Clear legal mandates for these functions can help ensure consistent institutional action over time.

Pakistan does not promote the role of citizens in collecting and analyzing water data. Citizen involvement in the planning, installation, and management of hydrometeorological or water quality monitoring networks could help improve water data and community knowledge, as demonstrated in other parts of the world (Paul et al. 2018; Zemadim et al. 2013). For Pakistan, this could be especially powerful for improved groundwater management.

Resource Planning and Allocation

At the national level, WAPDA has an institutional responsibility for strategic resource planning, and set national directions in 2004 in its Water Vision 2025. Water Vision 2025 reflects WAPDA's historical supply-side development focus, within limited consideration of basin-scale environmental sustainability, interprovincial sharing, or economic productivity. By approving the Water Apportionment Accord, the Council of Common Interests has adopted a procedural role in water resource planning. Within the framework established by the accord, IRSA has the primary responsibility for resource allocation guided by information from WAPDA on resource availability and information from provincial irrigation departments on irrigation demands. With growing but changing water demands, growing environmental concerns, and increasing climate change driven flow variability, a more robust allocation process and clear institutional responsibilities for long-term strategic resource planning are required. Within the provinces, water allocation is the responsibility of provincial irrigation and drainage authorities (PIDAs), which issue and revoke water licenses and settle water allocation disputes.

The NWP outlines six principles to guide resource planning processes at federal and provincial levels: (i) equity and participatory decision making; (ii) water is a strategic resource and access to affordable and safe drinking water is a fundamental human right; (iii) efficiency and conservation; (iv) environmental sustainability; (v) practicability and innovation; and (vi) command area development is the responsibility of farmers with government support for small land holdings. It emphasizes basin-level water resource planning including improved allocation across multiple sectors. Allocation changes are intimated for enhancing food security and climate adaptation and resilience. IWRM principles are highlighted, especially public participation, enhancement of public-private partnerships (PPPs), and improved institutional capacity. Priorities for institutional strengthening include improved implementation of the accord, coordination between provincial and national planning, and inclusion of hydropower development in resource planning. The National Climate Change Policy outlines key water resource planning concepts including new and rehabilitated storages, hydropower development, and contingency planning for water shortages.

The WAPDA Act (1958) provides legal support for federal water resource planning, although its provisions are very focused on water resource development. The legislation requires WAPDA to prepare "a comprehensive plan for the development and utilization of the water and power resources of Pakistan on a unified and multi-purpose basis." The provincial legal frameworks contain a few features that support inclusive planning. The Sindh and KP legal frameworks require the creation of water resources management plans and require water users to be represented in water resources management institutions. Punjab establishes a mechanism to promote women's participation in water resources management institutions, and Balochistan specifies the required components of water resources management plans. In other countries, however, legal frameworks are often more comprehensive and require public consultation in the development of water resources management plans, mandatory timelines for periodic updates, water allocation decisions consistent with water resource management plans, the establishment or adoption of water resource quality criteria, water quality objectives for water bodies, and quotas or other mechanism to promote women's participation in water resources management institutions. Managing water resources typically requires managing how people interact with the resource, but water conditions, water uses, and objectives all change through time, and a plan is useful only if current.

Pakistan has some legal foundations that could support the establishment of a modern water rights or permit system for water allocation, but there are significant gaps. In Sindh, a permit or right is required before abstracting water, and in Balochistan, public notice of new water abstraction permit or right applications is required before a decision is made. In KP and Punjab, the length of this public notice period is legally defined. In other countries, legal frameworks sometimes go further, requiring the establishment of a priority order for water allocation between types of water uses, prescribing the procedure to acquire a new water abstraction permit or right, setting a duration for water abstraction permits or rights, providing a shorter or simpler procedure for water abstraction permit or right renewals, defining the length of a public notice period prior to a decision on a new water allocation permit or right application, and setting out required means of giving public notice of new water abstraction permit or right applications before a decision is made. Priority orders can help to rationalize daily allocation decisions, aligning them with broader objectives for the water sector. Specific procedures help to increase clarity and legal certainty for water users, so permit procedures don't become a barrier to development. Clear permit durations help provide investment security for water users and provide a defined period for water managers to periodically reevaluate water allocations. While permit renewals provide an important review point for water managers, they should not be so frequent as to create undue uncertainty. A clear notice period helps to ensure a predictable, inclusive process that meets minimum expectations for providing an opportunity to comment. A clear mechanism for public notice helps to ensure a predictable and inclusive process.

System Operations

The key institutions with operational functions for water management at the federal level are WAPDA and IRSA. WAPDA operates the major headwater reservoirs and hydropower facilities for water supply, flood mitigation, and power generation. In operating headwater reservoirs for flood mitigation, WAPDA is guided by flood forecasting by PMD, as well as their own modeling and analysis. IRSA specifies and reviews river and reservoir operations and communicates these to WAPDA and provincial irrigation departments. IRSA's role in specifying operations is based on the compilation and review of rolling provincial irrigation demand estimates to determine required reservoir releases.

Historically, provincial irrigation departments were responsible for the operation and maintenance (O&M) of barrages and irrigation canals for delivery of irrigation water services and flood mitigation. In 1997, as a part of broad irrigation reform, PIDAs were established by legislation to manage and distribute canal water, and to oversee the O&M of the main distributaries in association with area water boards (AWBs). AWBs devolve irrigation system management to stakeholder-based institutions, and, thus, PIDAs were intended to oversee irrigation and drainage systems within a largely decentralized governance architecture. This is supposed to make provincial irrigation departments more agile and less burdened with O&M tasks, and to improve equity in irrigation service delivery. However, PIDAs typically operate in parallel with the irrigation departments, increasing the complexity of water governance without increasing its effectiveness (WWF 2012).

Below the level of AWBs, farmer organizations of elected farmers from the Khal Panchayats manage local supplies, maintain on-farm distributaries, collect *abiana*, and make payments to AWBs. Khal Panchayats are watercourse-level water user associations created in conformity with irrigation management transfer policies of the 1990s to promote the devolution of authority and costs of irrigation systems to beneficiary-led groups (Mekonnen et al. 2015). The need to improve irrigation management was a key argument for the creation of water user associations (WUAs); however, it is difficult to quantify actual improvements (World Bank 1994). Evidence suggests that on-farm water use efficiency is higher for farmers belonging to farmer organizations (Chaudhry 2018), but equity is not necessarily improved in command areas managed by farmer organizations compared to those managed bureaucratically (Jacoby, Mansuri, and Fatima et al. 2018). This suggests that broader institutional factors, such as community characteristics and social interactions, influence community-based water governance and related improvements in water use efficiency (Chaudhry 2018).

The NWP has little to say about the operational functions of WAPDA and IRSA, except to note the need to revitalize WAPDA and strengthen IRSA's role in real-time monitoring. The policy highlights the importance of financial sustainability for provincial irrigation operations and the role of technology to improve operational efficiency and effectiveness.

Pakistan's legal frameworks include elements that help guide federal and provincial water operations. The Water and Power Development Authority Act (1958) gives WAPDA the legal mandate for "control over waters, power houses and grids," including control over "underground water resources of any region in a province." IRSA's establishing legislation gives them specific legal mandates to "specify river and reservoir operation patterns" and to "issue consolidated operational directives to Water and Power Development Authority for making such releases from reservoirs as the Authority may consider appropriate." The legislation that established PIDAs, AWBs, and farmer organizations focuses on administrative aspects of the institutional setup, rather than prescribing legal mandates or operational powers and responsibilities.

Environmental Sustainability

The primary responsibility for environmental management rests with the federal and provincial environmental protection agencies (EPAs). The federal EPA was established under the Pakistan Environmental Protection Act (1997) to enforce the environmental rules and regulations contained in the act; conduct environmental impact assessments and initial environmental examinations; establish the National Environmental Quality Standards; and promote environmental research. With the 18th Amendment to the Constitution, environment issues have become provincial responsibilities, each of which has an independent EPA, but weak enforcement capacity undermines effective environmental management. The regulatory responsibility of the Pakistan EPA now applies only to the Islamabad Capital Territory. For major federal water and power projects, the environmental cell within WAPDA conducts environmental impact assessments, monitors environmental impacts during construction and operation, and implements environmental management plans. PCRWR researches water and agricultural environmental issues.

Pakistan has national and provincial environmental policies and regulations for environmental management and pollution control. However, implementation is slow and incomplete, and regulatory enforcement is inadequate. Several NWP objectives address environmental sustainability, including watershed management and restoring and maintaining the health of water-dependent ecosystems (including Ramsar and other wetland sites). Groundwater regulation is advocated to curb overabstraction and enhance recharge, as well as to help prevent seawater intrusion into coastal aquifers. Environmental flows are highlighted, and renewable energy is promoted. These objectives however, are unsupported by specific or strong regulatory measures, which will hamper implementation. Environmental sustainability features strongly in the National Climate Change Policy, particularly the issue of environmental and resource resilience. The policy stresses the importance of protecting environmental resources, including rational groundwater use, wetland and watershed protection, and enhanced environmental flows. The National Food Security Policy notes the threats posed by resource degradation and key soil-water interactions, including soil-water retention, water pollution, and reservoir sedimentation. Water pollution with agrochemicals is highlighted for attention to improve the environmental sustainability of the food system.

All four provinces recently enacted environmental protection acts, which provide general frameworks for environmental sustainability, including for water management. However, provisions to support managing water pollution and water depletion are limited, and the new legislation is yet to be supported with any detailed regulations. Water resources protection is better supported in KP given provisions in its Rivers Protection Ordinance (2002) and Integrated Water Resources Management Board Ordinance (2002). Sindh has measures for managing water shortages in its Water Management Ordinance (2002); however, legal provisions for water quality management are lacking in all the provinces.

Governance of Water Supply and Sanitation

In 2006 the federal Ministry of Environment published a National Sanitation Policy focused on driving behavior change and ensuring safe waste disposal and universal access to basic sanitation. This was followed by a National Drinking Water Policy in 2009, focused on improving water access, treatment, and conservation through enhanced community participation and public awareness, cost-effective infrastructure, research and development, and PPPs. Following the 18th Amendment to the Constitution, however, water supply and sanitation responsibilities—including legislation, policy, planning, and service provision—moved fully to provincial governments. The earlier national policies provide general guidance to the provinces, which have each developed policy frameworks.

Despite policy progress, provincial institutions have largely resisted reforms because of entrenched and contested interests, amplified by a lack of capacity. The policy frameworks do not adequately separate institutional roles for water supply, asset ownership or management, and service delivery, and the absence of an independent regulator further undermines progress. Service delivery is spread across many institutions with varying capacities, differing reporting lines, and limited coordination. Relevant institutions include public health engineering departments (PHEDs), local government departments (LGDs), and water and sanitation agencies (WASAs). Although LGDs have broad service delivery responsibility, rural service delivery remains de facto with PHEDs and urban services in the large cities are delivered by WASAs.

Provincial planning and financing frameworks are relatively well developed, but planning is hampered by inadequate data, lack of institutional cohesion, and the absence of an independent regulator. While broad service goals and targets have been defined, there is no planning process and no agreed timeframe for meeting the agreed targets. The virtual absence of regulation, the inability to raise tariffs to recover costs, and poor cost recoveries, force municipal entities to rely heavily on large annual subsidies that are increasingly difficult to sustain. Sector monitoring is weak, with a lack of definitional consistency, clear targets, and unified data sources. Standardized monitoring has been discussed for some time, but it has yet to be established at national or provincial levels. In the face of deteriorating service delivery, recent judicial inquiries by apex courts in Sindh and Punjab have demonstrated the political will to enforce the basic constitutional right to safe drinking water.

Provincial approaches to water supply and sanitation governance differ, but most are characterized by residual policy and institutional overlaps and unclear legal mandates. In Punjab, there is a lack of role delineation between the LGD, the Urban Unit, and PHED. In Sindh, multiple policies for drinking water and for sanitation and solid waste have been produced by multiple departments without implementation. Policy overlaps lead multiple agencies to seek to establish mandates to obtain additional resources. Policy implementation varies according to departmental priorities, capacity, and operational norms, creating further confusion and conflict. The situation is often exacerbated by political masters selectively delegating responsibilities and by the provision of donor funds to institutions lacking clear legal mandates.

Political Economy Challenges

Informal governance—the political economy—significantly influences the water sector. The political economy of water in Pakistan is discussed in terms of the evolution of irrigation governance and Karachi's urban water sector. Pakistan faces serious irrigation and urban water governance challenges, and future reform progress will require tackling difficult political economy issues based on an understanding of where and why past reform efforts have failed.

Political Economy of Irrigation Governance

The foundations of irrigation in Pakistan date back to the late 19th century when the British government of the Indian subcontinent began construction of the canal network and passed the Canal and Drainage Act 1873).

Despite political, economic, and demographic change—and continued infrastructure investment—there has been continuity across a century and half in the public administration of irrigation by state and provincial governments, which adopted the colonial legislation (with some amendments) as provincial acts.

Scrutiny of irrigation performance (chapter 5) highlights the lack of financial sustainability of irrigation and its reliance on subsidies (Strosser 1997), poor performance of hydraulic infrastructure (Rinaudo and Tahir 2003), low agricultural water productivity, widespread rent-seeking and corruption (Jacoby and Mansuri 2018; Jacoby, Mansuri, and Fatima 2018), and poor administration that has enabled illegal water trading and theft (Mustafa et al. 2017; Rinaudo, Strosser, and Thoyer 2000; Rinaudo and Tahir 2003;). Pressure since the early 1990s to transform irrigation from a centralized bureaucracy to devolved, inclusive, service-oriented management was partly triggered by reforms advocated by the World Bank (1994). These reform proposals became a component of a World Bank loan that financed the National Drainage Program (Rinaudo and Tahir 2003); it has three core pillars:

- Restructuring PIDAs into decentralized public utilities at the command area level, with the autonomy to collect and spend water tariffs, enabling progressive withdrawal of subsidies and, potentially, eventual privatization. The government renamed these utilities as AWBs and proposed PIDAs as regulators. The government neither explicitly ruled out privatization nor overtly embraced the concept.
- Farmer-led management at the distributary level, including water tariff collection and expenditure decisions. This was accepted by government in spirit and was pursued via farmer organizations and WUAs.
- Establishment of water markets, and, potentially, water trading, which includes delinking water rights from land ownership. Again, this has not been ruled out by government, but has not been explicitly endorsed.

The reform effort that began in 1994 culminated in the Provincial Irrigation and Drainage Act (1997). However, this legislation is markedly different in both spirit and vision from what was originally proposed. It is far less effective at transforming irrigation to an equitable, sustainable, and participatory management model for several reasons. Farmers have absolute majority in the executive committees and general assemblies of PIDAs and AWBs and have the final say on tariff increases. The responsibility for water pricing has been transferred from provincial governments to PIDAs, meaning pricing innovation critical for financial sustainability is unlikely given the control of PIDAs by large land-holding farmers. Supply disconnection as a penalty for tariff nonpayment has been removed, eliminating the most powerful means for tariff enforcement. Water rights remain coupled to land ownership, preventing water trading or any formal water market. The Canal and Drainage Act (1873) remains in force, retaining elements of the old centralized governance model. Although PIDA powers and responsibilities are clearly described in the act, those for AWBs and farmer organizations are vague, undermining decentralization.

Some of these seemingly regressive revisions reflect a degree of pragmatism, given the sheer scale and complexity of modernizing the low-technology, supply-driven irrigation system, which would be required to enable these reforms. However, other revisions reflect entrenched interests that successfully reframed the reform agenda during consultations on the draft PIDA Act and the public debate by experts and opinion leaders. Privatization, although not central to the reforms, was emphasized and characterized as a push for foreign control of Pakistan irrigation. The proposal to delink water rights from land rights was portrayed as land reform, which was sensitive given reform efforts of the 1970s that failed partly because of the dominance of large landowners in federal parliament, as well as a verdict against land reform by the Supreme Court.

By 1996, the draft legislation, by then widely seen as a donor-driven attempt at privatization and land reform, was strongly rejected by nearly all stakeholders, including the Pakistan Kissan Board (a small farmer lobby group), which had originally been strongly supportive. Primarily large landowners and provincial irrigation departments would have had to concede power. Van der Velde and Tirmizi (2004) identify important overlaps in political, professional, and informal authority positions of key individuals who reframed the reform discourse. These include overlaps between large landowners and politicians, and between irrigation departments and irrigation engineering consulting firms. One large landowner was both the head of a powerful lobby group and a high-ranking state official. A former senior official of a provincial Irrigation Department also held a stake in an engineering firm delivering irrigation projects. In addition to individuals holding multiple positions with conflicting interests, there was collusion between large landowners, politicians, and irrigation department officials, which negatively impacts system performance and small farmer welfare (e.g., Ali 2015; Gazdar 2009; Hussain 2008; Malik 2008).

It is less clear why small farmers who stood to gain from these reforms objected. Most commentators blame the absence of a government-framed narrative explaining the need for reform, which created an information vacuum filled by misinformation. Central government was ineffective at communicating to small farmers how they would be empowered by management decentralization. Instead, small farmers were swayed by local irrigation department officials and *patwaris* (revenue officers), supported by a media narrative dominated by the rural elite and large farmer lobbies (Rinaudo and Tahir 2003). Van der Velde and Tirmizi (2004) cite "Privatization of Canal System to Be Disastrous for Economy"—a 1996 article in the English newspaper *The Muslim*—for illustration. The following excerpt is a statement attributed to spokespersons of the Farmers Association of Pakistan and the Pakistan Engineering Congress (p233):

> "*What was being proposed was not even genuine privatization. The plan is to sell irrigation channels to big landlords under the umbrella of this newly created PIDA. It is a diabolical scheme against the rural masses and our agricultural economy. The proposed law denies water rights to poor farmers by changing entitlement of irrigated lands to water by making canal irrigation water freely and independently tradable to land owners with money and under their own authority.*"

Urdu dailies carried similar claims that the government was handing over Pakistan's canals and water resources to external financers, while senior government officials continued promising to prevent "foreign privatization" of Pakistan's water resources. The World Bank advised the government in late 1995 that decentralization was to facilitate participatory management and did not entail privatization. Nonetheless, negative framing of the reforms contributed to their dilution and reinforced other concerns. In mid-1996, in a joint meeting with the president and prime minister of Pakistan, both the Pakistan Kissan Board and the Farmers Association of Pakistan rejected the draft act on two grounds: first, because of inadequate representation of farmers in PIDA and AWB executive committees; and second, because of insufficient accountability to ensure increased tariffs would be invested in irrigation (Rinaudo and Tahir 2003). In hindsight, these were well-founded concerns.

Despite the wider stakeholder pushback, it was ultimately provincial irrigation departments that prevented full implementation of the reform agenda. Ostensibly, the rejection of the draft legislation by the PIDs was to protect small farmers, who, it was claimed, would struggle to compete in water markets given their poor education, impoverishment, and traditional farming methods. This narrative helped convince small farmers to join the protest. However, it overlooked legislative and institutional developments in the late 19th century, which created or reinforced many of these inequalities and factionalisms, that were key drivers of the reforms, especially those linked to land ownership (Ali 1988; Gilmartin 2015). The colonial Punjab Irrigation Department introduced *chakbandi*—the assignment of fixed areas (*chaks*) around remodeled water channels—that made access to water contingent upon access to land. Once landholding size became the determinant of an individual's "water right," any market for water trading independent of land was impossible, and inevitably land inequity fostered water inequity (Mustafa et al. 2017).

PIDs also claimed the reforms were ill-designed because system decline was so pervasive that even the technically competent and legally empowered PIDs were struggling to operate and maintain it. What chance would poor uneducated farmers have? Yet PIDs' struggles were, of course, key drivers for the reforms. Suggesting that farmers were not competent to manage their own inputs and assets also implicitly undermined the existing *warabandi* system of water distribution proportional to land holding, although never led to any call to reform *warabandi*.

More concrete reasons underlay the defensive stance of PIDs in the reform debate yet were scarcely discussed. First, devolution of irrigation management and O&M to farmers would have made thousands of irrigation staff redundant. There was also a fear that the composition of PID management—overwhelmingly from engineering backgrounds—would be diluted by recruitment of staff trained in management sciences, economics, and social sciences, opening the door to private sector management consultants (van der Velde and Tirmizi 2004). Second, decentralization would reduce opportunities for rent-seeking by irrigation staff. PIDs acknowledged the decrepit state of the irrigation system they were tasked to manage, but neither accepted responsibility for the situation, nor felt that institutional transformational was required. Van der Velde and Tirmizi (2004) conclude (p226): "*Although many PID functionaries were willing to concede that by the 1990s departmental discipline had deteriorated to levels that adversely impacted upon canal system O&M, few were willing to acknowledge any institutional responsibility for that condition.*"

The PIDA Act reduces control of the irrigation bureaucracy; however, the concessions mostly favor large farmers, not small or tenured farmers, and the concessions are not conducive to broadening the expertise guiding irrigation performance improvement. While the farmer lobbies eventually fully accepted the reforms, reluctance from PIDs persisted. The absence of a comprehensive and conducive legal framework, lack of cooperation and ownership of the partial institutional reforms by irrigation departments, and rent-seeking behavior by irrigation officers have made the introduction of participatory irrigation management extremely difficult and undermines WUAs and the larger irrigation reform process in Sindh. This has been illustrated by Starkloff's (2001) review of the failure of a 1995–97 participatory irrigation management pilot, as well as many reflections on the AWB and farmer organization pilots over the last two decades. The popular view is one of some, but limited, success of participatory irrigation management, but despite—rather than because of—the PIDA Act. Mustafa et al. (2017) (p33–34) assert that "*implementation of participatory water reforms reflects the deeper structural problems that persist within the Pakistani water bureaucracy*" and confirm the reluctance of PID staff to facilitate farmer-based management.

The 1990s reform effort was focused mainly on governance and economic performance, paying less attention to infrastructure modernization. Two decades on, many of the governance and economic challenges remain pertinent, but there is a new opportunity to invest in improved hydraulic infrastructure at all levels of water distribution, and to improve performance through data-driven control systems. Improved data and information around water allocations and distribution would be critical to the establishment and effective operation of a formal water trading system. Such a system may not be fully devolved, but would require clear roles and accountability across multiple levels of irrigation governance. The principle of subsidiary is pertinent here, and some increased decentralization is likely to be critical for reducing operational costs to improve financial sustainability. Moving forward with the irrigation reforms outlined in the NWP will require recognizing the following lessons from earlier reform efforts:

- Irrigation reform requires genuine ownership and clear willingness to share power by those in positions of authority.
- Irrigation reform requires clear messaging on the purpose and process, agreed among federal and provincial governments, donors, development partners, and sector specialists. Social media can quickly propagate misleading narratives, which can be hard to counter.
- The extent and success of farmer participation will depend on farmers' legal empowerment and the degree of their integration into multilayered irrigation governance. Handing over watercourse management is unlikely to succeed without early farmer participation and adequate capacity building for financial management, conflict resolution, and O&M—together with initial external financial and technical support.
- Rural land-based inequality and power asymmetry persists and precludes small farmers acting against the interests of large landowners or kinship-based authorities. The PIDA Act's lack of clarity on AWB and farmer organization powers means these institutions cannot enforce the accountability envisioned by the act. Legislative amendments are required to define and establish the powers and responsibilities of AWBs and farmer organizations.
- Conflicts of interest of individuals engaged in higher-level decision making on irrigation reform must be avoided or identified and properly managed.
- Overlaps and contradictions between the remits of the PIDs and PIDAs, which arise from dual legislation, must be resolved for role clarity and efficiency.
- New technological opportunities for data-driven operational management will likely an important foundation for improved irrigation governance.

Political Economy of Karachi Water Services

The political economy of Karachi's water services is a relevant case study due to the size and economic importance of Pakistan's largest city, and because many of its local issues are emblematic for the challenges of the country's urban water sector. In Karachi, only about 55 percent of water demand is being met, and NRW is estimated to be 58 percent. Only 25 percent of industrial and commercial customers have metered supply, and there is no metering for retail customers. An average tariff of only US$0.13 per cubic meter and a collection efficiency below 50 percent contribute to the lack of cost recovery by the Karachi Water and Sewerage Board (KWSB) (World Bank 2018).

Until recently, water theft was widespread: illegal water hydrants far outnumbered legal sources, and water was stolen from Keenjhar Lake and the Hub Dam before it even reached the city (Felbab-Brown 2017). Water theft supported illegal tanker operators, delivering water valued at over US$500 million per year, with those providing assistance and protection within and outside KWSB also benefitting (Hashim 2017). In 2017 however, a Supreme Court order led to the closing down of illegal hydrants, leaving just six government-approved hydrants that now provide metered water through legal tankers.

Although rather dated now, the most recent comprehensive assessment of water infrastructure and management needs for Karachi (JICA and KWSB 2008) proposed a master plan to tackle wastage, theft, and NRW. Ten years later, the operational and financial sustainability of water services remains elusive. There is broad agreement on technical and financial solutions (infrastructure rehabilitation, comprehensive metering for retail supply, reducing NRW, and transforming KWSB into a modern efficient utility) and consensus that Karachi's water problems are a problem of governance and not water resource scarcity (ADB 2007; Mansuri et al. 2018; SBP 2017).

Consumer and utility issues are the key political economy factors that contribute to poor service delivery in Karachi. Consumer issues center on a lack of trust and dissatisfaction with service quality, and hence a low willingness to pay and a readiness to use informal sources of water. JICA and KWSB (2008) report that only 30 percent of water users across Karachi (and none in the *katchi abadis*) trust KWSB. An estimated half of registered KWSB customers pay their bills (World Bank 2018), and many Karachi residents are not registered as customers at all. Utility issues, including inefficient administration, political interference, and corruption, aggravate financial unsustainability and thus subsidy dependency. The resulting lack of autonomy constrains the utility's scope for reform and investments and thus its ability to improve services and increase trust—a vicious cycle.

For retail consumers, the distinction between ability and willingness to pay is important. JICA and KWSB (2008) conclude that only the latter was a constraint, both for domestic and retail customers. Attempts to increase cost recovery by offering concessions to bill defaulters were unsuccessful. Beyond poor water supply, a major reason for nonpayment was simply never receiving a bill, reflecting an inefficient billing and tariff collection system. Briscoe and Qamar (2005) note that residents of poorer localities lacking access to reliable piped supply pay more to tanker operators and informal vendors than they would for piped supply, and that people would be willing to pay higher tariffs if there were commensurate improvements in service delivery. Global experience—for example from Phnom Penh, Johannesburg, and Manila—indicate that financially sustainable water service delivery is possible provided incentives exist for service providers to improve service quality (World Bank 2005). Improving cost recovery will require additional efforts to ensure payment of water bills by provincial government institutions and senior officials and politicians, which figure prominently in published lists of bill defaulters and an 2012/13 report from the Auditor General of Pakistan.

On the utility side, ADB (2007) identifies corruption as the most notable governance issue in the urban water sector and concludes there are inadequate incentives for utility staff to implement technical solutions that reduce corruption. Mustafa et al. (2017) identify an insufficient revenue base and corruption amid lower-level staff among KWSB's most pressing problems. Corruption is a consequence and a cause of KWSB's financial problems and constitutes a structural problem rather than just one of individual morality. JICA and KWSB (2008) highlight low morale and a lack of motivation and enthusiasm among utility workers, resulting from top-down imposition of rules and regulations that neither recognize good performance nor punish bad behavior. This has had a reputational cost for KWSB, discouraging talented and hardworking professionals from joining the utility, further constraining performance improvement.

The financial dependence of Pakistan's water utilities on provincial governments limits their autonomy (SBP 2017). KWSB relies on direct subsidies from the Sindh government as well as federal funds for payments to Karachi Electric, infrastructure expansion, and debt servicing (World Bank 2018). In line with the Sindh Local Government Act 2013, the Sindh government retains influence by "approval of budgets, regulations and tariffs, hiring and postings, and provision or facilitation of locally mobilized funds or foreign loans or grants" (World Bank 2018). State and local control overlap, however, because the Karachi Metropolitan Corporation (KMC) (of which KWSB was part prior to 1996) is represented on the utility's board. The incomplete devolution and ambiguous institutional responsibilities have caused tension between provincial and municipal governments in Karachi, which has had a destabilizing influence on the governance of the urban water sector.

These structural problems have aggravated financial and human resource management challenges at KWSB. In the absence of comprehensive (provincial and local) water supply and sanitation policy, financial support to KWSB has been ad hoc and most often directed toward relieving immediate financial constraints (e.g., payments for electricity) or financing urgent pump station repairs. Politically motivated hiring of staff—enabled by loopholes in the KWSB Employees' Rules (1987) and the KWSB Act (1996)—has been widely reported. In the 1980s and 1990s, thousands of employees were hired based on political and ethnic affiliations, laying the foundation for "ghost employees" at KWSB. Periodic acknowledgement of this problem has triggered mass employment terminations. However, overstaffing remains a major issue, with 6.5 KWSB employees per 1,000 connections—more than three times the benchmark staffing ratio for low-income countries (LICs). With around 13,500 employees, salaries, benefits, and electricity charges represent over 90 percent of KWSB expenditure (World Bank 2018).

Poor service, inefficient cost recovery, corruption, and political interference on the one hand—and low consumer trust and willingness to pay on the other—have led to a decline in the quality and coverage of urban water services in Karachi, with access to improved water sources falling from 90 percent to 86 percent over the past decade (World Bank 2018).

There is no single simple entry point for water governance reform in Karachi, given the interwoven and cascading causes and effects. However, a critical starting point is to address the structural deficiencies that enable political interference and undermine utility autonomy. The KWSB Act (1996), that was supposed to ensure autonomy, has been managed by the provincial government through chairing the utility's board. The ambiguous and outdated legal framework should be updated to support autonomous water management and regulation. This requires rationalizing the overlaps in the provincial policy frameworks and aligning these with Local Government Act (2013), as well as establishing a legally empowered independent sector regulator for service providers.

Financing

Federal government revenue in Pakistan is mainly from income tax, general sales tax, wealth tax, capital gains tax, and custom duties. The Pakistan National Finance Commission divides this revenue into federal and provincial shares. The provincial share is distributed between provinces primarily based on population. Total revenue has more than doubled in the last decade, and the provincial share has increased from around 20 percent to more than 30 percent.

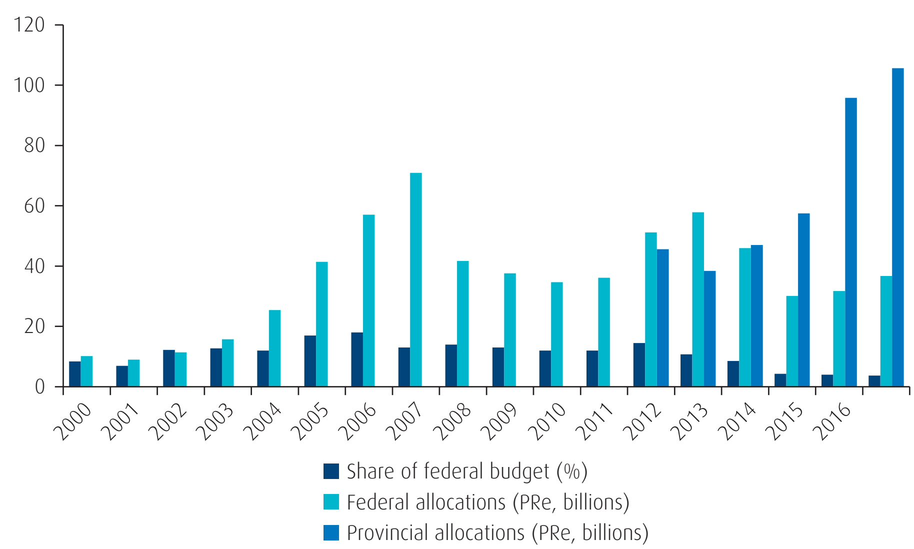
Expenditure is dominated by debt servicing (around 40 percent) and other nondevelopment expenditure (around 40 percent; half of which is defense spending). Development expenditure—through the Public-Sector Development Program (PSDP)—is thus around one-fifth of the total budget and allocated approximately equally at the federal and provincial levels. The PSDP is the government's primary mechanism for directing public sector resources to development goals and targets. Annual federal PSDP plans indicate the financial allocations for individual development projects, grouped under 41 ministerial divisions, two corporations, and some special programs. Historically, the relevant water sector ministerial division is the water and power division. Provincial governments use Annual Development Programs (ADPs) to allocate financial resources to support development visions.

In addition to receiving a share of federal government revenue, the water sector is financed by urban service tariffs, irrigation tariffs, private sector investment, and donor contributions. Urban service tariffs cover only 16 percent of the cost of urban water supply and sanitation services. Water supply and sanitation budgets are not correlated to need or poverty level, and the largest share of available finance goes to provincial capitals, rather than the rural poor. Irrigation tariffs fund a small fraction of irrigation O&M costs.

At the federal level, allocations to the water sector have averaged 11 percent over the last 18 years and only 4 percent over the last three years (figure 4.11). In 2018–19, the total allocation to PSDP was around PRe 2,000 billion. Given the significant increases in the total government revenue, the absolute allocations to the water sector in recent years are similar to the long-term average (figure 4.11). At the provincial level, the allocations to the water sector have more than doubled over the last five years (figure 4.11).

To assess water sector financing, government investment and expenditure are compared to investment recommendations of the Water Sector Task Force (FoDP 2012), which set priorities and describe interventions for a four-year period across five action areas: (i) major infrastructure and associated institutions; (ii) raising agricultural productivity; (iii) living better with floods; (iv) sustainable urban

Figure 4.11 Federal and Provincial Government Water Sector Funding Allocations and Percentage of Total Federal Budget in Pakistan, 2000–17



Source: GoP 2018.

services; and (v) knowledge management. For each action area multiple subactions are recommended, with indicative costs and timelines. A summary is presented in appendix C (table C.1). A detailed analysis of the federal PSDPs and provincial ADPs has been undertaken to assess allocations to, and expenditure against, priority projects that align to the Water Sector Task Force recommendations.

Sector financing over the four-year period 2013–17 was a little more than US$6 billion—one-fifth of the level of financing recommended by FoDP (2012). The underperformance is a mixture of undercommitment (commitment is 57 percent of recommended) and underexpenditure (table 4.4). Performance has been poorest for the action area "major infrastructure and associated institutions," followed by "raising agricultural productivity." Commitments against "sustainable urban services" and "knowledge management" have exceeded recommendations, but actual expenditure has been only a little over half the recommended level (table 4.4).

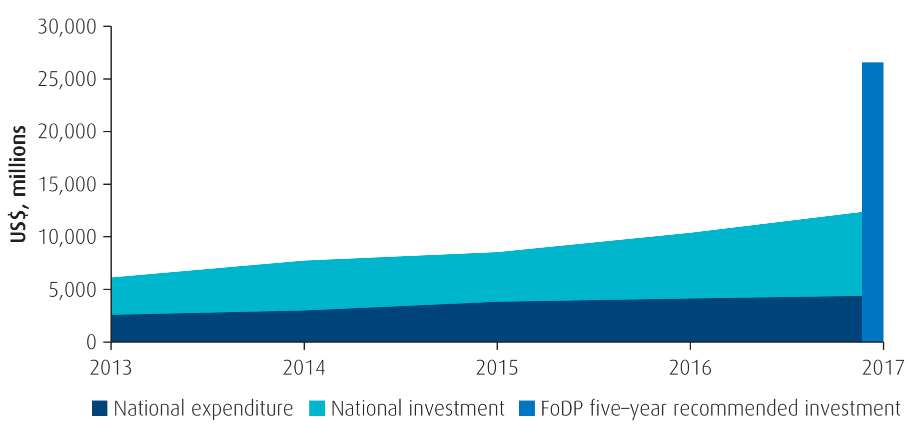
For the action area "major infrastructure and associated institutions," FoDP (2012) recommends investment in large storage dams, rehabilitation of water infrastructure, and strengthening institutional capacity, especially regarding IRSA. These investments represent 83 percent of the total recommended by FoDP (2012). A major proportion of the recommended investment was to rehabilitate three barrages and construct new large dams. Remaining funds were for IRSA reforms, developing revenue sharing and resettlement frameworks, and determining and implementing environmental flows. Federal and provincial investment is around half of the level recommended by FoDP (2012). The main reason for the shortfall is that despite government prioritizing investment in dams, commitments for these were not made during 2013–17. Actual expenditure has been 35 percent of funds committed (figure 4.12).

Table 4.4 Recommended Investments in Priority Actions Areas, Commitments, and Expenditures by Pakistan's Water Sector Task Force, 2013–17
US$, millions

Action area	Recommended investment	Actual commitment	Commitment as share of recommended	Actual expenditure	Expenditure as share of commitment	Expenditure as share of recommended
Major infrastructure and associated institutions	26,556	12,605	0.47	4,411	0.35	0.17
Raising agricultural productivity	1,920	1,406	0.73	338	0.24	0.18
Living better with floods	1,120	1,047	0.93	269	0.26	0.24
Sustainable urban services	2,299	3,134	1.36	1,198	0.38	0.52
Knowledge management	115	164	1.43	61	0.37	0.53
Total	**32,010**	**18,356**	**0.57**	**6,277**	**0.34**	**0.20**

Source: Author calculations.

Figure 4.12 National Investment and Expenditure for First WSTF Action in Pakistan, 2013–17



Source: Author calculations.
Note: The first action area is "major infrastructure and associated institutions." FoDP = Friends of Democratic Pakistan; WSTF = Water Sector Task Force.

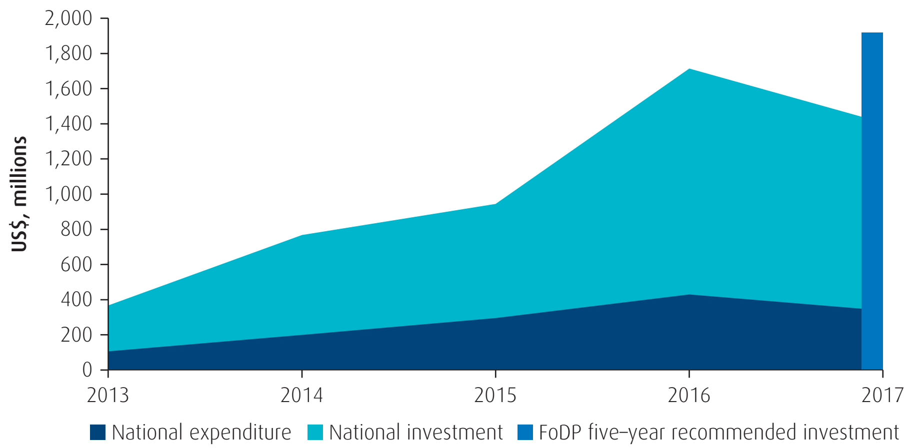
For the second action, "raising agricultural productivity," federal and provincial governments have made significant financial commitments; however, actual expenditure has been only at one-quarter of the planned investment level (figure 4.13). Cumulative investment and expenditure for some projects are reported under PDSP and ADP as reducing over time, reflecting both adjustments in planning and corrections to prior reporting.

For the third action, "living better with floods," FoDP (2012) recommends US$1.1 billion of investment to mitigate flood impacts and improve resilience. National investment commitment during the four-year period was close to the recommended level, mainly for key elements of the National Flood Protection Program IV. Actual expenditure, however, has been only one-quarter of the investment commitment, reflecting, in part, the delays in reaching a federal-provincial funding agreement for this work (figure 4.14).

The fourth action area, "sustainable urban services," promotes productive, secure, and sustainable cities, addressing major social challenges of urbanization in Pakistan. Federal and provincial commitment have exceeded the level recommended by FoDP (2012), which only considers investments for one large city. Expenditure progress has been steady (figure 4.15).

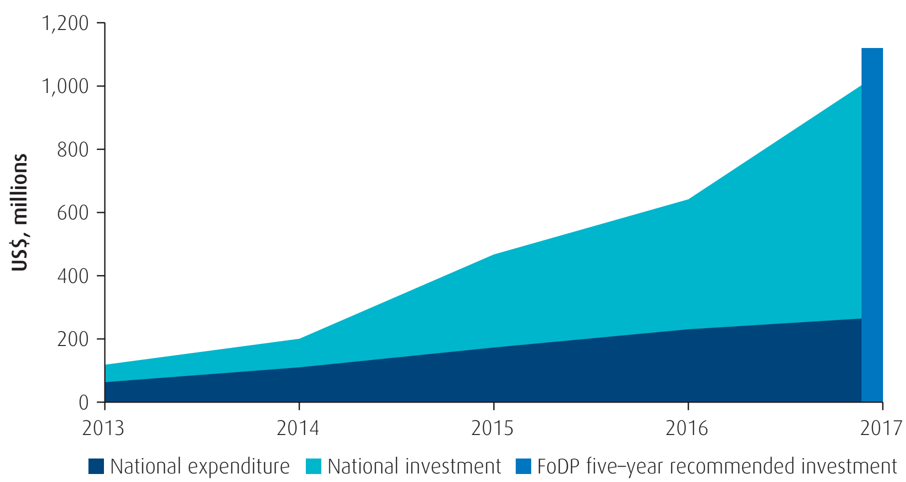
For the fifth action area, "knowledge management," FoDP (2012) recognizes the inadequacies of water research, modeling, and analysis in Pakistan. Recommendations cover capacity building for management and research, development of water models, a groundwater knowledge base and

Figure 4.13 National Investment and Expenditure for Second WSTF Action in Pakistan, 2013–17



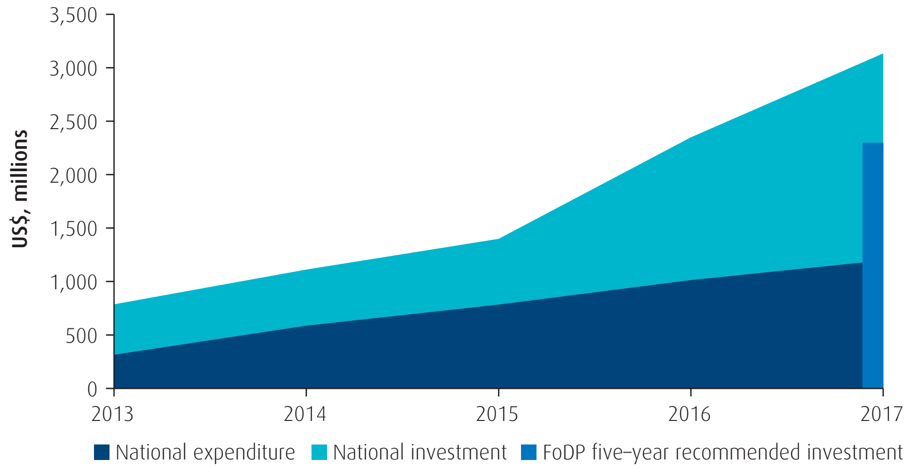
Source: Author calculations.
Note: The second action area is "raising agricultural productivity." FoDP = Friends of Democratic Pakistan; WSTF = Water Sector Task Force.

Figure 4.14 National Investment and Expenditure for Third WSTF Action in Pakistan, 2013–17



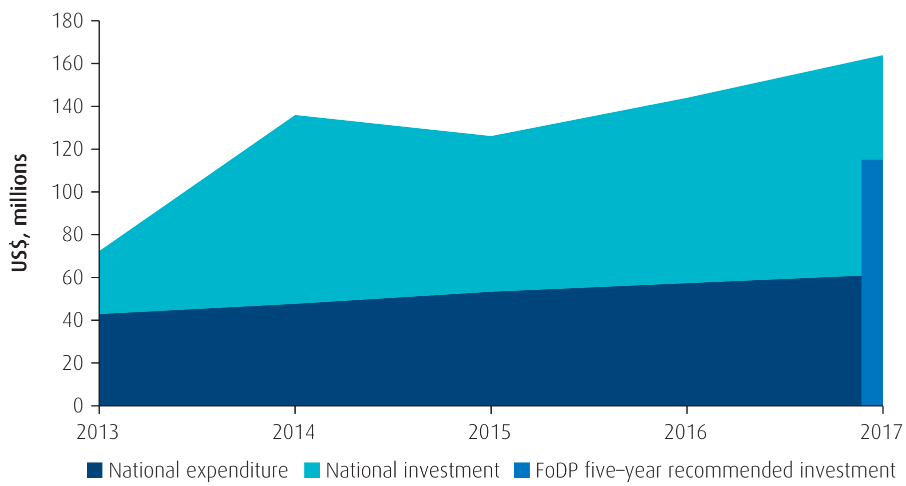
Source: Author calculations.
Note: The third action area is "living better with floods." FoDP = Friends of Democratic Pakistan; WSTF = Water Sector Task Force.

Figure 4.15 National Investment and Expenditure for Fourth WSTF Action in Pakistan, 2013–17



Source: Author calculations.
Note: The fourth action area is "sustainable urban services." FoDP = Friends of Democratic Pakistan; WSTF = Water Sector Task Force.

Figure 4.16 National Investment and Expenditure for Fifth WSTF Action in Pakistan, 2013–17



Source: Author calculations.
Note: The fifth action area is "knowledge management." FoDP = Friends of Democratic Pakistan; WSTF = Water Sector Task Force.

decision support systems, and international agency collaboration. The planned investment for this priority action has been US$164 million, well above the recommended level (figure 4.16). The largest project under this action is the World Bank–financed Water Sector Capacity Building and Advisory Services Project. Actual expenditure is low.

The preceding analysis shows that sector financing is inadequate. The biggest problem is slow expenditure, with only around one-third of the committed funds spent over the last four years. While expenditure remains low, it will be difficult to make the case for any additional funding for the sector. Slow expenditure reflects low institutional capacity and a risk-averse public sector; these will be slow to change.

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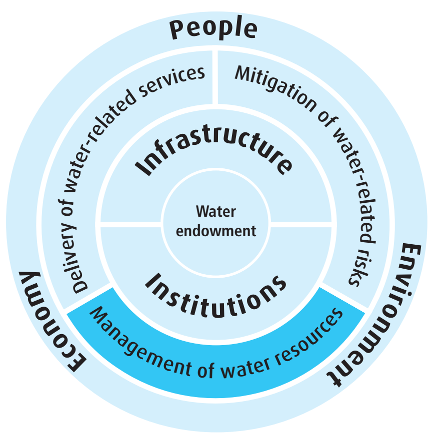
CHAPTER 5

Pakistan's Water Sector Performance

This chapter assesses the performance of Pakistan's water sector in terms of the management of water resources, the delivery of water-related services, and the mitigation of water-related risks. Flood management and pollution control—although water-related risks—are covered under water resources management. Risk mitigation covers exogenous and longer-term risks, including intersectoral complexities and climate change.



Water Resources Management

Management of water resources is central to water security. To assess performance in managing water resources the following aspects are considered:

- *Data, information, and analysis*. For water resource assessments and accounting; drought and flood forecasting; and data and information management and sharing.
- *Resource planning and allocation*. Strategic basin planning; flood planning; drought planning; and water allocation between and within provinces.
- *System operations*. Reservoir operations for irrigation supply; flood management; hydropower; and environmental flows.
- *Environmental sustainability*. Specification and management of environmental flows; sustainable groundwater management; pollution and water quality.
- *Productivity*. Economic productivity of water and land; water footprints; and land fragmentation.

Key Messages

- Basin-level water resources management in Pakistan is constrained by insufficient data and analysis, and a lack of strategic basin planning to guide sustainable resource use and economic development. There is a lack of clarity in risk sharing between provinces and sectors in times of acute scarcity.
- Within provinces there are no formal mechanisms for intersectoral reallocation of water in the face of changing demand patterns and changing climate. Water allocation processes are suboptimal in terms of efficiency, equity, and transparency, which contributes to the low productivity of irrigated agriculture and a lack of trust between farmers and service providers.
- The economic productivity of water is very low, especially in agriculture. Increasing productivity requires improving clarity and accountability in water governance, modernization and improving operational performance of irrigation systems, agricultural policy reform, improving on-farm water management and diversification of crop types, and reversing the fragmentation of land holdings.
- Groundwater is overexploited in parts of Punjab and Balochistan, but depletion is a small fraction of the annual groundwater balance, except in a few local cases. Severe depletion is problematic for urban water supply, especially in Lahore and Quetta. The greatest long-term risk to groundwater sustainability is pollution.
- Pakistan does little to protect water-dependent ecosystems through either environmental flows or water quality management. Efforts to protect the quality of the water resource base are inadequate. Climate change and increasing water demand will intensify the challenge of improving the sustainability of water management.
- Reservoir operations should be systematically reevaluated to assess their adequacy for meeting multiple benefits (including environmental benefits) across the Indus Basin in the face of a changing climate and changing demand patterns.

Data, Information, and Analysis

Monitoring and Water Information Systems

Although average Indus inflows to Pakistan and outflows to the Arabian Sea are well known based on reasonably long-term and reliable records, there is only partial monitoring of runoff within Pakistan. Hydrological monitoring across the Makran Coast and Kharan Desert drainage areas is almost nonexistent. The data for internally generated water are typically ignored in water resource assessments and planning. Gross canal withdrawals are reasonably well monitored, although there are concerns about the veracity and transparency of these records given the tensions surrounding interprovincial water sharing.

As shown in chapter 3, the internal recycling of water in the Indus Basin and the high level of water loss mean that monitoring of inflows, outflows, and canal withdrawals is insufficient to arrive at a fully accurate and reliable water balance that resolves internal fluxes—even on a long-term average basis. A dynamic water account is required to inform seasonal water allocation decisions, irrigation system management, and conjunctive surface water and groundwater management. This requires much better monitoring and analysis. The significant river gains and losses, which as shown in chapter 3 are not in dynamic equilibrium, are poorly quantified and poorly understood.

Farm-level water use is not monitored, leaving much uncertainty in how, when, and where it is used. Pakistan—with its water scarcity issues—should be concerned about its inability to accurately describe what happens to around half of the total resource. Flow to the sea supports important environmental assets and functions, especially in the delta region, but is still widely considered a waste in Pakistan. Unaccounted losses, including beneficial consumptive landscape water use and large nonconsumptive losses in irrigation, are around three times the magnitude of flow to the sea, and should a primary focus for improved water resources management. Pakistan urgently needs to strengthen hydrological monitoring systems and develop robust water accounting to guide improved water resource planning and allocation. This should combine ground-based observations with Earth observations in robust modeling and accounting frameworks.

Pakistan needs to adopt modern, integrated systems for data storage, retrieval, and sharing. Numerous federal and provincial agencies collect data but use different software platforms for data storage—with limited interoperability and manual sharing. Few data from before the 1990s have been captured in electronic form and so are difficult to access. This limits the value of these data to water planners and managers, as well as to researchers. While some real-time data are shared by federal and provincial agencies, historical data are not routinely placed in the public domain, and accessing these data is difficult and slow. Donor-funded assistance to the Pakistan Water and Power Development Authority (WAPDA) is helping to establish a modern water data management system, but much work is required to capture legacy data, encourage wider adoption of this platform (or compatible platforms) across other federal and provincial agencies, establish processes and protocols for interagency data exchange, and facilitate for online public data access.

Failure to develop and maintain transparent water information systems undermines water management efforts, creating uncertainty and controversy over the size of the water resource and the volumes allocated for use. There remain ongoing controversies over measuring flows at both the barrages and in distributary canals. Each province is responsible for measuring water diversions. In principle, other provinces may send officials to "check" observations; however, the arrangement does not work effectively. An Indus Basin telemetry system intended to provide confidence in measurement of water flows at key locations failed (Bhatti, Anwar, and Aslam 2017; FoDP 2012). New telemetry investments that will overcome past technical deficiencies, supported by improved governance arrangements, are planned with World Bank support.

There have been many hydrologic studies of the Upper Indus Basin, including assessing current climate change impacts and projecting potential future changes. However, all have been hampered by a paucity of long-term, good-quality hydrometeorological data. In the Upper Indus there is one gauge for precipitation for approximately each 5,000 square kilometers (UNDP 2017), well below the WMO (1994) standard of one gauge per 250 square kilometers. ADB (2010) recommends that at least 75 automatic weather stations (AWS) and 35 hydrological monitoring stations should be installed at high elevation across the Upper Indus Basin. A denser monitoring network will capture seasonal variations across the basin and correct the current bias due to a predominance of valley floor monitoring stations. Better hydrometeorological data from the Upper Indus Basin will be especially important for research into the changing hydrology and glaciology of the Indus. Increases in flow variability at different time scales are expected and understanding these is critical for future water management.

Forecasting

Pakistan's weather and flow forecasting are largely insufficient to meet diverse stakeholder information needs. Currently, one- to two-day weather forecasts, three- to five-day outlooks, and 24-hour hydrological forecasts are generated (World Bank 2018). These are insufficient to meet the needs of stakeholders who require information for short-term operations (including more actionable forecasts and warnings) and for medium- to long-term planning, particularly in the context of increased climate variability. Provincial irrigation departments need improved hydrometeorological information to better manage irrigation water distribution, and provincial agriculture departments need monthly weather outlooks tailored to 19 agricultural zones. Better hydrologic forecasts, including of transboundary flows, are needed to guide reservoir management and hydropower operations. Improved river flow forecasts should inform interprovincial water allocation.

Flood forecasting is important for Pakistan, and while good progress has been made, capabilities are still relatively rudimentary. Data from weather radar, telemetered AWS, and a larger manual network are used mostly for manual analyses (e.g., hand-drawn hydrograph analysis and simple regress analysis for snowmelt estimation) as well as for some computer modeling. Quantitative precipitation forecasts are generated using the flood early warning system (FEWS). Hydrologic modeling is conducted with the U.S. NOAA/NWS Sacramento Soil Moisture Accounting Model; and hydraulic simulation of flood wave routing and flood inundation mapping is conducted using SOBEK.

The current forecasting system has many weaknesses. The sparse AWS network has limited telemetry and inadequate radar coverage. The monitoring network has operational problems, such as inadequate power supply backups and a lack of centralized data storage and management. Forecasting is of river stage only (not flow), there is no routine monitoring of the upper basin snow pack or snow pack modeling for flow prediction, and there is no reservoir simulation modeling. Routine data analysis is not automated and there is no objective process for forecast verification. Interagency data sharing is very limited. The Indus Water Treaty provides for data sharing with India for flow forecasting, but there are no arrangements for data sharing with Afghanistan or China.

Flood forecasting and early warning coverage are incomplete and should be extended to the remote areas of the country, especially the hill torrents and Swat and Kabul rivers (Ali 2013). The steep topography of these catchments means runoff is particularly rapid, generating dangerous flash floods, especially during the monsoon. The 2010 flood was largely caused by exceptional rainfall in the Kabul and Swat basins of the Upper Indus, which were not monitored. This delayed early warnings and flood responses (Tariq and van de Giesen 2012). Coordination with Afghanistan on flood forecasting for the Kabul could help mitigate floods.

Existing hydrometeorological monitoring is inadequate for drought forecasting and planning. Monitoring and forecasting focus on rainfall, snowfall, and irrigation system inflows, but ignore soil moisture and other water parameters needed to identify the onset of agricultural drought (Khan and Khan 2015). Drought planning suffers from a lack of standardized risk assessments, and drought response suffers from inadequate data sharing protocols (Khan and Khan 2015). These shortcomings hinder drought preparation and mitigation.

Groundwater and Water Quality

There is limited monitoring of groundwater levels and quality in Pakistan, despite the importance of groundwater and the growing challenges of salinization and depletion. Data are collected and published on the growing number of private tube wells, but there are few operational programs for systematic groundwater condition monitoring (Bhatti et al. 2017). Groundwater is monitored in some urban areas, but in agricultural areas, only Punjab has any semblance of an institutionalized and systematic monitoring program. The Punjab program monitors levels and quality through a network of piezometric wells and water quality sampling points (Bhatti et al. 2017). Greater investment in groundwater monitoring and analysis is required to inform sustainable groundwater use, conjunctive surface water and groundwater management, and irrigation drainage and salinity management.

There is some, but far from adequate, monitoring of water quality across Pakistan. Sediment concentrations are monitored routinely at the regular gauging stations (table 4.3), mostly in the Upper Indus Basin, and some chemical samples are collected approximately monthly. Some provincial authorities monitor the quality of drinking water supplies—surface water and groundwater—but monitoring is infrequent and inconsistent. National and international scientific organizations have monitored water quality to assess the status and trend in environmental conditions and the risks to human health (e.g., Grigg et al. 2018). But there is no consistent approach to data storage or access, limited data quality assurance, and limited data sharing between agencies. Some sediment and contaminant concentration data have been collected, but no comprehensive analysis has been undertaken of loads or transport and how these have changed with agricultural expansion and urban and industrial development.

Modeling

Numerous hydrologic and water resource simulation models have been developed for the Indus, including by the World Bank and several research organizations. WAPDA is the custodian of the latest version of the Indus Basin Model Revised (IBMR) developed by the World Bank and used in Yu et al. (2013). A variant, linked to a computable general equilibrium (CGE) model of the national economy, is used here (see chapter 6). The IBMR is an optimizing model, focused on monthly water allocations to irrigation agriculture. While it represents the complex river and canal network, it does not a model the hydrologic routing of flows through the system. More recently, an Indus River System Model (IRSM) has been developed for the Indus using the Source modeling platform (Stewart et al. 2018). IRSM is a daily flow routing and allocation model that includes river gains and losses to and from groundwater. This model has been developed to strengthen water accounting and flow allocation processes at the Indus River System Authority (IRSA), but is also suitable for strategic basin planning. While significant effort has been put to capacity building in the use of IRSM, it has not been adopted to inform the seasonal water allocation process, which continues to rely on daily manual updating of spreadsheets and sharing allocation assessments with the provinces by facsimile. There is an important opportunity to modernize this process for more reliable water accounting and more transparent and efficient data and information sharing.

Resource Planning and Allocation

Strategic Basin Planning

In Pakistan, water resources planning has focused strongly on supply-side infrastructure with much of the water resources development discourse revolving around new dams. There is no established mechanism for strategic basin-scale planning—either for the Indus Basin or the minor basins of Balochistan—that comprehensively considers sustainable management of existing infrastructure assets, surface water and groundwater interactions, interprovincial water sharing, intersectoral water management, environmental sustainability, or basin-scale management of sediment and salinity and other water quality issues. Flood planning and interprovincial sharing have been addressed with some success, and management of some major system assets—especially the headwater dams—has been the responsibility of WAPDA with development financing support.

The 2018 National Water Policy (NWP) and the Balochistan Integrated Water Resources Management (IWRM) policy espouse a desire to operationalize a more comprehensive and integrated approach to water resources management, but this has yet to be seriously tackled. As noted in chapter 4, this requires institutional reforms and a more comprehensive legal framework. IRSA, as a key institution with a basin-scale perspective, currently has a narrow operational role in water distribution, and has neither the mandate nor the capacity to embrace a more strategic planning function. Nonetheless, establishing a process of strategic basin planning is increasingly critical for Pakistan, given increasing water demands and shifting sectoral balance, the growing challenges of climate change, and the increasing evidence of environmentally unsuitable water management with significant negative consequences. Strategic planning is recommended for the entire Indus Basin of Pakistan for long-term environmentally sustainable economic development, as well as for subbasins such as the Kabul and key river basins in Balochistan. For the Kabul, there are opportunities to establish transboundary governance arrangements with Afghanistan to support joint water resources planning and development. While many aspects of water resources planning can and should happen at the provincial level, issues of environmental sustainability, sediment management, major asset management (dams and barrages), interprovincial sharing, and transboundary water issues require a suitably resourced (funding and capacity) and sufficiently empowered federal institution with mechanisms for effective provincial consultation.

Flood Planning

Flood planning is one aspect of basin-scale management that has received long-standing attention in Pakistan, with the establishment in 1977 (following the 1976 floods) of a Federal Flood Commission and a sequence of strategic plans backed by significant investment. While flood planning has traditionally followed a largely infrastructure-based approach, there has been a positive shift toward more integrated flood management solutions in recent years. This includes the work of the National Disaster Management Authority, established in 2010. Its mandate is to implement vulnerability assessments, multihazard early warning systems, and community-level vulnerability reduction programs; and to promote disaster preparedness planning.

Initial flood investment plans supported the construction of the current system of spurs and levees to train manage flood discharges and protect riverbanks from erosion. The latest iteration—the fourth 10-year National Flood Protection Plan—describes an investment of around US$1.7 billion, of which nearly 90 percent is related to infrastructure. Although the Federal Flood Commission (FFC) recognizes the significant climate change risks confronting Pakistan, the current investment plan has few specifics on how to address these risks beyond undefined studies. Given the changing intensity and frequency of hydrological extremes under climate change, flood planning needs to make specific provisions for floods that exceed the design criteria of existing infrastructure, and revise existing design standards, if necessary. Current inspection protocols for flood protection structures should be reviewed in the short term, to strengthen or upgrade flood protection infrastructure, and over the medium term. NFPP IV prioritizes improvements in flood forecasting and notes the importance of other nonstructural measures such as vulnerability and risk assessments, floodplain zoning, and land-use planning and enforcement. However, beyond the forecasting work, these critical nonstructural improvements are left to provincial governments. because they are outside the current financing envelop, they are not likely to progress.

The FFC should show stronger leadership on nonstructural aspects of flood planning, because a basin-scale approach is required that addresses the trade-offs between flood risks and the benefits arising from floodplain development. These strategic planning questions need to be addressed within the national flood management framework, because they guide flood management investments. In evaluating nonstructural measures, flood management needs to more prominently include catchment management, especially in the north and northwest of the country. Catchment management in the hill torrent areas, using community-based approaches, can help reduce flash flood risk and reduce river flood peaks while providing irrigation water in the Hindu Kush Himalaya (Saher et al. 2015; Shrestha, Shah, and Karim 2008). While federal and provincial governments have agreed to a cost-sharing arrangement to finance NFPP IV, the FFC requires considerable additional capacity to effectively oversee implementation of this major program.

Drought Planning

Droughts occur frequently in Pakistan (table 5.1) and can affect almost one-third of Pakistan (map 5.1). The most drone-prone areas include Cholistan in Punjab, Thar in Sindh, and the Chagai-Kharan region in Balochistan (Khan and Khan 2015). Balochistan is by far the most drought-prone province because of its arid to hyper-arid climate (van Gils and Baig 1992). Balochistan's agricultural sector has

Table 5.1 Droughts in Pakistan

Extent	Year or period
Pakistan	1871,1881, 1899, 1902, 1920, 1931, 1935, 1947, 1951, 1998–2001
Balochistan	no early data, 1967–69, 1971, 1973–75, 1994, 1998–2002, 2009–15
Khyber Pakhtunkhwa	1902, 1951, 1986, 1999
Punjab	1899, 1920, 1935, 1999–2001
Sindh	1871, 1881, 1899, 1931, 1947, 1999, 2014, 2015

Sources: Ahmad et al. 2004; Ahmed et al. 2016; Ata-ur-Rahman and Shaw 2015.

Map 5.1 Percentage of District Population Vulnerable to Drought in Pakistan

Source: Shariff 2015.

experienced major drought losses, especially from 1998 to 2002 when agricultural productivity halved (Ahmad et al. 2004). Nationally, this drought was the most extreme since independence. It affected more than 3.5 million people, caused hundreds of deaths, and increased migration from rural Balochistan (GoP 2004). Three years of drought from 2012 to 2015 had further serious impacts across the arid zone (WFP 2015).

The institutional arrangements for drought planning are well defined and managed by the National Disaster Management Authority (NDMA). It is hampered, however, by a lack of capacity, and its functions do not include basin-scale water sharing arrangements during periods of extreme scarcity. The extent to which NDMA effectively advises decision makers on droughts is unclear. Given the far-reaching impacts of droughts on Pakistan's economy and society, more attention needs to be paid to drought planning, including development and implementation of a drought forecasting system. Sánchez-Triana et al. (2015) recommend a three-tiered drought forecasting system based on rainfall predictions including (i) probabilistic one- to 15-day forecasts at 25-kilometer resolution for agriculture and water resource management; (ii) probabilistic 15- to 30-day forecasts using extended monthly forecasts statistically adjusted for intraseasonal variability; and (iii) probabilistic one- to seven-month national drought forecasts.

Drought planning should include medium- and long-term measures that increase resilience to drought and improve water management outcomes, including intercropping for soil diversification and amelioration, drought-resistant crops, soil water accounting, and conservation agriculture. Farmers in Sindh are more affected by drought than those in Punjab because of limited access to groundwater (FAO 2016). More equitable water sharing during extreme scarcity is required to compensate for this disparity.

Water Allocation

Water allocation refers to the rules and procedures that define access to water in relation to availability. This section examines existing water allocation mechanisms between and within the provinces of Pakistan. Pakistan's water allocation framework provides a basis for water sharing and water access—in the absence of any legal system of water property rights. Despite providing some level of certainty to water users, the framework fails to ensure equitable and efficient water delivery, is not sufficiently transparent, and fails to adequately address environmental sustainability.

Interprovincial Water Allocation

Interprovincial water disputes, especially between Punjab and Sindh, predate the creation of Pakistan by many years. Prepartition ambitions of Punjab to divert water for irrigation were opposed by Sindh, and in 1945 the British imposed a solution on the two provinces, giving priority to Sindh's right to access Indus waters. This arrangement remained in place until 1970. Subsequently, the federal government began allocating water on an ad hoc basis, leading to ongoing disputes. Numerous commissions failed to reach agreement, until the four provinces agreed to the 1991 Water Apportionment Accord.

The Accord is focused on the distribution of canal water entitlements between the provinces. Rather than explore hydraulic or economic optimality, it specifies and protects existing uses of canal water for each province. It also recognizes the importance of an environmental flow allocation and provides guidance on how the balance of river supplies—above the baseline allocation volumes—should be shared. The Accord notes proposed environmental flows, but the signatories did not agree on quantity or rules and deferred the decision to further studies (Anwar and Bhatti 2018).

An international panel of experts recommended a continuous minimum environmental flow with an occasional larger flow (Gonzalez et al. 2005). Gippel (2015) is critical of this recommendation because it was not based on scientific analysis and notes the diverse environmental flow objectives and lack of robust scientific study to determine the flows required to meet specific environmental objectives. The Accord thus makes no specific allowance for environmental flows. Current flow to the delta is essentially a default unmanaged environmental flow of seemingly marginal benefit. This remains a major shortcoming of water basin-scale management in Pakistan.

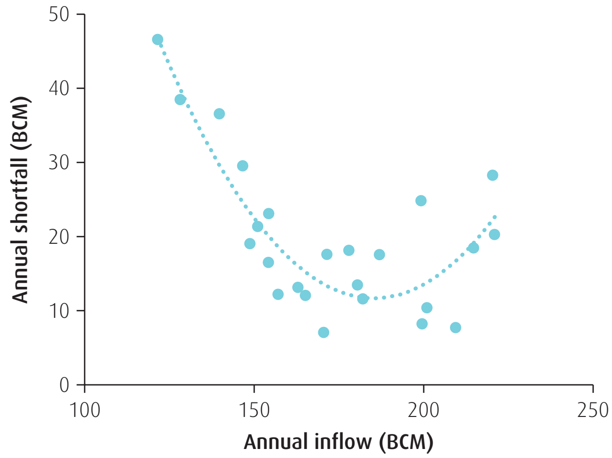
The Accord shares a baseline volume of 144.749 billion cubic meters per year between the provinces in the following approximate shares: Punjab, 48 percent; Sindh, 42 percent; Khyber Pakhtunkhwa (KP), 7 percent; and Balochistan, 3 percent. Anwar and Bhatti (2018) estimate that this volume has been available in 90 percent of the years on record. The Accord also indicates—in appendices agreed after signing—how these shares will be allocated across 21 separate irrigation systems. This sharing is summarized in Anwar and Bhatti (2018). In the 10 percent of years when the available water is below the baseline volume, the shortfalls need to be shared between provinces. While the Accord gives some guidance on this issue, the provinces have different interpretations of this guidance, and this remains an area of interprovincial dispute. As flow variability increases with climate change, and as the intersectoral balance of water demands change, more sophisticated and economically efficient approaches to water sharing during periods of temporary scarcity will become increasingly urgent. Further, a key aspect of this improved drought planning will be clarity on appropriate environmental objectives, environmental water allocations, and necessary protections for these allocations.

The Accord provides guidance for the sharing of water above the baseline volume in the wettest 10 percent of years: Punjab and Sindh receive 37 percent each, KP, 14 percent; and Balochistan, 12 percent. This sharing is less contentious than that of shortfalls, because in excess years, KP and Punjab, in particular, typically receive higher than average rainfall, and thus demand for additional irrigation supply in these provinces in these years can be low.

Since the adoption of the Accord, actual total annual canal withdrawals have averaged 19.7 billion cubic meters (or 13.6 percent) below the baseline allocation volume. In low inflow years, withdrawals are of course constrained by supply volume; however, in wetter years withdrawals are lower than full allocation because rainfall in the command areas reduces canal water demand, or because of canal capacity constraints. Anwar and Bhatti (2017) suggest that canal capacity constrains affect withdrawals for Punjab and Sindh in years when system inflows exceed around 162 billion cubic meters and 167 billion cubic meters, respectively. Additionally, withdrawal shortfalls reflect the aggregate outcome of the incremental process through the year (on a sequential 10-day basis) of assessing irrigation demand, announcing allocations, and making reservoir releases, allowing for river gains and losses. Operationally, a high priority is placed on achieving a carry-over storage volume at the end of the rabi season to meet early kharif demands. This places another constraint on allocations and may lead to more conservative allocations earlier in the year. The Accord does not specify detailed operating rules. These, however, have evolved over time, and the current (post-2003) approach is typically presented by IRSA as a "three-tier rule" (Anwar and Bhatti 2018) for low, medium, and high levels of annual water availability defined in terms of levels of historic withdrawal over a specified period.

Canal withdrawal shortfalls relative to the Accord's baseline allocation volume has been lowest in years around the median annual flow (figure 5.1). At the provincial level, withdrawal shortfalls in some cases simply reflect an inability to use the available allocation. Because of topography and limited infrastructure, Balochistan is unable to use its full

Figure 5.1 Relationship between Annual Irrigation Shortfall and Total Annual Inflow in Pakistan, 1992–2015



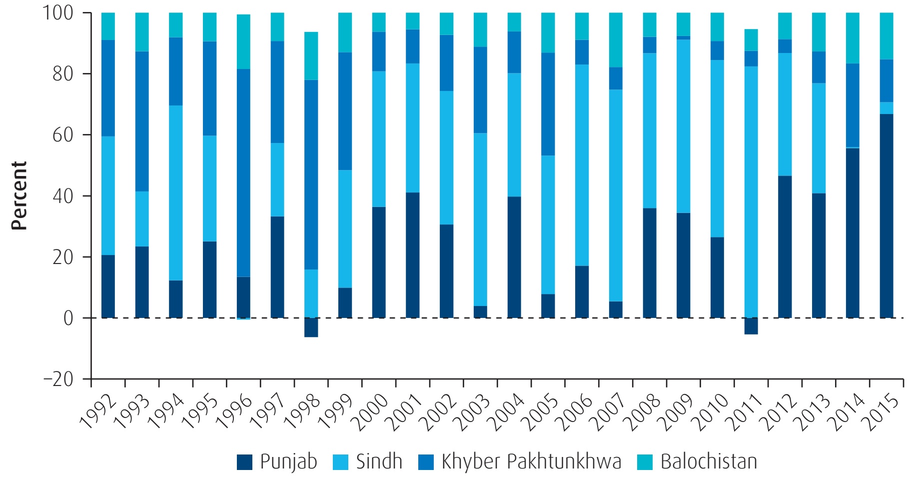
Source: WAPDA unpublished data and author calculations.
Note: Shortfalls are withdrawals are relative to baseline allocation volume.

allocation; its annual shortfall has varied between 25 percent and 53 percent. Until 2005, KP was unable to use its full allocation, and its annual "shortfall" varied from 42 percent to 50 percent. Since 2005, when the Pehur High-Level Canal was commissioned—bringing an additional 5,000 hectares under irrigation—the KP annual shortfall has averaged 11 percent.

An analysis of the annual shortfalls between provinces shows that while Punjab has the greatest allocation share, it has had a lower share of annual shortfalls because it is better able to use its full allocation (figure 5.2). In 1998 and 2011, Punjab withdrew more than its baseline allocation volume (reflecting allocation of excess water), while other provinces withdrew less than their baseline allocations. In 1998, rainfall and inflows were above average, and KP was not equipped to use its full allocation. In 2011, inflows were below average, and Sindh went over 90 percent of the total shortfall (equivalent to around 17 percent of the basin baseline allocation volume). Although this is only a partial picture of interprovincial sharing, it suggests there remain equity issues in implementation of the Accord.

From an economic efficiency perspective, Yu et al. (2013), p7, conclude that the Accord is suboptimal, and that relaxing it and implementing an economically based water allocation mechanism would benefit both Punjab and Sindh and enable the provinces "to better manage extreme events by more reliably meeting system-wide demands." This view is consistent with other model-based assessments of the impacts of more flexible water allocation, which suggest increased flexibility would increase agricultural profits

Figure 5.2 Share among Provinces of Annual Shortfall of Canal Withdrawals Relative to Water Apportionment Accord Baseline Allocation Volume in Pakistan, 1992–2015



Source: WAPDA unpublished data and author calculations.

by 2.5 percent to 5.0 percent (Yang et al. 2014). Yang et al. (2014) suggest, however, that the largest gains in water allocation efficiency can be achieved through water transfers and reallocation within provinces.

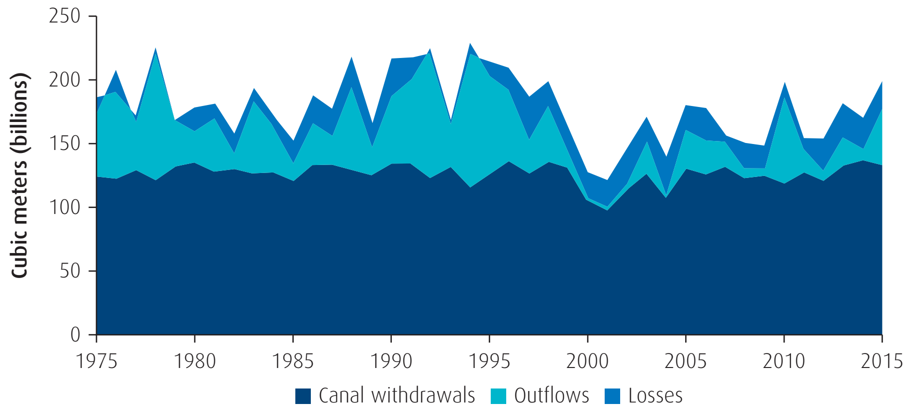
Moving to a more equitable and more economically efficient approach to interprovincial sharing requires advanced analytical approaches, including detailed modeling of water distribution, and ideally informed by improved flow monitoring and inflow forecasting. This in turn requires technical capacity strengthening, especially of IRSA, but also of WAPDA and the Pakistan Meteorological Department (PMD) for inflow forecasting. These advances would help improve the trust of the provinces in the interprovincial water allocation process.

The Accord does not constrain the provinces in how they use the allocated water. It does, however, require existing reservoirs to be operated to prioritize irrigation. While it acknowledges industrial and urban water demands, the lack of specific provisions leaves the issue of intersectoral allocation for provinces to address. This is especially problematic for Sindh, given the size and rate of growth of Karachi and its importance to the national economy, and the lack of viable alternative water supplies beyond limited groundwater and internal runoff.

Both intersectoral and interprovincial tensions are typically greatest during drought, as observed in 2000–01 and early 2018. A basin-level view of how annual inflows are partitioned between canal withdrawals, outflows below Kotri Barrage, and system losses (figure 5.3) shows that while withdrawals are remarkedly constant (suggesting adequate system storage)—only falling during the worst droughts—the generally lower inflows of the last 15 years have meant reduced outflows. Additionally, system losses have increased significantly. Because these losses are calculated as a water balance closure term, they combine errors in measurements (including falsification of withdrawal records), water theft, and natural system losses. One factor that may explain a fraction of the increasing losses over this period is climate warning in the Lower Indus Basin. Figure 5.4 compares system losses as a percentage of the total balance to the mean annual temperature anomaly (departure from the long-term mean) at Karachi: both show a significant and increasing trend.

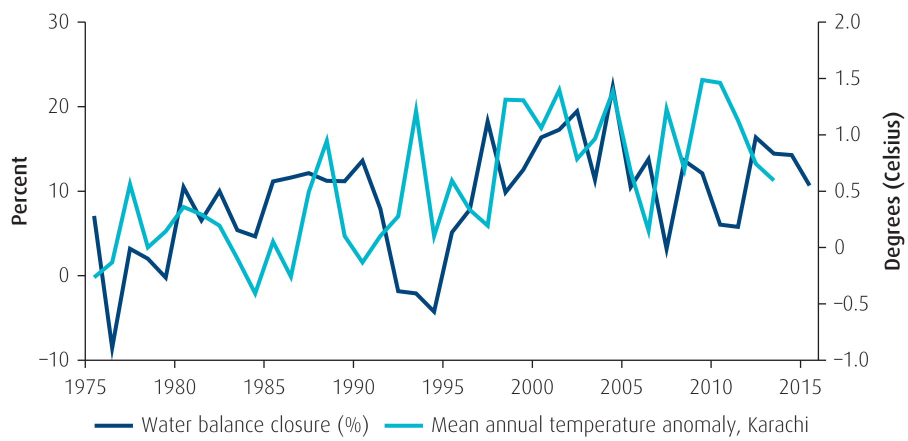
The basin water balance is clearly changing, which means the sharing arrangements of the Accord will increasing be tested, and their suboptimality will be increasingly challenged. Because the Accord is a consensus agreement between provinces and not a federal legislative instrument, it is extremely difficult to negotiate changes to the existing procedures. For example, the political process required to get all four provinces to agree to forsake a fraction of their water apportionment to augment supplies to the twin cities of Rawalpindi and Islamabad took many decades (Anwar and Bhatti 2017). Nonetheless, as systemwide demands grow, and climate change increases the variability of system inflows, the limitations of The Accord and its inflexibility will increase the vulnerability of the Indus Basin Irrigation System (IBIS) and Pakistan's water sector more broadly. The complexity of intergovernmental politics means this situation will not be easy to tackle without new federal legislation to articulate improved water sharing mechanisms and to empower and strengthen IRSA to implement these.

Figure 5.3 Annual Series of Total Canal Withdrawals, Outflow below Kotri Barrage, and Losses as Components of Indus Basin Inflows, Pakistan, 1975–2015



Source: WAPDA unpublished data.
Note: Losses calculated as water balance closure, and inflows refer only to rim station flows.

Figure 5.4 Annual Water Balance Closure and Mean Annual Temperature Anomaly for Karachi, Pakistan, 1975–2015



Source: WAPDA unpublished data; author calculations; and temperature data from http://berkeleyearth.lbl.gov/auto/Stations/TAVG/Text/157348-TAVG-Data.txt.

Intraprovincial Water Allocation

Within provinces, there are no established processes for formally allocating water to sectors or reallocating between sectors. Historically this has not been required, because the nonirrigation water demands have been comparatively small and, in many cases, are met largely by groundwater. However, as Pakistan's economy and population grow, competition for water between agriculture, industry, households, and the environment is increasing. Because options for supply augmentation are very limited, water will need to be reallocated from agriculture to industrial and domestic sectors, where its economic value is highest. Ensuring reliable urban supplies, especially during periods of extreme scarcity, requires more flexible and responsive mechanisms for intersectoral water allocation. Model-based assessments indicate that increased flexibility in surface water allocation within provinces—both within agriculture and between sectors—can increase agricultural profits and improve outcomes for domestic, industrial, and environmental water users (Yang et al. 2014). Establishing processes for intersectoral reallocation will be best achieved by restructuring provincial irrigation departments as agencies responsible and empowered to define and manage (through planning and operations) water for multiple outcomes.

Provincial government departments manage irrigation water allocations, and implement these through operation of barrages, major canals, and the distributary network. Water orders (or indents) are communicated by provincial irrigation authorities to IRSA every 10 days, which inform the release of water from headwater reservoirs and the distribution of water through the link canals and major canals, according to the detailed sharing arrangements of the appendices to the Accord. For significant periods of the year, however, water orders far exceed the available water and the capacity of the irrigation system. The irrigation system is thus often operated at capacity. Given the supply constraints, the IBIS is supply-driven rather than demand-driven (Shah et al. 2016), and shortages mean some land is often left fallow, and pressure on groundwater continues to increase.

The lowest level of water allocation follows the traditional *warabandi* system. Warabandi is the weekly schedule below the canal turnout (outlet) whereby water is distributed sequentially among land holdings, for durations proportional to the area of the land holding. Included in warabandi are canal operations plans (or rotational plans) that are typically applied at the tertiary (distributary) canal level. For any given week in a cropping season, these plans determine which tertiary canals remain open and which remain shut.

The warabandi system acts as a constraint to allocative efficiency. Economically efficient allocation means all farmers receive equal marginal net benefits from irrigation water (Akram 2013). Significant gains in total agricultural profits—in both Punjab and Sindh—could be achieved by implementing water allocation mechanisms that move water to those canal commands and crops that are relatively more profitable (Yang et al. 2014). While such a reallocation would be economically beneficial overall, there would of course be individual winners and losers. Reallocating water either by financial incentives (water pricing or markets) or by government-managed compensation schemes is complex and would require capable, trusted, and independently audited water institutions, supported by robust and transparent water accounting. A sensible first step would be to establish robust monitoring of water delivery across command areas, with all data shared openly and in near-time on multiple platforms including mobile phones.

System Operations

Operation of the major multipurpose reservoirs (Tarbela and Mangla) affects water distribution, hydropower generation, and flood mitigation. Although reservoir operation is one of the least discussed aspects of Pakistan's water resources management, optimizing operations may offer important opportunities for improving water outcomes with minimal investment. Tarbela and Mangla have been operated to maximize irrigation water supplies, with energy generation and flood protection as secondary objectives (Yu et al. 2013). Global experience suggests that adopting a dynamic, multipurpose approach to reservoir operation could increase economic benefits (OECD 2017). For the Indus, modeling suggests multipurpose operations could increase economic benefits by up to 20 percent (FoDP 2012).

Revised reservoir operations could improve flood mitigation. Following the 1992 flood the standard operating procedures for Tarbela and Mangla were revised for flood mitigation (GoP 2018a). This helped to mitigate the 2010 flood peak: Mangla operations reduced the flood peak in the Jhelum by 35 percent, and Tarbela operations reduced the flood peak in the Indus by 28 percent (Ali 2013). However, these reductions did not significantly reduce flood damages (Tariq and van de Giesen 2012). Noncompliance with standard operating procedures led to levee breaching near the Jinnah and Taunsa barrages with serious impacts in Punjab (Shah, Shakir, and Masood 2011). Recognizing the importance of fully capturing the flood mitigation potential of large reservoirs, the Pakistan Ministry of Water Resources has indicated the "strong need to review and improve Tarbela's existing operating policy to provide more flood mitigation relief to downstream areas" (GoP 2018a). Operating the headwater dams for greater flood mitigation requires improved hydrological forecasts—better skill and longer lead times—and processes to integrate these forecasts into reservoir operation.

Neither Tarbela's nor Mangla's standard operating procedures consider environmental flow management or reservoir sedimentation. Environmental degradation of the lower river and delta, including salinity intrusion (chapter 2), indicates current inadequate environmental flows especially during rabi, as well as sediment deprivation of the delta. Current flows to the sea are primarily unregulated monsoon flows. Revised reservoir operating protocols could incorporate managed releases for environmental flows during rabi. With the addition of Diamer Bhasha, enhanced storage capacity would enable these flows to be met with monsoon inflows with limited impact on irrigation supply.

Operating protocols of large dams influence sediment trapping, and even partial drawdown during flood seasons can increase sediment transport (Roca 2012). Rashid, Shakir, and Khan (2014) show that sediment flushing is more technically and economically feasible for Tarbela than dredging or trucking. Khan and Tingsanchali (2009) demonstrate alterative operating rules for Tarbela that reduce sediment trap efficiency from 93 percent to 80 percent with impact on the reliability of irrigation supply. However, development of the river downstream of the dam and the level of sediment accumulated may preclude such operations (Annandale et al. 2016). A detailed analysis of alternative reservoir management options and downstream consequences is required to assess the feasibility of flushing and any trade-offs with irrigation supply.

Advances in computer science and multi-objective optimization can inform design of reservoir operation rules that are resilient to a wide range of future climatic uncertainties and that balance multiple objectives (Giuliani et al. 2016). Trade-off analysis of multi-objective optimization of reservoir cascades can identify rules that can enable environmental flow releases while incurring impacts only for irrigation water security (Konrad, Warner, and Higgins 2012; Krchnak, Richter, and Thomas 2009). This analysis requires an advanced system modeling platform such as IRSM (Stewart et al. 2018), complemented by appropriate economic analyses.

Barrage operations are critical to system performance. Although the primary function of the barrages is irrigation supply, flood operations are also important for barrage safety. Inadequate maintenance and significant sedimentation upstream of the barrages have compromised the flood performance of key barrages including Sukkur, making rehabilitation and upgrading for better operational control critical. None of the barrages were designed with consideration of environmental issues. Barrages fragment river habitats into a series of ecologically disconnected reaches. Fish ladders were retrofitted to Muhammad and Kotri barrages but poorly designed for endemic species and have proved ineffective. Improved fish passages at key barrages should be investigated to offset some of the environmental impacts of flow regulation, and there should be a detailed analysis of environmental flow options.

Postflood disaster operations are important to reducing flood impacts. Disaster response is supposed to be coordinated between the NDMA and the Provincial Disaster Management Authorities (PDMAs). While the NDMA mainly has policy, planning, and guidance functions, it is also supposed to coordinate response efforts during events. PDMAs coordinate provincial relief, compensation, and rehabilitation efforts. Historically, postflood operations have been weak in Pakistan. Deficiencies include lack of flood response plans to guide overflow on the floodplain and identify embankment breaching sites; lack of citizen involvement; and limited access to early warning information for marginalized groups, including women (Mustafa et al. 2015). Developing flood response plans will require addressing political economy issues, including political influencing of flood peak diversion and embankment breaching sites.

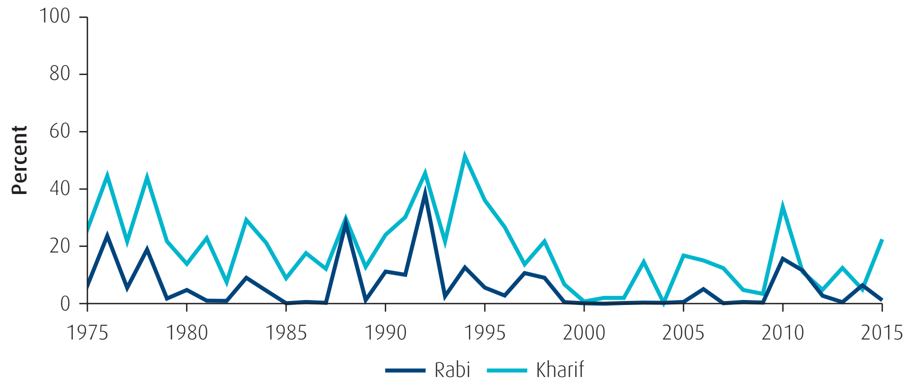
During the 2010 floods, the NDMA failed to adequately coordinate responses across the country (Sánchez-Triana et al. 2015). A judicial enquiry concluded flood preparedness and response were inadequate, and that deviating from standard operating procedures caused flood levees at the Jinnah and Taunsa barrages to breach (Shah, Shakir, and Masood 2011). Flood response plans should be based on improved forecasting and warning services. Evidence suggests that public response to flood warnings is very weak (Mustafa et al. 2015). Additional trials are required of community-based early warning systems that integrate improved forecasting and maximize citizen participation. Capacity building for agency staff is required in aspects of disaster prevention and forecasting. Few staff members have the skills required for sound barrage operation during floods or for assessment of structural weaknesses in the levee system. Professional training in the use of forecasting tools and in transforming medium-range climate forecasts into actionable probabilistic hydrological forecasts is needed.

Environmental Sustainability

Pakistan does little to protect water-dependent ecosystems (rivers, lakes, and wetlands—including the Indus Delta) by either water quantity or water quality management, and the efforts to protect the quality of the water resource base are inadequate. No environmental flow regime has been agreed or implemented for the Indus River. As noted in chapter 3, system outflows from Kotri Barrage—an indication of flow reaching the Indus Delta—have declined markedly in recent years. Since 2000, annual system outflows have averaged 18 billion cubic meters—just 10 percent of system inflows—and outflows during rabi season have averaged just 3 percent of rabi system inflows and were zero for half of the years in this period (figure 5.5). As discussed in chapter 3, reduction from inflows to outflows is not solely because of water withdrawal for consumptive use. As a semi-arid zone river, the Indus is characterized by high natural losses (or consumptive environmental water use—natural evapotranspiration) in the lower reaches. In absence of either prewater resource development measurement of outflows or detailed hydrologic simulation of an unimpaired river flow regime for comparison, the actual outflow reduction as a reduction on irrigation water use is uncertain. Suffice to say, the reductions are very large, especially during rabi, and are clearly environmentally unsustainable.

The Accord notes the need for an environmental water allocation; while noting that Sindh has proposed an annual volume of around 15 billion cubic meters, it does not specify an agreed or required volume. Current system management does not seek to deliver environmental flows, and flows to the delta are primarily a combination of poor quality irrigation return

Figure 5.5 Indus River System Outflows from Kotri Barrage as Share of System Inflow, by Season, 1975–2015



Source: WAPDA unpublished data.

flows during rabi and unregulated high flows during kharif, especially in wetter years. Efforts have been made to specify environmental flows, including three studies completed in 2005 for the FFC to guide the flows envisaged by the Accord, and an international panel of experts (Gonzalez et al. 2005), which reviewed these studies. More recently a comprehensive review was undertaken for WWF-Pakistan by Gippel (2015). The international panel of experts (Gonzalez et al. 2005) recommended around 31 billion cubic meters per year, on average, with a constant flow equivalent to 4.4 billion cubic meters per year and periodic larger pulses, managed over a five-year accounting period. However, Gippel (2015) notes there are widely divergent recommendations among the studies for environmental flows, reflecting divergent or unclear environmental objectives, different methods and assumptions, a lack of good data on which to base analyses, and many scientifically unsupported recommendations. Gippel (2015), p93, notes that the work undertaken for the FFC was "impressive in its breadth of coverage and extensive reporting, but disappointing in the number of errors, inconsistency in the data, vaguely stated or non-existent environmental flow objectives, and flimsy recommendations." He further notes (p93) that the subsequent international panel of experts did not adopt these recommendations, but instead "recommended a flow regime that was not supported by any scientific analysis."

The current annual average end-of-system volume is similar to that proposed by Sindh. The environmental benefits achieved by this flow, however, are likely to be minimal—with great environmental stress for much of the year—because it is primarily a short period of unregulated high flows during kharif, typically with several months of essentially zero flow during rabi. Indicative of this flow regime change is that while 18 percent of annual inflows occur during rabi, under current conditions, less than 5 percent of annual outflows are recorded during this season. Once Diamer Bhasha Dam is operational, providing greater capacity to store and regulate Indus inflows, it is likely that in the absence of an agreed environmental flow regime and the institutional capacity to deliver this effectively, end-of-system flows will be further eroded given an enhanced ability to meet rabi irrigation. The additional operational control that Diamer Bhasha's storage capacity will provide could enable the current end-of-system flow volume to be managed more effectively, with a fraction purposefully delivered to the delta during Rabi as an environmental base flow, with periodic environment pulses released and managed through the system. Even better, and as recommended by Gippel (2015), a more comprehensive environmental flow analysis is required that explicitly links environmental flow regime options with ecological health and ecosystem services outcomes, using a process that engages all stakeholders to ensure the trade-off involved in supplying water for irrigation and other consumptive uses are well understood, to avoid unrealistic expectations that modest environmental flows will ever restore the entire delta to ecological health. While there are technical and scientific and challenges in undertaking such an analysis, the main barriers are institutional, including not acknowledging the problem. Defining environmental flows needs to be a government-led process with inputs from all stakeholders, driven by a shared recognition of the importance of improved environmental sustainability in water resources management.

Seawater intrusion in the Lower Indus, compounded by the lack of fresh water below the Kotri Barrage, is degrading water-dependent ecosystems and agricultural productivity. Seawater intrusion has caused vast areas of agricultural land to become unsuitable for farming and some has even disappeared into the sea (Majeed et al. 2010). Coastal Sindh (especially the Badin, Sujawal, and Thatta districts) is more vulnerable to seawater intrusion than coastal Balochistan. Seawater has penetrated 30–50 kilometers inland in some coastal areas of Sindh (SCCDP 2012), which has affected groundwater quality, agricultural productivity, and the livelihoods of some of the poorest populations (Memon and Thapa 2011). In the coastal belt of Makran in Balochistan, the Gwadar District is affected in parts by seawater intrusion, which is degrading groundwater quality and exacerbating the already extreme water scarcity of one of the poorest and most underdeveloped regions of Pakistan.

Pakistan is often considered a global hotspot of groundwater depletion. Uncontrolled groundwater pumping, mostly via diesel-fueled private tube wells, has contributed to groundwater depletion in the Indus Basin, particularly in the Punjab, home to about 90 percent of the private pumps. Assessments based on satellite observations have sought to highlight this issue; however, published estimates of groundwater depletion vary widely. In a recent and high-profile global modeling-based analysis, Dalin et al. (2017) rank Pakistan third in the world in terms of groundwater depletion, citing an unbelievable depletion rate of nearly 28 billion cubic meters per year based on coarse-scale global hydrologic modeling. This estimate is supposedly validated against coarse-scale Earth observations (400 kilometer by 400 kilometer NASA GRACE satellite data). For Pakistan this validation has relied on an even coarser regional estimate for a much larger region spanning three states in India. A more realistic regional assessment by MacDonald et al. (2016) based on in situ measurements suggests a current net annual depletion rate for the entire Indo-Gangetic basin of 8 billion cubic meters per year (plus or minus 3 billion cubic meters), with groundwater levels stable or rising over 70 percent of the assessed area and falling over 30 percent. As indicated in the water balance analysis of chapter 3 (and appendix A), annual groundwater depletion across the Indus Basin of Pakistan, appears to be of the order of 1 billion cubic meters. This is a small fraction (about 2 percent) of the annual groundwater balance. As highlighted in map 3.2, depth to groundwater across most of the basin is less than 1.2 meters, with waterlogging and salinization major concerns. Groundwater depletion is a not basinwide concern, but is largely confined to Punjab and Balochistan, in agricultural hotspots, such as the Khanewal Division in Punjab (MacDonald et al. 2016) and the Kuchlagh region of Balochistan (van Steenbergen et al. 2015), and in urban areas, such as Lahore and Quetta. While serious, the exhaustion of the aquifer in the agricultural region of Kuchlagh is reported as one of adaptation to suboptimal outcome, rather than a crisis. However, this reflects the specific opportunities and social circumstances of this location and is not a generic conclusion.

In Balochistan, groundwater use exceeds recharge by an estimated 22 percent (Halcrow Group 2007) with overexploitation occurring in 10 of 19 subbasins. In the Pishin Lora Basin, where abstraction is four times the recharge rate, pumping has entirely depleted the shallow alluvial aquifer, and new deep wells with powerful electric pumps have been installed to access the underlying fractured rock aquifer (van Steenbergen et al. 2015). In the Pishin Lora, overexploitation has led to neither conflict nor cooperation for more strategic, sustainable, and productive use. Rather, in the absence of any intervention, urbanization and changing employment options simply saw a gradual shift away from high-value, low-cost horticulture to a less lucrative production system (van Steenbergen et al. 2015).

Groundwater depletion in urban areas is likely to represent the greatest challenge, because it affects the largest number of people for whom access to alternative water is limited. Groundwater levels around Lahore have been falling at by 0.5–0.8 meters per year since the mid-1960s because of increased abstraction in response to a loss of reliable supply from the Ravi River. Recharge has been reduced because of flow reductions in the Ravi River (Mahmood et al. 2013). Ravi flow reductions reflect upstream development in India as permitted under the Indus Waters Treaty. Mahmood et al. (2013) demonstrate that the groundwater cone of depression under Lahore expanded from 2004 when depth to groundwater was less than 38 meters everywhere. By 2011, depth to groundwater exceeded 38 meters across 150 square kilometers. A daily average volumetric groundwater balance for the Lahore aquifer suggests abstraction exceeds recharge by around 10 percent (Qureshi and Sayed 2014). The aggregate annual depletion volume is estimated to be around 0.25 billion cubic meters, leading to a fall in average groundwater levels of 0.55 meters per year. Qureshi and Sayed (2014) suggest that demand management (through education, regulation of groundwater pumping, and water pricing) and supply enhancement (including managed aquifer recharge, rainfall harvesting, and canal water) could ensure water security and sustainable use for Lahore.

Surface water and groundwater quality across Pakistan has deteriorated significantly because of point and nonpoint source pollution. Pollution sources include untreated domestic effluent, agricultural drainage contaminated with pesticides and fertilizers, and unregulated industrial effluents containing toxic chemicals. In addition to these anthropogenic sources, naturally occurring arsenic is increasingly contaminating groundwater across much of Pakistan.

For Lahore, several outfall drains discharge untreated municipal and industrial effluent to the Ravi River (Qureshi and Sayed 2014), which, combined with streamflow reductions, contributes to the deterioration in measured water quality downstream from this point and to the deteriorating quality of groundwater (Hassan et al. 2016). Many components of this effluent will not deteriorate with passage through sediments before reaching the water table and thus will contaminate the groundwater for drinking water and irrigation for years to come.

Inadequate solid waste management, uncontrolled wastewater discharge, and leakage of sewage result in microbial contamination of drinking water supplies in all major cities of Pakistan. In some cases, microbial contamination may even be linked to improper filtration at water treatment plants (Azizullah et al. 2011). In rural areas, open dug wells and low water tables mean that water supplies are often contaminated with fecal matter (Raza et al. 2017). The surface water quality situation has been deteriorating, and it is worst during dry months. Many of the major cities are located along the rivers, which directly receive untreated municipal and industrial wastewater. An estimated 95 percent of shallow groundwater supplies in Sindh are bacteriologically contaminated (PCRWR 2004). Discharge of untreated wastewater into irrigation canals is increasingly common, and these canals are widely used for rural drinking water supply.

An estimated one in every six industries in Pakistan are heavily polluting (Sial et al. 2006), the worst being textile and leather factories, agroprocessing factories (including oil and sugar mills), and petrochemical factories. These industries are located close to or in major cities, which have had contamination episodes (e.g., Ahmed 2015; Guriro 2016). An estimated 1 percent of industrial wastewater is treated only prior to discharge (Azizullah et al. 2011). Untreated industrial effluent seriously degrades surface water and groundwater. Lead, chromium, and cyanide have been detected in groundwater near Karachi and in the Layari and Malir rivers, which flow through Karachi to discharge into the Arabian Sea (PCRWR 2002). Chemical oxygen demand of rivers exceeds the national environmental quality standard, in some cases by more than 500 percent.

The use of pesticides and agrochemicals is increasing, and residues have been reported in waters in several parts of Pakistan. Currently, an estimated 5.6 million tonnes of fertilizer and 70,000 tonnes of pesticides are used in Pakistan annually (Daud et al. 2017), and a significant fraction reaches surface water or groundwater (e.g., Ahad et al. 2006; Shahid et al. 2016). Around 0.5 million Pakistanis are poisoned by agrochemicals each year, of which an estimated 10,000 die—many as a result of exposure to contaminated water (Shahid et al. 2016). The eastern tributaries of Indus—the Ravi and Sutlej—provide very limited wastewater dilution capacity of wastewater (because these waters are allocated to India), and metal and microbiological contamination in these two rivers (and nearby groundwater) is ubiquitous (Grigg et al. 2018).

Groundwater quality has been deteriorating because of salinity and contamination by agriculture and industry (MacDonald et al. 2016). The area affected by salinization has increased because of surface water and shallow groundwater evaporation and excessive pumping, which have mobilized older saline groundwater, especially in Sindh (MacDonald et al. 2016). Improved water management will be essential to prevent further groundwater salinization, in addition to changes in agricultural and industrial practices to prevent contamination. Although widespread, degradation of groundwater quality is less well recognized, and yet is great concern for the sustainability of this important resource.

Current water quality management is grossly inadequate. Unless prevention and control measures are taken, water pollution will increasingly affect the health and productivity of people, especially the poorest households. In the short term, better regulation of fertilizer and pesticide use and industrial discharges is required. This would build on the interim national environmental quality standards that are realistic for most polluters to meet. In the medium to long term, more stringent water quality standards and improved monitoring should be adopted. Monitoring is critical for targeting interventions for in areas of most concern. These efforts should be supported by institutions capable of enforcing quality standards and able to work across sectors (especially agriculture and industry) to implement and finance interventions.

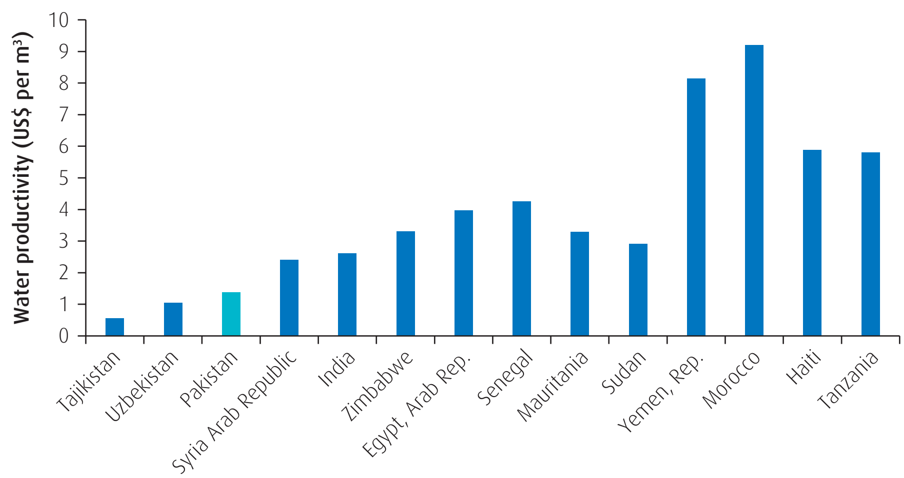
Significant improvements in water quality are not possible without better management of industrial discharges. This will require a major change for most manufacturers and agribusinesses, because very few have treatment facilities. Increasingly, international firms supplied by Pakistani manufacturers are demanding that environmental factors, including water quality, are considered. These pressures can be expected to encourage investment in the wastewater treatment facilities required to enable compliance with national regulations and to help firms remain competitive in international markets (Sánchez-Triana et al. 2015). Construction of common effluent treatment plants to serve industrial clusters and cleaner production methods that minimize the generation of wastewater can help improve performance. As institutional and monitoring capacity are strengthened, and as treatment infrastructure is put in place, pollution charge schemes could be introduced to incentivize pollution control at source and to generate revenues for provincial environmental protection agencies.

Water Productivity

Total water productivity, that is, the economic output per unit of water withdrawn from the environment, is low in Pakistan compared to most other countries. On 2015 data, Pakistan ranks eighth lowest in the world, generating just US$1.38 per cubic meter of water withdrawn. Pakistan ranks third lowest within a cohort of countries with (i) more than 80 percent of water use in agriculture; (ii) agriculture more than 10 percent of gross domestic product (GDP); (iii) less than 3,000 cubic meters of water available per capita annually; and (iv) GDP per capita of between US$800 and US$4,000—low-income but not the poorest rain-fed agrarian economies (figure 5.6). Pakistan's water productivity is 35 percent of the average for this cohort. (The double counting inherent in the withdrawal value [see chapter 1] does not affect Pakistan's ranking in this cohort.)

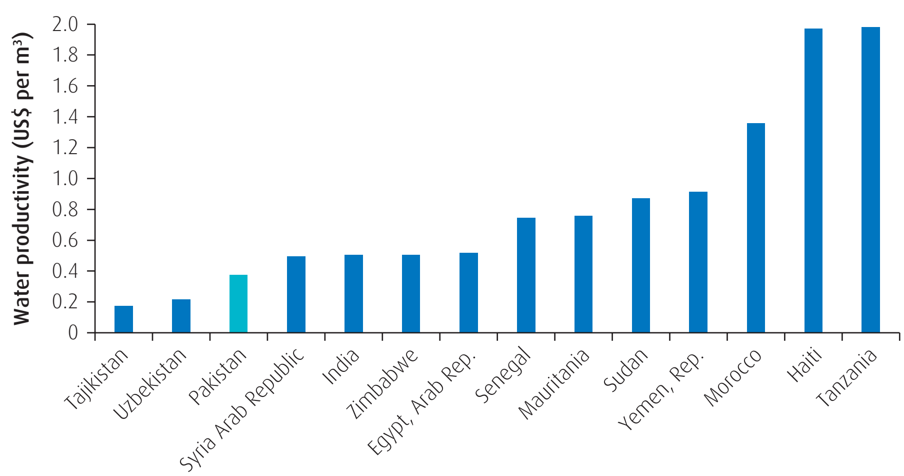
For water scare countries, the overall economic productivity is water is important. Additionally, the water productivity of agriculture is of interest, especially in countries with significant irrigation. On the same 2015 data, Pakistan's agricultural water productivity is US$0.37 per cubic meter of water withdrawn—again ranking third in the selected cohort (figure 5.7). Adjusting for the double counting in the withdrawal value would improve Pakistan's ranking to close to the middle of this cohort—similar to India, Zimbabwe, and the Arab Republic of Egypt—with a productivity value equivalent to 62 percent of the cohort average. Agricultural water productivity in

Figure 5.6 Total Economic Productivity of Water in Selected Countries



Source: FAO 2015.

Figure 5.7 Agricultural Water Productivity in Selected Countries



Source: FAO 2015.

Pakistan is thus very low, even within a cohort of low-income countries with low levels of investment in high-technology irrigation.

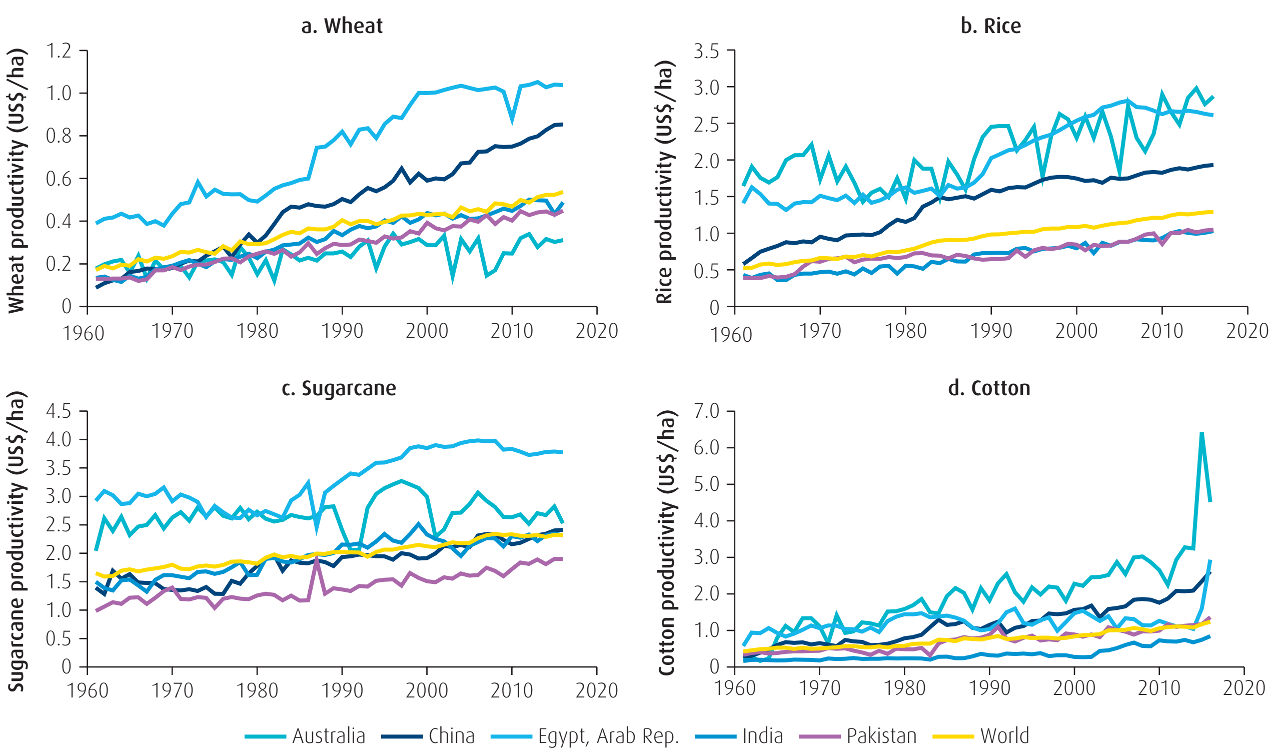
In the absence of good data on water use by crops, robust comparisons of crop-by-crop water productivity between countries is not possible. Some inferences can be made on the basis of crop modeling and data on cropped areas, and these are explored in chapter 6 based on results from CGE modeling. However, measures of agricultural productivity on an area basis can be used to compare between countries (figure 5.8, panels a–d).

Pakistan's performance on an area basis is best for cotton, for which productivity is equivalent to the world average and markedly better than in India. For the other major crops Pakistan's productivity is significantly below the world average, although its rate of productivity improvement over the last five decades largely mirrors the global trend. Australian wheat productivity is comparatively low, because it is mostly a dryland crop rather than irrigated; the interannual fluctuations reflect rainfall variability. Australian rice crops are highly productive, being high quality for niche export markets. High interannual variability reflects the flexible nature of the rice industry, which relies on low reliability water licenses that do not yield water in dry years.

Using crop production data (tonnes), estimates of total crop water requirement from Linstead et al. (2015) and modeled irrigation water use by crop (see chapter 6), allows green water (rainfall) and blue water (irrigation water) use for the major crops in Pakistan to be estimated. Blue water footprints (cubic meter per tonne) can then be determined. Because sugarcane has such a high moisture content at harvest, using harvested tonnage is misleading; therefore, the water footprint for raw sugar is estimated for comparison with other major crops (figure 5.9). This reveals that cotton, although the best performer on an area productivity basis, it is the most water thirsty of these major crops, requiring around 2,500 cubic meters per tonne of crop produced.

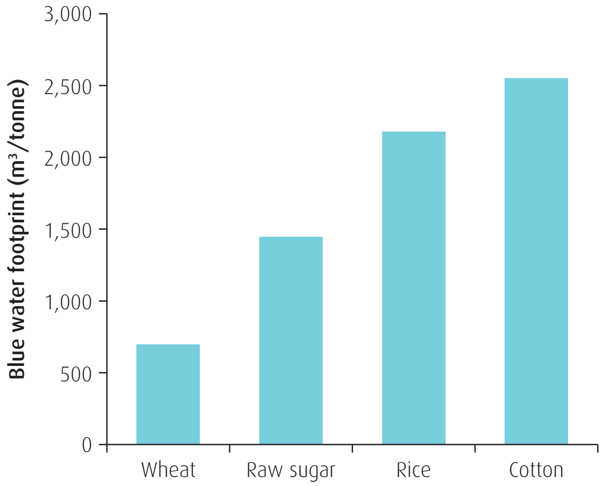
CGE modeling for Pakistan suggests that given the crop irrigation demands and areas typically grown, rice consumes around 32 percent of the water used by these four crops; wheat and cotton both consume around 25 percent; and sugarcane, 18 percent. Around half of the rice crop (and 5 percent to 10 percent of the sugarcane crop) is exported, thus presenting a very significant virtual water export. Growing low productivity paddy rice for export in an arid, water scarce country does not make good economic sense. Reforms and investment are required to move this water to higher-value crops (fruit and vegetables) for

Figure 5.8 Economic Productivity of Major Crops for Selected Countries and Globally, 1961–2016



Source: FAO 2016.

Figure 5.9 Estimated Average Blue Water (Irrigation) Footprints of Wheat, Raw Sugar, Rice, and Cotton for Pakistan



Sources: FAO 2015; Linstead et al. 2015.

export and to meet the growing domestic demand. These issues are explored further with the modeling work in chapter 6.

Cotton—with the highest blue water footprint of Pakistan's major crops—is an important component of the Pakistani economy. Pakistan is the world's fourth largest cotton producer. Cotton occupies 14 percent of the cropped area, employs 20 percent of the agricultural workforce, and represents nearly 12 percent of the agricultural value-add. Around 1.3 million farmers grow cotton in Pakistan, mostly on small holdings less than 5 hectares. Around 80 percent of the crop is grown in Punjab and 20 percent in Sindh. In recent decades, Balochistan has begun to grow cotton, but produces less than 1 percent of the national crop. Pakistan's textile industry is supported by domestically grown and some imported cotton. Textile production is the largest industrial sector in Pakistan, employing 40 percent of the industrial labor force, and generating 25 percent of industrial GDP and 57 percent of exports by value. The cotton crop is separated into cottonseed and cotton lint, with most of the value in the lint, which is spun into yarn from which textiles are produced. Annual lint production varies but has increased over the last 20 years from around 1.5 million tonnes to 2.4 million tonnes.

The blue water footprint of cotton in Pakistan is around double the global average; conversely its blue water productively (weight produced for given volume of irrigation water) is around half the global average. The blue water footprint of cotton varies by province, partly because crop water requirements vary with climate, and because of the different levels of green water (rainfall) availability. The combined blue plus green water footprint for cotton grown in Sindh is more than 20 percent higher than for Punjab, and the blue water footprint is over 65 percent higher in Sindh because of lower rainfall. In Punjab, where most of the cotton is grown, groundwater is key to irrigation—more than 20 percent of the irrigated area receives only groundwater, and 55 percent of the irrigated area receives canal water and groundwater. Punjab groundwater use exceeds recharge, and thus groundwater levels are falling in parts of the province. Around a quarter of the groundwater depletion in Pakistan is associated with agricultural exports, of which cotton represents a significant fraction. Cotton growing and cotton textile production also have a gray water footprint—the dilution volume required to bring irrigation drainage water (polluted with agricultural chemicals) or textile processing effluents to a quality suitable for subsequent use. Close to 20 percent of the estimated total water footprint of growing cotton in Pakistan is the gray water footprint. The wet processing and finishing of cotton yarn into textiles consumes a small volume of blue water, but has a large gray water footprint. Between one-third and a half of the total water footprint of producing cotton textiles is the gray water footprint of textile production from yarn. The gray water footprint of textile production would be the easiest fraction of the overall water footprint of cotton to reduce through cleaner production technologies and effluent treatment. Comparing water use in Pakistan cotton production to global averages, WWF (2015) concludes that while the overall water footprint per tonne is close to the global average, because of the lower green water input, the blue water footprint is 165 percent of the global average, and the gray water footprint is 162 percent of the global average.

Mekonnen and Hoekstra (2011) review agricultural water footprints by country. They show the blue water footprints for wheat and sugarcane (raw sugar equivalent) in Pakistan are around four times the world average, and for rice, more than six times the world average. Pakistan ranks second highest in the world for the blue water footprints for wheat and sugarcane (raw sugar equivalent), and seventh highest for rice. Chapagain and Hoekstra (2010) review the water footprints of rice production across the top 13 rice growing countries of the world. Pakistan grows just 1.2 percent of the global rice crop. However, Pakistan produces two-thirds of the global crop of basmati rice, and this is Pakistan second-largest export earner after cotton textiles. The Chapagain and Hoekstra (2010) water footprint analysis distinguishes between the evaporative water loss associated with paddy rice and the water that percolates into the soil for crop use. Paddy rice in Pakistan uses 2.8 times the average irrigation water use across the major rice growing countries, and the evaporative water loss from rice in

Pakistan is more than four times the average of the major rice growing countries (figure 5.10).

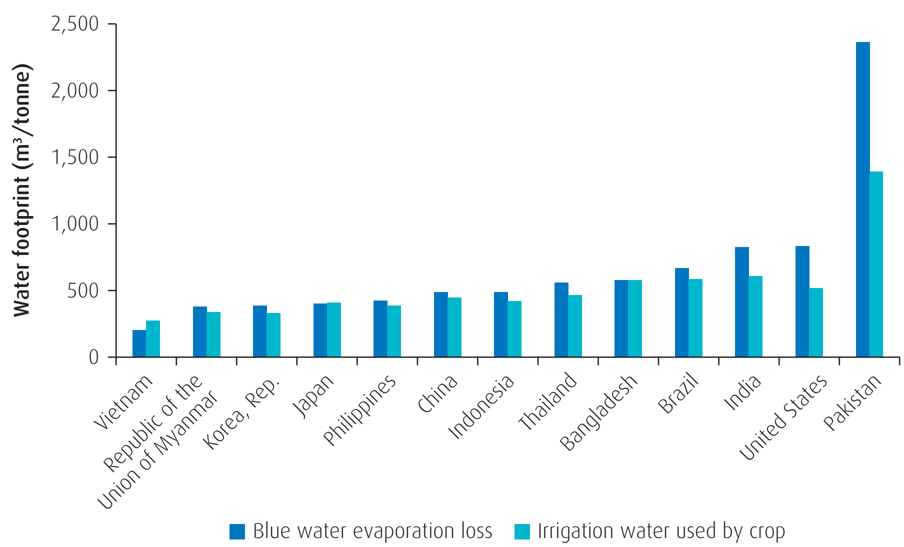
The System of Rice Intensification (SRI) has been used with some success in India to reduce water use. It has been introduced to Pakistan but has not been adopted widely. SRI is not a fixed package of technical specifications, but a system of production spanning soil fertility management, planting method, weed control, and water (irrigation) management. Critically, SRI aims to keep the root zone kept moist, not submerged, using intermittent water applications. Interesting recent innovations in rice cultivation trialed in the United Arab Emirates that might hold some promise for a very different rice industry in Pakistan include the use of hydroponics and salt-tolerant rice cultivars developed by Chinese scientists.

Ultimately, while both cotton and rice are major export earners for Pakistan, the water performance of these crops is very poor compared to that of other countries; combined, they account for well over half the total irrigation water use of Pakistan. For a water scarce country, directing over half of the water used to water-intensive crops that are not essential for domestic food security and that deliver comparatively poor economic return is not a good long-term option. The large volumes of water used in irrigation beyond what is required for food security could deliver much greater economic return by securing water for cities and industry. However, modeling of future scenarios (see chapter 6) indicates that improved water management and water productivity would enable Pakistan to ensure food security for a growing population, meet growing water demands outside of agriculture, and continue to allocate a significant volume of water to cotton in support of the textiles industry.

Farm size affects the productivity of the major crops in Pakistan (Ahmad et al. 2014a). It influences the extent to which practices are adopted and the system-scale effectiveness of these practices in terms of overall water use. Farm sizes in Pakistan are mostly less than 5 hectares. In recent decades fragmentation of land holdings has increased the proportion of very small farms (less than 1 hectare in area) (figure 5.11, panel a). By aggregate area, around half the total farmed area comprises farms between 3 hectares and 20 hectares (figure 5.11, panel b). The fraction of area associated with very small farms (less than 3 hectares) is increasing, as is the aggregate area from the largest farms (greater than 60 hectares). The aggregate area from farms between 3 hectares and 60 hectares is thus declining.

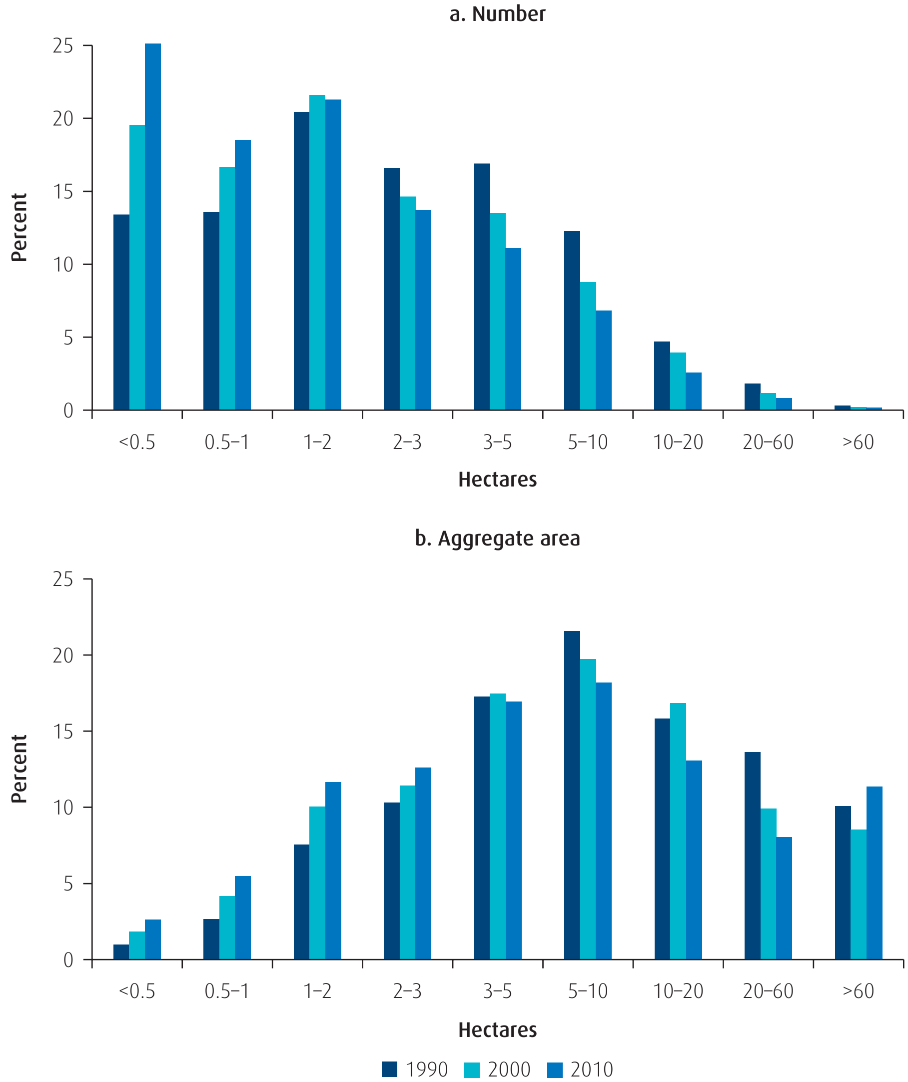
Farmers of smaller holdings tend to have less access to machinery, and being poorer, are typically less likely to be able to invest in water efficient irrigation technologies. However, adoption of water saving methods (such as zero tillage) may deliver water savings for farmers of smaller holdings, because they have less opportunity than farmers of larger holdings to increase cropping intensity or expand irrigated area to use any "saved" water. The use of conservation farming methods such zero-tillage wheat cultivation, laser land leveling, and crop residue retention can improve water management and crop productivity. In Pakistan, laser leveling and zero tillage wheat cultivation are used only across around 0.9 million hectares and 0.5 million hectares, respectively (Gill, Mujeeb-ur-Rehman, and Choudhary 2013). These methods, if closely monitored

Figure 5.10 Key Water Footprint Metrics for Rice in Major Rice-Growing Countries



Source: Chapagain and Hoekstra 2010.

Figure 5.11 Share of Farm Sizes in Pakistan by Number and Aggregate Area, 1990, 2000, 2010



Source: GoP 2017a.

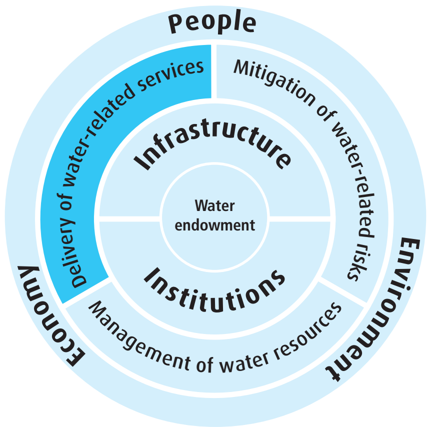
and accompanied by institutional mechanisms to control water use, can use reduce the application of irrigation water. Resource conservation technologies have likely reduced irrigation water applied at the field level in Pakistan by 25 percent and increased wheat yields by around 30 percent (Ahmad et al. 2014a). While these practices can improve water productivity, they do not necessarily generate basin-level water savings, because farmers may use the "saved" water for other on-farm activities or to expand their irrigated area.

While other countries in South and Southeast Asia have diversified away from rice (the main staple) toward high-value agriculture (horticulture, pulses, oilseeds, etc.), Pakistan has not diversified agriculture significantly (despite shifts in demand that favor high-value agriculture), thus limiting overall economic productivity of the sector. Over 90 percent of the cropped area in Pakistan remains under the major crops. with less than 10 percent dedicated to higher-value crops. The main reason is long-standing government subsidies that support major low-value crops (especially wheat, for which per capita demand is falling), rather than high-value commodities for which per capita demand is rising. These policies keep the sector locked in a high-cost and low-return mode that delivers low incomes for farmers and high prices for consumers. These policies serve vested interests, and reforms will be politically challenging. Government subsidies far exceed the public resources allocated to productive investments in agriculture, are often regressive in nature, and generate negative environmental externalities. Pakistan produces excess wheat at a high cost. Sugarcane productivity is very low and could be imported at far lower cost to the consumer. Government needs to reform the agricultural subsidies that drive farmer behavior and lock the sector into a low productivity mode.

Beyond the farm, agricultural productivity can be improved with better marketing. In Punjab, agricultural marketing (other than for cotton, sugarcane, and wheat) is regulated by the Punjab Agricultural Produce Markets Ordinance (1978). This gives government a monopoly on the establishment of wholesale markets, and only a limited number of licensed dealers can operate in the market. Market fees are high and incommensurate with the level of service provided. The Punjab Agricultural Marketing Regulatory Authority (PAMRA) Act (2018) is expected to significantly liberalize agricultural marketing by allowing any registered individual to establish a market dealing in primary agriculture produce, and by strengthening the regulations governing these markets. For livestock products, occasional price caps have little effect on prices paid by consumers, but act as a negotiating factor for intermediaries buying milk from producers and as a rent extraction mechanism for local officials. A similar situation prevails in the meat market. Price capping acts as a disincentive to producing better quality products. Discontinuation of notification of meat and milk prices would stimulate production and marketing of larger quantities and better quality and safer livestock products, thus raising the incomes of livestock farmers while enhancing supplies to urban areas. Thus, Pakistan has huge opportunities to improve agricultural productivity through improving water allocation mechanisms, improving water delivery to farms, improving on-farm water management, diversifying crop mix, reversing farm fragmentation, reforming agricultural policies, and improving the marketing of agricultural products.

Water Service Delivery

In this section the reliability, affordability, and financial sustainability of agricultural and municipal water services are assessed using existing datasets and prior analyses, including Mansuri et al. (2018), GoP (2012), and PCRWR (2016). For urban water supply and sanitation services, metrics of access, reliability, financial sustainability, quality, and customer satisfaction are used. For irrigation and drainage services, hydraulic efficiency, equity and affordability, and financial sustainability are reviewed.



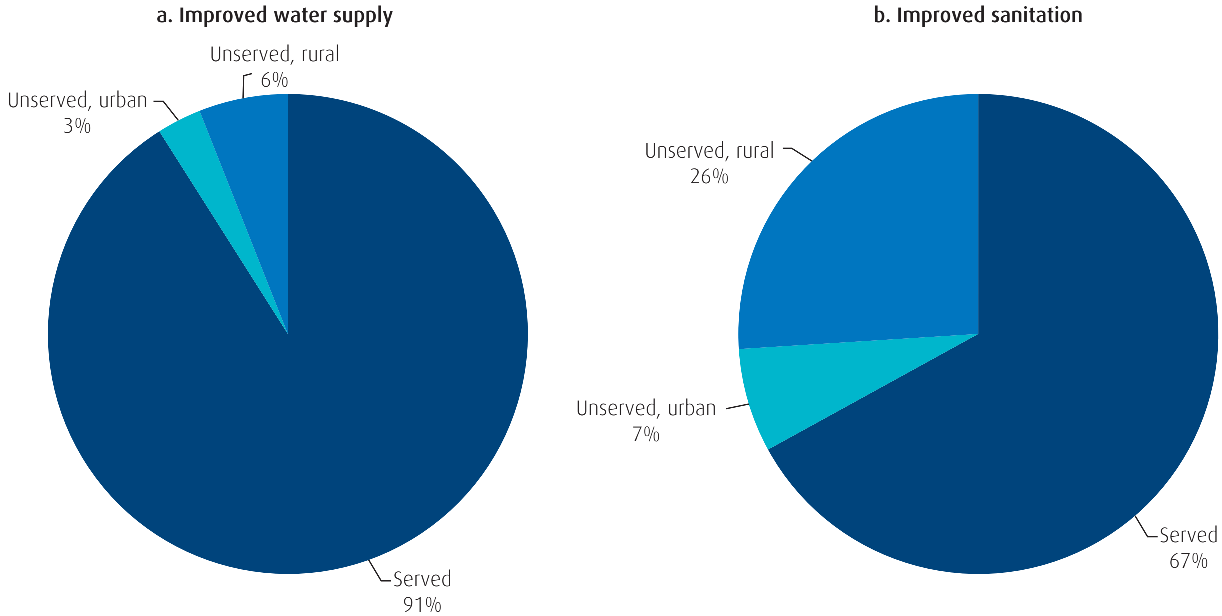
Water Supply and Sanitation Services

Nationally, Pakistan has achieved a high level of access to improved drinking water. Of the 9 percent of people lacking access, two-thirds are in rural areas (figure 5.12, panels a and b). However, rapid urbanization is contributing to a decline in access. Given rapid population growth the number of people lacking access increased by nearly 6 million between 2000 and 2015 (figure 5.13). In Karachi, access fell from 90 percent to 86 percent between 2005 and 2015, while the city grew from 12 million to 17 million people, nearly doubling the number of people without access. Access to sanitation services improved steadily over the last 15 years. But 13 percent—or over 26 million people—still defecate in the open (GoP 2016a), mostly in rural areas.

Key Messages

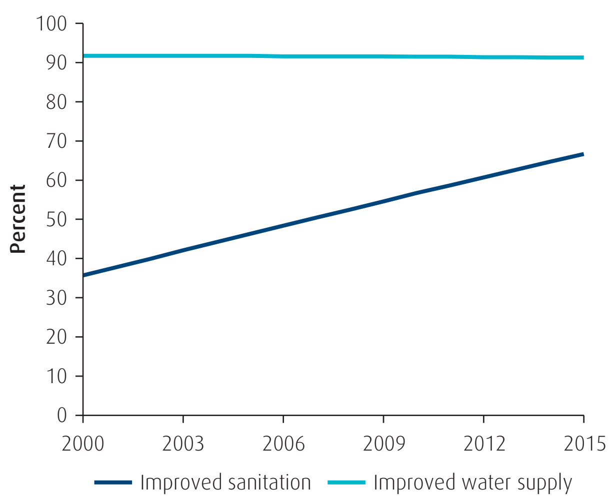
- Although coverage of drinking water supply service is high, especially in urban areas, coverage is declining with rapid urbanization, and service quality is generally poor. Sanitation services are variable: open defecation is at low levels, but the collection, treatment, and disposal of sewage effluent are grossly inadequate.
- Irrigation service delivery is poor and contributes to the low productivity of irrigated agriculture. Hydraulic efficiency of the distribution system is very low, and water delivery across command areas is inequitable. Irrigation services are not financially sustainable and financial performance is declining. Service tariffs are set too low and are decoupled from service quality. The operational costs of service providers are far too high.
- Poor operational performance in irrigation water delivery continues to exacerbate waterlogging and salinization, especially across much of Sindh. Despite large-scale reclamation efforts, high water withdrawals and poor drainage mean excess salt continues to accumulate in irrigation areas in both soil and groundwater, impacting agricultural productivity.

Figure 5.12 Share of Access to Improved Water Supply and Improved Sanitation in Rural and Urban Pakistan, 2015



Source: WHO/UNICEF 2015.

Figure 5.13 Share of Access to Improved Drinking Water and Improved Sanitation in Pakistan, 2000–2015



Source: WHO/UNICEF.

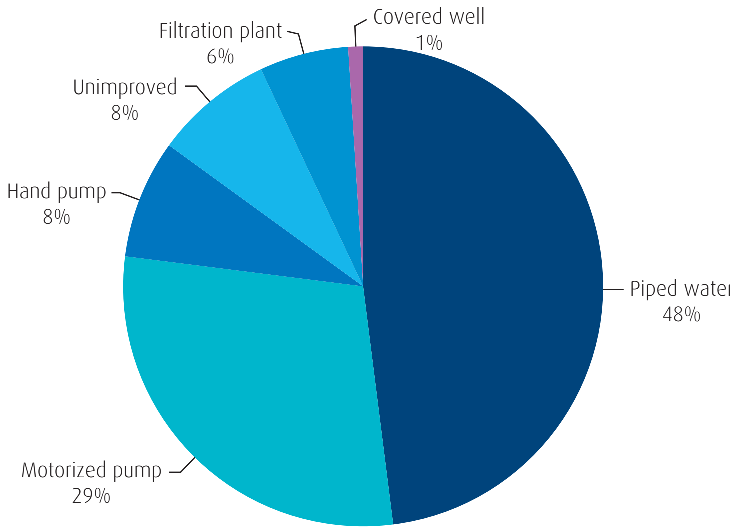
Urban Services

Socioeconomic improvement in urban areas has lowered poverty rates and increased access to water supply and sanitation services. However, for many urban dwellers, these services are low quality, unreliable, or unaffordable. Almost half of urban households rely on piped water (figure 5.14), although the percentage is decreasing in all provinces because of rapid unplanned urbanization. Access to piped water varies between provinces: Balochistan (68 percent), Sindh (65 percent), KP (54 percent), and Punjab (46 percent) (Mansuri et al. 2018). The completeness of piped supply coverage has fallen over the last decade, with a greater proportion of households forced to rely on motorized groundwater pumps (KP, Punjab, and Balochistan) and informal private vendors (Sindh and Balochistan).

Piped urban water supplies are unreliable. Only 27 percent of households receive water for more than 6 hours per day. Reliability is highest in Punjab (57 percent), but very low in Sindh and Balochistan where most households get water for only a few hours per day. Low reliability reflects poor customer orientation by water service providers. Intermittent services discourage users from paying water tariffs, impacting the financial sustainability of service providers, which further undermines service quality. In Sindh, supply reliability has decreased. Currently, 93 percent of households receive water for less than 6 hours per day compared to 87 percent a decade ago (Mansuri et al. 2018).

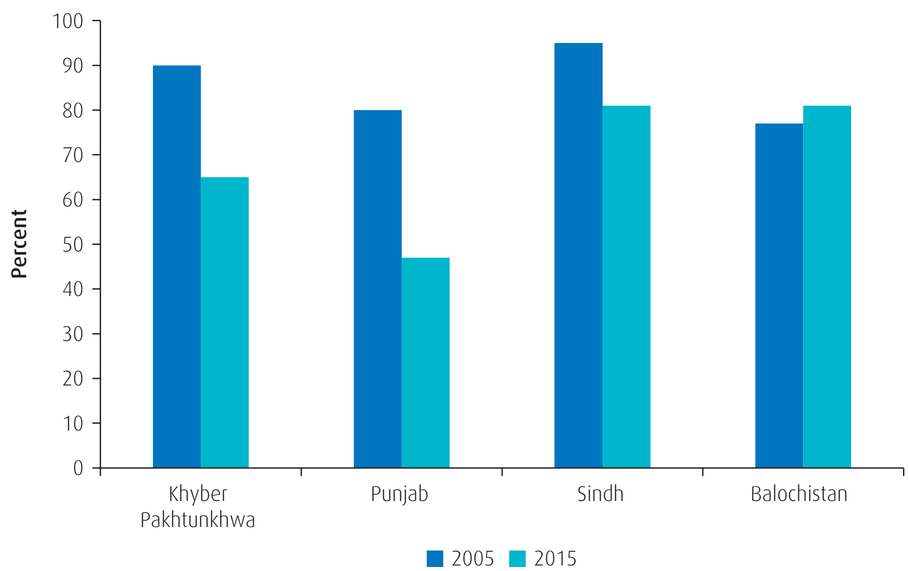
Karachi residents experience severe water shortages during summer because of poorly maintained and outdated pumping stations, a leaky distribution network, and theft from water mains. Bulk water supply for Karachi represents around 115 liters per capita per day, similar to consumption levels in some modern European cities. Thus, with efficient delivery and careful demand management, the current bulk supply should be sufficient. However, the hot climate and associated high evaporative losses and the

Figure 5.14 Urban Water Access by Source in Pakistan, 2015



Source: Mansuri et al. 2018.

Figure 5.15 Share of Urban Water Supplies Unfit for Human Consumption by Province in Pakistan, 2005 and 2015



Source: PCRWR 2016.

inevitability of some leakage mean an increased bulk supply is required. The projected additional 3 million inhabitants 2047 and the expected increases in per capita water demand with increasing wealth mean a 50 percent increase in the bulk water supply is likely to be required for Karachi.

The quality of urban water supplies is very low, with 80 percent being unsafe for consumption in Sindh and Balochistan (figure 5.15). Over the last decade major improvements have been made in Punjab and KP, while the already poor quality in Balochistan has worsened (figure 5.15). The most common problem is fecal contamination from cross connections between water mains and sewers (Haydar et al. 2009). Arsenic and iron levels exceed safety limits in 6 percent to 10 percent of piped urban supplies nationally (PCRWR 2016).

Cost recovery for urban water services is extremely low. Nationally, cost recovery is estimated to be 8 percent (Danilenko et al. 2014). With insufficient finances, utilities are unable to keep supply systems running continuously and lack the resources to expand services to keep pace with growing urban populations. Low cost recovery partly reflects low tariff levels, and partly reflects high levels of leakage and theft (nonrevenue water [NRW]). Nationally, NRW averages 57 percent

(Danilenko et al. 2014). In Karachi it is higher because of numerous illegal connections and an old, poorly maintained pipe network. Nationally, 62 percent of households pay their water tariffs, ranging from 21 percent in Quetta to 98 percent in Lahore (SBP 2017). Water utilities are subsidized by provincial governments for both operation and maintenance (O&M) costs and for debt servicing.

Failure to maintain distribution systems has led to large-scale, systematic illegal connections that benefit private water vendors and disadvantage poor populations (Rahman 2008). Tankers supply an estimated 20 percent of Karachi households, with monthly charges ranging from 50 percent to 100 percent of the average household income (Mustafa et al. 2017). Anecdotal evidence from Karachi's informal settlements suggests water from private tankers costs 30 times the government water tariff. This means water services are unaffordable for most urban poor households in Karachi, which often have access only to contaminated water (Alamgir et al. 2015). The common assumption is that residents of informal settlements have the poorest and least affordable service and must use extrajudicial solutions to solve water supply problems given low capacity to use established law or administrative procedures. However, recent interviews and focus group discussions across five of the largest informal settlements in Karachi reveal significant variation in water demand and access both across and within settlements, reflecting a long history of regularization of slums and state-society relations. The common narrative of urban poor households in slums being "caught up in webs of illegality" is thus simplistic, and the reality is more nuanced than dichotomies of legal or illegal, formal or informal, or civil or political. The Karachi situation is improving, as outlined in the political economy discussion in chapter 4.

Urban sanitation services vary considerably across Pakistan. Services are best in Punjab, in which 59 percent of the population have access to flush toilets connected to sewer systems and 26 percent are serviced by septic tank. In Sindh, 63 percent use flush toilets connected to sewers, but as conditions are generally unsuitable for septic tanks, more than one-third of the urban population is unserved by sewerage, and effluent is discharged to open drains (Mansuri et al. 2018). Services are worst in Balochistan and have worsened over the last decade. More than half of the urban population use toilets that flush to open drains, and 22 percent use simple latrines.

Across Pakistan, most wastewater is discharged untreated into rivers and coastal waters. This degrades ecosystems and impacts human health. Only four of the 10 cities with more than 1 million inhabitants (Islamabad, Lahore, Karachi, Faisalabad) have any wastewater treatment facilities. Existing facilities have capacity to treat less than 30 percent of the wastewater (Bashir 2012; Ensink et al. 2004). Karachi and Islamabad have secondary (biological) treatment, but less than 8 percent of wastewater in these cities is treated to this standard (Murtaza 2012). Rawalpindi, Multan, and Gujranwala have no wastewater treatment (World Bank 2016). Pakistan's urban population is expected to double over the next three decades to 155 million, posing huge challenges for water supply and sanitation services (Ellis et al. 2018).

Rural Services

Rural water services are far worse than urban services, reflecting the technical challenge of delivering water services over long distances and the financial challenge of higher costs and fewer customers. Water supply is mostly self-provided, and increasingly so. Groundwater is the predominant source. In Punjab and Sindh, 90 percent of rural households rely on groundwater (mostly motor or handpumps). KP and Balochistan have more diverse supplies, but around 29 percent and 21 percent, respectively, have access to piped supply (Mansuri et al. 2018). Few rural supplies are monitored for quality. Across much of Punjab and Sindh, arsenic in groundwater exceeds international standards for human consumption, exposing 50 million to 60 million people to serious health risks (Naseem and McArthur 2018; Podgorski et al. 2017).

Installation of toilets connected to septic tanks has improved rural sanitation across parts of Punjab and KP. In Sindh and Balochistan, however, one-half and two-thirds of the households, respectively, rely on unimproved toilets and pit latrines. Rural open defecation is still common in Punjab (23 percent) and Balochistan (17 percent) (Mansuri et al. 2018). Sewerage is almost nonexistent in rural Pakistan, although covered or underground sewers serve a small percentage of households in Sindh and Punjab. The complete absence of public services for rural wastewater management poses a significant health hazard. Despite improvements in rural sanitation, the lack of public water supplies essentially negates the human health benefits.

Irrigation Services

The discussion of water resources management covered aspects of irrigation performance from an allocation perspective and introduced the equity-based warabandi system. A deeper assessment of irrigation service delivery at the command area level is provided here, considering operational performance (hydraulic efficiency and drainage), equity and affordability, and financial sustainability.

Operational Performance

Operational performance—in terms of the overall efficiency of water delivery—is very low. Uncertainties in measurement and incomplete water accounting mean that the estimates of water delivery from barrage off-takes to the farm outlet vary widely from 20 percent (SBP 2017) to more than 60 percent (Raza et al. 2013). Much of the inefficiency comes from high levels of canal leakage, which is a major share of groundwater recharge. Some inefficiencies were accepted as part of the design of the distribution system, at a time when water was less scarce in relative terms. Other inefficiencies reflect poor maintenance of the system and poor operation. Investments in canal lining have improved delivery efficiency relative to original designs in some areas.

Another measure of operational performance is the delivery performance ratio (DPR). This compares the delivered flow to the delivery capacity (as a fraction or percentage), which is relevant because supply limitations mean the system is usually operated at full capacity. Jacoby et al. (2018) assess DPR for a nine-year period (2006–14) in kharif in more than 1,000 channels across Punjab. They compare values between the head and tail of the different distributaries. They find that the DPR varies between 56 percent and 80 percent with an average of around 70 percent, indicating water delivery is consistently below capacity. Noting that design capacity reduces with distance along the distributaries, they find that the delivery shortfalls relative to design capacity are higher at the tail than at the head, by around 5 percent, on average. The reduction in performance with distance along distributaries likely reflects the combined effects of inadequate channel maintenance and upstream water theft.

As the irrigation and drainage system has fallen into disrepair, the efficiency of delivery has declined. Irrigation efficiency in Pakistan is now among the lowest in the world. The deterioration of the irrigation infrastructure—including siltation of canals and degraded canal walls—and inadequate maintenance have resulted in increased water losses through seepage, exacerbating the problems of water logging and salinity. From a water balance point of view, most of the canal seepage in Punjab and KP is not lost because it recharges underlying shallow freshwater aquifers and is accessible through groundwater pumping. However, in Sindh, lost canal water recharges saline aquifers and thus can no longer be used for productive use. Across the Indus Basin, it is estimated that about one-third of all canal seepage is to saline aquifers (chapter 3). From an operational performance point of view, any canal seepage is undesirable (even if it recharges freshwater aquifers), because farmers receive less of their allocated amounts and experience lower levels of service. Groundwater pumping incurs additional costs.

Waterlogging and salinity affect an estimated 4.5 million hectares of irrigated land and reduce agricultural production by 25 percent (Qureshi 2016). The waterlogged area varies seasonally, with much greater areas affected at the end of the annual monsoon. Surveys in the 1980s have indicated 6 million hectares of salt-affected land, but four decades of Salinity Control and Reclamation Projects (SCARPs), costing US$2 billion, have enabled reclamation of significant areas. The extent of salinity varies strongly between provinces. Around half the farmland in Sindh and Balochistan is affected, and about 10 percent across KP and Punjab (Zulfiqar and Thapa 2017).

Seawater intrusion exacerbates salinization in coastal Sindh and Balochistan. Despite ongoing reclamation efforts, shallow groundwater is increasingly saline in coastal areas and 40,000 hectares are abandoned annually because of secondary salinization (WAPDA 2007). The current rate of salt imports to the basin by the river and salt mobilization from groundwater through pumping far exceed the contemporary rate of salt export in basin outflows. Salt is therefore accumulating in soil and groundwater of the basin (Butta and Smedema 2007). Not all salt accumulation is necessarily harmful, and a much more detailed understanding and quantification of salt dynamics across the basin is required to guide management. Ultimately, managing soil salinity will require irrigation modernization and improved operation, as well as adequate dry season environmental flows in the Lower Indus, to counter seawater intrusion.

Equity and Affordability

The warabandi system was designed distribute water equitably; however, there is no agreed measure of equity, which makes evaluation difficult. Equity is often assumed to be described by duration, prorated by area, which for equal flow rates imply equal volumes per unit area, or equal irrigation depth. However, delivery flow rates vary considerably between irrigation areas. KP has much higher delivery flow rates than Punjab or Sindh, because it has relatively limited irrigable land, and can thus "afford" to deliver more water per unit area from its allocation under the Accord. These differences are sometimes interpreted are "inequity by design" between irrigation areas. With command areas, some level of inequity was embedded in the original hydraulic designs (Van Halsema and Vincent 2006).

KP development investments (Mardan SCARP, Swabi SCARP, Pehur High Level Canal, Chashma Right Bank Canal, Warsak Gravity Canal) have all focused on improving existing irrigation systems rather than extending the irrigated area, thus doubling or tripling the delivery flow rates. In a context in which the water resource was available, and the existing irrigation system had limited capacity, an obvious solution was to upgrade the irrigation system and enhance the capacity. In contrast, when rehabilitation investments are undertaken in the Sindh or Punjab, and supply is limited, system capacity has not increased. Within command areas, operational inequity can occur, particularly as a result of opening and closing tertiary canals when insufficient water is available to operate all canals at, or near, capacity. The arising inequity is an unintended consequence of the "rotational program" that guides canal operations and that has remained largely unchanged since British colonial times.

Irrigation inequity can be measured by comparing flows through canal outlets in the top, middle, and bottom thirds of the canal (head-middle-tail). Measurements indicate that in many cases head outlets draw more than their share (e.g., Ghumman et al. 2014). A more detailed method uses discharge measurements at the head of a tertiary canal and at every outlet along its length across an entire season to calculate a Gini index (Shah et al. 2016). Shah et al. (2016) find no significant inequity at the tail end, contrary to widespread belief. Jacoby et al. (2018) find small reductions in performance (water delivery relative to design capacity) toward the tail end of distributaries. Equity in irrigation services appears to be worsening as a result of declining maintenance and the breakdown of the arrangements for control at the main and distributary canal levels (Blackmore and Hasan 2005), as well as manipulation of farm outlets (Rinaudo 2002).

In command areas in which delivery flows are high (as in KP), farmers often cease to irrigate earlier in the season, because crops have already received sufficient water. Anwar, Bhatti, and de Vries (2016) report that in the Pehur High Level Canal system of KP, 92 percent of farmers did not irrigate in September. Warabandi, however, supplies water at system capacity whenever possible, causing major spatial and temporal mismatches between crop water requirements and water delivery. Attempts at more flexible management—called "demand-based irrigation," "arranged demand-based irrigation," or "crop-based irrigation operations"—have been made in the Mardan SCARP, Pehur High Level Canal, and Chashma Right Bank Canal systems. Unfortunately, none have persisted, and all have reverted back to warabandi.

Originally, farmers were entitled to a water share equivalent to 70 percent of the design cropping intensity (Mustafa 2001). However, cropping intensities have risen to over 150 percent, supported by groundwater pumping (Khan 2009). Access to groundwater is not determined by any formal allocation mechanism, but simply by location. Quality and depth determine groundwater value. Shallow and good quality groundwater is found closer to leaky canals. From a water services delivery perspective, this raises the question of whether improved canal lining would affect access to groundwater, further exacerbating inequities. There is little agreement on the institutional responsibilities for groundwater and whether farmer organizations or water user associations (WUAs) could manage conjunctive water use (Nagrah and Rosell 2012). The proposal in the NWP to establish groundwater authorities in each province could be counterproductive in terms of irrigation efficiency and equity if not closely coordinated with the management and regulation of surface water delivery.

Financial Sustainability

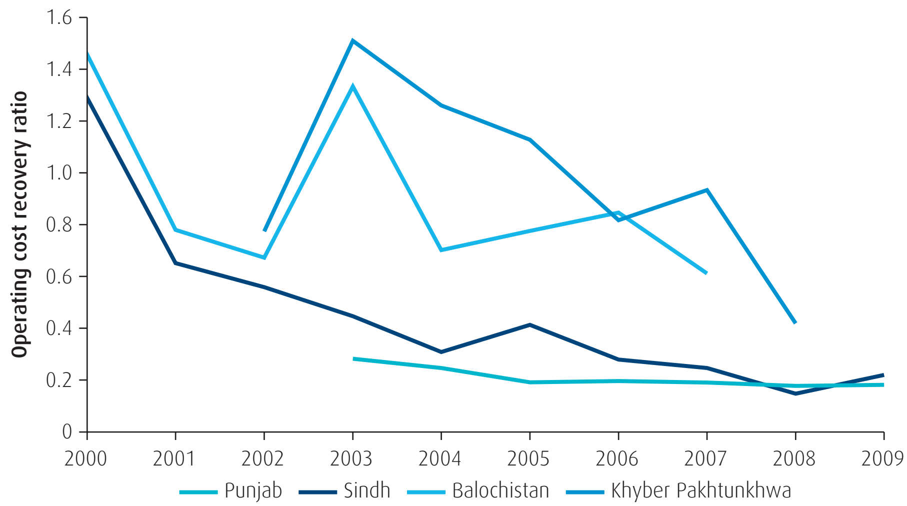
Irrigation management transfer reforms introduced in 1997 (chapter 4) were partly in response to low financial sustainability. The reforms included decentralization of irrigation service delivery and *abiana* (the system of irrigation tariffs) collection, but with mixed results in terms of financial performance.

Abiana can be considered affordable given the willingness of farmers to pay for improvements in service delivery and their significant expenditure on groundwater pumping (Bell et al. 2016). The cost of diesel for motorized pumps represent around 20 percent of farmers' incomes (GoP 2016b). Abiana is not based on water consumption, but is levied on cropped area, in some cases differentiated by crop type. This means that there is no incentive for water conservation and in many cases no incentive to shift to more water productive crops.

Abiana ranges from PRe 85 per hectare in Punjab to PRe 618 per hectare in KP (GoP 2012). These levels are grossly inadequate to cover operating costs, let alone the costs of system upgrades. On average, only 20 percent of the total operating cost of the distribution system is covered from abiana. This is dominated by the low cost-recovery in Punjab and Sindh (figure 5.16). Cost recovery in KP and Balochistan is higher because the limited extent of irrigation in these provinces means operating costs are lower. Low cost recovery is not unique to Pakistan. Few Organisation for Economic Co-operation and Development (OECD) countries achieve full cost recovery (OECD 2013), but Pakistan's financial performance for irrigation is among the lowest in the word (Bell et al. 2014).

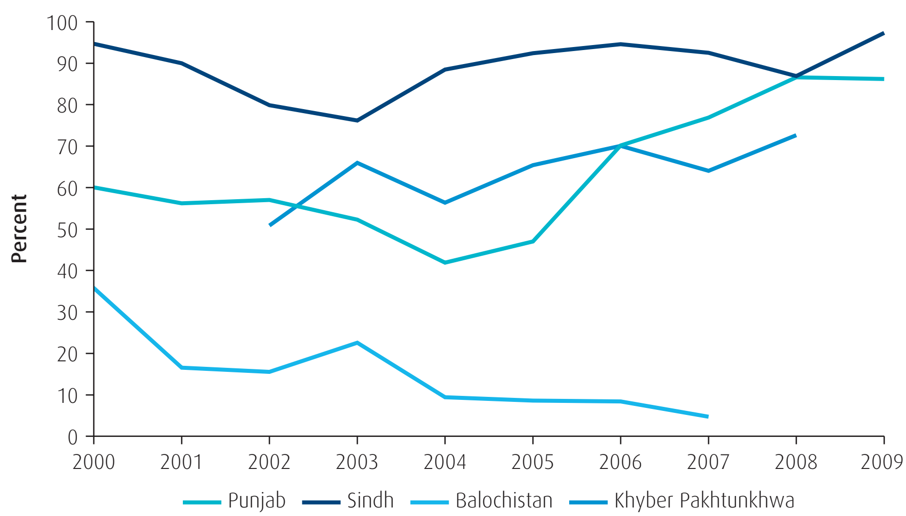
Cost recovery is partly determined by collection efficiency. Collection efficiency is very low in Balochistan and declining, but 70 percent to 90 percent in other provinces and improving (figure 5.17). Collection efficiency is often higher for tail enders who are pressured into paying while sometimes receiving poorer service. Those at the head of the distributaries are more likely to default on payments because they will receive water in any case. There is limited enforcement capacity and no legal basis for penalize

Figure 5.16 Operating Cost Recovery Ratio of Irrigation Departments by Province in Pakistan, 2000–09



Source: GoP 2012.
Note: data not available for all years for all provinces.

Figure 5.17 Abiana Collection Efficiency by Province in Pakistan, 2000–09



Source: GoP 2012.
Note: data not available for all years for all provinces.

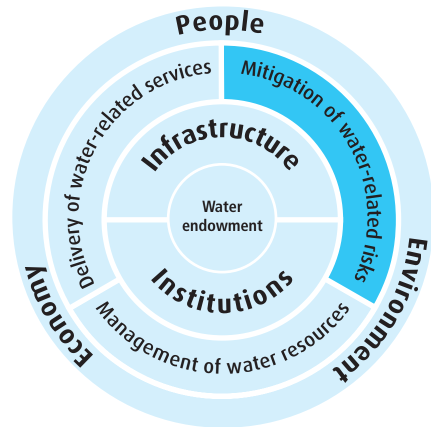
defaulters (SBP 2017). Because abiana is not linked to service quality and nonpayment does not affect service, achieving higher collection efficiency without coercion or stronger regulation will be difficult.

Irrigation departments are often perceived to be overstaffed and lacking the right balance of technical expertise. A substantial proportion of their O&M budget is therefore used for staff costs, making financial sustainability more difficult. In Punjab, salaries for more than 35,000 staff members consumes 76 percent of the operating budget. Operating budgets seldom increase with inflation, while staff salaries are tied to national or provincial pay scales and increase almost annually. To prevent staff salaries from consuming an increasing proportion of the operating budget, budgets need to be revised and linked to inflation.

In the 1970s, abiana fully covered O&M costs but a government decision to freeze abiana (Khan 2009) led to heavy subsidization. Subsidization was estimated to be US$44 million in 2012 (SBP 2017), covering 75 percent of O&M costs. Government subsidies are equivalent to around 2 percent of GDP. Service delivery costs need to be reduced and tariffs incrementally increased. Tariffs should to be linked to clear, published measures of service quality.

Water-Related Risk Mitigation

This section considers risks for which drivers are largely beyond the control of the water sector. In some cases, these risks may be mitigated by water sector actions; in other cases, adaptive responses are required. The risks are climate change, the unintended consequences of energy policies (water-energy nexus), and erosion and sediment transport. A description of current and future consequences is provided for each risk and an assessment of how well the risk is being recognized and mitigated.



Key Messages

- Pakistan's biggest water challenges are not externally imposed. However, climate change represents an additional challenge to improving water security. Adaptive responses are required.
- Climate change is not expected to have major impacts of the average availability of water in the coming decades. However, water availability is expected to become more variable (and less predictable) between and within years. This is expected to mean more extreme floods and droughts. In the Upper Indus Basin, accelerated glacial melting will greatly increase the risks of glacial lake outburst floods (GLOFs) that are often devastating at the local level. Improved data, modeling, and forecasting to guide preparedness and response to extreme events will be increasingly important.
- In the Lower Indus Basin, sea level rise and increases in the frequency and severity of coastal storms will exacerbate seawater intrusion into the delta and into coastal groundwater. In coastal Sindh, this will further degrade the groundwater resource, groundwater-dependent ecosystems, and the productivity of irrigation.
- Potentially the greatest challenge from climate change will be the increases in water demand, especially for irrigated agriculture. Climate change alone is expected to increase water demand by 5 percent to 15 percent over the next three decades, depending on the level of warming.
- Pakistan suffers chronic energy shortages, which have many connections with water management. Careful consideration the multiple cross-sectoral trade-offs between energy and water are required in the coming decades.
- Basin-scale sediment sourcing, transport, and deposition have been significantly modified by water resources development. This has consequences for the safety and operational performance of water infrastructure as well as for river and delta ecosystems. A more integrated approach to sediment management and better monitoring of sediment sources, erosion, and sediment transport are required to guide intervention strategies and environmental management.

Climate Change

Although Pakistan's biggest water challenges are internal, climate change is a significant additional challenge to improving water security. Expected climate change impacts for the water sector are summarized here. The investments in infrastructure, information, and institutions to build resilience and mitigate these climate change risks are discussed.

Climate Warming

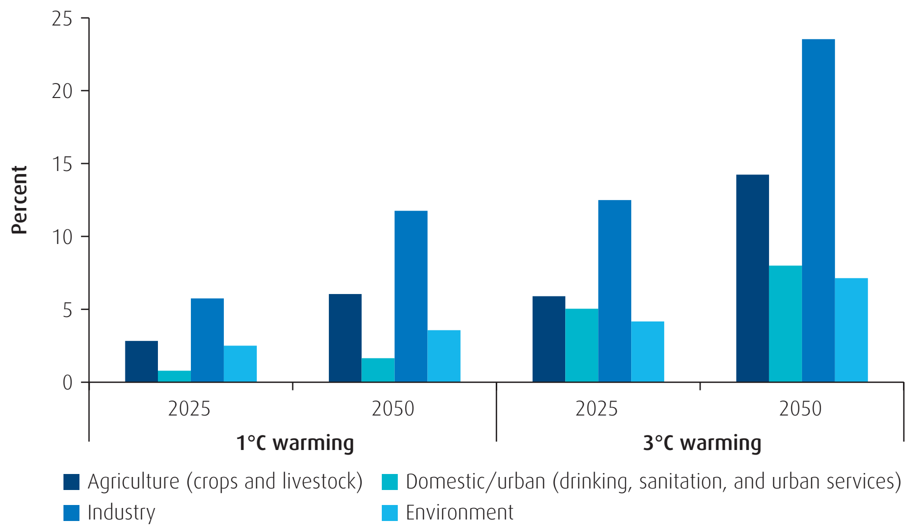
Warming of 0.23 degrees Celsius to 0.33 degrees Celsius per decade has been observed in the Lower Indus over the past 30 years (Ahmad et al. 2014). Unless the targets of the Paris Agreement are achieved, Pakistan's agricultural regions and coastal zones will experience a 1 degree Celsius to 2 degrees Celsius increase by 2050, with a sharp increase (4 degrees Celsius to 6 degrees Celsius) by the end of the century (Chaudhry 2017). Warming will increase the frequency of deadly heat waves by the end of the century (Im et al. 2017). Heat waves—with temperatures exceeding 40 degrees Celsius for 10 consecutive days—are expected to become more common in Punjab, Sindh, and Balochistan (Zahid and Rasul 2012). Heat waves increase urban water demand and the use of untreated water (ACAPS 2017). Heat waves also affect energy security because the warmer water used for thermal plant cooling reduces power output by up to 0.5 percent (ADB 2012). Warming increases evapotranspiration. Thus, crop water requirements and natural water losses through landscape evapotranspiration will increase. Without improved demand management severe water shortages will increase (Adnan et al. 2017b; Ahmad et al. 2014a).

Estimates of the impacts of warming on water demand suggest differing sensitivity by sector. Industrial water demands are most sensitive to climate warming. Under a faster warming scenario, warming could cause increase industrial demand by more than 20 percent by 2050 (figure 5.18). Under a faster warming scenario, total water demand could increase by 30 billion cubic meters (Amir and Habib 2015), or around 20 percent of current withdrawals. Because irrigation strongly dominates water use, increases in irrigation demand dominate the overall increase (figure 5.19), and alone could increase water demand by 25 billion cubic meters. Although uncertain, there is evidence that while climate change would increase crop water use, it may also enhance crop growth and thus increase yields, given longer growing seasons (Chaudhry 2017).

Hydrologic Change

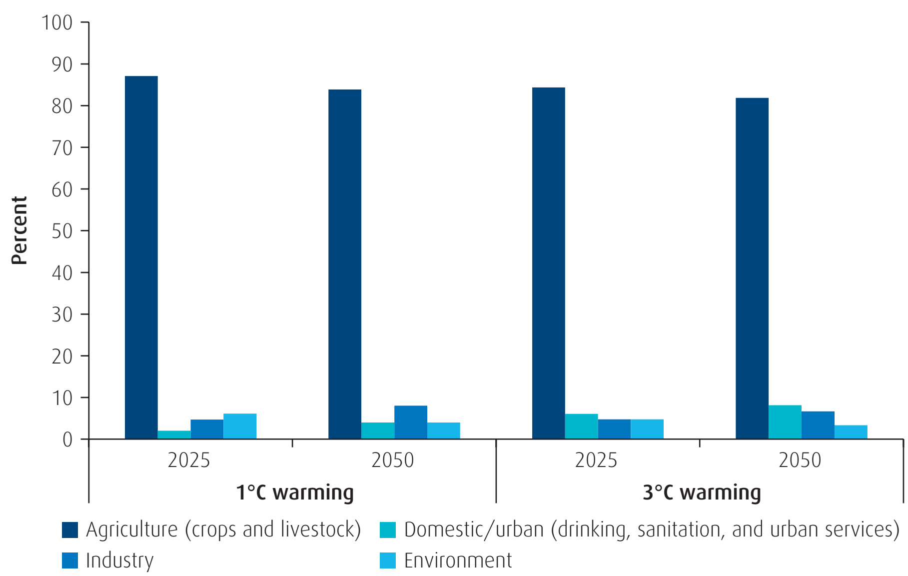
Annual precipitation averaged across Pakistan, while varying yearly, has increased by 25 percent (or 63 millimeters) over the past century (Yu et al. 2013). But there is considerable spatial

Figure 5.18 Estimated Increases in Water Demand Attributable to Projected Warming in Pakistan, 2025 and 2050



Source: Amir and Habib 2015.

Figure 5.19 Sector Shares of Water Demand Increase Attributable to Projected Warming in Pakistan, 2025 and 2050



Source: Amir and Habib 2015.

and seasonal variability in precipitation trends. The strongest increasing trends are for the Greater Himalaya and the Northern Balochistan Plateau, in the monsoon season. A significant reduction in monsoon rainfall has been observed for the Coastal Belt over this period.

Historical inflows to the Indus Basin of Pakistan reveal statistically significant trends. However, data records are relatively short and there is little evidence to attribute these changes to anthropogenic climate change. As indicated in chapter 3, the small but significant decrease in total Indus inflows appears to be largely a result of the increased water use in India on the eastern tributaries, as allowed under the Indus Waters Treaty. Yu et al. (2013) show a slight increase in the Chenab during rabi and a slight decrease in the Indus during kharif. Pakistan has a complex hydrology, and thus explaining observed hydrologic change and projecting future change is difficult. This is especially true for the Indus Basin, where rainfall runoff, snowmelt, and glacier melt all contribute to river flow, in proportions that vary considerably between tributaries.

While warming logically increases melting, there is scant temperature data from high elevations in the Indus Basin where meltwater is generated to evaluate climatic change. Changes in snowfall patterns and the dynamics of glaciers—including snow contributions to glacier volume, rates of glacier flow, the role of debris coverage, and black carbon—are complex and only partially understood. Most recent studies suggest a modest increase in streamflow in the Indus Basin for the next several decades as result of accelerated glacier melting (e.g., Lutz et al. 2016). Longer-term projections are highly uncertain. Because a significant fraction of the glaciated area in the Upper Indus Basin is at very high elevation, complete disappearance of glaciers is unlikely under expected warming trajectories. However, the extent to which residual ice volumes will generate meltwater is less clear and will depend on rates of snowfall addition to glaciers and the rates of ice flow down to lower, warmer elevations. A smaller fraction of future precipitation will occur as snow, and thus it is likely that the eventual residual glaciers will flow more slowly and contribute less meltwater.

The changing annual pattern of temperatures is expected to alter the timing of inflows. With warm temperatures earlier in summer, the first changes in river flow are expected to be gradual increases in meltwater flows from May to September, peaking when glaciers still cover substantial areas (Lutz et al. 2014; Mathison et al. 2015). In the Upper Indus, earlier onset of snowmelt and glacier melt—and likely increases in winter precipitation—would increase in flows during autumn and spring (Lutz et al. 2016). In lower altitude subbasins of the Indus, autumn and winter flows are likely to increase slightly because of increased winter precipitation; decreases in precipitation during the monsoon and higher evapotranspiration are likely to reduce runoff in these months (Lutz et al. 2016). Overall, annual mean river flows are expected to increase by around 10 percent by the end of the century.

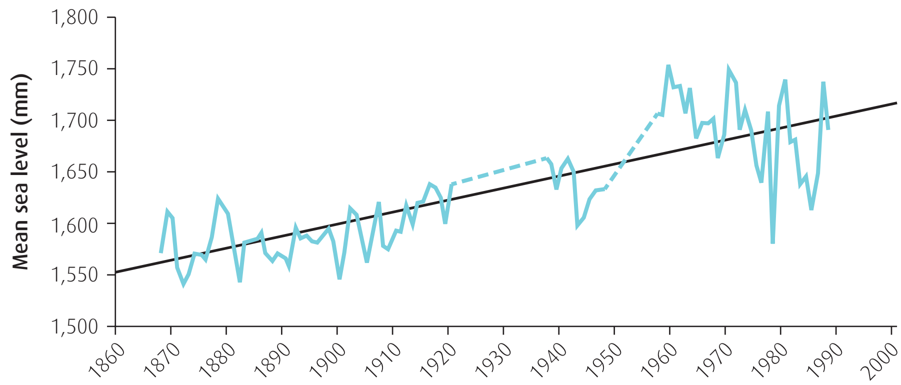
Climate change is expected to increase interannual flow variability. A greater proportion of precipitation is expected to fall as rain instead of snow, eventually reducing (but probably not eliminating) the glacier meltwater contribution, which is the least variable component of inflows. Yearly variations in precipitation are expected to increase and will increasingly dominate inflow variability. This will change the intensity and frequency of extreme discharge events (Lutz et al. 2016). River flood risk may double at the subnational level within 25 years, with Sindh and Punjab most affected (Willner et al. 2018).

The climate change impacts on Indus Basin flows apply in general to the Kabul subbasin, but the Kabul will have its own unique climate changes and responses. These need to be understood to guide joint development in this transboundary subbasin.

GLOFs occur when the ice wall retaining the lake fails, sending the entire stored water volume downstream as a flash flood. In the Upper Indus Basin, climate change will cause existing glacial lakes to get larger and cause new glacial lakes to form. Pakistan has around 2,420 glacial lakes, mostly in Jammu and Kashmir, of which 52 have been identified as GLOF risks (ICIMOD 2005). Since 2000, the number of glacial lakes in the Hindu Kush-Karakoram-Himalaya of Pakistan has increased (Ashraf et al. 2017), and an increase in GLOFs is expected (Bajracharya et al. 2015). Several GLOF events have been recorded in Pakistan, and there is evidence the frequency is increasing (Rasul et al. 2011). More than 7 million people are estimated to be at risk in Jammu and Kashmir and KP. Since 1996 GLOFs have killed more than 600 people and over 7,000 livestock, and more than 10,000 buildings have been damaged or destroyed (UNDP 2015). The increasing GLOF risk requires additional investment in monitoring, early warning systems, and, where appropriate, direct intervention to drain high-risk glacial lakes.

In the Makran and Kharan basins, the hydrological impacts of climate change will be very different to the Indus Basin. Balochistan has experienced a general warming trend since 1980, with an increase in extreme rainfall events especially in the coastal area (Abbas et al. 2018). It is likely to experience more variable rainfall and a reduction of snowfall at high altitudes (LEAD 2017). Balochistan is very vulnerable to climate change impacts, and the province's capacity to adapt to climate change is very low. To buffer increasing variability, the province will need to manage groundwater more strategically, scaling up managed aquifer recharge to capture high-intensity rainfall events. Balochistan should also incorporate measures to enhance climate resilience into its legal and policy instruments (LEAD 2017).

Figure 5.20 Mean Sea Level, Karachi Coast, Pakistan, 1860–2000



Source: Rabbani et al. 2008.

Pakistan's coastal areas are vulnerable to sea level rise. Observed rates of rise in Karachi average 1.1 millimeter per year (figure 5.20). Sea level rise will exacerbate land subsidence caused by overpumping of groundwater in urban areas (Rabbani et al. 2008). This will make irrigation drainage in Sindh even more challenging, increase the risk of coastal flooding, and exacerbate seawater intrusion into the delta and coastal groundwater.

Responding to Climate Change

Pakistan's climate change vulnerability is recognized in the National Climate Change Policy (2012), the Climate Change Act (2017), and the NWP (2018). These legislative and policy documents establish climate resilience as a key objective for all development interventions. Water security has been recognized as a key concern under a changing climate, and policy measures, ranging from additional storage to water conservation and awareness raising, are highlighted in the NWP.

To support Pakistan's water sector efforts toward climate resilience, policies could be complemented with adaptation targets and indicators that help assess the effectiveness of alternative measures and help guide development finance investment. International climate finance, technology development, and transfer and capacity building can all contribute to adaptation. Most investments in water security are also investments in climate change adaptation, and there are significant opportunities to make water-related investments more climate resilient, especially in Sindh and Balochistan. The required annual investment for climate change adaptation has been estimated to be US$7 billion to US$14 billion, including US$2.0 billion to US$3.8 billion to reduce flood vulnerability (UNFCC 2015). International climate adaptation finance in recent years has averaged US$500 million, well below what is required (LEAD Pakistan 2013).

Water-Energy Nexus

Pakistan is not energy secure. Chronic power shortage costs the economy around 2 percent of GDP per annum (Aziz and Ahmad 2015). Pakistan Vision 2025 sets ambitious targets for energy and water security. For energy, targets include closing the supply-demand gap and doubling generation capacity. For water, the primary target is ensuring all citizens have access to an adequate water supply, with improvements in efficiency and storage as key enablers. Achieving these energy and water targets will require integrating these sectors' planning to leverage synergies and avoid unintended trade-offs.

Water is used in the energy sector for coal mining and processing and for electricity generation (UNDP 2017). Pakistan's expanding coal mines use large volumes of water for dust suppression and processing, and discharge significant volumes of polluted water. Coal mining is focused in Sindh, in which water scarcity and pollution challenges are large. The Thar coalfield in Sindh is the largest in Pakistan and the sixth largest in the world (Ali et al. 2015). Thermal and nuclear power plants account for 64 percent and 6 percent of national generation capacity, respectively, and require water for evaporative cooling (GoP 2017b). Cooling water supply needs to be high quality and reliable. Although the energy sector accounts for only 1 percent of water withdrawals, water availability and variability already constrain electricity generation in Pakistan. Thirty percent of the electricity generation is from hydropower (GoP 2017b). Hydropower does not consume water, but energy demand patterns drive reservoir releases that do not fully match irrigation demands. Modeling suggests that optimizing dam operations (including Diamer Bhasha) solely for hydropower would increase energy production by 10 percent but reduce agricultural production by two-thirds (Yang et al. 2014). Careful tradeoff analyses are needed to identify solutions that balance energy and agricultural benefits, while accounting for environmental requirements (Zeng et al. 2017).

In the water sector, energy used for groundwater pumping and distribution (urban pump stations), as well as in water supply and wastewater treatment. The agricultural sector uses only 1 percent to 2 percent of the national total, and its share has been generally declining as other energy hungry sectors of the economy grow (FAOSTAT 2016). Total energy use in agriculture has more than doubled in the decade from the early 1980s with expansion of tube wells, but has fluctuated since with no overall increase (FAOSTAT 2016). The largest energy use in agriculture is groundwater pumping. Punjab, where groundwater pumping is concentrated, accounts for most of agricultural energy use (Siddiqi and Wescoat 2013). Around three-quarters of groundwater abstraction in Pakistan relies on diesel pumps (Qureshi et al. 2003), but electricity use in agriculture has grown steadily for several decades in response to government subsidies for electricity (Khair, Mushtaq, and ReardonÐSmith 2015). Subsidy reductions from 3 percent in 2011 to 0.8 percent in 2015 led to a reduction in agricultural electricity use (IMF 2017). Falling groundwater levels in parts of Punjab—partly attributable to electricity subsidies—have caused pumping costs to rise. This is mainly because as groundwater levels fall, diesel pumps need to be replaced with more powerful and energy-intensive electric pumps (Qureshi et al. 2010). Khan et al. (2016) estimate that the cost of groundwater pumping in Punjab could rise by 270 percent by 2030. Expanding wastewater treatment would require significant energy, potentially increasing total energy use by around 0.5 percent.

Doubling national electricity generation capacity in line with Vision 2025 would have significant water consequences. Failure to adequately consider water issues into energy sector planning could have significant unintended consequences for other water users. Optimizing the operation of storage reservoirs and increasing the use of run-of-the-river hydropower can reduce cross-sectoral impacts. Solar and wind energy can help close the energy supply-demand gap with minimal water impact. Although solar and wind account for only 1 percent of the total energy mix (Wakeel, Chen, and Jahangir 2016), their potential to contribute to Pakistan's energy security is substantial. The World Bank and the Alternative Energy Development Board (AEDB) estimate a theoretical national wind energy potential of 350 gigawatts (ESMAP 2015), and Pakistan's unexploited solar energy potential is very significant (IFC 2016). The low water footprint of these renewable energy sources makes them attractive options for a water scarce future. At the local scale, renewable energy sources may be most viable, especially for groundwater pumping. Solar groundwater pumping will need to be carefully managed to avoid exacerbating overexploitation of groundwater. Small-scale (less than 50 megawatts) hydropower potential is considerable and underdeveloped with only 128 megawatts in operation (AEDB 2018). The potential is estimated to be 3,100 megawatts (AEDB 2016; IRENA 2018), of which 20 percent is canal-based hydropower.

A water smart energy sector is critical to long-term energy security for Pakistan. In a water scarce world, the opportunity cost of water will increase, and the energy sector will have to compete for water with other users. Water-intensive power generation will be increasingly expensive. Options to assist Pakistan reach the Vision 2025 targets for energy should be assessed in terms of both energy and water issues (table 5.2).

Erosion and Sediment Transport

Erosion, sediment transport, and deposition affect water security. Sediment damages hydropower turbines, reducing their performance and effective life. Sedimentation in reservoirs—upstream of barrages and in irrigation canals—reduces hydraulic performance and can lead to scouring and erosion of the lower river and delta. Sediment loads affect water quality, channel morphology, riverine habitat, and delta development. Sediment trapping by reservoirs and barrages has reduced sediments to the delta, causing large-scale geomorphic changes and a loss of ecosystem services (see chapter 2).

Erosion and sediment transport depend on climate and catchment topography, geology, land use, and management, as well as water resource development. Catchment disturbance has been linked to increased sediment loads in the Indus Basin (WWF 2012), but in the absence of long-term monitoring the impact is unquantified. Naturally high erosion rates are expected with high relief, fast runoff, and low vegetation cover (Ali and De Boer 2010). Reduced vegetation cover will increase sediment loads. Deforestation rates are among the highest in Asia and are estimated at 0.4 percent (Qamer et al. 2016) to 2 percent (Ahmed et al. 2015) annually. In the Upper Indus Basin, however, snow and ice cover is probably the single most important factor controlling sediment supply (Ali and De Boer 2007).

River sediment transport capacity is a function of the flow regime, especially the flood regime (Lu et al. 2013; Walling 2009). Deforestation increases flood magnitude (Bradshaw et al. 2007), enhancing sediment transport. Increasing flood magnitude is occurring in some areas of Pakistan (Atta-Ur-Rahman and Khan 2013; Tariq and Aziz 2015; Webster, Toma, and Kim 2011). Sediment loads from the Upper Indus are likely to increase with more intense rainfall, more frequent GLOFs, and glacial erosion (Lu et al. 2010).

Table 5.2 Options to Achieve Government Pakistan Vision 2025 Energy Targets with Water-Energy Nexus Issues

Option	Water issues	Energy issues
New large HEP dams	Trade-offs with irrigation depending on location, design, and operation. Impacts on aquatic ecosystems.	Helps meet greenhouse gas emission targets. Trade-offs with irrigation. High O&M cost for transmission lines in difficult terrain.
Expand small-scale hydropower	Negligible impacts.	May reduce reliance on long-distance transmission lines.
Increase wind and solar energy	Negligible impacts, but increased risk of groundwater depletion without regulation.	Cost-effective, scalable, and indigenous energy. Helps meet greenhouse gas targets.
Increase biogas energy	Negligible impact, but relies on agricultural water supply.	Cost-effective, scalable, and indigenous energy. Helps meet greenhouse gas targets.
New coal-fired power stations (CPEC plans[a])	Water quality risks. Cooling water requirements.	Increases greenhouse gas emissions and lowers local air quality.
Increase energy imports	Minimized additional impact on local water resources.	Increased dependence on energy markets and exposure to volatile energy prices.

Note: CPEC = China–Pakistan Economic Corridor; HEP = hydroelectric power; O&M = operation and maintenance.
a. IER 2017.

Pakistan has implemented extensive watershed protection projects to reduce erosion. Community-led tree planting projects have been implemented upstream of Tarbela and Mangla reservoirs. These projects have been largely ineffective in reducing sediment loads because they cover only a small fraction of the catchment areas of the reservoirs (WWF 2012) and do not address areas exposed by snow and glacier retreat. A more integrated approach to sediment management is required that includes erosion control (through targeted revegetation and slope stabilization) and inclusion of sediment management in the design and rehabilitation plans of water infrastructure. To support a more integrated approach, better monitoring of sediment sources, erosion, and sediment transport is required. This will inform sediment budgeting and the modeling of sediment dynamics to guide intervention strategies and environmental management. The Dasu hydropower project reflects an increased awareness of sediment management, with nine 6.4-meter diameter low-level dam outlets and two 9.4-meter diameter flushing tunnels in the right abutment to facilitate drawdown flushing (Annandale, Morris, and Karki 2016).

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CHAPTER 6

Water Security Trajectories

Key Messages

- Reaching upper-middle-income (RUMI) status by 2047 is an ambitious goal that will require a significant change in the structure of the economy. The services sector must increase, while the agricultural sector must shrink. In absolute terms, however, the agricultural sector must continue to grow to meet rising food demands.
- Without significant reform and demand management, water demand could increase 50 percent by 2047 to significantly exceed supply. Population and economic growth will be the dominant drivers of demand increase, but climate warming will contribute significantly. The largest increases will be for irrigation, while the fastest rates of increase will be for domestic and industrial use.
- Despite projected population increase and climate change, water scarcity will not prevent Pakistan from RUMI status. Water consumption in agriculture can increase provided major improvements in water use efficiency are achieved to reduce losses. Even so, within a few decades, increasing municipal and industrial demand will restrict any further increase in agricultural water use.
- As incomes rise, diets will change to reflect more expensive but more nutritious choices. A falling demand for basic cereals will enable water to move to higher-value crops (either to meet changing domestic demands or new exports) or to other more economically profitable sectors.
- Current subsides for wheat and sugarcane should be phased out. This will encourage diversification toward higher-value commodities to help meet changing consumer food preferences and to deliver significant trade dividends.
- Pakistan's major agricultural exports consume a large fraction of the water used, and profitability is sensitive to international prices. The sector needs to become more responsive to changing international prices and to variations in water availability. This will increase the economic returns from water, while prioritizing social water needs.
- Increased flows below Kotri Barrage will become increasingly important in the future both to meet the increasing demand for Karachi and to restore and sustain the Indus Delta. An increase in end-of-system flows may reduce agricultural production slightly, but the value to Karachi and the environmental benefits would far exceed these losses.
- If the required reforms and performance improvements are not achieved, the consequences will be significant. Water capture by agriculture would increasingly affect the ability to provide adequate water services to industrial and service sectors. Even a 5 percent impact on productivity in industry and services is equivalent to 70 percent of the value of the four major irrigated crops.
- Recent gains in agricultural water productivity have relied on unsustainable groundwater exploitation. A continuation of business as usual and the current slow rate of economic growth would exacerbate groundwater depletion, fail to address declining health of the Indus Delta, and would most likely see urban water security decline.

Introduction

This chapter explores a range of water security trajectories out to 2047. The primary analytical basis for this chapter is scenario modeling of the Pakistan economy using a computable general equilibrium (CGE) model of the Pakistan economy coupled to a water system model of the Indus Basin. Appendix C provides a description of the coupled CGE-W model and its assumptions, plus comparisons to prior hydro-economic modeling for Pakistan.

The macro drivers of change in the model are economic growth, population growth, urbanization, and climate change, with economic growth driven by increases in productivity, labor, capital, and land and water resources. To explore the effects of these macro drivers and alternative water policies on economic and environmental outcomes from water, a set of future scenarios is defined and modeled as 33-year simulations from the base year of 2013/14 (table 6.1). Assumed rates of economic growth are a key aspect of scenario definition, while population growth and urbanization are represented in labor force changes, increasing demands for food and water, and sectoral shifts in water demands. Water availability projections for Pakistan are uncertain, and so consideration of climate change is limited to warming, which significantly affects water demand in all sectors (chapter 5). The scenarios explore the role of water policy and management in determining economic outcomes in the context of population growth, climate change, and changing consumer preferences, and thus describe a range of potential water security futures.

The baseline BAU scenario is a continuation of the current rate of growth, both overall and by economic sector, to reach gross domestic product (GDP) per capita of about US$2,200 by 2047. A RUMI scenario explores the plausibility of Pakistan attaining a per capita income of US$6,000 by 2047. This requires an annual GDP per capita growth rate of 4.9 percent—higher than the comparator countries have achieved. This is a stretch goal for Pakistan but illustrates the importance of water security for economic growth.

Several variants of BAU and RUMI are explored. The base case for both BAU and RUMI includes moderate climate change, described simply as a 1 degree Celsius rise in mean annual temperature by 2047, consistent with the recent rates of warming. A climate change variant of BAU and RUMI explores more rapid warming—a 3 degrees Celsius increase in mean annual temperature by 2047. For the faster warming variant of RUMI, another variant explores the impacts of changing consumer preferences. As incomes and education improve, dietary preferences typically move away from cereals, fats, and sugar to include more protein, fruit, and vegetables. This shift can have significant impact on agricultural water use.

Two other RUMI variants are modeled (both at the higher warming level): (i) one that simulates agricultural policy reform and changes in international trade, and (ii) one that simulates increased environmental sustainability through provision of additional environmental flows to the Indus Delta. The first assesses removal of current policies that artificially raise the internal prices for wheat and sugarcane and assesses changes in the trade outlook for rice and cotton. Although considered a single variant here for simplicity, these agricultural reforms and trade outlook changes are considered both separately and in combination in the modeling. The RUMI environmental variant increases freshwater flow below the Kori Barrage, thus reducing water for irrigation. The different scenarios are summarized in table 6.1.

In recent years, Pakistan's economic growth has been the slowest of a cohort of comparator countries (table 6.2). By 2047, Pakistan could reach India's current GDP per capita with just a 1.4 percent growth rate, less than the longer-term rate of 1.9 percent in the country. However, if Pakistan and comparator countries maintain current rates of growth, Pakistan's GDP per capita would be only halfway to the average income of low- and middle-income countries (LICs and MICs).

The key to faster growth is productivity increases in all sectors of the economy. One of the easiest ways to increase productivity is increased output per laborer, which is also a necessary to raise household incomes. The best growth in output per laborer has been in the services sector (at 1.1 percent per year), while industrial and agricultural sector growth have stalled or declined, partly reflecting a rapidly growing but largely unskilled labor force (figure 6.1). Agricultural yields have been growing at 1.2 percent to 1.8 percent (figure 2.3), but less than half of this growth is from increased productivity, with the rest coming from increased inputs. Both productivity and input increases have been slowing in the last decade. In addition to output per laborer, the contribution to employment is important. In the 1990s, agriculture fell from 50 percent to about 42 percent of the economy. Output per laborer is highest in services: expansion of the services sector provided the potential for higher incomes. Current output per laborer and employment levels were used to set productivity growth rates by sector for BAU and these were increased for RUMI to simulate economic growth (table 6.1).

Structural Change in the Economy

The modeling simulates structural transformation of the economy, largely driven by changing labor productivity

Table 6.1 Summary of the Scenarios for Pakistan Modeled and Analyzed using CGE-W

Scenario	Description	Overall annual GDP growth	Assumed productivity growth by sector	Consumer preferences	Climate change
BAU-Lo	Business as usual with current rate of climate warming.	1.9% to reach US$2,200 per capita by 2047.	Agriculture 0.65% Industry 0.5% Services 1.0%	Unchanged	Baseline rate of climate warming: 1°C increase in mean annual tempera-ture by 2047.
BAU-Hi	Business as usual with faster rate of climate warming.	1.9% to reach US$2,200 per capita by 2047.	Agriculture 0.65% Industry 0.5% Services 1.0%	Unchanged	Faster rate of climate warming: 3°C increase in mean annual tempera-ture by 2047.
RUMI-Lo	Accelerated economic growth with current rate of climate warming.	4.9% to reach US$6,000 per capita by 2047.	Agriculture 1.68% Livestock 1.44% Industry 1.32% Services 2.5%	Unchanged	Baseline rate of climate warming: 1°C increase in mean annual tempera-ture by 2047.
RUMI-Hi	Accelerated economic growth with faster rate of climate warming.	4.9% to reach US$6,000 per capita by 2047.	Agriculture 1.68% Livestock 1.44% Industry 1.32% Services 2.5%	Unchanged	Faster rate of climate warming: 3°C increase in mean annual tempera-ture by 2047.
RUMI-Hi-Diet	Accelerated economic growth, current rate of climate warming and dietary shifts.	4.9% to reach US$6,000 per capita by 2047.	Agriculture 1.68% Livestock 1.44% Industry 1.32% Services 2.5%	Dietary shift to more meat, dairy, and fruit.	Faster rate of climate warming: 3°C increase in mean annual tempera-ture by 2047.
RUMI-Hi-Reform	Accelerated economic growth, current rate of climate warming, agricultural policy reforms (wheat and sugarcane taxed) and trade shifts (international prices for rice and textiles reduced).	4.9% to reach US$6,000 per capita by 2047.	Agriculture 1.68% Livestock 1.44% Industry 1.32% Services 2.6%	Unchanged	Faster rate of climate warming: 3°C increase in mean annual tempera-ture by 2047.
RUMI-Hi-Env	Accelerated economic growth, current rate of climate warming and increased environmental flows to the Indus Delta.	4.9% to reach US$6,000 per capita by 2047.	Agriculture 1.68% Livestock 1.44% Industry 1.32% Services 2.7%	Unchanged	Faster rate of climate warming: 3°C increase in mean annual tempera-ture by 2047.

Note: CGE-W = computable general equilibrium-water model; GDP = gross domestic product.

Table 6.2 GDP per Capita and Average GDP Growth Rate for 1970–2016 in Pakistan and Comparator Countries, with Growth Required for Pakistan to Reach Comparator Growth Rate by 2047, and Share of Food Expenditure

Country	GDP per capita (US$, 2010)	GDP growth rate (%)	GDP growth rate for Pakistan to reach comparator growth rate (%)	Food expenditure (% of total expenditure)
Pakistan	1,200	1.9	n.a.	37
India	1,900	3.5	1.4	—
Egypt, Arap Rep.	2,700	2.6	2.5	50
Indonesia	4,000	3.5	3.8	42
Turkey	11,100	2.6	7.0	—
Malaysia	14,100	3.6	7.7	21
LICs and MICs average	4,400	2.6	4.1	—

Source: World Bank data and calculations.
Note: GDP = gross domestic product; LIC = low-income country; MIC = middle-income country; n.a. = not applicable; — = not available; low-income countries are those with gross national incomes (calculated using the World Bank Atlas method) of $1,025 or less in 2015; middle-income countries are those with gross national incomes per capita between $1,026 and $12,475.

and hence an ability to pay higher wages. Higher incomes slow the growth in demand for agricultural and other basic goods, so the agricultural sector grows more slowly than other sectors. Rates of structural transformation reflect the rates of economic growth and the productivity improvements of the major sectors (figure 6.2, panels a–c).

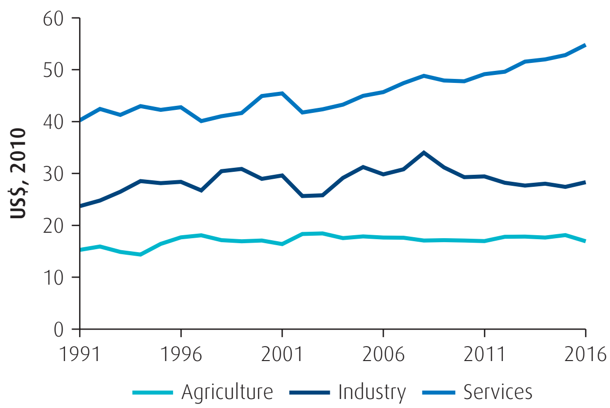
Under BAU-Lo, the agricultural share declines by 3.5 percent by 2047 as income per capita grows and demand for agricultural goods slows relative to other commodities. The industrial sector largely maintains its share (across both agricultural and other processing and manufacturing sectors), while the services sector share grows. Thus, demand for health, education, and financial services expands more than the demand for manufactured goods, and relative productivity gains in services makes them more competitive.

Under RUMI-Hi, the service sector share increases by 4 percent to become 58.5 percent of the economy, the agriculture sector share declines by 5 percent, and the industry share remains steady. The overall demand structure is the same in BAU and RUMI, so emergent differences are the result of sectoral productivity differences, which are highest in services and lowest in industry. Nonagricultural industry, with slightly lower productivity, but better demand prospects, increases it share marginally. The higher productivity growth in agriculture under RUMI reduces key input costs for agriculture-related industries, which partially offset the effects of slowing, allowing this sector to maintain its proportional share in the economy. The differentials between BAU and RUMI are shown in figure 6.2, panel c.

Future Water Demand and Use

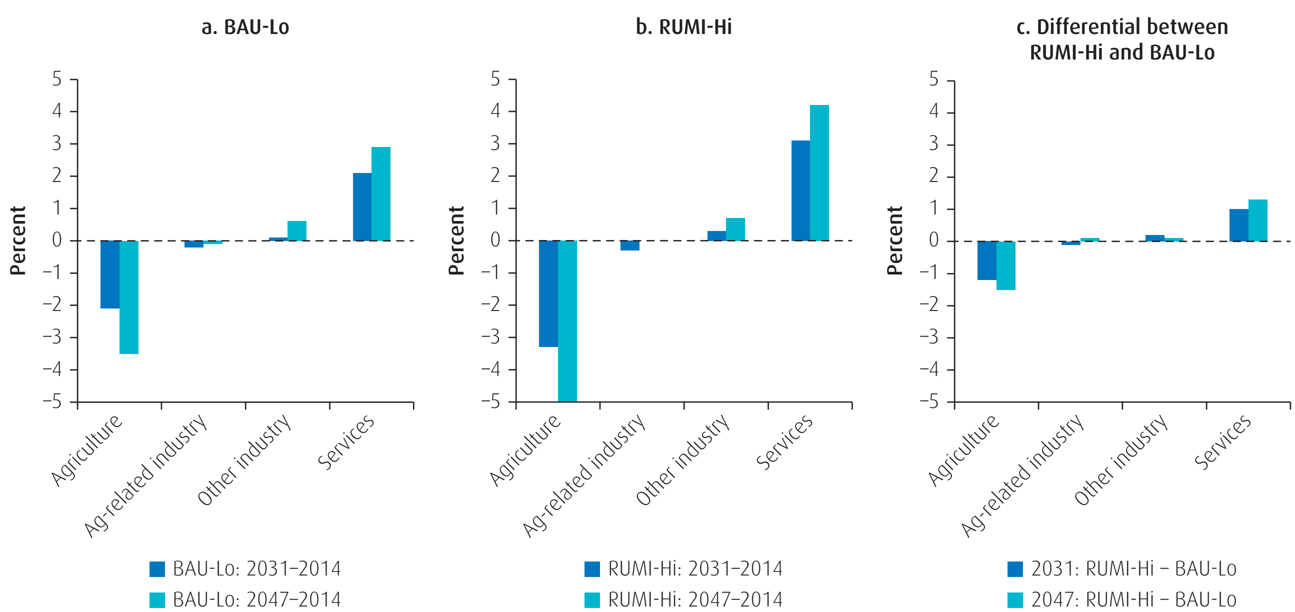
The CGE-W water balance (appendix C) sets the context for modeled water use. Agriculture dominates withdrawals, although less than 60 percent of water

Figure 6.1 Output per Laborer, by Sector, in Pakistan, 1991–2016



Source: GoP 2016a.

Figure 6.2 Changes in Sector Shares under BAU-Lo and RUMI-Hi by 2031 and 2047, and Differential between BAU-Lo and RUMI-Hi, in Pakistan, 2014 Baseline



Source: World Bank data.
Note: BAU-Lo = business as usual (with current rate of climate warming); RUMI-Hi = reaching upper-middle-income (accelerated economic growth with faster rate of climate warming).

withdrawn is consumed by crops. Of the water consumed by irrigation, 80.3 percent is for wheat, sugarcane, rice, and cotton. Wheat and sugarcane have politically sensitive policies that generate artificially high prices, while rice and cotton dominate current exports. At the commencement of simulations, evaporation and precipitation are roughly in balance. With rising temperatures in all scenarios, but no change in inflows, water demands rise relative to availability (see chapter 5).

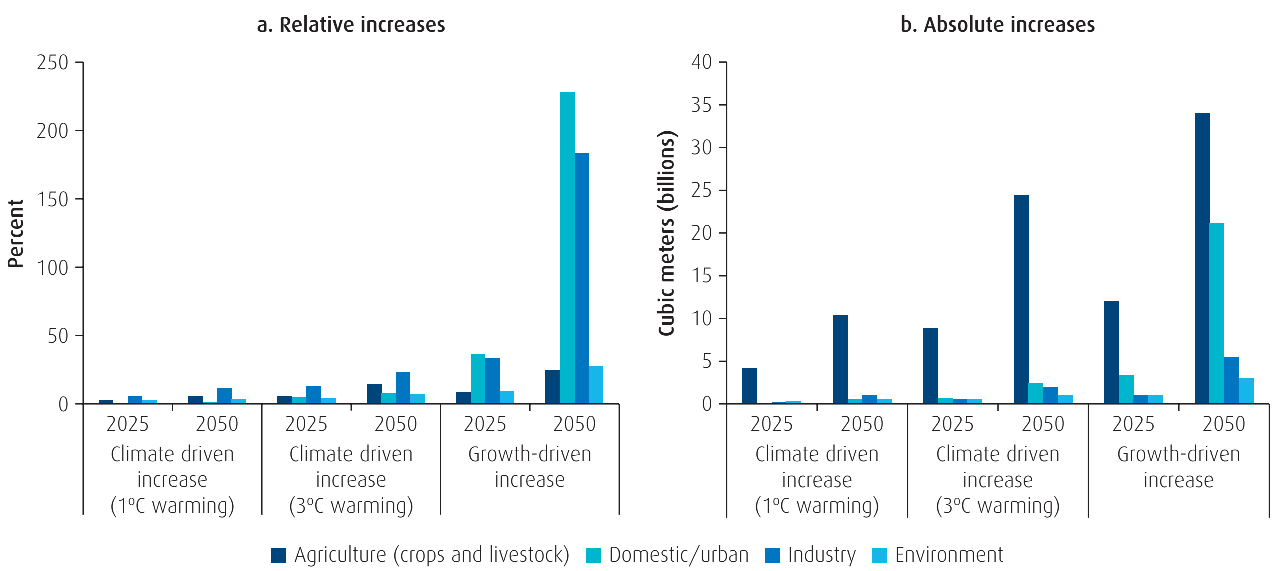
In addition to climate change and increasing population, urbanization and economic growth drive increases in water demand outside of agriculture. Domestic and industrial demand will grow several-fold by 2050 because of greater household incomes and industrial activities (figure 6.3, panels a and b). Growth—population and economic—is the biggest driver of demand increases across all sectors. In the absence of demand management, faster warming would cause significant additional increases, with the maximum projected water demand 58 percent higher than now. Agriculture will continue to dominate water demands (figure 6.4).

Amir and Habib (2015) demand projections include assumptions for irrigation distribution efficiency and economic growth, which differ from the assumptions embedded in CGE-W. Nonetheless, in the absence of reform or major structural change to the economy, the patterns of relative increase and approximate magnitude are realistic. The total projected demand by 2047 well exceeds the available water, highlighting the importance of a greatly increased emphasis on demand management. Dimensions of future water use—total amounts, intersectoral shifts, and shifts within agriculture—are explored using CGE-W, in the context of accelerated economic growth.

CGE-W correctly captures the very significant losses of water in the distribution system; however, the modeled flows downstream of Kotri Barrage are higher than observed, indicating that field-scale water use is more efficient in the model than in reality. This means that increasing water demand is met until 2038 in the model—longer than would be expected in reality. In the model, water required by industry (including water for livestock) is determined by the level of industrial output: the faster the economy grows, the greater the industrial activity, and the more water that industry demands. Similarly, growth in domestic water demand is driven by increasing household expenditure: as GDP per capita increases, so does domestic water demand. Under RUMI-Hi, domestic water use becomes 7.2 billion cubic meters higher than under BAU-Hi, and industrial and livestock water demand becomes 5.0 billion cubic meters higher (figure 6.5).

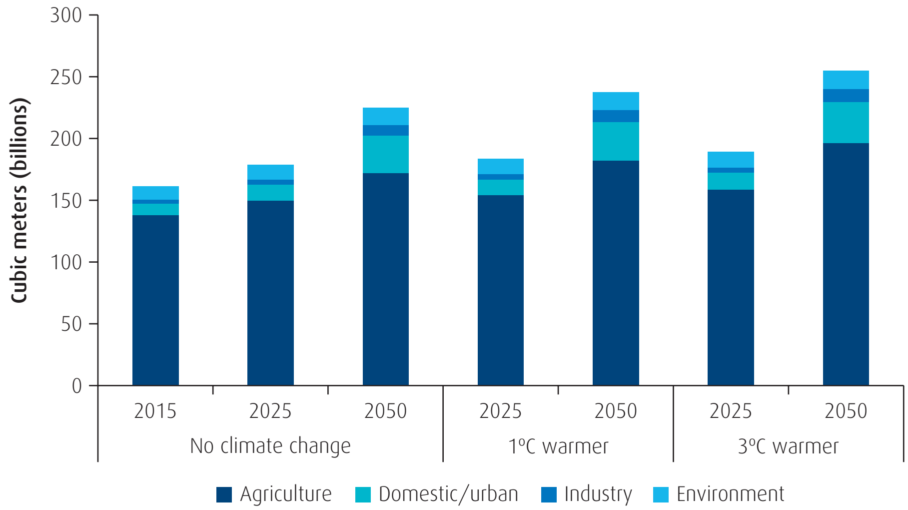
CGE-W demand projections differ from those of Amir and Habib (2015), partly because of differences in how livestock demand is categorized, and because in the modeling, domestic and industrial demands are met from groundwater, except for Karachi, for which demand is met from flows below Kotri Barrage. CGE-W nonagricultural demand projections (figure 6.5) are thus underestimates because they exclude

Figure 6.3 Projected Water Demand Increases, Relative and Absolute, Attributable to Slow and Fast Climate Warming and Growth, by Sector, 2025 and 2050



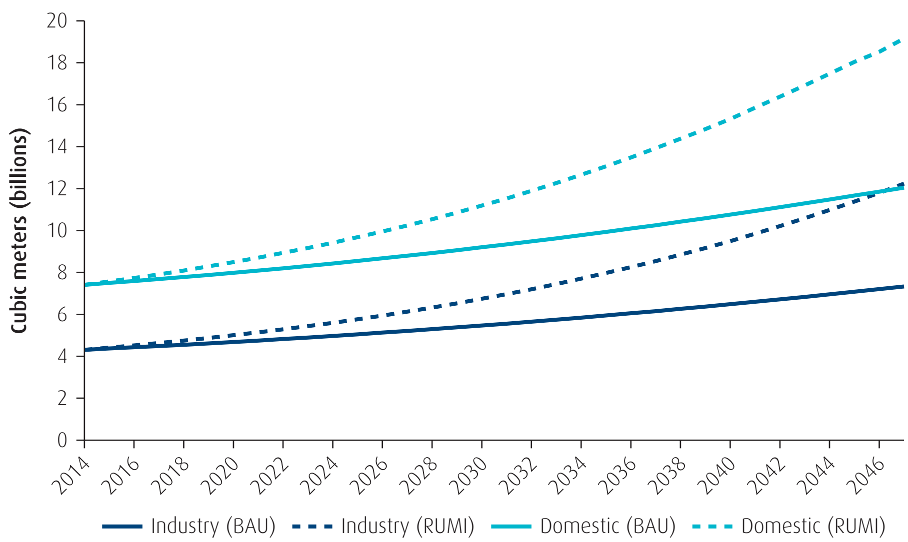
Source: Amir and Habib 2015.

Figure 6.4 Pakistan Total Water Demand in 2015 and Projected for 2025 and 2050



Source: Amir and Habib 2015.

Figure 6.5 Modeled Annual Nonagricultural Water Demands, by Scenario, 2014–47



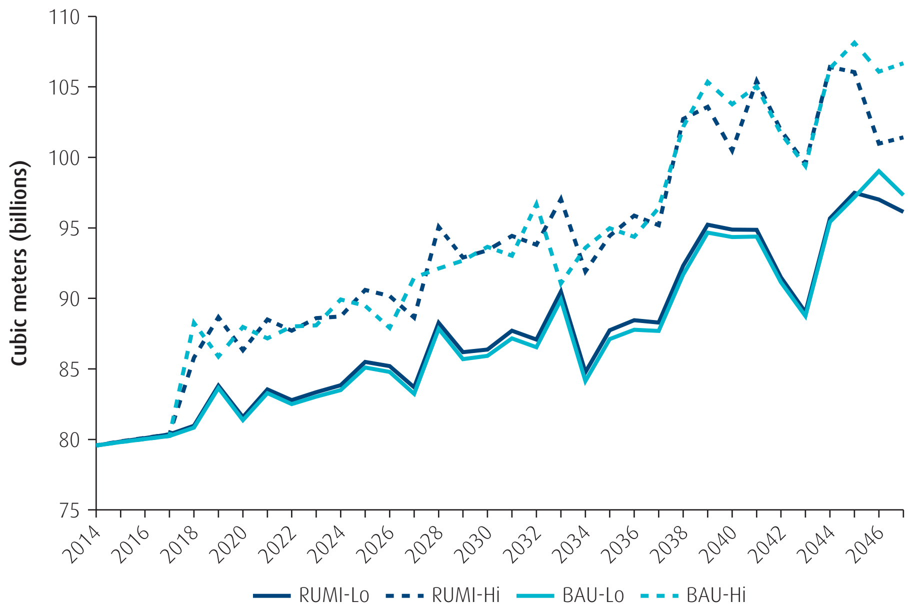
Source: CGE-W simulations.
Note: RUMI = reaching upper-middle-income; BAU = business as usual.

Karachi demand. Significant industrial and domestic demand growth will be a growing challenge for water resources management. The nonagricultural demand growth will not of course end in 2047, so long-term planning is required. Most industrial and domestic use is nonconsumptive, so there will be increased opportunities for wastewater reuse in agriculture. Untreated wastewater is too polluted for safe use in many agricultural applications, and detailed economic and technical analysis of wastewater treatment and reuse options will be required.

Water consumption in agriculture continues to increase to meet growing demand, even while faster economic growth reduces the relative contribution of agriculture to the economy. Faster climate warming could cause rapid increases in irrigation water use (figure 6.6). Irrigation water use is similar under BAU and RUMI in most years; however, late in the simulation period under a faster warming climate, irrigation water use declines under RUMI (this trend continues beyond 2047), because growth in nonagricultural demands constrains availability of water for irrigation.

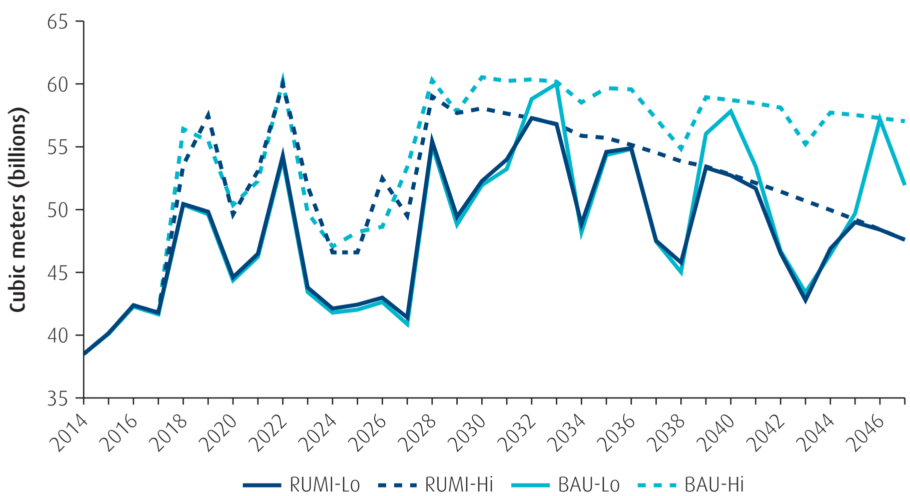
Groundwater consumption in irrigation changes and is strongly influenced by the rate of climate warming and the level of economic growth (figure 6.7).

Figure 6.6 Modeled Annual Irrigation Water Consumption, by Scenario, 2014–47



Source: CGE-W simulations.
Note: BAU-Hi = business as usual with faster rate of climate warming; BAU-Lo = business as usual (with current rate of climate warming); RUMI-Hi = reaching upper-middle-income (accelerated economic growth with faster rate of climate warming); RUMI-Lo = reaching upper-middle-income (accelerated economic growth with current rate of climate warming).

Figure 6.7 Modeled Annual Groundwater Irrigation Consumption, by Scenario, 2014–47



Source: CGE-W simulations.
Note: BAU-Hi = business as usual with faster rate of climate warming; BAU-Lo = business as usual (with current rate of climate warming); RUMI-Hi = reaching upper-middle-income (accelerated economic growth with faster rate of climate warming); RUMI-Lo = reaching upper-middle-income (accelerated economic growth with current rate of climate warming).

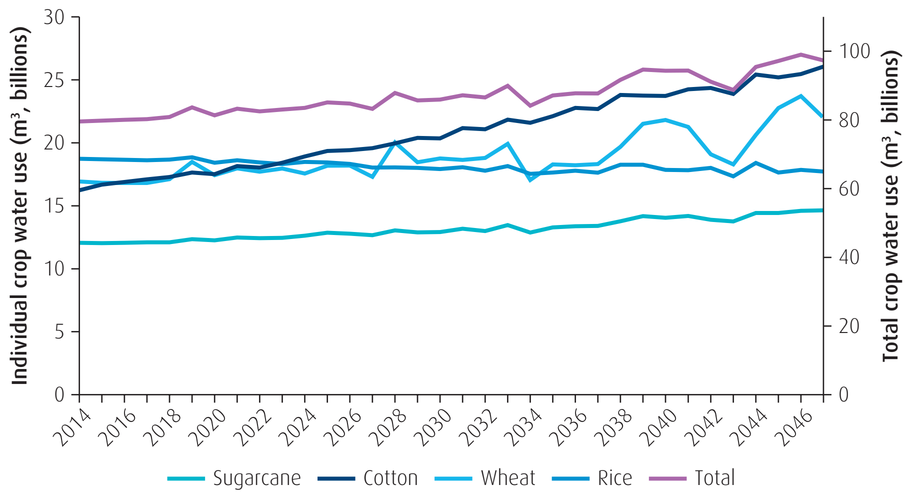
Until 2030, groundwater use varies significantly across years in response to changing surface water availability. From 2030, groundwater use in irrigation begins to decline as nonagricultural demand for groundwater increases. Under a faster warming climate, there is reduced variability between years after 2030, because the maximum available groundwater is used each year.

Around four-fifths of the water used in agriculture irrigates four major crops—wheat, sugarcane, rice, and cotton. Under BAU-Lo, the volume of water used by wheat, sugarcane, and cotton increases while water use for rice slowly declines (figure 6.8). Water use by wheat varies more between years than for other crops, because rabi water supply is less reliable. Nearly half of current rice production is exported. If prices remain steady, water for cotton becomes an increasingly better option than for rice. Cotton production supports exports of yarn, cloth, and garments, whose higher value leads to a transfer of water away from rice.

Under RUMI-Hi, total irrigation water use grows faster than under BAU because of greater economic activity and the effects of faster warming (figure 6.9). Total water use peaks around 2038, after which nonagricultural demands constrain growth in agricultural water use. Within irrigation, water moves away from cotton (and this trend continues beyond 2047) given increasing domestic food demand. In reality, the irrigation supply constraint revealed here would be reached sooner, unless current field-level inefficiencies were reduced. A mix of policy reforms, improved water management, and infrastructure and technology investments will be required to that ensure that nonagricultural demands are met, and that agricultural productivity growth continues.

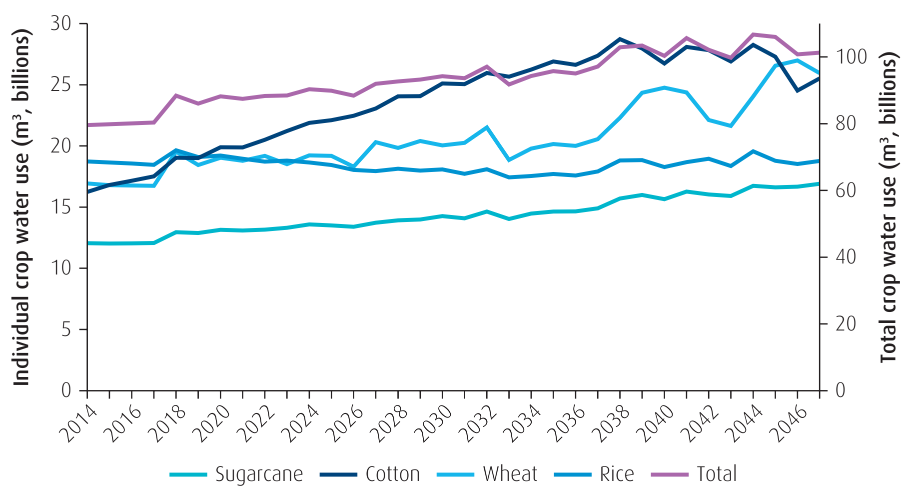
CGE-W provides information on crop water productivity (table 6.3). Baseline productivity varies from US$0.13 per cubic meter for rice to US$1.57 per cubic meter for maize in 2013/14 prices. Of the major crops, wheat has the highest water productivity. Productivity growth across all commodities is twice as high under RUMI as under BAU, highlighting the

Figure 6.8 Modeled Annual Crop Water Use in Pakistan under BAU-Lo, 2014–2047



Source: CGE-W simulations.
Note: BAU-Lo = business as usual (with current rate of climate warming).

Figure 6.9 Modeled Annual Crop Water Use in Pakistan Under RUMI-Hi, 2014–2047



Source: CGE-W simulations.
Note: RUMI-Hi = reaching upper-middle-income (accelerated economic growth with faster rate of climate warming).

Table 6.3 Water Productivity in Pakistan by Crop for Baseline Year (2013/14) and Productivity Growth Rates under BAU and RUMI

	Baseline water productivity (US$/m³)	Water productivity growth rate (BAU, %)	Water productivity growth rate (RUMI, %)
Wheat	0.42	1.5	3.4
Rice	0.13	1.3	2.7
Cotton	0.24	1.6	3.2
Sugarcane	0.20	1.2	2.6
Maize	1.57	1.7	3.3
Potato	0.53	1.1	3.4
Vegetables	0.16	1.4	2.9
Other crops	0.61	1.5	4.4
Fruit	0.29	1.9	3.7
Average	0.34	1.5	3.2

Source: CGE-W simulations.
Note: BAU = business as usual; RUMI = reaching upper-middle-income.

potential for higher incomes. RUMI will require rapid improvements in water productivity.

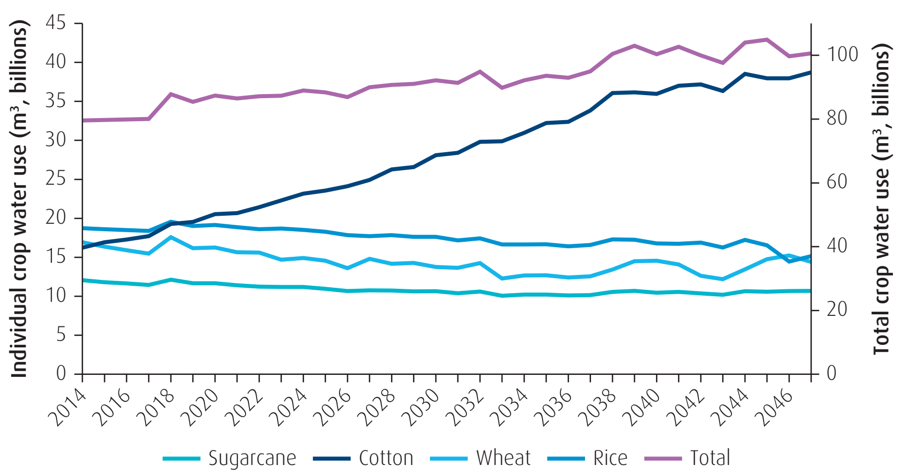
Changing Consumer Preferences

Consumption patterns change with income level, even though Pakistan households spend less of their income on food than those in wealthier comparator countries (table 6.2). This partly reflects higher urban populations and an ability to meet more of the food demand at less than international prices in these comparator countries. Proportional expenditure on staples does not appear to fall rapidly with rising income across these countries. In Pakistan, 17.8 percent of food expenditure is on cereals. In the Arab Republic of Egypt, with more than double the per capita income, the percentage is slightly higher. In Indonesia, with triple the per capita income, the level is 25 percent.

Changes in consumer preferences are expected to have a major impact on the patterns of irrigation water use (figure 6.10). While total irrigation use is not affected, a reduction in demand for cereals allows more cotton to be grown and the export share of textile production rises from 31 percent to 41 percent. Eventually, increasing water demand outside agriculture constrains cotton production, which peaks and stabilizes around 2047. Other agricultural or nonagricultural commodities could replace cotton given changing preferences and demands—cotton is simply the most profitable option in the model given the current configuration. Limits on even the best agricultural options are therefore likely to be encountered in the next few decades under strong economic growth and significant climate change. A range of policy options, awareness campaigns, education, information, and promotion of healthy lifestyles can support this transition.

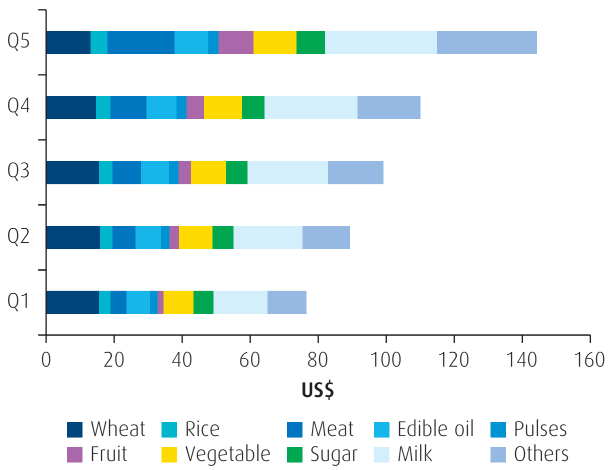
Comparison of the modeling results with Pakistan household survey data informs interpretation. Survey data indicate how the level and composition of food expenditure changes with income and captures cultural and supply differences better than inter-country comparisons. Figure 6.11 illustrates how absolute expenditures on food categories change as Pakistani households get richer. If relative expenditure

Figure 6.10 Modeled Annual Crop Water Use in Pakistan under RUMI-Hi-Diet, 2014–2047



Source: CGE-W simulations.
Note: RUMI-Hi-Diet = reaching upper-middle-income (accelerated economic growth, current rate of climate warming and dietary shifts).

Figure 6.11 Monthly Household Expenditure on Food Groups in Pakistan by Income Quintile, 2015



Source: GoP HIES 2016b.

Table 6.4 Modeled Growth in Commodity Consumption by Scenario in Pakistan
percent

	BAU-Hi	RUMI-Hi	RUMI-Hi-Diet
Wheat	1.3	1.9	0.7
Rice	2.4	3.8	2.9
Fruit and vegetables	1.5	3.1	3.0
Livestock	3.4	4.4	3.7
Dairy	4.3	5.1	3.6
Sugar	1.3	2.7	0.5

Source: CGE-W simulations.
Note: BAU-Hi = business as usual with faster rate of climate warming; RUMI-Hi = reaching upper-middle-income (accelerated economic growth with faster rate of climate warming); RUMI-Hi-Diet = reaching upper-middle-income (accelerated economic growth, current rate of climate warming and dietary shifts).

on a commodity declines with rising income, demand increase will tend toward the rate of population growth, as average income increases through time. If expenditure on a commodity increases with income, and if water availability to irrigation decreases given inter-sectoral competition, a decrease in exports (or an increase in imports) will be required to meet demand. Wheat is the only commodity for which absolute expenditures falls across quintiles. Expenditure on fruit, meat and milk all rise by between US$8 to more than US$18 per month. The largest increases are between the fourth and fifth quintiles. Consumption of sugar is very similar across the lower four quintiles.

Under RUMI, faster growth shifts the income distribution upward. Introducing changes in consumer preferences causes further changes in demand, consumption, and hence water use patterns. RUMI-Hi-Diet displays minimal growth in wheat consumption, while consumption of vegetables, livestock, and sugar increase, as suggested by the survey results (table 6.4). With economic growth, consumption will shift toward a more nutritious and diversified diet that improves the well-being of the population, while at the same time improving water security, provided that the necessary reforms and investments are made.

Policy Reform and Trade Shifts

Significant government investment supports wheat and sugarcane in Pakistan. For example, the Punjab government spent PRe 35 billion on wheat procurement in 2017. Two oft-discussed mechanisms to rationalize water use are reform of the wheat procurement program and reform of indicative sugarcane prices, which jointly cause domestic prices for these water-hungry commodities to be well above international prices. Cotton and rice are the main agricultural exports, but their dominance will depend on international prices. Vested interests and spurious food security arguments have prevented policy reform. Despite many attempts to move toward high-value produce, the base of exports remains tied to major lower-value, high water use crops, especially cotton. To simulate the removal of support to wheat and sugarcane, equivalent taxes on these commodities are introduced (17.8 percent for wheat and 18.4 percent for sugarcane). To explore the implications of international prices for rice and cotton on water use and economic outcomes, prices are reduced by 0.7 percent each year.

Policy reforms for wheat and sugarcane reduce water use for these crops by 1.4 billion cubic meters and 1.8 billion cubic meters, respectively (table 6.5). As no economic value is placed on environmental water below Kotri Barrage in the model, water stays in agriculture, simply moving to other commodities. These policy reforms alone would not reduce agricultural water use, but simply redistribute water within agriculture. Falling export prices for rice and cotton (column 5, table 6.5) shifts production toward meeting food domestic demand, with a small decline in overall irrigation water use. Cotton production drops by 26 percent overall and the fraction exported drops from 40 percent to 25 percent; water use for cotton reduces by nearly 7 billion cubic meters. Declining international prices for rice and rising domestic demand cause a near complete exit from the international market, but little change in production. The reduction in water use by cotton allows increases for other crops, especially fruit and vegetables, reflecting changing domestic demand. Water reallocation in the model is constrained by the baseline parameterization, which limits expansion of fruit and vegetables.

Combining policy reforms and trade shifts (column 6, table 6.5) reduces irrigation water use by 1.4 billion cubic meters. Most of this reduction comes from lower textile exports, which is not necessarily desirable. Adding changes in dietary preferences to these reforms (column 7, table 6.5) sees significant reductions in water use for wheat and sugarcane and increases for other crops (including fruit and vegetables); overall, irrigation water use falls by 3.2 billion cubic meters. If, in addition, environmental flows are included (column 8, table 6.5), irrigation water use declines by a further 3.4 billion cubic meters. However, there is a clear win-win outcome: nutrition improves, and water becomes available for other higher-value uses. These results are for RUMI-Hi variants, but if climate warms less quickly, lower irrigation demands for a given level of production would make it easier to shift water to other sectors.

The model retains water in agriculture because nonagricultural requirements are met first, and no value is placed on flows below Kotri Barrage. The various reforms (and dietary change) free sufficient water to meet about half the projected increase in nonagricultural water demand. Fully meeting these nonagricultural demands should not be difficult but will require appropriate regulatory measures and adequate investment.

Reducing subsidies on sugarcane and wheat reduces GDP per capita by 0.9 percent (column 3, table 6.6). Reducing wheat support decreases economic growth in all economic sectors by 0.6 percent to 0.8 percent, but taxing sugarcane has a disproportionate cost to agricultural processing given sugar's strong reliance on processing. Wheat reform, with or without sugarcane reform, encourages production in other agricultural products, and there is a net gain in the agricultural trade position: exports rise and imports fall. The price increases caused by added taxes reduces consumers' ability to purchase other goods and services, and thus has a small negative economic impact relative to the RUMI-Hi base case. This impact is, however, very small compared to the more than fourfold increase in GDP by 2047 under RUMI compared to BAU and is more than offset by other benefits.

Larger impacts occur in the scenarios with trade shifts, overwhelmingly because of reduced textile exports. GDP drops by 2.3 percent in 2047 relative to the RUMI-Hi base case (column 5, table 6.6); however, agriculture expands because the release of water from cotton supports additional higher-value cropping. Because textile production mainly appears as agricultural processing, it is here that the main reductions are seen, as well as in lower exports because of lower prices. Rising agricultural GDP and water released from cotton allows industrial growth, which expands by 2.0 percent. Industry draws resources and demand from the services sector, which is impacted by reduced exports of textiles and rice. A similar response occurs by adding wheat and sugarcane reforms to international price changes.

Table 6.5 Modelled Water Use by Major Crops in Pakistan under RUMI-Hi and Changes in Water Use for RUMI-Hi Variants, 2047

cubic meters (billions)

	Wheat	Rice	Cotton	Sugar-cane	Other crops	Total
RUMI-Hi	23.3	19.3	28.3	17.9	17.2	106
No wheat support	−1.4	0.2	0.7	0.2	0.5	0.2
No sugar support	0.4	0.4	0.5	−1.8	0.4	−0.2
No wheat, sugar support	−1.1	0.6	1.3	−1.7	0.9	0
LEPs for rice, cotton	1.3	0.1	−6.9	0.8	3.3	−1.5
No wheat, sugar support + LEP	0.2	0.6	−5.8	−0.9	4.5	−1.4
No wheat, sugar support + LEP, diet	−4.6	1.1	0.5	−5.5	5.3	−3.2
No wheat, sugar support + LEP, diet, environmental flows	−4.7	0.5	0.3	−5.6	2.9	−6.6

Source: CGE-W simulations.
Note: LEP = lower export price; RUMI-Hi = reaching upper-middle-income (accelerated economic growth with faster rate of climate warming).

Table 6.6 Modelled GDP under RUMI-Hi and Impacts of Policy Reforms, Changing Export Prices, and Consumer Preferences in Pakistan, 2047

	RUMI-Hi (US$, billions)	No wheat support (% change)	No sugar support (% change)	No wheat, sugar support (% change)	LEPs for rice, cotton (% change)	No wheat, sugar support + LEP (% change)	No wheat, sugar support + LEP, Diet (% change)	No wheat, sugar support + LEP, Diet, E-flows (% change)
Agriculture sector	382	−0.6	−0.2	−0.8	1.7	1.1	−14.3	−17.0
Agriculture processing	177	−0.8	−0.6	−1.4	−12.8	−13.9	−18.0	−16.8
Industry sector	215	−0.8	−0.2	−1.0	2.0	0.8	7.4	5.2
Service sector	1,083	−0.6	−0.2	−0.8	−2.8	−3.6	−0.9	−0.1
Total	**1,857**	**−0.6**	**−0.3**	**−0.9**	**−2.3**	**−3.1**	**−4.3**	**−4.6**
Agriculture exports	143	0.6	−0.6	0.1	−65.8	−65.0	−67.8	−63.7
Agriculture imports	113	−0.8	0.4	−0.5	−16.6	−17.6	−37.7	−37.9

Source: CGE-W simulations.
Note: GDP = gross domestic product; LEP = lower export price; RUMI-Hi = reaching upper-middle-income (accelerated economic growth with faster rate of climate warming.

Changes in consumer preferences shift demand away from agricultural commodities (column 7, table 6.6) so agricultural GDP declines by over 14 percent, impacting agricultural processing and exports. The changes favor the industrial and services sectors. Enforcing environmental flows (column 8, table 6.6) has only minor additional impact on total GDP because further decline in agriculture is largely offset by lower trade deficits and growth in services.

The economic losses from the combination of policy reforms, trade, and dietary shifts are very small relative to the rapid economic growth under the RUM-Hi base case. This combination of changes and interventions would free water from agriculture to support greatly improved urban water security and environmental sustainability. The resulting social and environmental benefits would far outweigh the minor reduction in GDP per capita from US$6,000 to US$5,700.

Reforming wheat and sugarcane policies would improve water security with minor potential economic impacts, which might be offset by trade improvements through reduced exports of low-value agricultural commodities, but increased export of higher value products. Political economy issues suggest the necessary reforms will be challenging (see chapter 4).

Policy makers should consider the economic costs of inadequate water services to the industrial and service sectors, and of course, the social costs of further decline in the quality of domestic supply and sanitation services. CGE-W does not offer insights into social outcomes, but does suggest the economic costs of inadequate water for industrial and service sector growth. Not all industries and services are heavily water dependent and establishing new industries in Pakistan can be slow and costly. If industry and service sector water demands are not met, this could conceivably reduce productivity by 5 percent. By 2047 this represents an annual GDP loss of US$45 billion, equivalent to 2.4 percent of total GDP, or 70 percent of the GDP from the four major crops. This scale of potential loss is easily sufficient to justify major investments in urban water supply and restricting increases in agricultural water use. Policies and investments that fail to restrict growth in irrigation water use will ultimately impose large economic (and social) costs on Pakistan, far outweighing the benefits in agriculture. Chapter 3 notes that the costs of inadequate water supply and sanitation are 3.9 percent of GDP; these are in addition to the costs of reduced industrial and services productivity assessed here. Without intervention, inadequate water for industry and services and inadequate domestic water and sanitation services could cost Pakistan more than 6 percent of GDP by 2047.

Improved Environmental Management

As noted in chapter 2, flows downstream of Kotri Barrage are critical for sustaining the ecosystems of the Indus Delta, as well as for meeting much of Karachi's water supply. Although the 1991 Water Apportionment Accord recognizes the importance of environmental flows, none are specified and there is no agreement among the provinces on appropriate environmental flows. Although not scientifically robust, widely accepted or implemented, prior work has suggested an environmental flow below Kotri Barrage of 5,000 cubic

Table 6.7 Annual Value of Lost Production with Increased Annual Water Demand below Kotri Barrage, Pakistan, under RUMI-Hi

	Demand (BCM)		Annual costs (US$, billions)	
	Environment	Karachi	Net present value	2047 value
Current	11.5	4.4	0.61	0.72
Moderate increase	17.5	7.4	3.28	1.76
Major increase	23.6	10.3	7.57	4.19

Source: CGE-W simulations.
Note: BCM = billion cubic meters; RUMI-Hi = reaching upper-middle-income (accelerated economic growth with faster rate of climate warming).

meters per second (4.44 billion cubic meters annually and 0.37 billion cubic meters per month). Even this constant and minimal flow is rarely achieved under current operations (Amir and Habib 2015), especially at a monthly level. During the 2000/01 drought, flows below Karachi were insufficient to even meet Karachi's demands, let alone provide an environmental flow for the delta.

Although Karachi's current volumetric supply is adequate, Karachi's demand will grow significantly, increasing the pressure for increased supply. This would further reduce flow to the delta, especially in dry years. Even in the absence of a fuller assessment of environmental flow requirements, Amir and Habib (2015) argue that environmental water demands will increase considerably because of climate warming and the need to counter seawater intrusion. To explore the implications of an increase in the end-of-system water requirements (combining consumptive and environmental needs), RUMI variants with different increases in flows below Kotri Barrage were modeled. These flows approximate the foregone agricultural production that results from taking securing higher monthly environmental flows to the delta (table 6.7).

The net present value of the annual costs to 2047 of meeting the current demands below Kotri Barrage is US$0.61 billion; the 2047 value of these costs is US$0.72 billion. A moderate increase in end-of-system demand, which includes the water supply level recommended by the Karachi Water and Sewerage Board (KWSB) and an environmental flow level slightly higher than that suggested by Amir and Habib (2015), yields more than a fivefold increase in the net present value (NPV) of costs or between a two- and threefold increase in 2047 value. A major increase in end-of-system demand further increases the economic cost. The magnitude of these losses (in 2047 value) is, however, very small in relative terms, being only 0.2 percent of GDP.

The future economic benefits to Karachi alone would far outweigh these losses. Therefore, mechanisms to achieve these end-of-system flow increases should be explored and implemented. As noted previously, the costs of poor health from inadequate water supply and sanitation and losses in economic productivity could reach nearly 6 percent of GDP. Because Karachi represents perhaps 20 percent of national GDP and 10 percent of national population, adequate water supply and services for Karachi could mitigate perhaps 1 percent of the water-related GDP loss, which is around five times the economic cost of reduced agricultural production. There are also many other benefits to the more than 1 million people dependent on delta resources, including the mangrove forests and productive fisheries, so the total benefits relative to the costs would be far higher.

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CHAPTER 7

Pathways to Water Security

This final chapter provides high-level recommendations for improving water security in Pakistan. The recommendations emerge from linking areas of weak sector performance (water resources management, service delivery, and risk mitigation) to aspects of sector architecture (policy, institutions, legal framework, infrastructure, and financing) that appear to be deficient. The recommendations are categorized for short- (less than five years), medium- (five to 15 years) and long-term (more than 15 years) action. Several recommendations are not new, and hence key political economy factors that appear to have prevented progress in the past are flagged. Without attention, these political economy factors are likely to continue to impede progress. Given the complex series of overlapping, intersecting, and poorly quantified cause-effect relationships among the many water security variables, it is not possible to precisely quantify the improvements in economic, social, and environmental outcomes that would accrue from the recommended actions.

The assessment of what Pakistan gets from its water makes it clear that Pakistan is not water secure. Modeling indicates that with continued incremental improvement in agricultural water productivity, the current rate of slow economic growth could probably be maintained, and the food demands of a growing population could continue to be met. However, under this business as usual (BAU) baseline, urban water security would be expected to decline, environmental degradation would worsen, and groundwater depletion would worsen. The resilience of the water sector would not be improved, leaving it more vulnerable to shocks.

A far higher rate of economic growth—sufficient to reach upper-middle-income status by 2047—is achievable and is not precluded by increasing water scarcity. This will require multiple reforms and investments over coming decades. A significant share of the water currently used for irrigation will need to be reallocated from agriculture to other sectors and users, including the environment. Water productivity in agriculture will need to be greatly enhanced. Between the BAU and high-growth pathways, many alternatives may emerge. The actual growth trajectory will depend on how aggressively the necessary policy and institutional reforms are tackled, how rapidly the climate warms, and whether unexpected shocks (e.g., major floods, droughts, security incidents, or political unrest) occur during the transition period.

The full scope of water security considered in this report was not captured in the modeling. No modeling was undertaken of new or modernized infrastructure, changed reservoir operations, conjunctive surface-groundwater management, improvements to urban and rural water supply and sanitation services, improved flood management, basin sediment management, or many of the governance aspects discussed. A mix of these intervention would be required to achieve the rates of economic growth assumed in the modeling, especially in agriculture. In addition to the evidence from the modeling, the recommendations are supported by the assessments and descriptions of current sector performance, governance, and infrastructure.

Twelve high-level recommendations and their key objectives are summarized in table 7.1. These are then discussed in more detail, outlining for each the required improvements in water governance (legal, policy, and institutional) and the nature and scale of infrastructure investment. There are six recommendations for improved water resources management, three for improved service delivery, and three for improved risk mitigation. The recommendations have been qualitatively assessed in terms of complexity,

Table 7.1 High-Level Recommendations and Finances Required by Performance Area in Pakistan

	Recommendation	Strategic objectives	Cost
Water resources management	Strengthen water data, information, mapping, modeling, and forecasting	• Improve water resources planning and system operations • Improve flood/drought risk assessment, planning, and mitigation • Increase transparency of, and access to, water information	US$1–10 million per year
	Establish a multistakeholder process of basin-scale water resources planning	• Guide long-term sustainable economic development • Define agreed upon basin-level environmental flows • Improve interprovincial sharing, especially during droughts • Build climate resilience across all sectors, including the environment	< US$1 million per year
	Establish provincial water planning and intersectoral water allocation mechanisms	• Support a smooth economic structural transformation • Better manage temporary water shortages, including risk sharing • Improve efficiency and equity of irrigation water distribution	US$1–10 million per year
	Accelerate increases in agricultural water productivity	• Ensure future food security, given water availability constraints • Increase farmer incomes • Facilitate labor movement to other sectors • Contribute to overall increase in economic benefits from water	US$1–10 million per year
	Adopt conjunctive planning and management of surface and groundwater	• Maximize the use of aquifer storage for drought resilience • Ensure sustainable groundwater use • Improve equity in water access across command areas • Reduce water logging and salinization	< US$1 million per year
	Construct limited new storage (when hydroelectric power justifies the expense) and review reservoir operations	• Better support multiple water management objectives • Manage changing flood risk and changing demand patterns • Improve reliability of rabi irrigation supply • Manage increasing variability of inflows, including flood mitigation • Mitigate sedimentation to improve storage longevity • Contribute to improved energy security	> US$1 billion per year

table continues next page

Table 7.1 continued

	Recommendation	Strategic objectives	Cost
Service delivery	Modernize irrigation and drainage and improve operations	• Improve irrigation service delivery in terms of efficiency and equity • Increase agricultural productivity, including more high-value crops • Ensure food security for a growing population • Enable reallocation of some water to cities and environment	US$10 million to US$100 million per year
	Reform urban water governance and close the infrastructure gap	• Improve quality, equity, and sustainability of urban water supply services • Reduce environmental and public health impacts of poor sanitation • Keep pace with population growth and urbanization	US$10 million to US$100 million per year
	Improve rural sanitation	• Improve quality and coverage of rural sanitation services • Reduce environmental and public health impacts of poor sanitation	US$1–10 million per year
Risk mitigation	Improve understanding and management of climate risks to the Lower Indus and Indus Delta	• Maintain natural green infrastructure for coastal protection • Protect coastal groundwater resources • Protect and restore delta ecosystems • Build climate resilience of lower basin agriculture	< US$1 million per year
	Strengthen planning and management of water-energy interactions	• Manage the trade-offs and synergies between energy and water development and planning • Inform investment choices	US$1–10 million per year
	Improve understanding and management of basin-scale sediment dynamics	• Protect and improve water infrastructure operations • Mitigate environmental impacts of changed sediment dynamics in the delta and lower river	US$1–10 million per year

urgency, and scale of water security impact. Figure 7.1 maps the recommendations on complexity and urgency axes; bubble sizes indicate the scale of impact.

Figure 7.1 suggests that the highest impact areas to tackle are generally the more complex. Progress on these challenges has therefore been limited, and they are becoming increasing urgent for Pakistan. These areas include improving irrigation and drainage services and establishing a long-term strategic basin planning process. Improving the quality of urban water supply services, especially in Karachi, is both urgent and complex, but would greatly enhance Pakistan's water security. Both irrigation services and urban water supply services are complex in part because of the political economy challenges explored in chapter 4. Progress will require strong political leadership to establish better governance. Areas that might initially be considered as "lower hanging fruit"—in that they are urgent but less complex—include strengthening water data and information systems and improving rural sanitation.

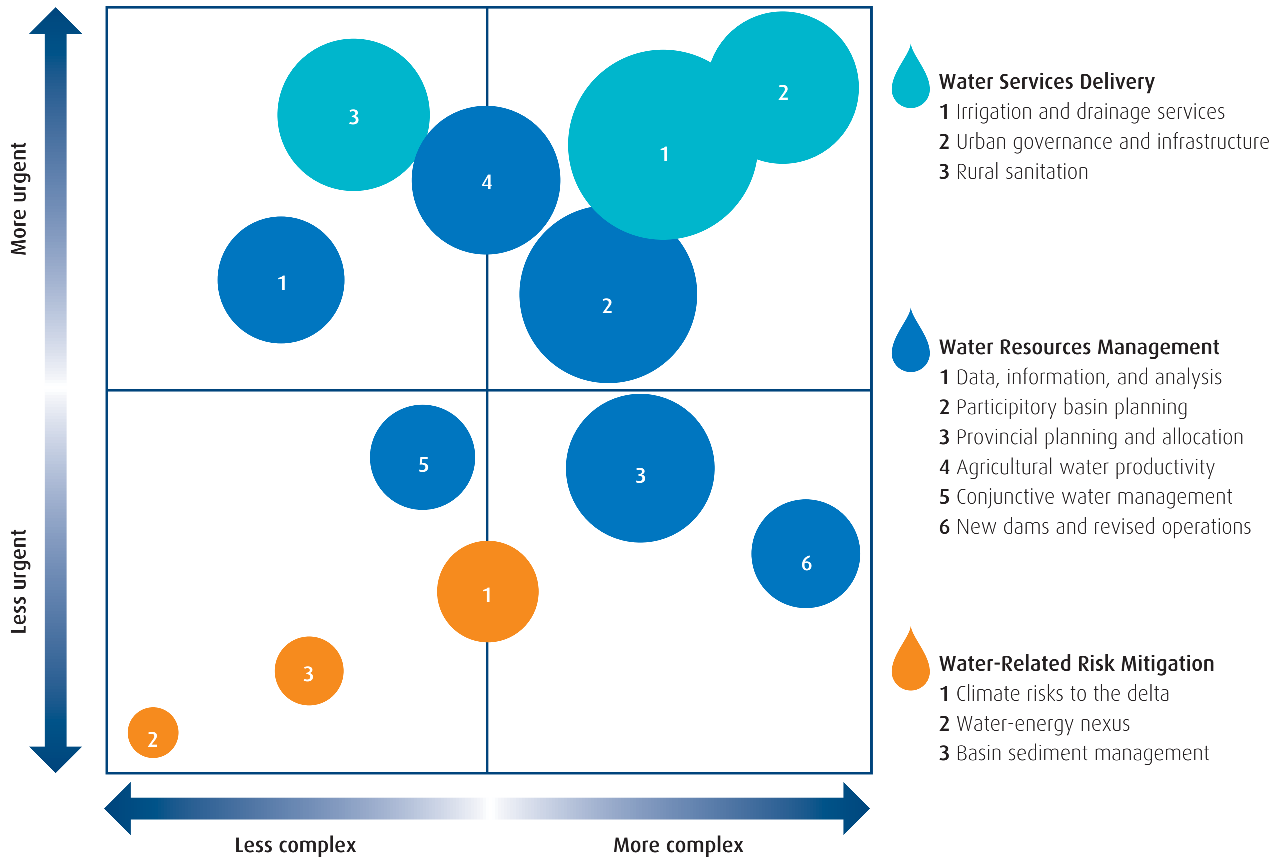
The following section presents each recommendation more fully. The recommended legal, policy, and institutional inventions are summarized, and the required infrastructure investments are presented. The time frames for these interventions are also indicated as follows: (i) short-term, less than five years; (ii) medium-term, five to 15 years; and (iii) long-term, greater than 15 years.

Water Resources Management

Strengthen Water Data, Information, Mapping, Modeling, and Forecasting

Water resources management in Pakistan is constrained by inadequate water data, information, modeling, and analysis. For a country worried about growing water scarcity and the increasing risk of climate change's impact on water resources, there should be a greater emphasis on and investment in sound hydrometeorological monitoring, data management, and analysis, and open sharing of water data and information.

Figure 7.1 Complexity, Urgency, and Scale of Impact of Key Recommendations for Pakistan



Note: Relative scale of impact is indicated by bubble sizes.

Water resource assessments and water accounting need to be improved based on enhanced hydrometeorological monitoring (including for groundwater) and use of Earth observations. This will improve the understanding of natural and induced water losses and the recycling of water in the Indus Basin. Combining Earth observations with traditional monitoring in hydrologic and agro-economic models can guide improved water resource planning and operations at basin, provincial, and subprovincial scales. Better data, analysis, and modeling are required for improved flood risk assessment, planning, and forecasting. Improved data and analysis will be critical for basin planning. Water data need to be openly shared among all stakeholders to build trust between water users and water managers.

Legal Reform

Medium term. Clarify the legal mandates at federal level for water information collation and sharing. Strengthen provincial legal frameworks for land-use planning that considers flood risks.

Policy Reform

Short term. Establish an implementation framework for the National Water Policy (NWP), with clear roles and responsibilities for water data and information. Develop standards and guidelines for flood risk mapping and a policy framework for floodplain zoning.

Institutional Reform

Short term. Strengthen the technical capacity in the Water and Power Development Authority

(WAPDA) and Indus River System Authority (IRSA) for water data management, modeling, and forecasting, including the use of Earth observations. Strengthen technical capacity in provinces, especially for monitoring and reporting water distribution and use. Strengthen the Federal Flood Commission (FFC) capacity for flood risk mapping and flood forecasting. Build capacity in provincial governments for floodplain zoning.

Infrastructure Investment

Short term. Expand national and provincial hydromet networks, including for cryosphere and groundwater monitoring. Establish interoperable national and provincial water information systems.

Establish a Multistakeholder Process of Basin-Scale Water Resources Planning

The highest priority for long-term sustainable water resources management is establishing a multistakeholder process for strategic basin planning. Current water sharing arrangements provide stability, but are not economically optimal, are insufficiently flexible to cope with expected future changes in water demands, and do not adequately embrace environmental sustainability. Basin planning is important for improving interprovincial water sharing, especially to clarify risk sharing arrangements during drought years. Climate change will increase drought severity, and without intervention interprovincial conflicts will escalate. Basin planning helps improve environmental sustainability. The Indus Delta and the health of the lower river system are in rapid decline. Basin planning should prescribe appropriate environmental flows to be delivered and monitored jointly by federal and provincial government agencies. National water planning is focused on major infrastructure and is dominated by federal agencies. A multistakeholder process needs to be established to inform basin planning. This should involve all provinces and a range of nongovernment organizations (NGOs) that represent diverse water users and interest groups.

Legal Reform

Medium term. Establish a sound legal mandate for federally led cooperative basin planning. Strengthen provincial legal frameworks for water resource planning.

Policy Reform

Short term. Establish an implementation framework for the NWP that articulates roles, responsibilities, time frames, and process for basin planning.

Institutional Reform

Establish a national water council, as proposed in the NWP, to provide strategic framing for cross-jurisdictional basin planning. Strengthen the federal government capacity for river basin management (either within IRSA, WAPDA, or by establishing a new authority), that cooperate with provincial governments. Establish consultative processes for effective and broad stakeholder input.

Establish Provincial Water Planning and Intersectoral Water Allocation Mechanisms

Under the umbrella of basin-level planning, there is a need for provincial water resources planning. Planning should consider all water using sectors, integrate across surface water and groundwater, and address economic performance and environmental sustainability. Key to implementing provincial plans will be processes that facilitate intersectoral reallocation of water to meet changing sectoral demands, and mechanisms to improve the efficiency and equity of irrigation water distribution. This will require strengthening of provincial legal frameworks for water resources management and establishing sound provincial water policies. Over the longer term, clear legal property rights should be established for water, separate from land. This would facilitate water trading that can help manage a scarce resource and mitigate the economic impacts of drought. Provincial irrigation departments will need to be incrementally transformed into water resources management agencies. These reforms are not simple and will need to surmount difficult political economy issues. They need to be coupled with large-scale modernization of the irrigation system to greatly enhance hydraulic control and data-driven instrumentation of flows and allocations. Given vulnerability to water-related risks, and the complexity of the water challenges, these reforms are most urgent for Sindh.

Legal Reform

Long term. Establish clear legal property rights (licenses) for water, separate from land, and legal requirements to maintain public register of water licenses.

Policy Reform

Short term. Develop and implement provincial water policies to establish sectoral priorities and to define allocation processes.

Institutional Reform

Medium term. Incrementally transform provincial irrigation departments into water resources management agencies with broad responsibilities including environmental management. Establish robust participatory processes to guide water allocation planning.

Accelerate Increases in Agricultural Water Productivity

Accelerating improvements in water productivity is important for overall economic growth and for growth in the agricultural sector. It can support dietary shifts that improve nutrition. Increasing productivity will require reforming agricultural policies that distort farmer incentives. It should be encouraged by incentives for wider adoption of water efficiency technologies and for diversification toward high-value crops. Investments for value-chain addition of agricultural products and liberalization of the markets for agricultural commodities will contribute to productivity improvements.

Legal Reform

Long term. Scope legal provisions to support pricing and trading of water rights.

Policy Reform

Short term. Phase out subsidies for wheat and sugarcane. Liberalize agricultural commodity markets. Support adoption of water efficiency technologies and diversification to higher-value crops.

Institutional Reform

Short term. Strengthen capacity for economic modeling within federal and provincial governments. Improve on-farm water management through farmer training and awareness raising. Introduce lower water use methods of rice cultivation. Increase investment in agricultural research.

Adopt Conjunctive Planning and Management of Surface Water and Groundwater

Given the growing problems of groundwater depletion in some areas and waterlogging and salinization in others, there is a big opportunity to adopt active conjunctive planning and management of surface water and groundwater. While this needs to be coordinated at the provincial level, planning and implementation should happen at the district level. Conjunctive use can improve climate resilience by using the storage capacity of aquifers. It can improve equity of water access, water use efficiency, and water productivity. This will require new regulatory frameworks to clarify the legal basis for groundwater access, and the legal responsibility and authority for groundwater regulation. It will also require capacity building within provincial government agencies and support to water user associations and farmer organizations to facilitate implementation of conjunctive plans.

Legal Reform

Short term. Establish provincial-level regulatory frameworks for groundwater access and for management and regulation.

Policy Reform

Short term. Develop conjunctive water management plans at the district level that focus on building drought resilience.

Institutional Reform

Short term. Strengthen the capacity of provincial water resources management departments for groundwater management and conjunctive planning. Strengthen water user associations (WUAs) for local-scale monitoring and management of groundwater resources in line with agreed conjunctive water management plans. Build capacity of the Pakistan Council of Research in Water Resources (PCRWR) for basin-scale modeling and analysis of surface water–groundwater interactions.

Construct Limited New Storage and Review Reservoir Operations

A widely held view is that water management in Pakistan is greatly constrained by inadequate storage. The evidence does not support this view. Given the current low productivity of water in Pakistan, it is not possible to justify expensive major storages on the economics of irrigation alone. Nonetheless, sedimentation reduces existing live storage, and climate change will increase flow variability, making it more difficult to match supply and demand. Multipurpose reservoirs, which can be economically justified by hydropower, should be constructed. These will help to manage increasing flood risks and help to improve the reliability of rabi irrigation supply. Diamer Bhasha, upstream of Tarbela, will reduce the sediment load to Tarbela, thus extending its life.

The operating procedures for Tarbela and Mangla should be subject to periodic review. Changing demand patterns and flood regimes, the opportunity to better manage sediment loads, and the increasing important of delivering a manage environmental flow regime mean revised operating procedures are probably required to better balance across these multiple objectives. A detailed modeling and optimization analysis should be undertaken to explore alternative operating procedures under historical and potential future inflow regimes.

Policy Reform

Short term. Review and revise reservoir standard operating procedures, based on detailed modeling and analysis.

Institutional Reform

Short term. Strengthen capacity at WAPDA and IRSA to enable periodic reviews of operating procedures and to support a multi-objective approach to operations.

Infrastructure Investment

Medium term. Secure financing for construction of Diamer Bhasha Dam and associated power generation and distribution infrastructure.

Water Supply Service Delivery

Modernize Irrigation and Drainage and Improve Operations

The quality of irrigation and drainage services across Pakistan is generally very low. This keeps farmer incomes low and retards improvement in water productivity. The hydraulic efficiency of water distribution is very low, and service delivery is not equitable across command areas. Irrigation services are not financially sustainable and financial performance is declining. Service tariffs are set too low and are decoupled from service quality. The operational costs of service providers are far too high.

Improving irrigation service delivery will require multiple interventions, including infrastructure investment, policy, and institutional reform and strengthening. These should be underpinned by more comprehensive provincial legal frameworks that clarify the hierarchy of roles and responsibilities in irrigation service delivery. Irrigation networks should be modernized, including rehabilitation of canals and distributaries, and installation of improved hydraulic control structures with flow monitoring and automation. Water allocation processes within command areas need to be updated to improve economic efficiency and to increase transparency and equity. Farmers should have clarity and certainty about the reliability of water supply. Provincial government agencies should gradually reduce the number of low-skilled field-level support staff. These low-level functions should initially be devolved to WUAs and farmer organizations, but increasingly replaced by increasing automation of water delivery.

These reforms will require confronting difficult political economy issues relating to land ownership, water access, wealth and political power. Given the sale and complexity of the surface water irrigation in the Indus, this modernization and associated reform are daunting and will need to be progressed incrementally. Realistic implementation plans should be established in each province, considering capacity and finance constraints.

Legal Reform

Medium term. Revise provincial irrigation and drainage authority (PIDA) legislation to clarify roles and responsibilities in irrigation management between PIDAs and provincial government departments.

Policy Reform

Short term. Replace *warabandi* with new water sharing rules based on economic efficiency and farmer equity. Reform *abiana* to reflect realistic operation and maintenance (O&M) costs.

Institutional Reform

Medium term. Strengthen the capacity of new provincial government water resources management departments to oversee PIDAs and performance of WUA and farmer organizations. Strengthen WUAs for improved system operation and improved abiana collection. Reform WUA and farmer organization governance to prevent elite capture.

Infrastructure Investments

Medium term. Modernize irrigation system, including new hydraulic control structures and lining of canals in waterlogged and saline areas. Automate control of hydraulic structures using real-time data acquisition systems. Systematically improve drainage infrastructure.

Reform Urban Water Governance and Close Infrastructure Gap

Urban water supply service delivery is not keeping up with the pace of urbanization. Poor quality, declining coverage, and inequity in urban water supply service delivery signal an urgent need to reform the sector and to increase investment. Current policy frameworks should be rationalized and simplified to clarify institutional roles and responsibilities. This will help improve efficiency and accountability in service delivery. Public utilities need to be continually strengthened across many aspects of performance. Tariff structures need to be reformed and collection enforced. An enabling environment should be created to involve private sector operators in infrastructure and service provision. Stronger coordination is required between public land owning and service delivery agencies to link service delivery to urban planning.

Major infrastructure investment is required, especially for wastewater treatment. This is critical to address widespread environmental pollution and public health impacts from untreated effluent. Greatly improved O&M of bulk water delivery systems and sewerage networks is required. Improving urban service delivery will require confronting difficult political economy constraints, because some powerful individuals benefit from the status quo.

Legal Reform

Medium term. Establish legal mandate for regulatory oversight of urban water supply service provider performance. Strengthen the regulatory framework for pollution discharges.

Policy Reform

Short term. Rationalize overlaps in the provincial policy frameworks and align with the Local Government Act (2015). Develop and disseminate standards for urban water supply service delivery and link service tariff increases to service quality.

Institutional Reform

Medium term. Strengthen and empower urban water supply service providers. Establish independent regulators to oversee service provider performance and to help reduce political interference. Establish an enabling environment for increasing private sector participation in the urban water supply sector.

Infrastructure Investment

Medium term. Greatly increase the capacity and performance of wastewater treatment. Improve O&M of existing major distribution infrastructure. Increase the coverage and reliability of urban water meters.

Improve Rural Sanitation

Rural sanitation services in Pakistan are inadequate. Poor rural sanitation contaminates water supplies with widespread public health and quality of life consequences, especially for women and children. Poor sanitation contributes to poor childhood development, cognition, education, and ultimately labor force productivity. Rural sanitation suffers from a huge public infrastructure gap, inadequate financing, and an absence of reliable revenue streams to cover O&M costs. Improving rural sanitation will also require increased public awareness and behavior change in rural communities.

Legal Reform

Medium term. Establish clear legal mandate for the provision of rural sanitation services.

Policy Reform

Short term. Establish provincial standards and targets for rural sanitation services.

Institutional Reform

Medium term. Strengthen the capacity and increase the financing of provincial government departments responsible for rural sanitation. Establish appropriate district-level institutional arrangements to engage with communities in infrastructure improvement. Establish appropriate mechanisms to ensure sustainable revenue base for O&M costs. Monitor and report progress toward rural sanitation targets.

Infrastructure Investment

Short term. Invest in public infrastructure for rural sanitation services, including wastewater collection and basic treatment and disposal at the village level.

Water-Related Risk Mitigation

Improve Understanding and Management of Climate Risks to the Lower Indus and Delta

There are several large, growing and unmitigated risks to the sustainability of the Lower Indus and its delta. Sea level rise and more intense coastal storms will increasingly threaten coastal Sindh and Balochistan. Declining end-of-system flows in the Indus and groundwater salinization are additional pressures. A better understanding of the multiple threats to the sustainability and productivity of the delta and lower basin, especially those associated with climate change, is urgently required. This can guide long-term cross-sectoral planning and mitigation and rehabilitation efforts. The technical and economic feasibility of barrier wells to slow saltwater intrusion should be investigated.

Policy Reform

Medium term. Develop long-term plans for sustainable management of the Indus Delta.

Institutional Reform

Medium term. Strengthen the technical capacity of water and environmental management agencies in Sindh for climate change impact assessments and mitigation planning. Resource relevant agencies for effective implementation of management plans.

Infrastructure Investment

Medium term. Assess the feasibility of barrier groundwater wells to slow seawater intrusion.

Strengthen Planning and Management of Water-Energy Interactions

The water-energy nexus presents important risks to both sectors. This nexus is not well addressed in policy and planning. Many energy sector policies and investments have had, and will continue to have, impacts on the water sector. Careful consideration of trade-offs and synergies is required through broader economic analyses and cooperation between water and energy policy agencies at federal and provincial levels.

Legal Reform

Short term. Establish provincial-level regulatory frameworks for groundwater access and management.

Policy Reform

Short term. Analyze the synergies and antagonisms between current national energy and water policy frameworks to inform policy implementation.

Institutional Reform

Short term. Increase coordination between government departments at federal and provincial levels. Strengthen capacity for joint energy-water analysis that considers economic and environmental outcomes.

Infrastructure Investment

Medium term. Expand solar and wind power investment where sensible. Explore feasibility for small-scale hydro on irrigation canals. Continue major hydroelectric power investment with run-of-river focus.

Improve Understanding and Management of Basin-Scale Sediment Dynamics

Basin-scale sediment management requires much more attention. Sediment sourcing, transport, and deposition are not well monitored or studied, but have been greatly modified by water resources development, affecting the safety and performance of water infrastructure, and contributing to the decline of the lower river and delta. Better monitoring is required to guide the development of intervention strategies and the operation of water infrastructure. Additional investment in sediment control measures in the Upper Indus Basin is recommended.

Policy Reform

Medium term. Develop a management plan to guide long-term, basin-scale sediment management.

Institutional Reform

Short term. Strengthen capacity in relevant technical institutions for multiple aspects of sediment monitoring, modeling, and analysis.

Infrastructure Investment

Short term. Ensure that new reservoir designs and barrage rehabilitation projects consider sediment-related risks to structural safety and operational performance.

APPENDIX A

Pakistan Water Balance Data Sources

Table A.1 Indus Basin Water Balance

Component	Value (BCM)	Uncertainty level	Data source, reference, remarks
River water balance			
Inflows			
Indus, Jhelum, Chenab inflows	170	Low (±5%)	Mean rim station inflows, 1922–2016 (WAPDA). Indus at Kalabagh (including Kabul); Jhelum at Mangla; Chenab at Marala.
Ravi, Sutlej, Beas inflows	3	Moderate (±10–20%)	While no water is allocated to Pakistan under the Indus Waters Treaty from these tributaries, this value is the combined mean annual average gauged inflow since 2000 when Ranjit Sagar Dam was completed in India.
Internal inflows	32	High (±>20%)	FAO (2011) value for total internal national resource (runoff plus recharge) less (i) the internal resources for the Makran and Kharan drainage units, and (ii) rainfall recharge estimate for the Indus (Pakistan) from van Steenbergen and Gohar (2005).
Total	**205**		
Outflows			
Withdrawal minus returns	103	Moderate (±10–20%)	Gauged canal withdrawals, 1977–2016 value (125) less the return flow estimate from Karimi et al. (2013). The return flow has not been not adjusted for the saline drainage fraction.
River and flood recharge to groundwater	4	High (±>20%)	Estimate from Laghari, Vanham, and Rauch (2012).

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Table A.1 continued

Component	Value (BCM)	Uncertainty level	Data source, reference, remarks
Natural losses (evapotranspiration)	68	High (±>20%)	Water balance closure term. Includes flood waters escaping to floodplains and evapotranspiration of wetlands, delta, riparian vegetation and open water evaporation.
Kotri outflow	30	Low (±5%)	Gauged average at Kotri Barrage, 1975–2016.
Total	**205**		
Groundwater balance			
Inflows			
Rainfall recharge	13	High (±>20%)	Estimate from van Steenbergen and Gohar (2005).
Canal recharge	27	Moderate (±10–20%)	Estimate from Ahmad and Rashida (2001). Equivalent to ~22% of withdrawals.
Irrigation recharge (includes saline)	17	High (±>20%)	Estimate from Karimi et al. (2013). This value includes losses at the watercourse level.
River and flood recharge	4	High (±>20%)	Estimate from Laghari, Vanham, and Rauch (2012).
Groundwater depletion	1	Moderate (±10–20%)	Water balance closure term. Consistent with MacDonald et al. (2016).
Total	**62**		
Outflows			
Withdrawal	62	Moderate (±10–20%)	FAO (2011).
Total	**62**		
Withdrawal balance			
Inflows			
Surface water (withdrawal minus leakage)	98	Moderate (±10–20%)	Gauged canal withdrawals, 1977–2016 value, less leakage estimate from Laghari, Vanham, and Rauch (2012).
Groundwater withdrawal	62	Moderate (±10–20%)	FAO (2011).
Total	**160**		
Outflows			
Consumptive use	80	Moderate (±10–20%)	Modeled crop water use consumption from IFPRI CGE-W. Includes some field-level evaporation associated with crop growth.
Evaporative loss	41	High (±>20%)	Water balance closure term.
Irrigation recharge (includes saline)	17	High (±>20%)	Estimate from Karimi et al. (2013). This value includes losses at the watercourse level.
Return flow	22	High (±>20%)	Flow estimate from Karimi et al. (2013). Return flow has not been not adjusted for the saline drainage fraction.
Total	**160**		

Note: BCM = billion cubic meters; CGE = computable general equilibrium; IFPRI = International Food Policy Research Institute.

Table A.2 Makran Coast Water Balance

Component	Value (BCM)	Uncertainty level	Data source, reference, remarks
River water balance			
Inflows			
Internal inflows	5.50	Moderate (±10–20%)	Halcrow Group (2007).
Total	**5.50**		
Outflows			
Withdrawals	1.20	High (±>20%)	Halcrow Group (2007).
Natural losses	2.00	High (±>20%)	Water balance closure estimate.
Outflow	2.30	High (±>20%)	Water balance closure estimate.
Total	**5.50**		
Groundwater balance			
Inflows			
Rainfall recharge	0.74	Moderate (±10–20%)	Halcrow Group (2007).
Total	**0.74**		
Outflows			
Withdrawal	0.69	Moderate (±10–20%)	Halcrow Group (2007).
Environmental use, loss	0.05	Moderate (±10–20%)	Water balance closure term.
Total	**0.74**		
Withdrawal balance			
Inflows			
Surface water (withdrawal minus leakage)	1.20	Moderate (±10–20%)	Halcrow Group (2007).
Groundwater withdrawal	0.69	Moderate (±10–20%)	Halcrow Group (2007).
Total	**1.89**		
Outflows			
Consumptive use	1.20	High (±>20%)	Water balance closure estimate.
Evaporative loss	0.69	High (±>20%)	Water balance closure estimate.
Total	**1.89**		

Table A.3 Kharan Desert Water Balance

Component	Value (BCM)	Uncertainty level	Data source, reference, remarks
River water balance			
Inflows			
Internal inflows	2.90	Moderate (±10–20%)	Halcrow Group (2007).
Total	**2.90**		
Outflows			
Withdrawals	0.50	High (± >20%)	Halcrow Group (2007).
Natural losses	1.20	High (±>20%)	Water balance closure estimate.
Outflow	1.20	High (±>20%)	Water balance closure estimate.
Total	**2.90**		
Groundwater balance			
Inflows			
Rainfall recharge	0.56	High (±>20%)	Halcrow Group (2007).

table continues next page

Table A.3 continued

Component	Value (BCM)	Uncertainty level	Data source, reference, remarks
Irrigation recharge, groundwater depletion	0.24	High (±>20%)	Water balance closure term.
Total	**0.80**		
Outflows			
Withdrawal	0.80	Moderate (±10–20%)	Halcrow Group (2007).
Total	**0.80**		
Withdrawal balance			
Inflows			
Surface water (withdrawal minus leakage)	0.50	Moderate (±10–20%)	Halcrow Group (2007).
Groundwater withdrawal	0.80	Moderate (±10–20%)	Halcrow Group (2007).
Total	**1.30**		
Outflows			
Consumptive use	0.68	High (±>20%)	Water balance closure estimate.
Evaporative loss	0.50	High (±>20%)	Water balance closure estimate.
Irrigation recharge	0.12	High (±>20%)	Estimated, assuming similar percentage of withdrawals as for Indus.
Total	**1.30**		

Note: BCM = billion cubic meters.

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APPENDIX B

Legal Framework for Water Resources

Introduction

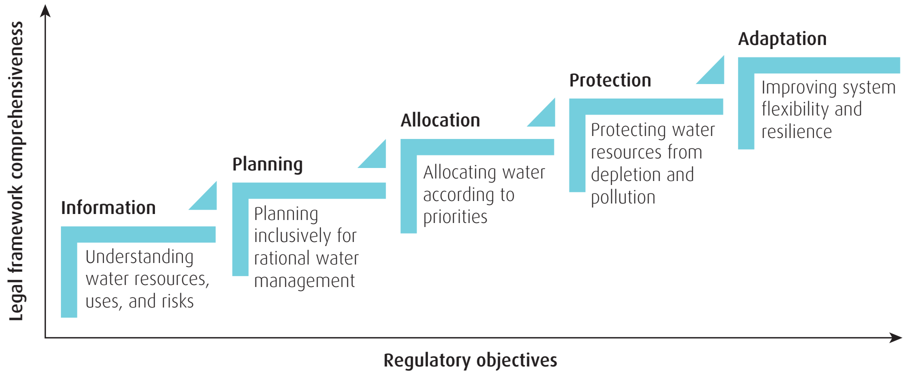
This appendix summarizes the current content of the national and provincial laws and regulations in Pakistan, which can be used to support the management of water resources. It is not a detailed legislative assessment informed by inputs from local experts; rather, it assesses the presence or absence of basic "legal elements" for water resources management, and compares the Pakistan legal framework to that of other countries. This summary may provide a foundation for the critical review of the legal framework called for in sec. 27 of the Pakistan National Water Policy (2018).

A legal element is a provision in a law or regulation that contributes to one or more policy objectives. For example, a legal element could establish a mandate for an organization to monitor the quality and quantity of water resources. A legal element for this purpose may look different from a legal element for a similar purpose in a different country or province given differing contexts. This assessment identifies only whether specific elements are in place, not whether they are being applied, or if so, how effectively. The assessments are aggregated into proxy indicators of the comprehensiveness of the legal framework, which highlight provinces that have adopted similar or different approaches.

Five components of water resources management, and thus regulatory objectives, are used for assessing the legal framework and for aggregation (figure B.1): (i) *information*, or understanding water resources, uses, and risks; (ii) *planning* inclusively for rational water management; (iii) *allocation* of water according to agreed priorities; (iv) *protection* of water resources from overexploitation and pollution; and (e) *adaptation* to enhance system resilience. As indicated in figure B.1, these five objectives represent a maturing sequence of water resources management. The assessment considers the presence or absence of 48 specific legal elements relevant to these five components.

The assessment commences with a consideration of national functions and arrangements. It then considers the legal framework that supports the five components of water resources management, noting that in a federal system, relevant legal elements may be either national or provincial, depending on how the Constitution specifies areas of competence. In a federal system, certain legal elements are particularly important for policy coordination and for the management of river basins that cross provincial boundaries.

Figure B.1 Hierarchy of Regulatory Objectives for Water Resources Management in Pakistan



National Level

Chapter 4 provides an overview of relevant constitutional matters and key national legislation; details of the legislation can be accessed using the website URLs listed in table B.1.

In federal systems, legal provisions relevant for water resources management are typically distributed across the provincial and national levels, with wide scope for customization. However, national attention is important in these federal systems, among others: national policy and planning for water resources; flood management; and management of transboundary water (international and interprovincial).

A legal basis for national policy and planning exists in Pakistan but is scattered and often implicit in broad or indirect provisions. The 2018 National Water Policy (NWP) in 2018 derives from amendments of 2017 to the 1973 Rules of Business of the executive authority. Under the Rules of Business—which allocate functions within entities of the executive authority—the Ministry of Water Resources has the broad remit of "matters related to the development of water resources of the country." This reasonably encompasses national water policy and planning but is not a direct legal mandate. Similarly, under the Constitution, the Council of Common Interests has competence for policy making on groundwater and hydropower development, matters covered by the Water and Power Development Authority Act. One function of the Pakistan Council of Research in Water Resources (PCRWR) is to provide the government with policy advice on the development, management, conservation, and utilization of water resources. The federal institutional and policy arrangements therefore provide adequate scope for national water policy and planning, but no clear legal mandates are established for these functions.

The legal basis for flood management nationally is not clearly anchored in constitutional provisions or primary or secondary legislation. The primary basis is long-standing agency practice that developed in response to devastating floods. Flood management is the responsibility of the Federal Flood Commission (FFC), an agency housed in the federal Ministry of Water Resources. Following a series of major

Table B.1 Links to National Legislation Relevant to Water Resources Management in Pakistan

Legislation	Enacted	Last amended
Penal Code, Act XLV	1860	2016
Easements Act	1882	1960
Water and Power Development Authority Act	1958	1998
Constitution of the Islamic Republic of Pakistan	1973	2015
Water Apportionment Accord	1991	1991
Indus River System Authority Act	1992	1992
Environmental Protection Act	1997	1997
Indus River System Authority (Amendment) Ordinance	1998	1998
Statutory Notification 1033 (1)98	1998	1998
Water and Power Development Authority (Amendment) Ordinance	1998	1998
Indus River System Authority (Amendment) Ordinance	2000	2000
Indus River System Authority (Chairman and Members Conditions of Service) Rules	2000	2000
IRSA Regulations	2000	2000
Council of Research in Water Resources Act	2007	2007
IRSA Regulation for Issuance of NOC and Water Utilization Cess for Hydel Power Projects/Power Projects Requiring Use of Water	2010	2010

Note: IRSA = Indus River System Authority; NOC = No Objection Certificate.

floods, the FFC was established in 1977 based on an interprovincial agreement confirmed by resolution. FFC's institutional functions are summarized by the Ministry of Water Resources as national flood protection planning, "scrutiny" of flood control and protection schemes funded by the federal government, review of flood damage, improving flood forecasting and warning systems, researching floods, standardizing and recommending designs, and evaluating progress under plans. Research on flood mitigation has a stronger legal basis because it has been allocated as a function of the PCRWR. Pakistan has a reasonably comprehensive set of functions for flood protection and management, but the legal framework provides only partial support to these functions and does not define clear legal mandates for many of these functions.

The legal basis for interprovincial water management is stronger and clearer. The Constitution provides a mechanism for resolution of disputes on water allocation between provinces, and water allocation between provinces is supported by the powers and duties allocated to Indus River System Authority (IRSA) under the Indus River System Authority Act (1992). This gives IRSA broad powers to "lay down the basis for the regulation and distribution of surface waters amongst the Provinces according to the allocations and policies spelt out in the Water Accord." However, there is very limited legal support for broader aspects of water resources management that go beyond the question of interprovincial water shares.

For international transboundary water management, there is a reasonably clear yet limited legal foundation. Under the Constitution, international treaties such as the 1960 Indus Waters Treaty fall under the competence of the federal government. The 2017 amendments to the 1973 Rules of Business of the executive authority list the Indus Waters Treaty and general liaison with international engineering organizations in the water sector within the scope of activities of the Ministry of Water Resources. Thus, transboundary water management has a clear federal scope, but direct legal mandates for these functions are limited.

Legal Frameworks Applicable to the Provinces

The legal framework relevant for each province includes the laws and regulations of that province, overlain by relevant national provisions (table B.2). Of the 48 specific legal elements examined, only 27 are present across all provinces, and only 16 to 19 of the 48 are found for any one province. Hence there is significant room for strengthening of the legal frameworks.

Table B.2 Presence or Absence of Key Legal Elements in Pakistan's Provincial Legal Frameworks for Five Areas of Water Resources Management

	Balochistan	Khyber Pakhtunkhwa	Punjab	Sindh
A. Information: understanding water resources, uses, and risks				
Water resource inventory	N	N+P	N+P	N+P
Inventory, updating	a	a	a	P
Inventory, public availability	a	a	P	P
Water user registry	P	P	P	P
Registry, public availability	a	a	P	P
Monitoring planning	a	a	a	a
Monitoring plan updating	a	a	a	a
Monitoring	P	P	P	P
Monitoring results, public availability	P	a	a	P
Pollutant discharge information	a	a	a	a
B. Planning: planning inclusively for rational water management				
Water resource planning	N	N	N+P	N+P
Plan components	P	a	a	a
Plan public consultation	a	a	a	a
Plan updating	a	a	a	a
Binding nature of plans	a	a	a	a

table continues next page

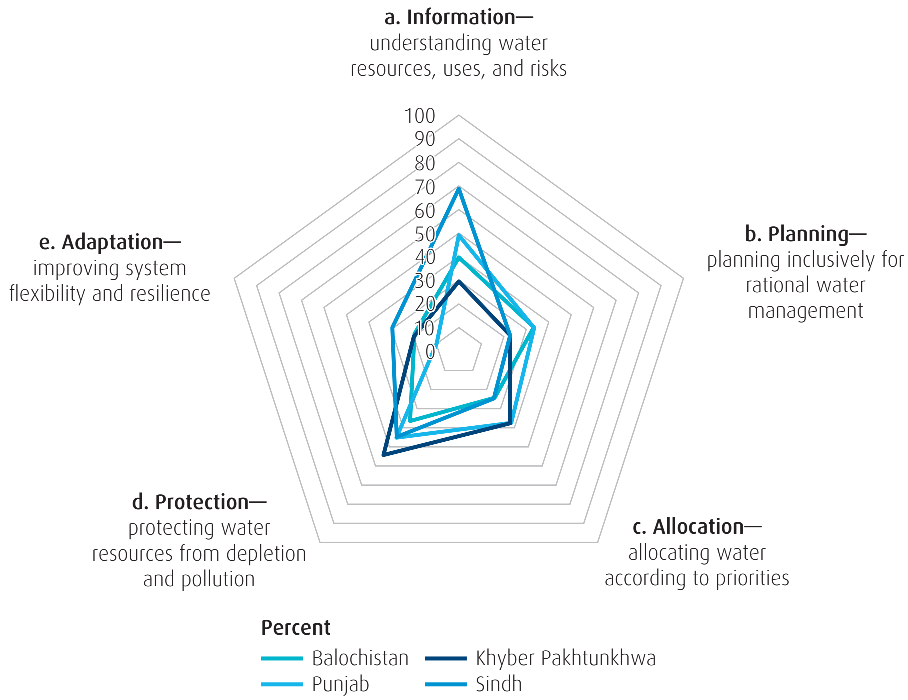
Table B.2 continued

	Balochistan	Khyber Pakhtunkhwa	Punjab	Sindh
Water resource quality criteria	a	a	a	a
Water quality objectives	a	a	a	a
Water user representation	N+P	N+P	N+P	N+P
Women representation	a	a	P	a
C. Allocation: allocating water according to priorities				
Priority orders	a	a	a	a
Water abstraction permits, rights	P	P	P	P
Abstraction permits, rights procedures	a	a	a	a
Abstraction permits, rights duration	a	a	a	P
Abstraction permits, rights renewal	a	a	a	a
Predecision public notice	P	P	P	a
Predecision public notice duration	a	P	P	a
Predecision public notice means	a	a	a	a
D. Protection: protecting water resources from depletion and pollution				
Special measures	a	a	a	P
Reserve flows	a	a	a	a
User recordkeeping	a	a	a	a
Setbacks	a	P	a	a
Discharge restrictions	P	P	P	P
Nonpoint source pollution	a	a	a	a
Discharge permit procedures	a	a	a	a
Inspection mandate	a	P	P	a
Inspection powers	P	P	P	P
Offenses	N+P	N+P	N+P	N+P
Penalties	N+P	N+P	N+P	N+P
E. Adaptation: improving system flexibility and resilience				
Conservation	P	P	a	a
Efficiency	P	P	P	a
Obligation to pay resource charges	a	a	a	a
Mandate to set resource charges	a	a	a	a
Calculation of resource charges	a	a	a	a
Mandate to collect resource charges	a	a	a	a
Permits, rights transfers	a	a	a	P
Transfer separate from land	a	a	a	P
Transfer notification	a	a	a	P
Transfer procedure	a	a	a	a

Note: a = absent; N = national laws only; N+P = national and provincial laws; P = provincial laws only.

Provinces' legal frameworks are similar, but there are differing strengths and weaknesses (figure B.2). The legal frameworks of Sindh and Punjab are more comprehensive in provisions to support water information systems, because both include elements for water resource inventories and water user registries. Both legal frameworks also contain provisions to support public access to inventory and registry information. In contrast, Balochistan does not require the creation of a water resource inventory.

Figure B.2 Share of Completeness of Provincial Legal Frameworks in Pakistan



Source: Author analysis.

All four provinces have relatively sparse legal frameworks for water resources planning. The Khyber Pakhtunkhwa (KP) legal framework contains no supporting provisions. The legal framework of Sindh has an anchor provision in the Sindh Water Management Ordinance to support water resources planning, but supporting legal elements for planning are missing. Similarly, in Punjab, there is a basic provision in the Punjab Canal and Drainage Act for water resource planning, but no specific legal elements to support this.

None of the provinces have adequate legal frameworks to support implementation of a modern permit system for water use (even for high-volume water users), and none have the full legal foundations to support advanced features such as water resource pricing or formal transfers of water between water users. For water resources protection, the KP legal framework is relatively comprehensive compared to other provinces, thanks to provisions in KP Rivers Protection Ordinance, the KP Integrated Water Resources Management Board Ordinance, and the KP Canal and Drainage Act. Sindh has special measures in the case of water shortage in the Sindh Water Management Ordinance; however, detailed legal provisions to support water quality management are largely lacking across in all provinces.

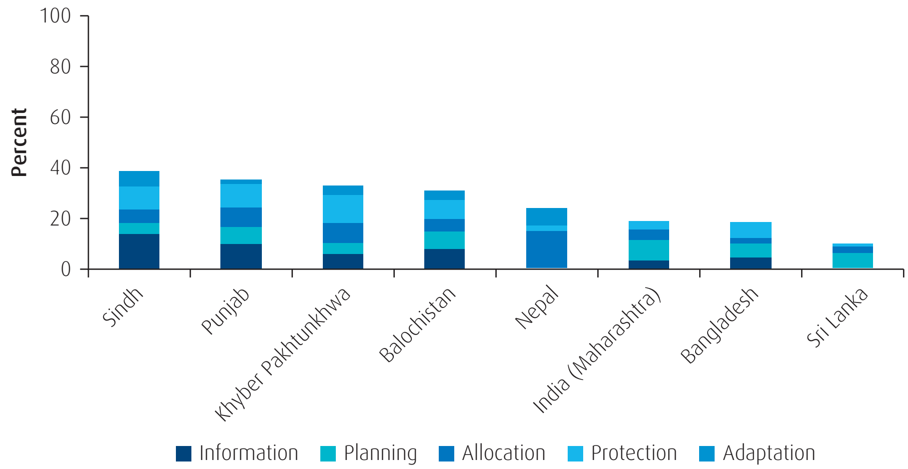
The legal frameworks for water resources management in Pakistan's provinces are generally more comprehensive than elsewhere in South Asia (figure B.3). They are less comprehensive than the global average, however, particularly for water resources planning, water quality management, water allocation, and support for water pricing and water transfers. Pakistan is one of the world's most irrigation-dependent and water-stressed countries. Global comparisons (figure B.4) reveal that many of the most water-stressed countries also have weak legal frameworks, suggesting that the inadequate legal frameworks have contributed to reaching this level of water stress, but also suggesting that dealing with these challenges will be more difficult with legal reform.

From a national wealth perspective, Pakistan legal frameworks for water resources management are not exceptional. Many countries have less complete legal frameworks, but many have more comprehensive frameworks, particularly in Central Asia and Sub-Saharan Africa (figure B.5).

Legal Framework for Groundwater Management

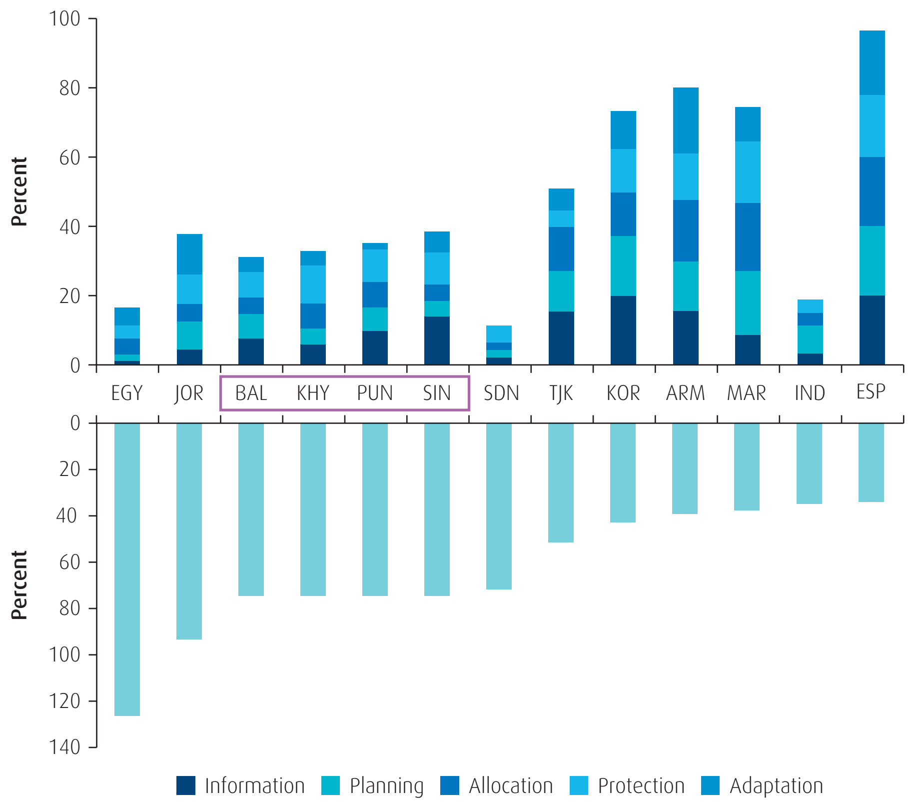
Groundwater management has received relatively little attention in the development of Pakistan's federal and provincial legal frameworks. Historically, groundwater use was left largely uncontrolled and unregulated under the common law principle of capture. Similar provisions from the colonial era are within the

Figure B.3 Comparison of Completeness of Legal Frameworks for Water Resources Management across Pakistani Provinces and South Asian Countries



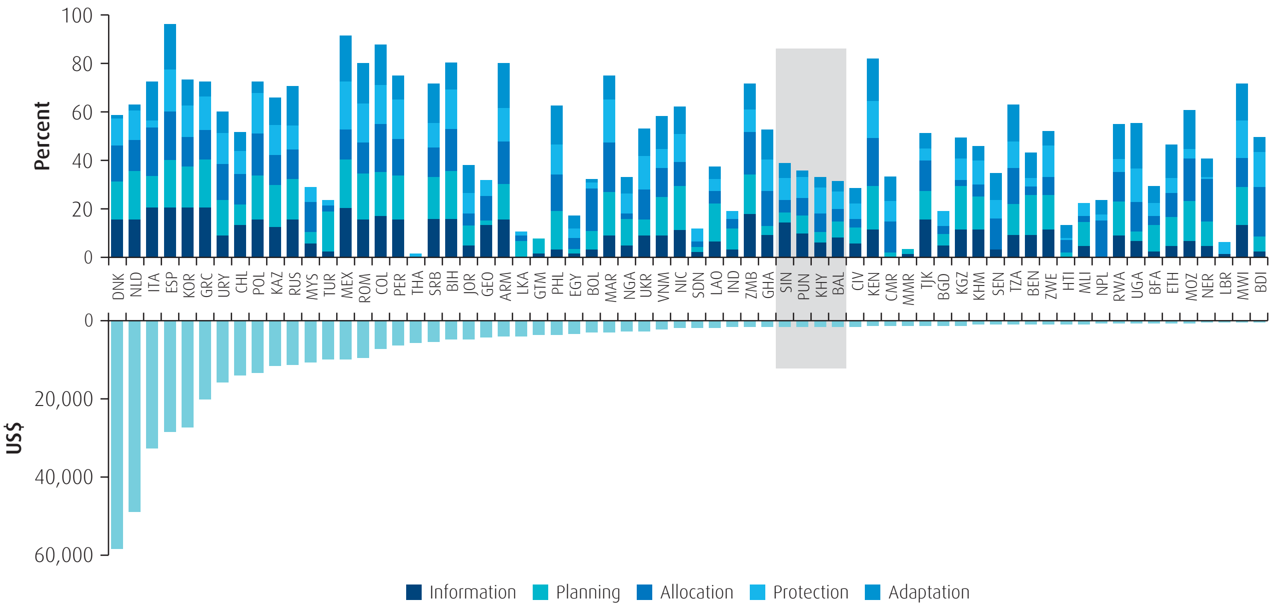
Source: Author analysis.

Figure B.4 Completeness of Legal Frameworks for Water Resources Management in Pakistani Provinces and Comparator Countries, and Level of Water Stress Given as Withdrawals as Share of Total Renewable Resource



Source: World Bank, eba.worldbank.org.
Note: Pakistan province abbreviations: BAL = Balochistan; KHY = Khyber Pakhtunkhwa; PUN = Punjab; SIN = Sindh. For ISO country codes see https://unstats.un.org/unsd/tradekb/knowledgebase/country-code.

Figure B.5 Comparison of Completeness of Legal Frameworks for Water Resources Management in Pakistani Provinces, Countries for which Similar Assessments Exist, and GNI per Capita



Source: World Bank, eba.worldbank.org.
Note: GNI = gross national income. Pakistan province abbreviations (box highlight): BAL = Balochistan; KHY = Khyber Pakhtunkhwa; PUN = Punjab; SIN = Sindh. For ISO country codes see https://unstats.un.org/unsd/tradekb/knowledgebase/country-code.

Figure B.6 Evolution of Provincial Legal Frameworks in Pakistan

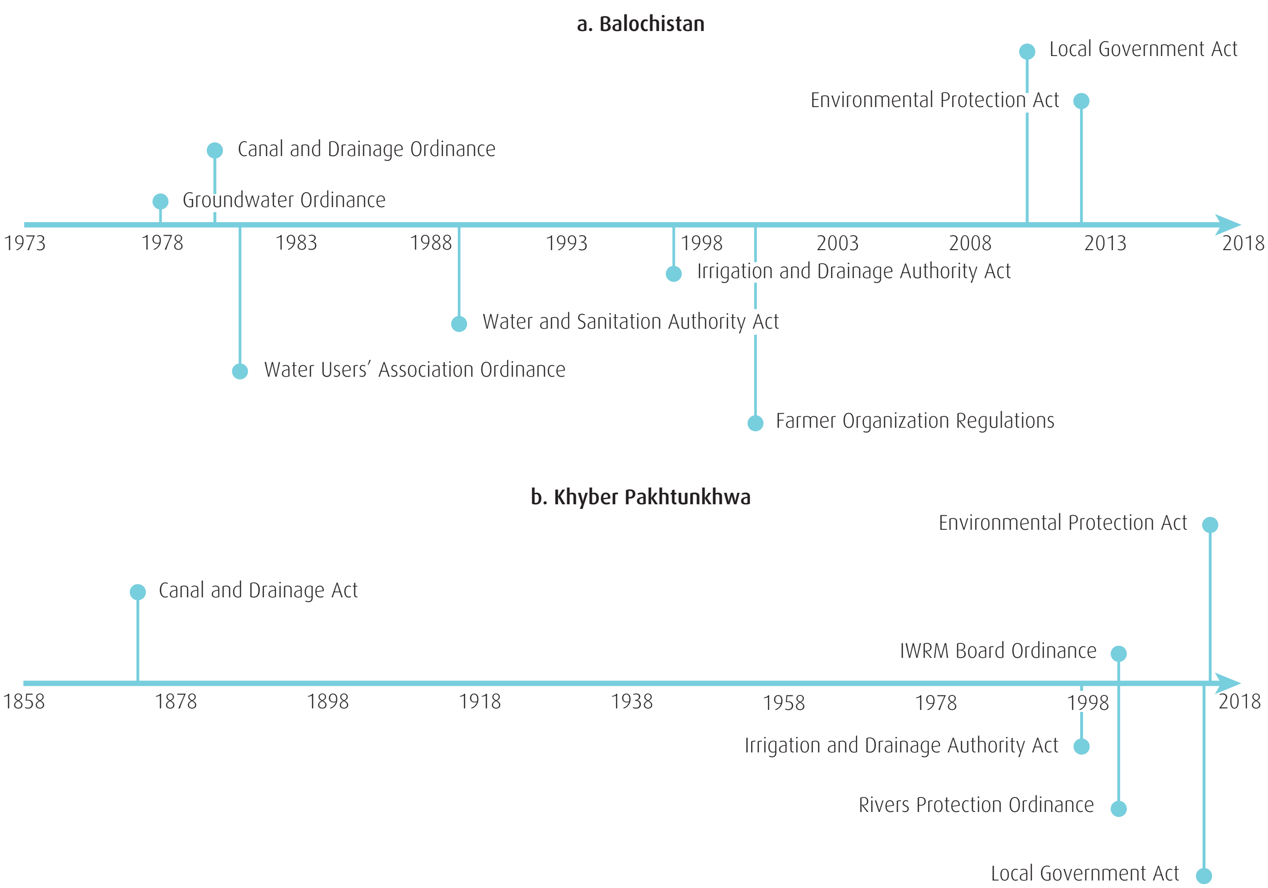


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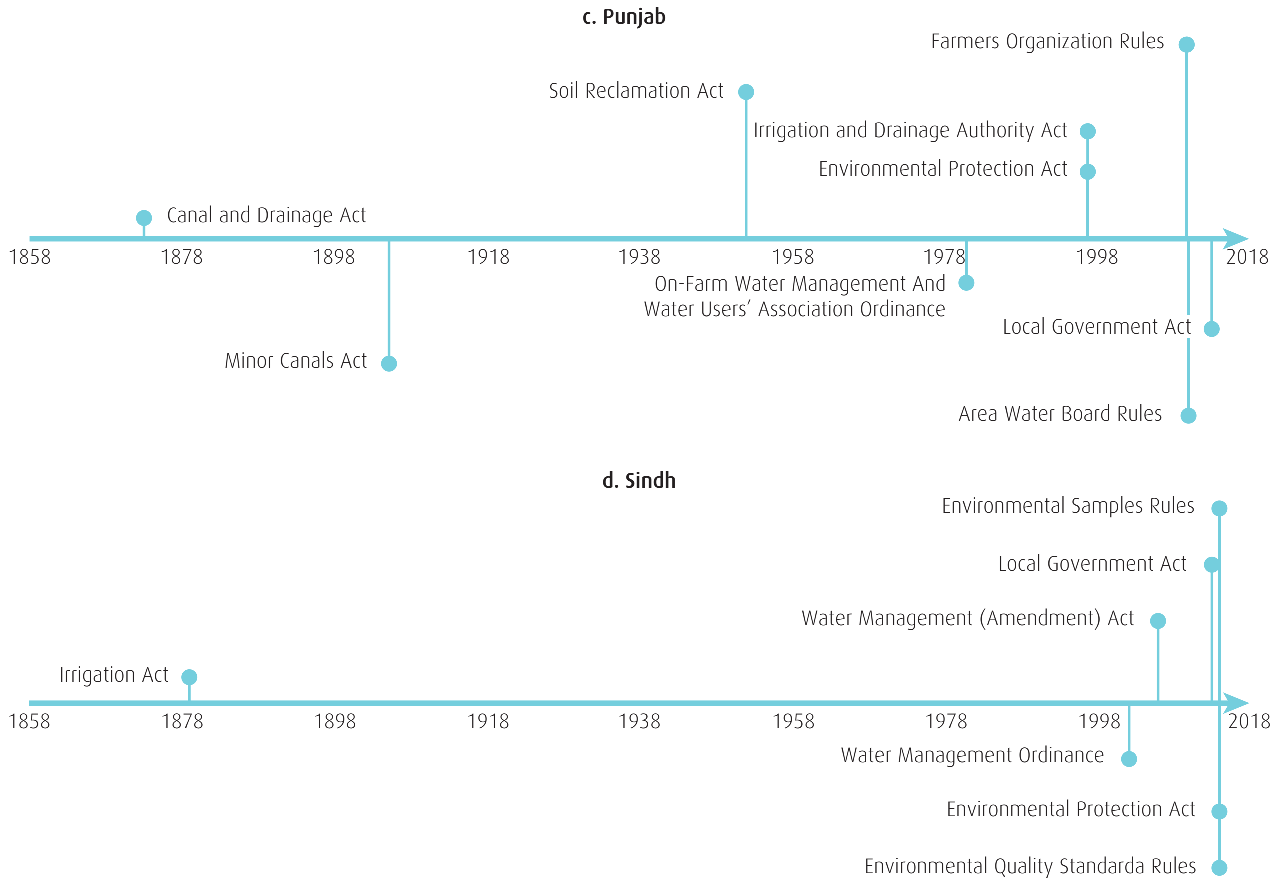
Figure B.6 continued



Note: IWRM = Integrated Water Resources Management.

Table B.3 Links to Provincial Legislation in Pakistan

Balochistan	Enacted	Last amended
Balochistan Irrigation and Drainage Authority Act	1997	1997
Balochistan Ground Water Rights Administration Ordinance	1978	2001
Balochistan Canal and Drainage Ordinance (not currently online)	1980	2006
Balochistan Water Users Association Ordinance (not currently online)	1981	1981
Balochistan Water and Sanitation Authority Act	1989	1989
Balochistan Community Irrigation Farmer Organization Regulations	2000	2000
Balochistan Local Government Act	2010	2010
Balochistan Environment Protection Act	2012	2012
Khyber Pakhtunkhwa		
Khyber Pakhtunkhwa Canal and Drainage Act	1873	2015
Khyber Pakhtunkhwa Irrigation and Drainage Authority Act	1997	1997
Khyber Pakhtunkhwa Integrated Water Resources Management Board Ordinance	2002	2002
Khyber Pakhtunkhwa Rivers Protection Ordinance	2002	2002
Khyber Pakhtunkhwa Local Government Act	2013	2013
Khyber Pakhtunkhwa Environmental Protection Act	2014	2014

table continues next page

Table B.3 continued

Punjab	Enacted	Last amended
Punjab Canal and Drainage Act, Act VIII	1873	2016
Punjab Minor Canals Act	1905	2003
Punjab Soil Reclamation Act	1952	1977
Punjab On-Farm Water Management and Water Users' Association Ordinance	1981	1981
Punjab Environmental Protection Act	1997	2012
Punjab Irrigation and Drainage Authority Act	1997	2014
Punjab Local Government Act	2013	2017
Punjab Irrigation and Drainage Authority (Area Water Boards) Rules	2010	2010
Punjab Irrigation and Drainage Authority (Farmers Organizations) Rules	2010	2010
Sindh		
Sindh Irrigation Act	1879	2012
Sindh Water Management Ordinance	2002	2006
Sindh Irrigation and Drainage Authority Financial Regulations and Powers	2003	2003
Sindh Local Government Act	2013	2015
Sindh Environmental Protection Act	2014	2014
Sindh Environmental Quality Standards (Self-Monitoring and Reporting by Industry) Rules	2014	2014
Sindh Environmental Samples Rules	2014	2014

Easements Act (1882), which allow landowners to withdraw unlimited groundwater from below their property, as long as there is no malice or waste. Since then, there have been limited attempts to introduce legal provisions to support the active management of groundwater, which are uneven across the provinces.

The Pakistan Water and Power Development Authority (WAPDA) Act (1958) provides a limited legal foundation for groundwater control and management across the country, but its chapeau includes a hedge against other in-force provisions, and any efforts by WAPDA would require the provincial agreement. This provision does not appear to have been used by WAPDA, leaving groundwater management largely to the provinces. However, few provinces have introduced provisions to replace the Easements Act guidance on groundwater and provide a robust foundation sustainable management and regulation of groundwater resources.

In Punjab, the provisions of the Easements Act have been partially supplanted by provisions that empower public authorities to manage groundwater, including sec. 26 of the Punjab Soil Reclamation Act (1952, as amended), sec. 62A of the Punjab Canal and Drainage Act (1873, as amended in 2006). In Balochistan, the legal foundations for groundwater management and regulation include sec. 12(e) and sec. 14 of the Balochistan Water and Sanitation Authority Act (1989) and sec. 3 and sec. 4 of the Balochistan Groundwater Rights Administration Ordinance (1979). Neither Sindh nor KP have explicit legal provisions for groundwater; in these provinces groundwater is subject to relevant common law and the Easements Act (1882).

Pakistan needs to establish a clear legal mandate for the groundwater management and regulation, whether at the provincial or national level. This would sensibly be supported by legal provisions that establish a mandate to develop a stronger information base on available groundwater and current extractions, to incorporate groundwater in water resources planning (as Punjab has introduced), and to establish powers to introduce controls for at least major extractions (as Balochistan has introduced).

APPENDIX C

Summary of WSTF Priority Actions

No.	Action, subaction	Objectives	Primary responsibility	Timeline	Indicative financing (US$, millions)
1	**Major infrastructure and associated institutions**				
1.1	Rehabilitation of three major barrages	System sustainability	Provincial irrigation departments (PIDs)	2012–16	400
1.2	Bhasha Dam in Jammu and Kashmir	Hydropower and irrigation	Water and Power Development Authority (WAPDA)	2011–20	12,000
1.3	Kurram Tangi, Munda, Dasu, Kohala, Golen Gol, Bunji	Flood control and hydropower	WAPDA	2011–20	14,000
1.4	Indus River System Authority (IRSA) reforms	Increase transparency and predictability, and reduce conflict	IRSA	2012–13	3
1.5	Revenue-sharing framework	Enhance equity and project acceptance	Ministry of Water and Power (MOWP)	2012–13	1
1.6	Resettlement framework and capacity	Enhance equity and project acceptance	WAPDA	2012–13	2
1.7	Environmental flows in the delta	Sustainability and equity	IRSA, Sindh Province	2012–13	150

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No.	Action, subaction	Objectives	Primary responsibility	Timeline	Indicative financing (US$, millions)
2	**Raising agricultural productivity**				
2.1	On-farm water management	Increase agricultural productivity	Provincial agriculture departments, Jammu and Kashmir, Federally Administered Tribal Areas (FATA)	2012–16	560
2.2	Public-private partnerships (PPPs) for small dams	Increase agricultural productivity	PID and agriculture departments, Jammu and Kashmir, FATA	2012–16	460
2.3	Improved management of main canals	Increase agricultural productivity	PIDs	2012–16	500
2.4	Spate irrigation	Increase agricultural productivity	Provincial agricultural departments, FATA	2012–16	300
2.5	Optimal but judicious use of groundwater	Sustainable productivity	Provincial agricultural departments, FATA	2012–16	100
3	**Living better with floods**				
3.1	Construction on new dams (see priority area 1)	Reducing flood peaks	WAPDA	2012–2020	Included in priority area 1
3.2	Long-term institutional development by partnership with a successful organization (e.g., Mississippi River Commission)	Capacity building	FFC (Federal Flood Commission) and the provinces	2012–16	20
3.3	Key elements of the National Flood Protection Plan IV, including floodplain zoning and enforcement; early warning systems; community-based disaster risk management; flood protection infrastructure	Pre-, during, and postflood management	FFC, Pakistan Meteorological Department (PMD), federal and provincial disaster management agencies, Jammu and Kashmir, FATA and provincial governments	2012–16	500
3.4	Some federal and provincial actions, including asset management plans, and rehabilitation and maintenance of existing infrastructure and new construction	Rehabilitation and maintenance of flood protection schemes (including spurs and bunds), estimated at US$500 million by the FFC	Provinces, Jammu and Kashmir, FATA	2012–16	500–600
3.5	Watershed management in Jammu and Kashmir, and Khyber Pakhtunkhwa (KP)	Reduce severity of hill floods and reduce erosion	Federal government, Jammu and Kashmir and KP	2012–16	50
4	**Sustainable urban services**				
4.1	Automatic tariff revision	Improve financial sustainability	Provincial governments and WASAs	2012	No cost action
4.2	Start reducing nonrevenue water (NRW) in 20 utilities	Improve service quality and financial sustainability	WASAs	2012–16	5
4.3	Defining groundwater entitlements and regulating groundwater abstraction	Secure resource base	Provincial governments	2012–16	10

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No.	Action, subaction	Objectives	Primary responsibility	Timeline	Indicative financing (US$, millions)
4.4	Punjab Municipal Water Act	Model for urban water reform	Provincial governments	2012–16	4
4.5	Save Quetta Ground Water	Help secure the future of Quetta	Government of Balochistan	2012–16	40
4.6	Finance “wedge” to get to sustainability	Sustainable services	Provincial governments	2012–16	35 (for one large city)
4.7	Infrastructure for quality water services if they reform	Service quality	Provincial governments	2012–16	250–700 (per large city)
4.8	Pilot industrial pollution control projects	Environmental health	Provincial governments	2012–16	50 (per city)
5	**Knowledge management**				
5.1	Partnership with an institution (e.g., eWater) to develop the architecture and culture which produces integrated, demand driven knowledge product	Consistent knowledge base for operations at different levels	MOWP, FFC, IRSA, WAPDA, PIDs	2012–16	30
5.2	An operational simulation model for the Indus Basin	Management and investment decisions	WAPDA with PIDs	2012–16	20
5.3	Knowledge base for groundwater management	Sustainability and productivity	MOWP, PIDs, FATA, Space and Upper Atmosphere Research Commission (SUPARCO)	2012–16	20
5.4	Other decision support systems for data sharing, canal, assets management, and managing climate change	Operation of the 1991 Indus Water Accord and infrastructure, improved water productivity	PMD, IRSA, WAPDA, SUPARCO, PIDAs (provincial irrigation and drainage authorities), and PIDs	2012–16	30
5.5	Capacity building for management and research	Developing capacity	Higher Education Commission (HEC), MOWP, Ministry of Science and Technology, standing committees of the National Assembly and Senate on water and energy, universities and research institutions	2012–16	15

Source: FoDP 2012.

Reference

FoDP (Friends of Democratic Pakistan). 2012. *A Productive and Water-Secure Pakistan: Infrastructure, Institutions, Strategy*. Islamabad, Pakistan: Water Sector Task Force, FoDP. http://metameta.nl/wp-content/uploads/2013/11/FoDP-WSTF-Report-Final-09-29-12.pdf.

APPENDIX D

CGE Modeling Approach and Assumptions

This appendix summarizes the model and modeling approach used for the consideration of water security futures. Reference to and results from previous water modeling efforts in the Indus Basin (Robinson and Gueneau 2014; Yu et al. 2013) are made, with differences in analytical approaches explained.

Modeling Framework

The simulations for future water security (chapter 7) were run using the International Food Policy Research Institute's (IFPRI's) Computable General Equilibrium–Water (CGE-W) model (Robinson and Gueneau 2014), based on the most recent version of the IFPRI standard CGE model (Lofgren, Harris, and Robinson 2002). Several CGEs exist for Pakistan including GEMPAK,[1] PEP,[2] and GTAP[3]; these are reviewed by Robinson and Gueneau (2014). These CGEs have been used for trade analyses, gender evaluations, and climate change impacts on agriculture, among other topics. The CGE-W however, is the only model that interfaces with a detailed water model that includes water demand, water routing, and water stress modules.

The CGE-W model consists of an annual economywide CGE, a water demand module, a water basin management model (the Regional Water System Model for Pakistan [RWSM]), a water allocation model that allocates available water to crops based on the impact of water stress on crop yields and crop values (water allocation and stress model [WASM]), and a hydropower module (not used in this study). The water models all use a monthly time step. In this study historical monthly precipitation and river inflows are used as hydrologic input to the water modules. All the component models are coded in the General Algebraic Model System (GAMS), which allows for integrated solution of the suite of models.

CGE Model

The IFPRI CGE for Pakistan links consumers, producers, and government entities through production, consumption, trade, and taxes. A Social Accounting Matrix (SAM) connects the financial flows between these actors for the base year (2013–14). Households receive income from wages paid by producers, from owned assets and remittances abroad, and through government transfers. Households buy goods from domestic producers and international imports. Producers sell to domestic entities and exports. Households and producers pay taxes to the government, which purchases goods and services, and makes transfers (including subsidies) to actors in the economy. The model includes agricultural information to represent the effects of water shocks on the economy—as well as disaggregated labor and household categories—needed to capture the distributional impacts of policy choices.

The CGE includes 64 activities: 17 in agriculture, 34 in industry, and 13 in services; for a detailed description see Saeed (2017). The agricultural sector in the models includes 12 crops (rainfed wheat, irrigated wheat, basmati rice, irri rice, cotton, sugarcane, and other field crops and vegetables or horticulture) in three regions (Sindh Province; Punjab Province; and the rest of Pakistan). Rainfed agriculture is included only for Punjab. Industrial activities include eight food processing activities (e.g., meat, dairy, oils and fats, grain milling of wheat and rice, and sugar refining) among others. Raw cotton production is transformed into cotton lint, yarn, cloth, knitwear, garments, and other textiles, all of which are sold domestically and as exports (these are the country's primary exports). These production activities use various inputs, two major ones being land and labor, with land considered as an input only for agriculture. Land is categorized into small, medium, and large rainfed parcels growing only wheat, and small, medium, and large irrigated farms. Labor is also disaggregated: family workers are separately identified for small, medium, and large farms, with the labor in the smaller farms separated across regions because they are assumed to be less mobile. The model considers agricultural wage workers and nonagricultural unskilled and skilled workers.

The model uses 18 household groups. Farm household cohorts are defined by size and location, and nonfarm households are split into income quartiles. Farm households are represented as small, medium, or large holders, for Punjab province or all other provinces (six cohorts). Nonfarm households are represented as rural landless agricultural households, rural nonfarm households, and urban households, with income quartiles for each category (12 cohorts). Household demand is estimated using a linear expenditure system that relates expenditure on a commodity to total household expenditure for a household group. Expenditures grow with income from wages, investments, transfers from the government, and remittances. Full formal model specification is provided in Lofgren et al. (2001). The model uses elasticity values that define the percentage change in consumption of a commodity resulting from an increase in household expenditure. The elasticity values have a large impact on scenario outcomes. The elasticity values used for RUMI-Hi and RUMI-Hi-Diet are given in table D.1 for farm households and in table D.2 for nonfarm rural and urban households.

Table D.1 Farm Household Expenditure Elasticities by Farm Size for RUMI Hi and RUMI Hi-Diet in Pakistan

Commodity	RUMI-Hi			RUMI-Hi-Diet		
	Small farms	Medium farms	Large farms	Small farms	Medium farms	Large farms
Food consumption elasticities						
Wheat flour	0.69	0.52	0.43	0.62	0.44	0.47
Rice	1.02	0.69	0.69	0.62	0.44	0.47
Refined sugar	1.02	0.86	0.69	0.62	0.44	0.47
Vegetable oil	1.02	1.04	0.69	1.04	0.44	0.47
Potato	1.11	1.04	0.92	0.62	0.65	0.71
Meat	1.02	0.69	0.92	1.04	0.87	0.95
Dairy	1.02	0.69	0.92	1.04	0.87	0.95
Food away	1.02	1.30	1.38	1.56	1.63	1.78
Selected manufactured goods elasticities						
Garments	1.02	1.04	1.38	1.14	0.98	0.83
Appliances	1.02	1.30	1.38	1.35	1.41	1.54
Selected services elasticities						
Transport	1.02	1.04	1.38	1.25	1.31	1.42
Dwellings	1.02	1.04	1.38	1.56	1.63	1.78
Education	1.02	1.30	1.38	1.56	1.63	1.78
Health	1.02	1.04	1.38	1.56	1.63	1.78

Source: IFPRI data.
Note: RUMI = Reaching upper-middle-income; Diet = changed consumption.

Table D.2 Rural Nonfarm and Urban Expenditure Elasticities for Reaching Upper-Middle Income-Hi and Upper-Middle Income-Hi-Diet for Income Quartiles in Pakistan

Commodity	RUMI-Hi				RUMI-Hi-Diet			
	RNF (Q1)	RNF (Q4)	Urban (Q2)	Urban (Q4)	RNF (Q1)	RNF (Q4)	Urban (Q2)	Urban (Q4)
Food consumption elasticities								
Wheat flour	0.71	0.39	0.53	0.39	0.65	0.41	0.62	0.40
Rice	1.05	0.63	0.71	0.62	0.65	0.41	0.62	0.40
Refined sugar	1.05	0.63	0.88	0.62	0.65	0.41	0.62	0.40
Vegetable oil	1.05	0.63	1.06	0.62	1.09	0.41	1.03	0.40
Potato	1.14	0.84	1.06	0.83	0.65	0.62	0.62	0.60
Meat	1.05	0.84	0.71	0.83	1.09	0.82	1.03	0.79
Dairy	1.05	0.84	0.71	0.83	1.09	0.82	1.03	0.79
Food away	1.05	1.26	1.33	1.24	1.63	1.54	1.55	1.49
Selected manufactured goods elasticities								
Garments	1.05	1.26	1.06	1.24	1.20	0.72	0.93	0.69
Appliances	1.05	1.26	1.33	1.24	1.41	1.33	1.34	1.29
Selected services elasticities								
Transport	1.05	1.26	1.06	1.24	1.31	1.23	1.24	1.19
Dwellings	1.05	1.26	1.06	1.24	1.63	1.54	1.55	1.49
Education	1.05	1.26	1.33	1.24	1.63	1.54	1.55	1.49
Health	1.05	1.26	1.06	1.24	1.63	1.54	1.55	1.49

Source: IFPRI data.
Note: Q = income quartile; RUMI = Reaching upper-middle-income; RNF = rural nonfarm; Diet = changed consumption.

RWSM

The RWSM closely follows the Indus Basin Model Revised (IBMR), most recently summarized by Yang et al. (2013) and Yu et al (2013). It models the nine main rivers of the Indus Basin that flow through Pakistan and provide irrigation water (from east to west: Sutlej, Ravi, Chenab, Jhelum, Soan, Indus, Swat, Kabul, and Haro) as well as the main Indus Basin dams (Tarbela, Mangla, Chasma, and Chotiari). Water is routed through 47 nodes of the Indus system in Pakistan, including reservoirs, link canals, and barrages. Inflows, precipitations, runoff, and crop water need data are generated externally by a climate model downscaled to Pakistan using historic data. Routing takes into account river routing time, reservoir evaporation, and link canal capacity. The model disaggregates the 45 main irrigation canals of the Pakistan Indus basin into 12 agro-economic areas, based on provinces and crops grown. Four of these zones are in Sindh; five, in Punjab; two, in Khyber Pakhtunkhwa (KP); and one, in Balochistan. Three other zones cover the rest of Pakistan, in Punjab, Balochistan, and KP, respectively. The water balance is broadly similar to that of the IBMR, although groundwater is more complete in the latest version of the IBMR.

The RWSM assumes nonirrigation water (other than Karachi) is drawn solely from groundwater. The IBMR maximizes the sum of producer and consumer surplus in agriculture by zone and does not have trade, government, or nonagricultural sectors. The CGE-W, therefore, is more appropriate given the interest in nonagricultural water security in groundwater pumping is allowed only in nonsaline groundwater areas (each zone is disaggregated into fresh and saline areas), and an annual cap of 62 billion cubic meters is imposed on abstractions (as per Briscoe and Qamar [2005] and Yu et al. [2013]). The model does not consider the water resources of the Makran Coast or the Kharan Desert hydrological units in Balochistan.

CGE-W Balance

The coupled water system model considers the water resources of the Indus Basin of Pakistan—both surface water and groundwater. The CGE-W uses the 2013/14 value of 182.3 billion cubic meters as the average annual inflows at the Indus rim stations; this is higher than the current annual average inflow of 173.8 billion cubic meters reported in chapter 2, which reflects the reduced inflows in the eastern rivers in recent years. Although the CGE-W value is thus arguably too high, it is appropriate for future scenarios over the next three decades, given the expected small increase in inflows with increased glacial melt. Notably, however, water withdrawals, delivery efficiencies, and crop water use largely drive model performance.

Average annual canal withdrawals in the CGE-W are 128.9 billion cubic meters, which is the value cited by SBP (2017) for the period 1975–2015; the value of 122 billion cubic meters cited in chapter 2 is based on Food and Agriculture Organization (FAO) AQUASTAT reporting based on data to 2008. For groundwater, the CGE-W uses the base year groundwater demand of 39.5 billion cubic meters for agriculture and an estimated 11.7 billion cubic meters for nonagricultural demand from Habib and Amir (2015). The CGE-W also includes green water, which provides a supply of 46.9 billion cubic meters from precipitation to agriculture.

Water availability at the field level is considerably less than the aggregate withdrawals because of losses from the canal and watercourse, especially seepage to groundwater. In addition, some losses of groundwater reflecting tube well inefficiencies are captured in the model. The losses assumed in the CGE-W water balances are summarized in table D.3.

Solving CGE-W Model

The CGE-W is solved dynamically in a two-step procedure each year (figure D.1). First, the economic model is solved for a given year assuming exogenous trends on various parameters, which provides projected outputs by sector and allocation of land to various crops. Expected water stress is set to the average of the previous three years, which creates harvest expectations and a resulting allocation of land to different crops. The model is dynamic in that it steps through time after being solved for the base year (2013–14). Each following year is solved independently after bringing lagged values forward (such as exchange rate or international prices) and adjustments to important parameters, such as productivity levels in different sectors. This permits an evaluation of trends coming from different assumptions on exogenous factors.

The shock due to water stress is defined as the ratio of crop yields for the current year compared to the base year yield. The base year data define the equilibrium of the water system in 2013–14 under an average weather pattern. In the first CGE run for each year, the external water shock anticipated by farmers is assumed to be the average of the four previous years, so farmers anticipate a short-term moving average level of water stress; this allows for some adaptation. The CGE then solves for irrigated and rainfed crop areas based on these expectations.

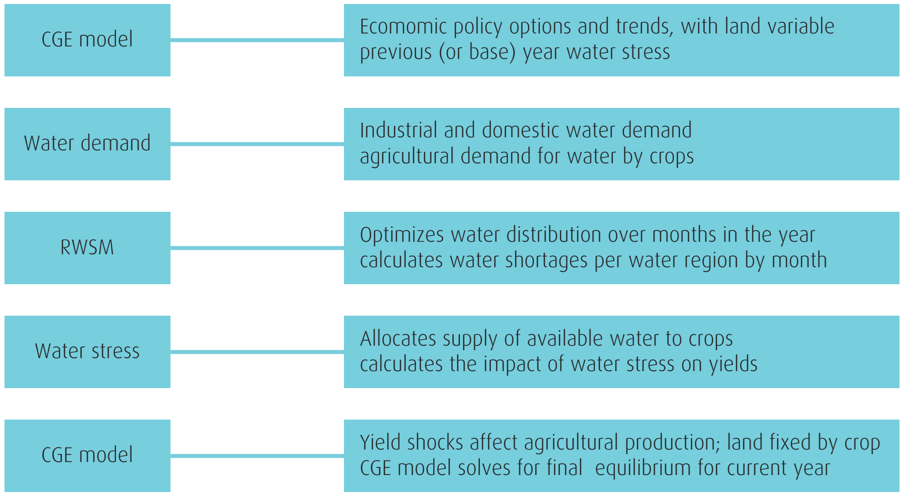
After the first CGE run, the Water Demand module calculates water demand for crops, industry, households, and livestock. Industrial water demand, for a given agroecological zone and month, varies in proportion to the square root of industrial gross domestic product (GDP), livestock demand varies with the square root of livestock GDP, and household demand varies with the square root of aggregate household expenditures. These demands, therefore, increase more slowly than economic output, reflecting some efficiencies and economies of scale. These three

Table D.3 Key Average Annual Water Balance Terms for the CGE-W Model in Pakistan
billion cubic meters

Water balance term	Value	Sources and comments
Canal withdrawals (a)	128.9	Source: SBP (2016)
Surface water losses to field level (b)	70.4	Losses in canals and watercourses
Surface water at field level (a–b)	58.5	
Groundwater pumped for agricultural use (c)	39.5	Modeled groundwater irrigation demand for base year
Groundwater pumped for nonagricultural use (d)	11.7	Habib and Amir (2016)
Groundwater irrigation tube well losses (e)	5.5	Estimated at 14%
Field-level evaporation and drainage losses (f)	12.9	Estimated at 14%
Groundwater pumped (c+d)	55.2	75 percent from canal/watercourse seepage
Groundwater at field level (c–e)	34.0	
Field-level total water availability (a–b+c–e)	92.5	
Field-level crop water consumption (a–b+c–e–f)	79.6	

Note: CGE-W = Computable General Equilibrium–Water.

Figure D.1 Sequence of Modeling in the Linked CGE-W Framework



Source: Robinson and Gueneau 2014.
Note: CGE-W = Computable General Equilibrium–Water; RWSM = Regional Water System Model.

demands are combined and are met from available groundwater prior to meeting irrigation demands. The water demand for irrigation, summed across all crop types, is a function of the areal irrigation demand for a crop minus the soil moisture in a given month, multiplied by the area of the crop for a given agroecological zone. Nonagricultural demands are met first. Water is then allocated across canals, regions, and crops using the routing model in RWSM and in a manner to minimize water stress in WASM.

RWSM uses the computed water demands, along historical inflows and climate parameters, to partition water among crops and regions each month, given the objective function to maximize the value of production in a risk-averse manner. WASM then allocates water among crops in an area, given the economic value of the crop. Because optimizing the total value of production given fixed prices leads to excessive specialization in high-value crops, a measure of risk aversion for farmers is included in the objective function, which preserves a diversified production structure even in case of drought. The stress model produces a measure of yield stress for every crop, irrigated and rainfed, in each agroecological zone; these are aggregated to the provincial level to match the regions in the CGE model.

Finally, new yield shocks are calculated and applied to the CGE, which is solved a second time for the final equilibrium, assuming allocation of land to crops is fixed since farmers cannot change their cropping decisions after planting. This solution yields all economic variables, including quantities and prices of outputs and inputs, and all income flows. The process then moves to the next year, updates parameters on trends, and starts calculations again.

CGE-W Assumptions

The objective of the economic modeling in this study is to examine how basic drivers of change (population growth, changing consumption preferences, climate change) affect water-related economic outcomes. The focus is on broad changes across water and food demand patterns and productivity growth. Commodity, household, and taxation options are not considered, because these would require more in-depth examination of specific policies.

Several important assumptions are made in each simulation. On the demand side, preferences are set outside the model as elasticities that vary by household type, but do not vary between years. Household expenditures within a simulation are determined as a function of prices of goods and family income. On the supply side, production is affected by the external choice of productivity growth for each commodity, as are growth rates for key inputs (such as land and labor). Population is not considered in the model directly, but it is captured as growth in the labor force. Household expenditures are made on behalf of nonworking family members, so they are captured in the model's economic outcomes. With these choices, the model solves for supply, wages are paid so households receive incomes, and profits are earned by businesses that invest and save.

Domestic prices are determined by interactions of supply and demand, and prices guide many of the outcomes in expenditures, production, and water use. International export and import prices remain fixed in these simulations, except under one scenario of policy and trade change. However, model outcomes are sensitive to changes in prices, especially when a commodity has a high proportion that is imported or exported. Because labor needs to be pulled from other industries, or consumers need to make substantial changes, the structure of the economy is somewhat resistant to change. However, when products have large trade positions, their reactions can be large and driven by changes in international prices relative to domestic ones. In the base year for these simulations, textiles and rice have large trade positions.

Critical to these simulations is the growth in household, industrial, and livestock water demands, which the model meets from groundwater supply before meeting irrigation demands. Specifically, the water required by industry (including livestock) is affected by the level of industrial and services output, so the faster the economy grows, with greater industrial and services activities, the more water is required. Likewise, domestic demand is driven by household expenditures, so, with greater GDP per capita, more water is used for domestic purposes. As temperatures have been rising historically, the baseline model includes a rise of 1 degree Celsius over the simulation period (an increase of 5 percent in evaporation levels), which is the low end of the range estimated by Amir and Habib (2015). Volumetrically, this increase primarily affects crop water demand.

The water resources situation is fixed across all simulations, using a sequence of inflows based on the historical pattern. However, to avoid implying an end-of-scenario decline, and to explore recovery from severe drought, the historical sequence was rearranged to place the sequence containing the worst drought on record (years 2000–14) in the middle of the simulation period. The sequence of historical flows used as input to the 34-year simulations modeling is thus: 1975–88 (14 years), 1999–2008 (10 years), and 1989–98 (10 years).

Thus, while dynamic, the model should not be considered as providing forecasts, but rather as providing quantitative comparisons between scenarios with different assumptions about key variables such as temperature, productivity performance, and trade. Economic recovery from shocks is quicker in the model than in reality, because changes in asset values and their impact on consumption and production are not included. Similarly, if the government enters an International Monetary Fund (IMF) program, the model does not account for debt consequences and exogenous effects. The model prevents dramatic transformations in the structure of the economy. Although urban household incomes rise faster than rural ones, and thus urban household expenditures rise faster to become a larger fraction of the economy, economic structure can change only as fast as labor can shift between sectors, which is constrained by the many interactions across the economy.

Comparisons with Prior Economic Modeling

Yu et al. (2013), Yang et al. (2013), Robinson and Gueneau (2014), and Davies et al. (2016a, 2016b) use either a CGE or the IBMR to investigate issues relating to water resources given climate change and population growth, including food security implications and economic growth. To address these topics, the economic benefits and costs of the following interventions were investigated: (i) improved watercourse efficiency, (ii) water trading between provinces, (iii) additional storage, and (iv) improved timing of water delivery. There are differences in emphasis, however, because the IBMR does not include hydropower, and Yu et al. (2013) do not integrate the CGE with the hydrological model. The latter integration has been done by Robinson and Gueneau (2014) and has been used in Davies et al. (2016a, 2016b), as well as in the current analysis.

The results from all simulations show that improvements in watercourse efficiency add significant benefits to GDP (around 2 percent relative to a base simulation, and higher in water scarce years) (Davies et al. 2016a). For other interventions, there is less agreement from the modeling. The value of new storage is much lower in Yu et al. (2013) than in the CGE modeling because of the inclusion of hydropower. In Davies et al. (2016a), climate change scenarios reduce GDP by up to 1.25 percent, but additional storage under climate change increases GDP up to 0.5 percent; this almost 2 percent differential is similar to the benefits from enhancing watercourse efficiency. Additional storage reduces the economic costs of shortfalls in water supply during drought years. Hence in Davies et al. (2016a) a forecasted drought year sees a GDP drop of nearly 4 percent, but only 2 percent with the Diamer Bhasha Dam in place.

The IBMR (Yu et al. 2013) gives a much higher value for water trading across provinces than the CGE-W, possibly because of differences in model structures. Yield effects are much stronger in Yu et al. (2013), adding 3.66 percent to GDP, but less than 1 percent in Davies et al. (2016b). In principle, from the perspective of an economic model, yield improvements should have a large effect because outputs are increased without additional inputs; however, the CGE-W simulations only alter yields for some crops and locations, while the IBMR simulations assume more widespread increases in yield.

Past studies demonstrate potential economic gains from investment in the irrigation system, and the current study has not sought to replicate this finding. Rather, this new modeling puts a greater focus on exploring the value for productivity increases across sectors (agricultural yields, industry, and services) that enable targeted levels of GDP per capita to be reached. In addition, prior work has put less focus on the demand side of water management and responding to quantity and quality demands from all water users is key to water security. Currently four major crops consume most of the water, and agricultural policies and other support ensure their dominance of water use. The focus of the modeling for this study is to examine the full spectrum of water demand, including industry and services, and to recognize the important environmental demands for water that have been largely ignored in prior modeling.

Notes

1. See the GEMPAK website, www.copsmodels.com/gempack.htm.
2. See the PEP website, www.pep-net.org/pep-standard-cge-models.
3. See the GTAP website, www.gtap.agecon.purdue.edu/.

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