

MIT Open Access Articles

Two Years in the Life of the Indus River Basin [book chapter]

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

Citation: "Two years in the Life of the Indus River Basin." (2013). In Winston Yu, Yi-Chen Yang, Andre Savitsky, Donald Alford, Casey Brown, James Wescoat, Dario Debowicz, and Sherman Robinson. "The Indus Basin of Pakistan" (April 18, 2013). p.17-33.

As Published: http://dx.doi.org/10.1596/9780821398746_CH01

Publisher: World Bank

Persistent URL: <http://hdl.handle.net/1721.1/90884>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

Terms of use: Creative Commons Attribution



Two Years in the Life of the Indus River Basin

This study was undertaken at a pivotal time in the region. The weak summer monsoon in 2009 created drought conditions throughout the country. This followed an already tenuous situation for many rural households faced with high fuel and fertilizer costs and the impacts of rising global food prices. To make matters worse, catastrophic monsoon flooding in 2010 affected more than 20 million people, their housing, infrastructure, and crops. Damages from this single flood were estimated at around US\$10 billion (ADB and World Bank 2010), with about half attributed to losses in the agriculture sector. Whether such observed extremes were evidence of climate change and the extent to which the country is resilient to these shocks were the questions these events raised. It is thus timely, if not critical, to focus on climate risks for water, agriculture, and food security in the Indus Basin.

Background and Problem Statement

The Indus Basin has an ancient and dynamic record of irrigation development and change. Settlements of the Indus valley's Harappa civilization date back some five millennia. Traces survive of inundation channels that flowed across the floodplains during the monsoon season, enabling flood farming of fuel, fodder, and small grain crops within the riparian corridor. Large check dams known as *gabarbands* impounded water on hill torrents and tributary watersheds. Sophisticated urban sewage systems and baths served cities like Mohenjo-Daro in the lower Indus valley. These cities and smaller settlements were abandoned in the second millennium BC, by some accounts due to flooding, salinity, and river channel change (Giosan et al. 2012; Wright 2010). In one major drainage on the arid eastern side of the middle Indus valley, the Ghaggar-Hakra river channel shifted course in the Harappan era, leading to the abandonment of hundreds of settlements. These historical events invite questions about long-term sustainability in the context of dynamic hydroclimatic variability (Mughal 1997).

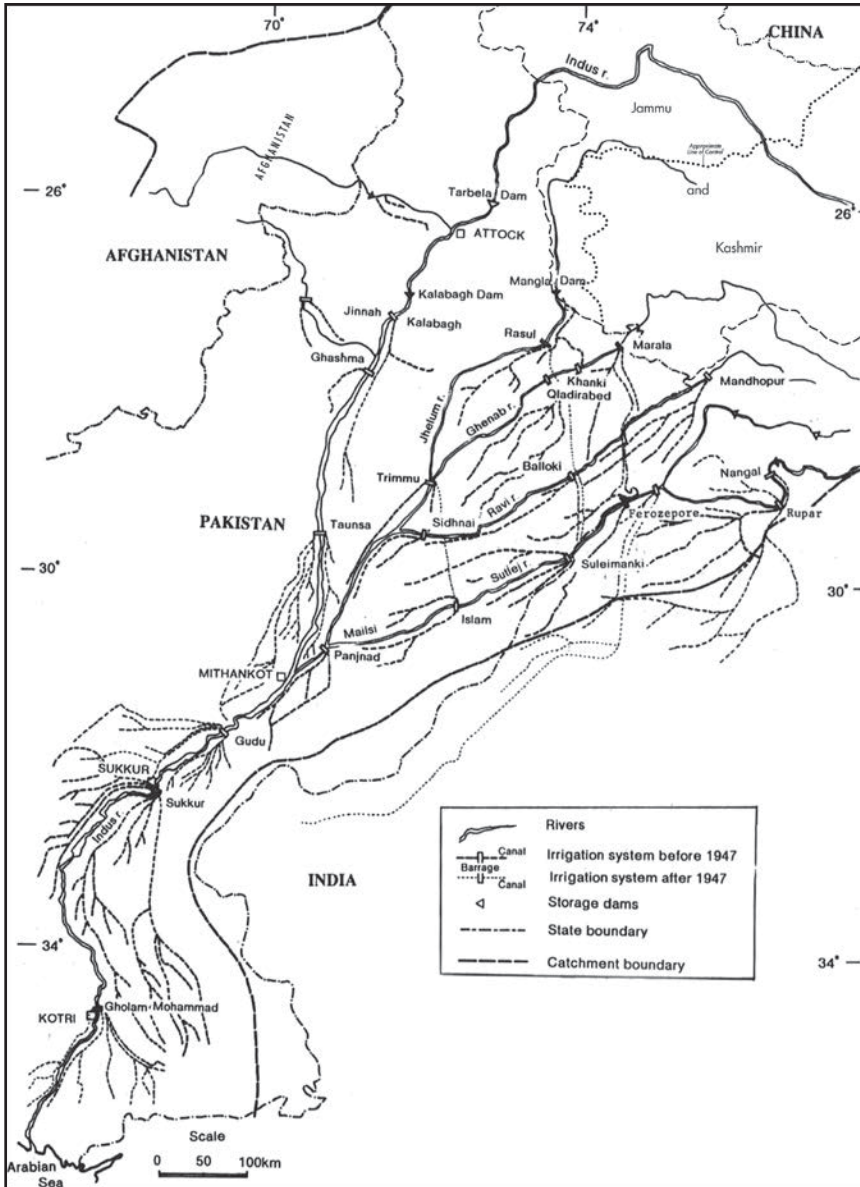
Localized irrigation flourished again during the medieval period. Innumerable shallow, hand-dug, masonry-lined wells provided water for local irrigation agriculture and livestock husbandry. Water buckets were lifted by ropes, pulleys, and Persian wheels (geared mechanisms that lifted chains of terracotta water pots) powered by humans and draft animals. In Balochistan, deeper wells tapped into hillside groundwater supplies, and tunnels known as *qanats* conveyed water to irrigated fields and settlements. These local groundwater systems were succeeded by a vast surface water canal irrigation system diverted by long masonry-clad barrages across the Indus and its major tributaries from the mid-19th to late 20th century. The benefits of dramatically expanded irrigated acreage and production were offset in some areas by seepage, waterlogging, salinity, and depleted environmental flows. Development of tubewell pumping technology in the mid-20th century improved the flexibility of irrigation and groundwater management but brought its own issues of unregulated withdrawals and secondary soil salinization. At the start of the 21st century, the core challenge was to achieve dramatically higher productivity through improved management of soil moisture, groundwater, canal irrigation, and environmental flows in ways that are adaptive and resilient.

Pakistan relies on the largest contiguous irrigation system in the world, known as the Indus Basin Irrigation System (IBIS), providing basic food security and water supply for all sectors of the economy (map 1.1). The basin that supports this irrigation system comprises the Indus River main stem and its major tributaries—the Kabul, Jhelum, Chenab, Ravi, and Sutlej rivers. The IBIS has 3 major multipurpose storage reservoirs, 19 barrages, 12 inter-river link canals, 45 major irrigation canal commands (covering over 18 million hectares), and over 120,000 watercourses delivering water to farms and other productive uses. Annual river flows are about 146 million acre-feet (MAF), of which about 106 MAF of water is diverted from the river system to canals annually (COMSATS 2003). The total length of the canals is about 60,000 km, with communal watercourses, farm channels, and field ditches running another 1.8 million km. These canals operate in tandem with a vast and growing process of groundwater extraction from private tubewells.

The IBIS is the backbone of the country's agricultural economy. The agriculture sector supported by this system plays a critical role in the national economy and the livelihoods of rural communities. Agriculture contributes some 22 percent to Pakistan's gross domestic product (GDP), down from 27 percent in 1989 and 46 percent in 1960, due primarily to more rapid growth in the services sector; 45 percent of the labor force is employed in the agriculture sector. The value of agricultural production continues to grow at an average annual rate of approximately 3 percent (figure 1.1a). However, the inter-annual variability of agricultural value added to GDP is high (figure 1.1b), demonstrating existing vulnerabilities to climate risks.

The largest crop by tonnage is sugarcane, followed by wheat, milk, rice, and cotton (FAOSTAT 2012). In terms of economic value, milk tops the list, followed by wheat, cotton, rice, meat, and sugarcane. These patterns indicate

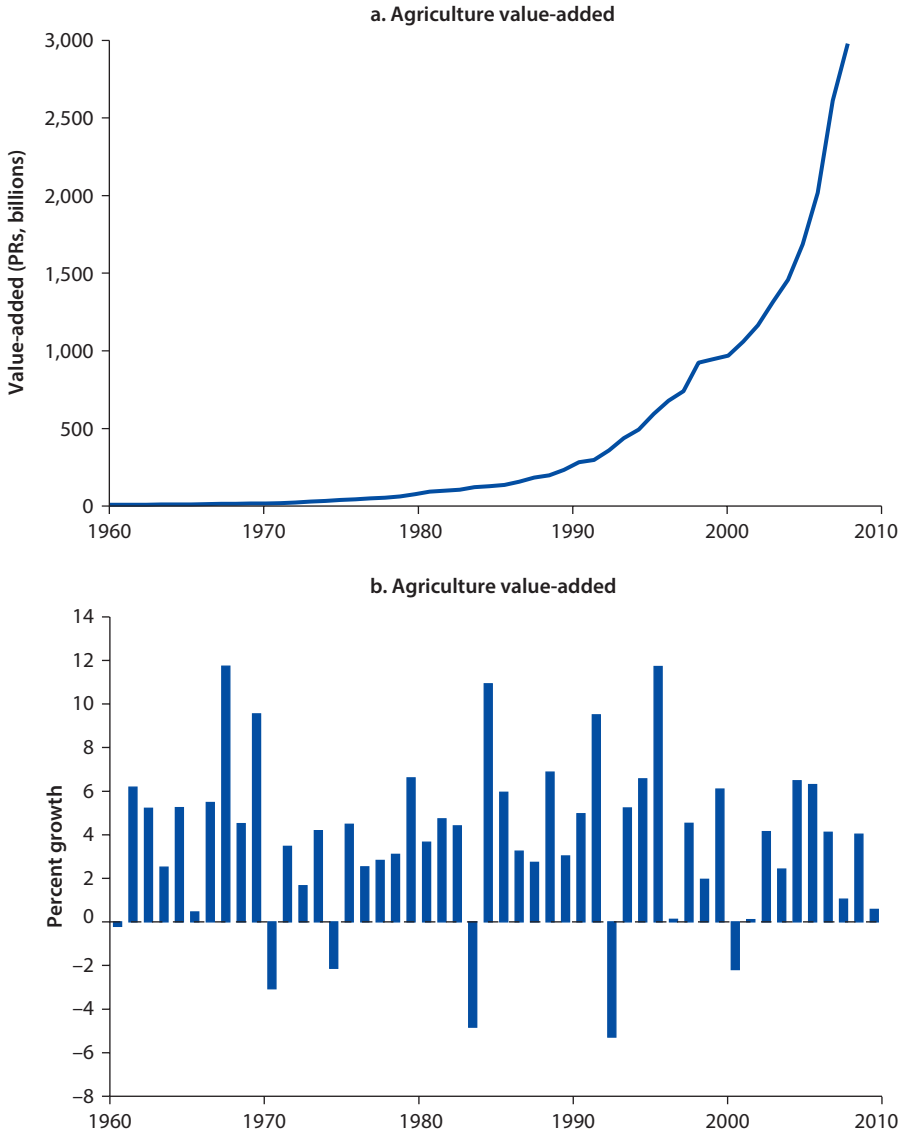
Map 1.1 Indus Basin Irrigation System



Source: © United Nations University Press. Reproduced, with permission, from United Nations University 1995; further permission required for reuse.

the rising economic significance of dairy and livestock products. Some 64 percent of Pakistan’s population is rural, and an estimated 40–47 percent of the labor force is involved in agriculture (World Bank 2012b). Women constitute an increasing proportion of the agricultural labor force, at 30 percent, double the proportion of 20 years ago (FAOSTAT 2012). Agricultural

Figure 1.1 Value and Growth of Agricultural Production



Source: World Development Indicators 2012.

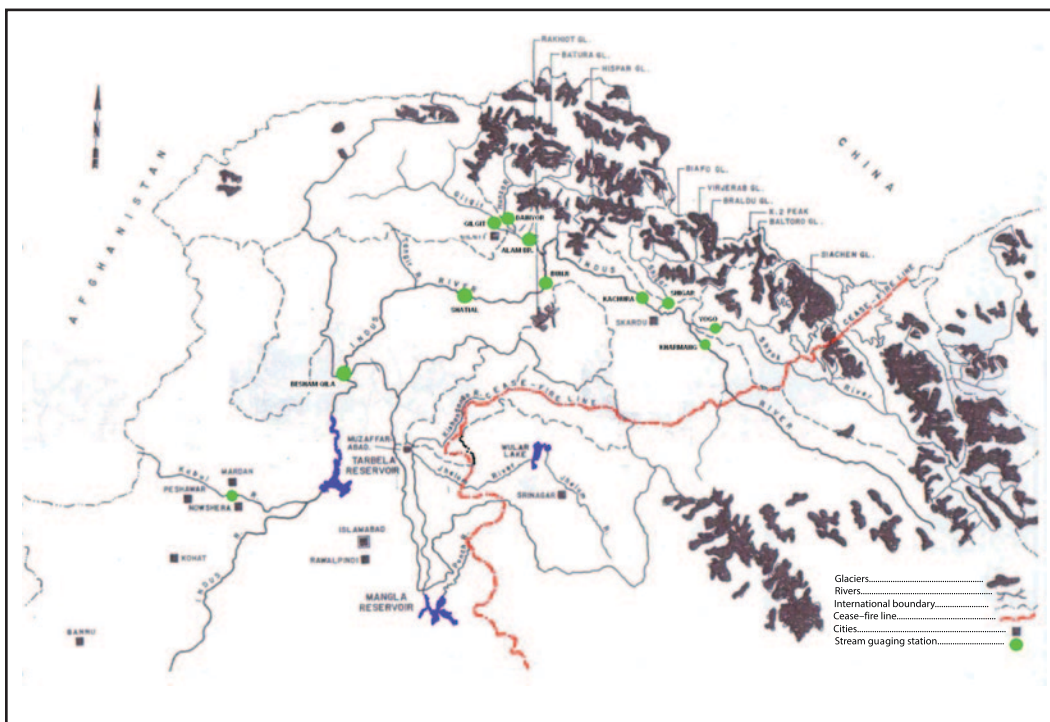
mechanization has also increased at a rapid rate; tractors have completely replaced draft animal power, and new technologies of precision land leveling and drip irrigation have expanded.

Irrigated land supplies more than 90 percent of agriculture production. Agriculture in most areas is not possible without irrigation because the climate of Pakistan is arid to semi-arid, with low and variable rainfall. Only 28–35 percent of the total land area is arable, and that proportion has not

increased significantly in recent decades. However, the irrigated portion of arable land has grown over the past decade (from about 65 percent in 2001 to almost 75 percent in 2009), which has contributed to increased agricultural production and yields. Rain fed (*barani*) crops, with much lower and less reliable yields than irrigated crops, nevertheless are increasingly important but are highly vulnerable to climate variability. Annual rainfall over much of the lower basin is not more than 150 millimeters (mm) per annum, with high potential evapotranspiration rates, ranging from 1,250 to 2,800 mm per annum. However, a substantial amount of water flows into the Indus Basin, which drains 70 percent of the country (566,000 km²).

The rivers of the Indus Basin have glaciated headwaters and snowfields that, along with monsoon runoff and groundwater aquifers, provide the major sources of water for Pakistan. Currently, about 50–80 percent of the total average river flows in the Indus system are fed by snow and glacier melt in the Hindu-Kush-Karakoram (HKK) part of the Himalayas, with the remainder coming from monsoon rain on the plains. There are more than 5,000 glaciers covering about 13,000 square kilometers (km²) in the Upper Indus river basin catchment (map 1.2).

Map 1.2 Glaciers and Drainage Area in Upper Indus Basin, Pakistan



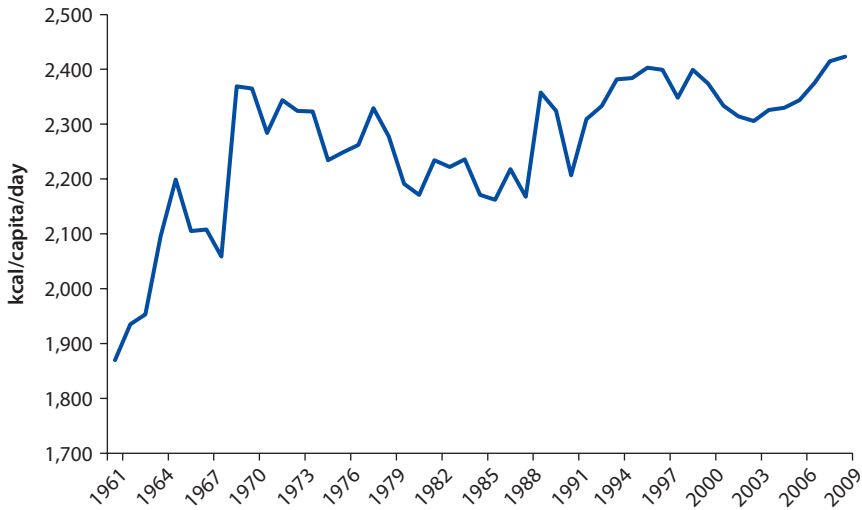
Source: © Pakistan Water and Power Development Authority. Reproduced, with permission, from WAPDA 1990; further permission required for reuse.

The supply of water stored in glaciers and snow is projected to decline globally during the 21st century. However, the patterns of depletion and accumulation vary regionally and locally. Some glaciers in the Upper Indus are increasing in depth and size, in contrast with the more general (but still variable) pattern of glacial retreat in the Himalayan range to the east. However, the bulk of the melt waters in the region come more from snow fields than glaciers (see chapter 3). In part because of this complex mix of sources, the variability observed in the Indus is not as large as for other major rivers in the world (for example, the Ganges). Variability in the distribution and timing of snowfall and changes in the melting of snow and ice, however, may be amplified by climate change and have implications for managing basin water resources.

Monsoon rainfall contributes to flood hazards in highly variable ways. The remainder of the water availability after melts is from the annual monsoon system. This contribution is even more variable than that of Upper Basin inflows. Monsoon floods have displaced hundreds of thousands of people in Pakistan (in 2003, 2005, 2008, 2010, and 2011) in the last decade alone (Brakenridge 2012). The same decade witnessed a severe multiyear drought. Finally, changes in temperature, precipitation, and atmospheric CO₂ concentrations have a direct impact on agricultural yields. Such changes, in addition to climate risks that the country already faces, pose major challenges for water managers over the coming 20–30 years.

Managing groundwater resources continued to be a major challenge in the Indus Basin. Waterlogging and salinity have been major concerns over the past century since the expansion of canal irrigation. Groundwater levels and quality conditions vary across the plains during the irrigation and monsoon seasons (Qureshi, Shah, and Akhtar 2003). The Government's early strategy of constructing public SCARP (Pakistan's Salinity Control and Reclamation Projects) tubewells to manage waterlogging has been rapidly overtaken by an estimated 1 million unregulated private tubewells constructed for irrigation purposes. Some 87 percent of these tubewells run on diesel fuel, rather than unreliable and less flexible electricity supplies. When tubewells tap into brackish groundwater, they accelerate the secondary salinization of irrigated soils, which injures crops and reduces yields.

Food self-supply is an escalating concern in Pakistan. Food security can be defined in terms of the availability, access, and utilization of food supplies.¹ Although agricultural production and yields continue to grow, the annual population growth rate also remains high, at 2.2 percent. Per capita food supply varies from year to year (figure 1.2) and is below the global average of 2,797 kcal/capita/day. Despite increased food production, there has been no change over the past two decades in the estimated 25 percent of the population who are undernourished (FAOSTAT 2012). In 2004, the World Food Programme and the Sustainable Development Policy Institute prepared a national assessment of Food Insecurity in Rural Pakistan 2003 (WFP and SDPI 2004). The report concluded that (1) the common view that Pakistan's gross production could satisfy aggregate food needs belies a condition in which

Figure 1.2 Pakistan per Capita Food Supply, 1961–2009

Source: FAOSTAT 2012.

Note: kcal = kilocalorie.

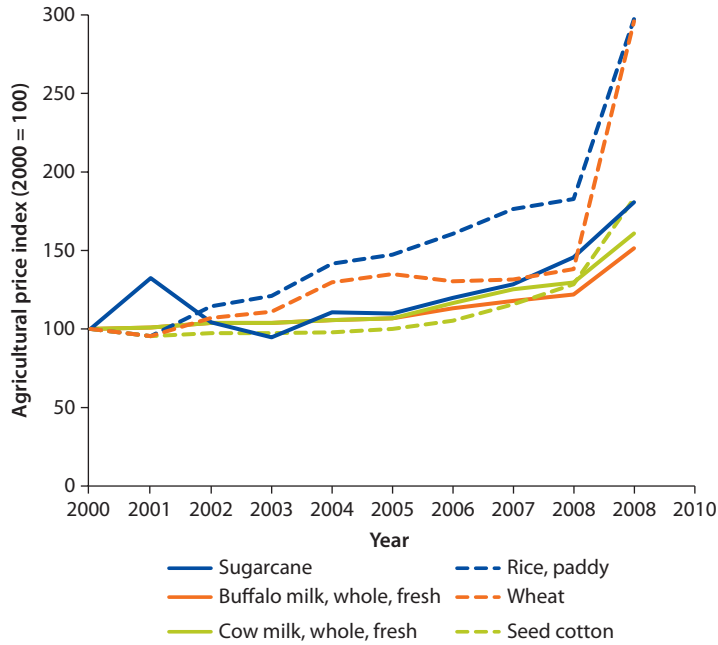
80 percent of the rural population experiences some level of food insecurity, and (2) the provinces vary significantly in the proportion of their districts that are food insecure, from a low of 29 percent in Punjab, to 65 percent in Sindh, and 85 percent in Balochistan. The National Nutrition Survey of 2011 (Bhutta 2012) reports that 57 percent of the population is food insecure. This report raises concerns about adverse childhood and lifelong developmental impacts from vitamin and micronutrient deficiencies.

Water and agricultural production depend on managing these many forms of resource variability and uncertainty. The overarching pattern that can be seen is that while the Indus Basin is richly endowed with land and water resources vital for the agricultural economy, it faces high levels of variability and uncertainty in climate, hydrology, agricultural sustainability, food consumption, and natural hazards.

Difficult Years for the Indus Basin: 2009–11

Each year the Indus Basin experiences a unique combination of weather, water, and agro-economic events. In 2009, the global economy and low-income people worldwide struggled to cope with the dramatic food price increases of 2008. Figure 1.3 indicates that the sharpest increases hit the staple food crops of wheat and rice, with wheat prices more than doubling in a year. Rice prices increased 60 percent between 2008 and 2009, after having already been increasing through the decade. Prices for high-value milk and meat products increased 24 percent. Nonfood crops like cotton increased by over 40 percent. Sugarcane has a lower base price, but it too increased by 24 percent that year. The causes of these shocks are debated as are future food price

Figure 1.3 Agriculture Prices, 2000–09
constant PRs per ton



Source: FAOSTAT 2012.

projections. Some of the causes examined include increasing energy prices, biofuels policies, shifts toward more resource-intensive food consumption, reduced food stockpiles, and market distortions. While some global food prices dropped in 2009, they rose again in 2011. Following these events, the Government of Pakistan (GPPC 2009) issued a Task Force on Food Security report in 2009. The food security task force recommended policies to increase agricultural growth to at least 4 percent per year, coupled with pro-poor food and employment programs.

A weak monsoon hampered agricultural production in 2009. Average monsoon rainfall was about 30 percent below normal (PMD 2009). Drought was an extensive problem throughout the country. Punjab and Balochistan experienced net annual rainfall deficits of 26 and 41 percent, respectively. Sindh received around 50 percent less than average rainfall in August and September. While these deficits would normally have been offset by inflows from the Upper Indus and its tributaries, melt waters that year were also 15–30 percent below normal. These water constraints delayed winter wheat sowing until December 2009, posing risks to that staple food crop. At that time, diminished irrigation supplies led to questions about potential impacts of climate change and the associated concerns about the future of the glaciers in the Upper Indus. Increasing trans-boundary conflict over water development on the Jhelum and Chenab rivers exacerbated these concerns. Pakistan’s increasing vulnerability to water scarcity

was also highlighted in the literature (for example, Archer et al. 2010; Immerzeel, van Beek, and Bierkens 2010; Laghari, Vanham, and Rauch 2011). Around that time, the Government of Pakistan also issued a report of the *Task Force on Climate Change* (GPPC 2010).

In January 2010, a large landslide near the village of Attabad dammed the Hunza River valley, a tributary of the Upper Indus, inundating villages and destroying 19 km of the Karakoram Highway and cutting off the upper basin that produces seed potatoes as a cash crop from its markets down-country. Relief for this disaster included relocation of villagers and evacuation camps for those with irrigated lands downstream of the landslide. But these resettlement and reconstruction efforts were eclipsed by devastating floods later in the year.

The Indus River System Authority (IRSA), which is responsible for administering provincial water allocations under the 1991 Indus Water Accord, faced increasing conflicts over reservoir releases, 10-daily water allocations, and requests for canal closure, particularly between Punjab and Sindh. In 2011, there were increasing demands for releases for electricity generation, as well as objections to such releases. IRSA has had particular difficulty allocating water during periods of low inflows because of the structure of the Accord, which limited reservoir storage, water measurement constraints, and organizational capacity.

As late as June 2010, the Pakistan Meteorological Department (PMD) forecast a “normal (+10 percent)” monsoon. In late July, however, heavy rains fell over the Upper Indus main stem and the adjoining tributaries in the Kabul basin, causing extensive flash flooding in Khyber-Paktunkhwa province that cascaded through the districts that line the Indus from Punjab to Sindh and parts of Balochistan over the following month. Extremely high floods were recorded at the Chasma and Taunsa barrages, and a near historical flood peak was recorded at the Kotri barrage. Main stem levees were breached in many places, destroying the spring-season *kharif* crops of rice and cotton, as well as grain stores and seed for the winter-season *rabi* wheat planting. Additionally, flash floods and landslides triggered by the rain caused severe damage to infrastructure in the affected areas. More than 20 million people were adversely affected, with more than 1,980 dead and 2,946 injured. About 1.6 million homes were destroyed, and thousands of acres of crops and agricultural lands were damaged, some areas experiencing major soil erosion.

Massive international assistance was mobilized in response. A joint Asian Development Bank and World Bank (ADB and World Bank 2010) *Flood Damage and Needs Assessment* estimated that the total direct damages and indirect losses amounted to about US\$10 billion; the agriculture, livestock, and fisheries sectors suffered the highest damages, calculated at US\$5.0 billion.

As the 2011 monsoon season approached, the PMD forecast a slightly below normal (−10 percent) monsoon, with some areas expected to experience slightly above normal rainfall (+10 percent) (PMD 2011). However, heavy rains flooded the lower Indus Basin districts in Sindh and Balochistan, adversely affecting 5 million people, damaging 800,000 homes, and destroying 70 percent of

the crops on flooded lands in what were already the most food insecure provinces in Pakistan (UNOCHA 2011). Although very different in hydroclimatic terms, the two floods of 2010 and 2011 had compounding damages on agricultural livelihoods and food security in the lower Indus Basin.

The years from 2009 through 2011 offer a perspective on the current challenges of water and food security, along with mounting future uncertainties that the federal and provincial governments must face. The prospects of climate change amplify these concerns. With growing populations and increasing water demand across all sectors, these risks must be anticipated and managed. This study will present a modeling framework for these purposes.

Literature Review on Indus Basin Modeling

This study follows a long legacy of research and planning for Pakistan's Indus Basin. The first major application of a multi-objective planning model for the Indus Basin was the World Bank's *Indus Special Study* of 1964–68, published as the three-volume report on *Water and Power Resources of West Pakistan: A Study in Sector Planning* (Liefertinck, Sadove, and Creyke 1968). It was an early use of linear programming and optimization modeling to weigh investment alternatives, which included Tarbela Dam and irrigation and agricultural development projects. The study developed a linear programming model to maximize the net economic benefits of production activities and projects in 54 canal commands under five different water budget conditions. Later, Duloy and O'Mara (1984) would develop the first version of the Indus Basin Model (IBM). It included farm production functions for different cropping technologies in the canal command areas and was based on a detailed rural household survey conducted in 1978. The analysis also linked hydrologic inflows and routing with irrigation systems, thereby showing where efficiencies could be gained in water allocation. Efficient allocation and economic pricing were shown to have substantial economic benefits that could support widespread tractor and tubewell investment, as well as increased farm income. Interestingly, the report concluded that by 1995, "all water resources [would be] fully utilized and thereafter gains would have to come from technical progress or substitution of more valuable crops in cropping patterns" (Duloy and O'Mara 1984, v).

This more streamlined version of the IBMR model ("R" was added for revised) was used in the Water and Power Development Authority's (WAPDA) next major basin analysis, known as the *Water Sector Investment Planning Study* (WSIPS) in the late 1980s, which focused on mid-term (10 year) development alternatives (WAPDA 1990). That study drew upon a 1988 farm survey to update farm production technologies and functions by canal command and nine agro-economic zones in the IBMR. The WSIPS evaluated a range of investment portfolios: no change, minimum investment, a Basic Plan of PRs 75 billion that optimized net economic benefits subject to a capital constraint, and a maximum plan contingent on additional investment funds being made available. A "plan generator" was also developed using mixed-integer programming techniques to assist in project scheduling and to ensure adherence to financial and other

Table 1.1 Increased Agricultural Production with and without the Basic Plan

<i>Crop</i>	<i>Requirement 2000 (tonnes, thousands)</i>	<i>Without basic plan (% increase)</i>	<i>With basic plan (% increase)</i>
Wheat	20,399	79	92
Rice	5,777	65	80
Sugarcane	47,204	80	98
Cotton	2,075	84	150
Pulses	991	83	92
Oilseeds	1,880	36	39

Source: WAPDA 1990.

macro-economic constraints (Ahmad and Kutcher 1992). The IBMR modeling showed what proportion of production targets for 1999–2000 could be met with and without the basic plan (table 1.1).

A detailed guide to the IBMR was written by Ahmad, Brooke, and Kutcher (1990). Ahmad and Kutcher (1992) followed this with a study looking at environmental considerations for irrigation planning, which incorporated salinity and groundwater variables in the IBMR water budget, flow routing, and management alternatives. This study noted slowing growth, increasing water scarcity, deteriorating infrastructure, extensive waterlogging and salinity, reduced growth of yields, and the high cost of drainage. It created large-scale groundwater and salt balance models and evaluated irrigation and drainage alternatives for achieving groundwater balance. The IBMR was later used for various projects and programs, for example, Kalabagh Dam (Ahmad, Kutcher, and Meeraus 1986); waterlogging and salinity under different scenarios of crop yield and tubewell investment in Sindh province (Rehman and Rehman 1993); and salinity management alternatives for the Rechna Doab region of Punjab (Rehman et al. 1997).

At about the same time, a team from WAPDA and the USEPA (United States Environmental Protection Agency) used the IBMR model to assess complex river basin management for Pakistan, which jointly analyzed general circulation model (GCM) climate scenarios along with WAPDA development alternatives (Wescoat and Leichenko 1992). The WAPDA-USEPA study of the Indus Basin examined temperature warming scenarios that ranged from an arbitrary +2°C to GCM-driven scenarios as high as +4.7°C. As precipitation was more uncertain and remains so, arbitrary ± 20 percent scenarios were included. Upper basin snowmelt was modeled on the Jhelum River to generate inflows to the rim stations of the main IBIS. GCM warming scenarios in the upper Jhelum model simulated increased and earlier runoff. Water development scenarios were based on government plans for medium-term development that included the following scenarios: no projects, minimum development, and maximum development. The model was run with two different water allocation rules: 100 percent of historical water allocations and 80 percent of historical allocations with the remainder redirected to economically optimal uses. The net economic effects of these climate and water allocation scenarios are presented in table 1.2. All but

Table 1.2 Indus Basin Case Study Results: Total Economic Value-Added
PRs, billions

Case study scenarios	No climate change	+2°C 0% P	+2°C +20% P	+2°C -20% P	GISS ^a +30% P	GFDL ^b +20% P
1988 water management						
100% allocation	90.515	88.114	92.797	Infeasible	89.475	88.643
80% allocation	94.203	n.a.	n.a.	88.829	n.a.	n.a.
2000 with no new projects						
100% allocation	Infeasible	Infeasible	136.923	Infeasible	Infeasible	132.903
80% allocation	138.641	134.862	n.a.	127.647	136.164	n.a.
2000 with minimum investment						
100% allocation	136.511	Infeasible	140.184	Infeasible	Infeasible	134.854
80% allocation	143.162	139.417	n.a.	133.882	138.956	n.a.
2000 with maximum investment						
100% allocation	143.434	Infeasible	147.178	Infeasible	Infeasible	138.996
80% allocation	149.202	146.351	n.a.	140.593	144.585	n.a.

Source: Wescoat and Leichenko 1992.

Note: n.a. = not applicable.

a. NASA (U.S. National Aeronautics and Space Administration) Goddard Institute for Space Studies.

b. NOAA (U.S. National Oceanic and Atmospheric Administration) Geophysical Fluid Dynamics Laboratory.

the “+2°C +20% P” scenario had a negative impact on the objective function. Impacts ranged from -7.9 to +2.7 percent of total value-added (or from about one to three years of economic growth at 3 percent). Changing the allocation rule had a greater positive economic effect of +4.0 to +4.9 percent. These gains were largely eliminated by climate change scenarios.

This early study was also able to compare the potential economic impacts of climate change scenarios on different investment portfolios. For example, it showed that climate change diminished the net economic benefits of the minimum investment plan from 40 to 100 percent. This earlier work also demonstrated that, with some exceptions, the Indus Basin irrigation baseline seemed relatively robust in the face of the types of climate variability considered. This may reflect high levels of inflow and monsoon variability, system redundancy, groundwater availability, and/or compensating farming decisions in the optimization model.

Habib (2004) used the HYDRAM model to scope out the reallocation opportunities in the Indus Basin. This study built on a detailed analysis of water budgets and canal diversions (Kaleemuddin, Habib, and Muhammad 2001; Tahir and Habib 2001). The study identified important network and operational constraints, flexibility, and tradeoffs for meeting water allocation and delivery targets. Khan et al. (n.d.) used the Soil and Water Assessment Tool (SWAT) model in a regional watershed analysis of the Upper Indus Basin. This study prepared a digital elevation model of the watershed, along with large-scale land use and soil maps to model agricultural hydrology in the Upper Indus. Also, a 2002 version of the IBMR was used to assess economic and water management

benefits of raising Mangla Dam by different heights (Alam and Olsthoorn 2011). Finally, the Global Change Impact Study Centre (GCISC) in Pakistan undertook a number of adaptation studies (for example, Ali, Hasson, and Khan 2009). Using a sophisticated crop model, these studies focus primarily on examining how climate change may impact wheat and rice yields and production (Iqbal et al. 2009a, 2009b, 2000c).

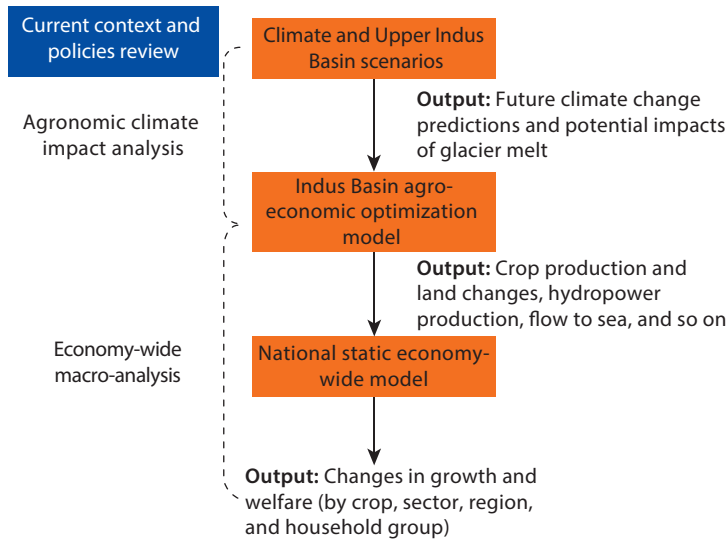
Based on this literature review, the following four needs stand out: (1) a wider perspective on the policy environment, (2) expansion of the scientific basis for snow and ice hydrology in the upper basin, (3) advanced and updated modeling of hydroclimatic impacts on water and food systems using the IBMR, and (4) agro-economic modeling with a more sophisticated computable general equilibrium (CGE) and social accounting matrix (SAM) approach. A framework for addressing these gaps will be described here and in later chapters.

Study Approach: A Framework for Integrated Water and Agriculture Assessment

The objective of this study is to assess the potential impacts of climate risks and various alternatives for minimizing those impacts on water and food security in the Indus Basin of Pakistan. The study analyzes interrelationships among the climate, water, and agriculture sectors to gain a better understanding of how these factors are linked in order to help guide the prioritization and planning of future investments in these sectors. Attention is also given to analysis by province, as provinces are the primary level of water and agricultural governance in the federal system. Analytically, the study objective is achieved by integrating several different modeling environments: a model of Upper Indus snow and ice hydrology, an agro-economic optimization model of the IBIS, and an updated CGE model of Pakistan's wider macro-economy. This integration of models helps frame the recommendations for strengthening water, climate, and food security planning, policies, and research priorities for the Indus Basin. The five key tasks for this analysis are shown in figure 1.4.

First, this study will review the major challenges and the current water and agriculture context, plans, and policies. Chapter 2 surveys the current policy environment for addressing water and agricultural issues in a changing climate. This policy environment is shaped by economic development plans at the national and provincial levels, sector plans for water and agriculture (from long-term, multi-decade plans to medium-term and annual plans), and recent cross-cutting policy documents on climate change. This policy review establishes the context for scientific and modeling efforts in subsequent chapters.

Second, the study will assess glacier-melt and snowmelt dynamics in the upper Indus Basin and implications for downstream inflows. Chapter 3 examines the state of the science associated with the snow and ice hydrology in the Upper Indus Basin and reviews the literature and data available on the present and projected role of glaciers, snow fields, and stream flow. A simple hydrologic model is developed to estimate the relative contributions of glaciers and snow to

Figure 1.4 Framework for Integrated Water and Agriculture Assessment

the hydrologic regimes of the Upper Indus Basin. Topographic imagery is used to delineate basin areas, area versus altitude relationships, hypsometry, and ablation processes. The results of these analyses contribute to climate scenario construction for the downstream IBIS modeling.

Third, climate scenarios are constructed for analysis with the Indus Basin Model Revised (IBMR). Chapter 4 examines the literature and available data on hydroclimatic variability and change on the Indus Basin plains. It compares historical fluctuations in climatic and hydrologic variables in the Indus Basin. Scenarios of climate change derived from GCMs are also reviewed, including the generation of future scenarios of changing snow and ice melt in the Upper Indus Basin.

Fourth, two primary models are described in chapter 5. The IBMR model is a powerful agro-economic optimization model used and refined over three decades by the World Bank and Government of Pakistan. The first part of chapter 5 describes the model, the updates made for this study, and the dependent variables in the model output. Sensitivity of the model to key water, agricultural, and land use indicators is also given. The second part of chapter 5 describes the use of an updated social accounting matrix and CGE model to explore the economy-wide impacts of changes in the agriculture sector. This model includes 49 economic activities and 48 commodities. It includes the quantities and prices of agricultural inputs and agricultural industries beyond crop production, which offers a more complete assessment of economic impacts. The model also differentiates across 19 types of households by farm size, tenancy, and poverty level to give more detailed insights into social impacts.

Fifth, the results of the various scenarios using these models and policy and investment implications are discussed in chapter 6. Chapter 7, the final chapter,

draws together the findings from the chain of analyses. It distinguishes between the relative significance of different scenarios, impacts, and adaptations, and highlights recommendations for research, planning, and policies that can help to expand the range of options for Indus Basin management.

Note

1. *Food availability* is defined as having sufficient quantities of food on a consistent basis. *Food access* is defined as having sufficient resources to obtain appropriate foods for a nutritious diet. *Food use* is defined as appropriately using food for one's basic nutrition and care, as well as having adequate water and sanitation (FAO World Food Summit 1996).

References

- ADB (Asian Development Bank) and World Bank. 2010. "Pakistan Floods 2010 Damage and Needs Assessment." Paper presented at the Pakistan Development Forum, Islamabad, November 14–15.
- Ahmad, M., A. Brooke, and G. P. Kutcher. 1990. *Guide to the Indus Basin Model Revised*. Washington, DC: World Bank.
- Ahmad, M., and G. P. Kutcher. 1992. "Irrigation Planning with Environmental Considerations: A Case Study of Pakistan's Indus Basin." World Bank Technical Paper 166, World Bank, Washington, DC.
- Ahmad, M., G. Kutcher, and A. Meeraus. 1986. *The Agricultural Impact of the Kalabagh Dam (As Simulated by the Indus Basin Model Revised)*. Vols. I and II. Washington, DC: World Bank.
- Alam, N., and T. N. Olsthoorn. 2011. "Sustainable Conjunctive Use of Surface and Groundwater: Modeling on the Basin Scale." *International Journal of Natural Resources and Marine Sciences* 1: 1–12.
- Ali, G., S. Hasson, and A. M. Khan. 2009. *Climate Change: Implications and Adaptation of Water Resources in Pakistan*. Research Report GCISC-RR-13, Global Change Impact Study Centre, Islamabad.
- Archer, D. R., N. Forsythe, H. J. Fowler, and S. M. Shah. 2010. "Sustainability of Water Resources Management in the Indus Basin under Changing Climatic and Socio Economic Conditions." *Hydrology and Earth System Sciences* 14: 1669–80.
- Bhutta, Z. 2012. *Pakistan—National Nutrition Survey 2011*. Karachi, Pakistan: Aga Khan University Pakistan Medical Research Council Nutrition Wing, and Ministry of Health.
- Brakenridge, G. R. 2012. "Global Active Archive of Large Flood Events." Dartmouth Flood Observatory, University of Colorado, Boulder, CO (accessed January 25, 2013). <http://floodobservatory.colorado.edu/Archives/index.html>.
- COMSATS (Commission on Science and Technology for Sustainable Development in the South). 2003. *Water Resources in the South: Present Scenario and Future Prospects*. Islamabad: COMSATS.
- Duloy, J. H., and G. T. O'Mara. 1984. "Issues of Efficiency and Interdependence in Water Resource Investments: Lessons from the Indus Basin of Pakistan." World Bank Staff Working Paper 665, World Bank, Washington, DC.

- FAO World Food Summit. 1996. *Rome Declaration on World Food Security*. Food and Agriculture Organization of the United Nations, Rome, Italy.
- FAOSTAT (Food and Agricultural Organization of the United Nations Statistical Database). 2012. Database of Food and Agriculture Organization of the United Nations, Rome. <http://faostat.fao.org>.
- Giosan, L., P. D. Clift, M. G. Macklin, D. Q. Fuller, S. Constantinescu, J. A. Durcan, T. Stevens, G. A. T. Duller, A. R. Tabrez, K. Gangal, R. Adhikari, A. Alizai, F. Filip, S. VanLaningham, and J. P. M. Syvitski. 2012. "Fluvial Landscapes of the Harappan Civilization." In *Proceedings of the National Academy of Sciences*. doi: 10.1073/pnas.1112743109. <http://www.pnas.org/content/109/26/E1688> (accessed January 28, 2013).
- GPPC (Government of Pakistan, Planning Commission). 2009. *Final Report of the Task Force on Food Security*. Islamabad.
- . 2010. *Task Force on Climate Change Final Report*. Islamabad.
- Habib, Z. 2004. "Scope for Reallocation of River Waters for Agriculture in the Indus Basin." PhD thesis. Ecole Nationale du Genie Rural, des Eaux et des Forets, Paris.
- Immerzeel, W. W., L. P. H. van Beek, and M. F. P. Bierkens. 2010. "Climate Change Will Affect the Asian Water Towers." *Science* 328 (5984): 1382–85.
- Iqbal, M. M., M. A. Goheer, S. A. Noor, H. Sultana, K. M. Salik, and A. M. Khan. 2009a. *Climate Change and Rice Production in Pakistan: Calibration, Validation and Application of CERES-Rice Model*. Research Report GCISC-RR-15, Global Change Impact Studies Centre (GCISC), Islamabad.
- . 2009b. *Climate Change and Agriculture in Pakistan: Adaptation Strategies to Cope with Negative Impacts*. Research Report GCISC-RR-16, Global Change Impact Studies Centre, Islamabad.
- . 2009c. *Climate Change and Wheat Production in Pakistan: Calibration, Validation and Application of CERES-Wheat Model*. Research Report GCISC-RR-14, Global Change Impact Studies Centre, Islamabad.
- Kaleemuddin, M., Z. Habib, and S. Muhammad. 2001. "Spatial Distribution of Reference and Potential Evapotranspiration." Working Paper 24, Pakistan Country Series number 8, International Water Management Institute, Lahore, Pakistan.
- Khan, A. D., J. G. Arnold, M. DiLuzio, and R. Srinivasan. n.d. "GIS Based Hydrologic Modeling of Upper Indus Basin." Unpublished manuscript.
- Laghari, A. N., D. Vanham, and W. Rauch. 2011. "The Indus Basin in the Framework of Current and Future Water Resources Management." *Hydrology and Earth System Sciences* 14 (8): 2263–88.
- Lieftinck, P., R. A. Sadove, and T. A. Creyke. 1968. *Water and Power Resources of West Pakistan: A Study in Sector Planning*. Baltimore, MD: Johns Hopkins Press.
- Mughal, M. R. 1997. *Ancient Cholistan: Architecture and Archaeology*. Lahore, Pakistan: Ferozsons.
- PMD (Pakistan Meteorological Department). 2009. *Flood Report 2009*. Flood Forecasting Division, Pakistan Meteorological Department, Lahore, Pakistan (accessed May 1, 2012). <http://www.pakmet.com.pk/FFD/cp/fr2009.pdf>.
- . 2011. "Outlook for Monsoon Season (July–September 2011)." National Weather Forecasting Centre, Pakistan Meteorological Department, Lahore, Pakistan. <http://pakmet.com.pk/MON&TC/Monsoon/monsoon2010.html>.

- Qureshi, A. S., T. Shah, and M. Akhtar. 2003. "The Groundwater Economy of Pakistan." Working Paper 64, International Water Management Institute, Lahore, Pakistan.
- Rehman, A., and G. Rehman. 1993. *Strategy for Resource Allocations and Management across the Hydrologic Divides*. Volume 3 of *Waterlogging and Salinity Management in the Sindh Province, Pakistan*. Report R-T0.3, International Irrigation Management Institute, Lahore, Pakistan.
- Rehman, G., M. Aslam, W. A. Jehangir, A. Rehman, A. Hussain, N. Ali, and H. Z. Munawwar. 1997. *Salinity Management Alternatives for the Rechna Doab, Punjab, Pakistan*. Volume 3 of *Development of Procedural and Analytical Links*. Report R-21.3, International Irrigation Management Institute, Lahore, Pakistan.
- Tahir, Z., and Z. Habib. 2001. "Land and Water Productivity: Trends across Punjab Canals." IWMI Working Paper 14, Pakistan International Water Management Institute, Lahore, Pakistan.
- UNOCHA (United Nations Office for the Coordination of Humanitarian Affairs). 2011. *Pakistan Monsoon 2011*. Situation Report 14, Islamabad (accessed May 1, 2012). <http://pakresponse.info/LinkClick.aspx?fileticket=nu4xv8K2MZ4%3D&tabid=87&mid=539>.
- WAPDA (Water and Power Development Authority). 1990. *Water Sector Investment Planning Study (WSIPS)*. 5 vols. Lahore, Pakistan: Government of Pakistan Water and Power Development Authority, Lahore.
- Wescoat, J., and R. Leichenko. 1992. "Complex River Basin Management in a Changing Global Climate: Indus River Basin Case Study in Pakistan—A National Modeling Assessment." Collaborative Paper 5, Center for Advanced Decision Support for Water and Environmental Systems, University of Colorado, Civil, Environmental, and Architectural Engineering, Boulder, CO.
- WFP and SDPI (World Food Programme and the Sustainable Development Policy Institute). 2004. *Food Insecurity in Rural Pakistan 2003*. Islamabad: World Food Program VAM Unit.
- World Bank. 2012. "World Development Indicators Databank (WDI)." <http://databank.worldbank.org/ddp/home.do?Step=12&id=4&CNO=2>.
- Wright, R. 2010. *The Ancient Indus: Urbanism, Economy and Society*. Cambridge, U.K.: Cambridge University Press.

