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Islamic Republic of Pakistan: Glacial Melt and Downstream Impacts on Indus Dependent Water Resources and Energy

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Final Report

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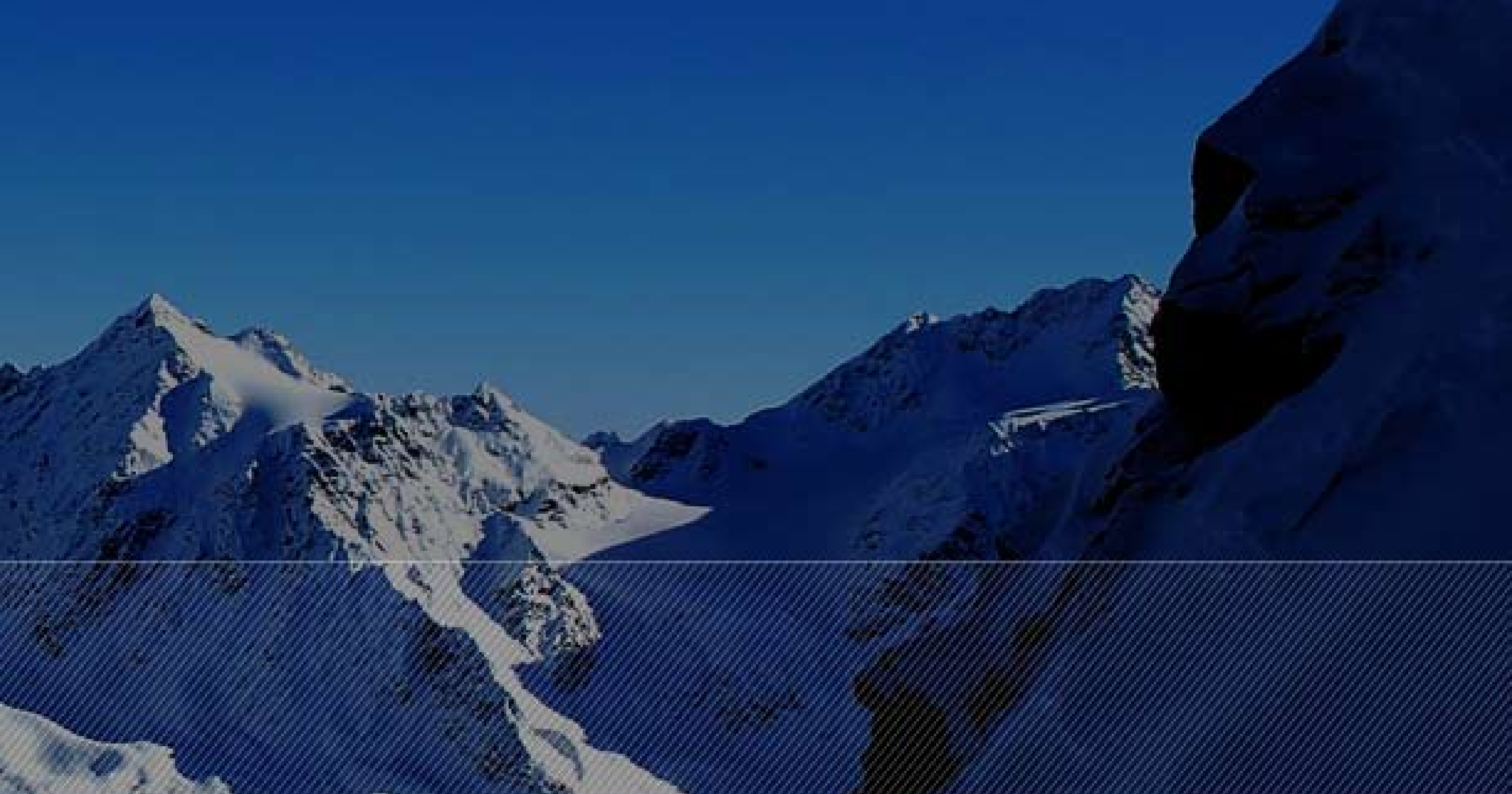
Asian Development Bank



Glacial Melt and Downstream **Impacts** on Indus Basin-Dependent **Water Resources** and **Energy**

ENVIRONMENT, NATURAL RESOURCES, AND AGRICULTURE

Pakistan

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FULL REPORT

RETA 6420-PAK Promoting Climate Change Impact and Adaptation in Asia and the Pacific

Glacial Melt and Downstream Impacts on Indus Basin–Dependent Water Resources and Energy

Full Report

International Centre for Integrated Mountain Development
Kathmandu

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ADB IUCN ICIMOD

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Abbreviations

ADB	Asian Development Bank
CDM	Clean Development Mechanism
CRU	Climate Research Unit
ENSO	El Niño Southern Oscillation
GCISC	Global Change Impact Studies Centre
GCM	general circulation model
GLOF	glacial lake outburst flood
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
MW	megawatt
NGO	nongovernment organization
PMD	Pakistan Meteorological Department
SGAA	Small Grant Adaptation Action
UNEP	United Nations Environment Programme
WAPDA	Water and Power Development Authority

Acknowledgments

This report is based on the activities of the Small Grant for Action (SGA) on Adaptation, "Glacial Melt and Downstream Impacts on Indus Dependent Water Resources and Energy." This SGA was graciously funded by the Regional and Sustainable Development Department of the Asian Development Bank (RETA 6420), through generous support from the Government of the United Kingdom and the Japan Special Fund, and implemented by the International Centre for Integrated Mountain Development, with assistance from Pakistan's International Union for Conservation of Nature.

Executive Summary

This research study, conducted by the International Centre for Integrated Mountain Development (ICIMOD) in collaboration with the key national partners in Pakistan and Afghanistan including the Pakistan Meteorological Department and Ministry Water and Energy, Afghanistan, is largely based on the secondary information, literature review, and intensive stakeholder consultations. It has also benefited from the extensive network of contacts and the latest knowledge from ICIMOD and its partners in mountain water resources management, including the global and regional understanding of the growing impacts of climate and socioeconomic changes on the Hindu Kush Himalaya (HKH) region. The major features of the study are

1. Key issues. There is a growing recognition that countries of the Indus River Basin face major and changing threats to their water security and thus to their people's critical food and energy needs. Downstream areas are highly dependent on water resources originating in the upper catchments mountainous water sources. The Indus River has one of highest dependence on meltwater recharge and the generally semi-arid basin is naturally water stressed. The river is lifeline of Pakistan's huge and growing population. It has the world's largest irrigation system dependent upon transboundary water. The countries in the basin are already facing water shortages in terms of water withdrawal and per capita water availability. Climate and socioeconomic changes are further aggravating the situation. There is a need for in-depth study, thorough analysis, and the consolidated study of the multiple factors that link climate change, glaciology, and runoff hydrology.

2. Study approach and framework. ICIMOD, based on its regional intergovernmental position and its decade-long pioneering work on monitoring glaciers of the HKH region, convened a partnership-based research team and conducted an analytical and collective stock taking of the current issues, challenges, and opportunities. The results provide a good synopsis of the current situation and trends regarding increasing variability in water supply, growing risk of climate change scenarios, and possible impacts on the socioeconomy of millions of people living in the downstream areas. Furthermore, recognizing the transboundary nature of the Indus River, the study team included experts from other countries sharing the river—principally Afghanistan, the People's Republic of China, and India. The aim was to stimulate regionally coordinated inter-disciplinary research, and knowledge sharing that could provide critical information for policy and decision makers to enhance their understanding of environmental risks and challenges, and how they can better plan and design water resources development programs in an integrated and holistic manner to address emerging issues. The framework of the study allowed scientists and water resources managers to reach useful conclusions.

3. Methodology and process. The year-long study carried out: (i) a comprehensive report on Glacial Melt and Downstream Impacts on Indus Basin–Dependent Water Resources and Energy; (ii) the setting up of an interactive digital knowledge platform; (iii) a series of national, regional, and international stakeholder workshops and consultations; and (iv) climate risk screening of six ADB water and energy-related projects in the Indus Basin including four in Pakistan and two in Afghanistan. A modified version of ORCHID (Opportunities and Risks of Climate Change and Disasters) software package was used for the risk screening of the select ongoing projects that included desk screening of all the projects and field screening of three projects.

4. The major results. The findings of the study have to be seen in the context that basic data and information is lacking in making appropriate policies and decisions to address challenges related to climate change in managing the water resources of the basin.

Results have been therefore divided into two categories:

- **Constraints.** These included the following elements: (i) a scarcity of critical mass of automatic weather and hydrological stations in glacial areas, (ii) a lack of basin-wide and transboundary models to provide trends and future scenario in water supply situation, (iii) the shortage of basin-wide data on glaciers and their dynamics including changes in mass and their impacts on meltwater river runoff, (iv) variability in annual water availability due to uncertainty in precipitation projections, and (v) the lack of scientific consensus on the impact of climate change on glacier fluctuations that are of mixed nature.
- **General conclusion on trends.** These trends were (i) decreasing temperature during monsoon season and increasing temperatures in spring and winter; (ii) increasing trend of precipitation—more rainfall than snow fall during winter; (iii) average volumes may be changing, but so are annual variability, seasonality and intensity of flows, thereby increasing flood risks; (iv) in the Karakoram region, the average temperature has decreased while precipitation has increased, along with the size of some glaciers; (v) indications are that mean annual temperatures in Afghanistan are increasing and mean rainfall has decreased slightly, mainly due to a decrease in spring precipitation; and (vi) in Afghanistan, glaciers are retreating and prolonged drought has been experienced in recent years due to decreasing annual precipitation and general warming trend.

5. Future research and development agenda. Analysis of the above findings indicates the need to develop and share knowledge to improve scientific understanding and decision making for the judicious management of water resources of Indus River in an integrated and less risk-free manner. Areas identified for focus are

- **Data and information availability.** The hydrometeorological monitoring network in higher mountain areas is sparse; there is a need for integration of data from different institutions and access to national and transboundary data, as well as to published and unpublished information.
- **Scientific knowledge.** Downscaling capacity for developing regional scenarios with low uncertainties is inadequate; data is lacking for detailed knowledge of glacier resources and dynamics, their impact of glacier dynamics, especially meltwater runoff on water resources, and the effects of socioeconomic factors on water resources.
- **Adaptation capacity.** There is a dearth of activities to promote appropriate adaptation strategies, options, and action and an absence of tools for risk management.
- **Technical capacity.** Trained human resources are lacking, equipment and instruments are inadequate; and computational capacity is weak.
- **Institutional arrangements.** Interdepartmental and transboundary collaboration and coordination is lacking.
- **Public awareness.** The general population and institutions have low awareness on climate change issues.

6. Sharing results with global scientific community. As a desk study based largely on existing data and limited investigation, the findings were presented and verified by international expert consultations among stakeholders from the four riparian countries and selected international researchers and scientists. The above findings were presented to this scientific community, which mostly confirmed them, and added the following observations for future work: (i) monitoring stations for the regular and reliable data collection, specifically hydrometeorological stations above the timberline, need to be augmented and regularly attended to; this is critical because of a changing precipitation pattern with elevation and exposure; (ii) the phenomenon of surging glaciers in the Karakoram needs scientific and detail investigation in order to gain good understanding of risks, vulnerabilities, and opportunities due to climate change; and (iii) there is a general lack of mutual exchange and knowledge sharing among the scientific community and institutions working in the basin.

7. Recommendations

- Strengthen the capacity of national institutions to monitor and project climate change impacts. This includes the technical capacity to provide downscaled climate change scenarios to subbasins, the transboundary assessment of glacier dynamics (particularly glacier mass balances and their impact on meltwater flow) through field-based and remote-sensing approaches and water resources modeling of the Indus River and its tributaries. Build capacity in terms of training and education, setting up of required geo-spatial analysis and computational capacity at relevant line agencies, and instruments and equipment support for adequate field investigation and monitoring
- Identify options for climate adaptation and risk management in the Indus Basin water and energy sectors through enhanced and collaborative research, pilot studies, and integrated planning. Collaborative research demands the integration of different disciplines and the participation of research organizations. National research organizations require technical and funding support that could be organized through a competitive research grant system.
- Organize activities in a coordinated program that takes into consideration the complexity of problems related to the connectedness of cry sphere, biosphere, hydrology, and human activities, using regional and global knowledge bases to improve projections of trends and their impacts on water resources.
- Make water and energy programs and projects of the Asian Development Bank (ADB) and Government of Pakistan adaptive to climate change in the medium and long terms through the application of knowledge and tools to identify vulnerabilities and threats and risk management activities. The suggested screening tool and framework may play a major role in this and therefore should be tested in the field and adapted in policies, programs, and plans.
- Create awareness among policy and decision makers and the public of the crucial importance of adaptation to climate change to create a favorable environment for the implementation of strategies and policies.

8. Suggested way forward. Based on the preliminary results of the study, the stakeholders—including the regional and international scientific and management communities—felt strongly that a second and longer phase of work with emphasis on field verification is necessary. Such applied and coordinated work can be expected to yield the following outputs and outcomes:

- Enhanced forecasting capacity of water-cycle components, including river flows, groundwater resources, and glacier meltwater at different locations in the Indus Basin (including the Indus, Chenab, and Jhelum and Kabul rivers).
- Enhanced forecasting capacity of monsoon tracks and patterns of the westerlies.
- A fully operational and effective Pakistan Climate Change Adaptation Network.
- Upgraded hydrometeorological network in the uplands of the Indus Basin. Appropriate tools and methods need to be developed to support applicable adaptation strategies.
- Testing of a framework within which planners may be able to develop a first assessment of potential hazards, associated vulnerabilities, and potential risk management and adaptation options.
- Long-term monitoring and analysis of indicators of changes in upstream and downstream areas leading to the development of an integrated model of climate/environmental changes in different subbasins. This can contribute in sustainable land use and natural resources management in the basin.

The role of ICIMOD. Within its mandate to develop regional knowledge and as an enabling organization, ICIMOD is committed to (i) enhance the basin-wide exchange of data, information, knowledge, and good practices including traditional or local knowledge focusing the upper Indus Basin; (ii) strengthen the network of hydrometeriological stations, particularly above the timberline, to reduce the "data gap;" (iii) monitor the changing nature of glaciers in different subbasins and assess the vulnerabilities in form of natural and human-induced hazards and risks; and (iv) continue, in particular, to facilitate a regional knowledge platform involving all the stakeholders.

ICIMOD will specifically support (i) the creation of a favorable environment for the implementation of long-term climate change research and adaptation activities, (ii) capacity development of relevant national institutions to adequately monitor and project the impacts of climate change, (iii) harmonization of data/methodologies in view of the needs of end-users, and (iv) the development/updating of the knowledge and exchange platform.

In the above framework and rationale for a new and substantive phase of work, ICIMOD is ready and interested to work in close collaboration with ADB and other key partners in developing a long-term and cooperative result-based knowledge and development partnership in the Indus Basin.

Introduction

Climate change is posing a real threat to the economies of the world, and developing countries are particularly vulnerable. Global warming and the associated changes in precipitation, unexpected and extreme weather events, glacial melt, and sea-level rise, among others, are causing considerable impacts, direct and indirect, on socioeconomic and environmental sectors such as water, agriculture, health, biodiversity/ecosystems and land resources. These are increasingly threatening already stressed livelihoods, thus hindering the development process.

Extreme events, including floods, droughts, forest fires, and tropical cyclones, have increased in temperate and tropical Asia. Decreases in agricultural productivity and aquaculture due to thermal and water stress, sea-level rise, floods and droughts, and tropical cyclones would diminish food security in many countries. Runoff and water availability may decrease in arid and semi-arid areas, threatening human health by possible increased exposure to vector-borne infectious diseases and heat stress. Rising sea levels and an increase in the intensity of tropical cyclones would displace tens of millions of people in low-lying coastal areas. Increased intensity of rainfall would raise flood risks.

Climate change would increase energy demand, adversely affect transport, and decrease tourism in some parts of Asia. It would also exacerbate threats to biodiversity due to land-use and land-cover changes and population pressure. Pole-ward movement of the southern boundary of the permafrost zones of Asia would result in a change of thermokarst and thermal erosion, bringing negative impacts on social infrastructure and industries.

Besides being very vulnerable, the adaptive capacity of human systems is low in the developing countries of Asia (Intergovernmental Panel on Climate Change [IPCC] 2007). This is due to high levels of poverty, fragile natural resource–based economies, and low resilience to changing conditions.

Pakistan is a natural resource–based economy with more than a quarter of its land area (22.2 million hectares) under agricultural use. Due to its highly diverse physiographic and climatic conditions, it is classified into 11 geographical, 10 agro–ecological, and 9 major ecological zones. This unique geographical placement exposes the country to multiple threats; from glacial melt, natural disasters, and droughts, to sea-level rise. Pakistan also has low forest cover (4.5%), with a deforestation rate as high as 0.2%–0.4 % per annum. The country has a highly fragile economic base. In 2007, Pakistan's Human Development Index (HDI) ranked it 0.572 (141 out of 182 countries). Per capita gross domestic product (GDP) ranked it 125th in the world and wealth is distributed highly unevenly. One-quarter of the population in Pakistan is classified as poor.

2. Project Context

2.1 Project Background

ADB pledges to address the risks posed by climate change vulnerability through a variety of measures including:

- **Portfolio at-risk assessment** with improved understanding of climate risks and how best to respond to them through analysis of the ADB active loan portfolio;
- **Project screening** with improved understanding of project-level risks associated with climate change impacts, thus supporting mainstreaming of climate adaptation in ADB operations through, for example, climate proofing;
- **Country assessments** providing data and analyses to create adaptation road maps and analyzing gaps between country needs and current lending practices;
- **Climate proofing** helping to ensure that development projects are neither vulnerable to climate change nor exposed to its impacts;
- **Increasing sector resilience** by providing policy and technical guidance to address climate change and variability issues in agriculture, infrastructure, transport, health, water, and other sectors;
- **Addressing social dimensions** by improving the understanding of social dimensions such as migration, governance, the role of women, and resilience building in communities.

The ADB President approved the regional technical assistance "Promoting Climate Change Impact and Adaptation in Asia and the Pacific," on 21 November 2009, to

- strengthen regional cooperation on climate change,
- strengthen ADB developing member countries' response to climate change adaptation, and
- mainstream climate change adaptation considerations at ADB.

Technical assistance design includes the financing of Small Grant Adaptation Actions (SGAAs) to pilot-test, demonstrate, or further develop technical assistance outputs. The Central and West Asia Energy and Natural Resource Division submitted an SGAA proposal entitled, "Glacial Melt and Downstream Impacts on Indus Dependent Water Resources and Energy." The ADB Adaptation and Land Use Working Group approved it on 29 October 2008.

The International Centre for Integrated Mountain Development (ICIMOD) in collaboration with the International Union for Conservation of Nature (IUCN) signed a technical assistance contract with ADB to implement this project on 14 September 2009.

2.2 Project Rationale

As documented in other parts of the world, global warming is causing the retreat of glaciers across Asia, increasing overall climate variability and climatic extremes affecting water-dependent ecosystems and infrastructure with potentially immense downstream repercussions on livelihoods, food security, water security, energy security, and public safety in human settlements.

The Indus Basin is of major importance to the economies of several countries of South Asia. It consists of six main rivers (the Indus, Jhelum, Chenab, Ravi, Sutlej, and Kabul) originating from glaciers in the Western Himalayas and provides irrigation to more than 16 million hectares. of agricultural land and generates up to 13 gigawatts of electricity through hydropower plants in Pakistan, India, and Afghanistan. Glacial retreat and changes in precipitation patterns from anthropogenic climate changes are expected to alter river basin behavior significantly and jeopardize hydropower generation and the production of irrigated agriculture. Initial short-term increases in water flow may endanger the sustainability of downstream infrastructure. Expected long-term reduction in water flows will reduce power generation potential and irrigation supply, with dramatic effects on overall agricultural yields, consequently altering people's livelihoods. This will be particularly catastrophic for Pakistan where an estimated 50% or more of river runoff flowing into the Indus Basin Irrigation System originates from glacial melt (Archer 2001).

Moreover, the Indus Basin Irrigation System supports 75% of the country's cultivated areas and 34% of electric generation capacity. Similarly, loss in hydropower generation capacity may directly induce the carbonization of the power sector (countries returning to thermal power plants to make up for reduced hydropower potential). A resulting increase in greenhouse gas emissions would contribute further to atmospheric global warming and subsequent glacial melt.

Field observations, satellite imagery, and historical hydrologic records have been used to investigate the reduction of the Western Himalayan glaciers, but results fail to accurately document and sometimes even contradict climate impacts. Even with relative consensus on global warming, and recorded increases in overall regional temperature, uncertainties remain regarding glacial melt and climate impacts in the Western Himalayas. Consequently, predictive downstream impacts (in terms of both timeframe and intensity) are not sufficiently reliable to inform decision makers.

ADB's current loans/programs portfolio in the water and hydropower sector in Pakistan and Afghanistan include the

- $900 million Punjabi Irrigated Agriculture Investment Program in Pakistan (2006),
- Upcoming $300 million Water Resource Development Project in Afghanistan (which will include investment on the Kabul river),
- $400 million Sindh Water Development and Management Investment Program in Pakistan (2010), and
- $500 million Renewable Energy Development Sector Investment Program in Pakistan (2006) (which focuses essentially on hydropower generation).

These projects and programs rely heavily on Indus Basin water resources, which are dependent on downstream glacial outflows and stable upland mountain ecosystems.

These large-scale ADB-financed operations are located in two geo-climatic zones noted for their relative vulnerability to climate change impacts: fragile mountain ecosystem and river basins. In the first instance, this vulnerable zone is subject to accelerated and unprecedented threats such as increasing water flow patterns and downstream flooding due to irreversible glacial melt, fluctuations in temperature stressors, altered recharge to water catchment areas, onset of floral species, and human migration. In the second instance, impacts in this vulnerable geo-climatic zone include: runoff changes, riverine flash floods and siltation, and destabilized water-courses for the agriculture sector. The development and introduction of climate adaptive measures would help reduce some of the potentially adverse climate impacts on food production and environmental degradation, and build enough climate resilience in target watersheds to begin to address extreme events, climate variability, and disaster scenarios.

It becomes crucial to have a better understanding of global warming impacts on water, energy, and transport projects to inform future risk management development planning and introduce adaptive infrastructure design criteria. Without an acceptable level of precision through closing the knowledge gap at regional, national and project levels, developing member countries will not be able to achieve meaningful adaptation strategies and lower-risk investment portfolios.

3. Project Impact, Outcomes, and Outputs

3.1 Anticipated Impact of the Small Grant Adaptation Action

Better alignment of development projects sponsored by ADB and the Government of Pakistan, in the medium-term, to risk management and adaptation requirements supporting the water and hydro-energy sectors in the Indus Basin (Pakistan, Central and East Afghanistan, and North India), given the anticipated impacts of climate change and glacial melt in the Western Himalayas.

3.2 Expected Outcomes

- The Government of Pakistan and ADB have identified priority activities in research, policy, planning, institutional strengthening, and climate proofing of ADB project and program activities in the water and energy sectors in Pakistan and Afghanistan, where there are knowledge gaps to fill.
- Improved Pakistan and ADB operations to adapt to climate change in the project/program areas.

3.3 Five Outputs

Output 1: Gap analysis on the state of knowledge (hydrometeorological data analysis, modeling, impacts, risk analysis) in the Western Himalayas (Afghanistan, Pakistan, and North India), and ADB's water and hydro-energy project/programs. In particular:

- Critical review of current knowledge on impact and adaptation, and modeling and impact scenarios data for loan-related glacial and river basins;
- Inventory and review of current and planned climate impact and adaptation research and risk management capacity; and
- Identification of priority risk management and adaptation activities to be undertaken.

Output 2: Partnership(s) established with national and regional institutions (Global Change Impact Studies Centre [GCISC], Ministry of Environment [MoE], International Union for Conservation of Nature [IUCN], and other partners) to facilitate the Small Grant Adaptation Action.

Output 3: Presentation of a simple screening tool formulated in concert with the MOE, GCISC, IUCN, and other partners to begin addressing climate impacts on ADB's hydro-energy and water sectors project and programs portfolio in Pakistan and Afghanistan.

Output 4: Desk and field rapid climate impacts and risk screening of ADB's project portfolio and pipeline in the water and energy sectors in Afghanistan and Pakistan, for consideration and use in the proposed Phase II Climate Change Fund loans climate proofing.

Output 5: Potential Climate Change Adaptation Phase II activities scoped, costed, and discussed with the host government and other partners.

4. Climate Change in the Indus Basin: Current Understanding and Gaps

4.1 The Indus Basin

The Indus Basin is shared by five countries (Table 1): Afghanistan, People's Republic of China (PRC), India, Nepal, and Pakistan, with the largest portions of the basin (52.48%; United Nations Environment Programme [UNEP] 2002) lying in Pakistan and India (33.51%). The main river originates at Lake Ngangla Rinco on the Tibetan Plateau in the PRC (IUCN, undated), and includes the flow of the tributaries Ravi, Beas, and Sutlej in India; Swat, Chitral, Gilgit, Hunza, Shigar, Shyok, Indus, Shingo, Astor, Jhelum, and Chenab in Pakistan; and Kabul River draining parts of Afghanistan (Figure 1). The 10 square kilometers (km^2) of the basin covered by Nepal is negligible and therefore generally not considered.

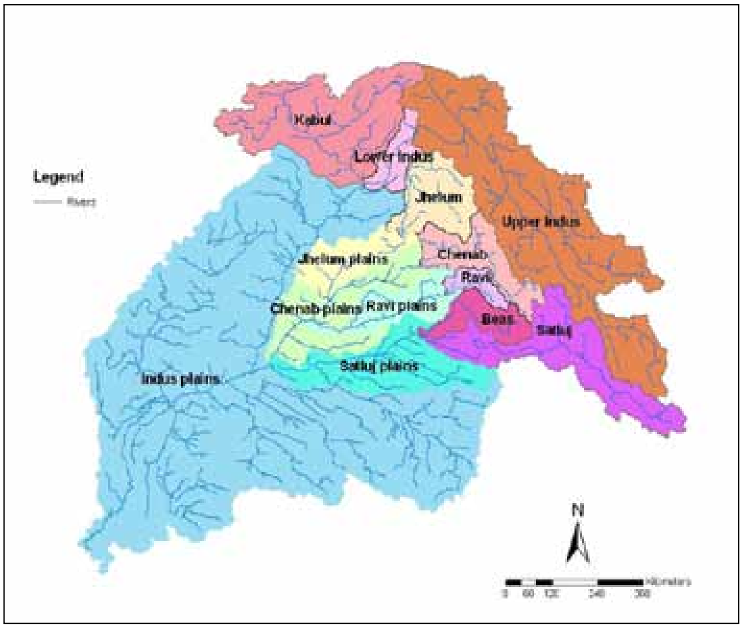
The river flows about 3,000 kilometers (km) through mountains, the plains of the Thar desert, and the deltaic ecosystems to the Arabian Sea covering an area of about 1,081,718 km^2 (IUCN et al. 2004), forming the sixth largest fan-shaped delta of the world (IUCN, undated). About 45% of the basin's area is below 1,000 meters (m) above sea level. (Myint and Hofer 1998) and considered to be lowlands, i.e., roughly about half of the basin area depends on the other half lying in uplands half that reach up to more than 8,000 m.

Table 1 Indus Basin and the different portions of different countries

Countries	Area of basin in country	
	km^2	%
Pakistan	597,700	52.48
India	381,600	33.51
PRC	76,200	6.69
Afghanistan	72,100	6.33
PRC control, claimed by India	9,600	0.84
Indian control, claimed by the PRC	1,600	0.14
Total basin area	**1,138,810**	**100.00**

km^2 = square kilometer, PRC = People's Republic of China.
Source: UNEP 2002.

Figure 1 Indus River Basin including subbasins



Source: Own compilation.

The Indus Basin is characterised by a very high percentage of dry land area: 63.1% of its area. Croplands are mainly distributed in the lower stretches of the river and form one of the world's largest irrigation systems (Messerli 1998), roughly about three times the size of Switzerland (Dudley and Stolton 2003). Farmers have used the waters of the Indus since prehistoric times, and irrigation from the Indus and its tributaries makes the cultivation of arid land along their courses possible (Kajander 2001). Forest cover is extremely low at 0.4% as more than 90% of the original cover has been lost mainly in the upper parts of the basin.

Importance of the Indus Basin

The Indus Basin ranks among the biggest basins of the world in terms of human dependence. The river supports a population of about 215 million people (UNEP 2008), whose livelihoods are directly or indirectly dependent on it. This leads to a very high population density in the basin and an approximate water availability of 1,329 cubic meters (m^3). Several large cities—11 according to IUCN et al (2004)—are located in the basin, including Amritsar and Hyderabad in India; Faisalabad, Islamabad, Karachi, Lahore, Multan, Peshawar, Quetta, Rawalpindi, and Sukkur in Pakistan.

The Indus River is the primary source of water for Pakistan. The basin is estimated to have a total hydropower potential of 55,000 megawatts (MW), out of which about 35,700 MW is technically feasible (Kugelman and Hathaway 2009). At present, only 6,444 MW, i.e., about 12%, has been developed. Socioeconomic development of Pakistan, thus, largely depends on optimal utilization and prudent distribution of the basin's precious water resources.

The intensive increase in the region's population in addition to recent climate changes has produced more stress on the water supply from the Indus Basin system. The lower part of the basin particularly is now one of the most water-stressed areas in the world and is going to deteriorate further to reach water scarcity (Briscoe and Qamar 2005). Further anomalous weather episodes may increase the risk of flooding and/or droughts in the area. In addition to these issues, the impact of climate change looms above the region. IPCC (2007) indicates the following expected pressures:

- By the 2050s, freshwater availability in Central, South, East, and Southeast Asia, particularly in large river basins, is projected to decrease.
- Coastal areas, especially heavily populated mega delta regions in South, East, and Southeast Asia, will be at greatest risk due to increased flooding from the sea and, in some mega deltas, flooding from the rivers.
- Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanization, industrialization, and economic development.
- Endemic morbidity and mortality due to diarrheal disease primarily associated with floods and droughts are expected to rise in East, South, and Southeast Asia due to projected changes in the hydrological cycle.

Indus Basin Knowledge Management Platform

The Indus basin has a rich but highly fragmented knowledge base. Many articles appear in international journals to which most of the institutions in the region do not have access. Many reports produced by institutions are not publicly available. As part of this project, a knowledge platform was initiated that will be further developed and continuously updated.

This knowledge platform, as was also proposed by Burton and van Aalst (2004) in the risk management approach with the aim of incorporating climate change adaptation into World Bank operations, is at the heart of the identification of current knowledge and gaps. The development of the application is described in detail in ICIMOD (2010d).

The database includes currently available published and unpublished research reports, papers, and project documents, among others, related to the project objectives. The documents were digitized and stored along with an executive summary, and are accessible to project partners. The knowledge platform also provides access to the following information:

1. Metadata or where possible actual hydrological, snowfall and meteorological data available from various organizations in summarized form for various subbasins;
2. Metadata or where possible actual satellite imagery, maps, video, etc.

Figure 2 The Indus Basin knowledge management platform: A screen capture

The platform is accessible under http://geoportal.icimod.org:8081/geonetwork/srv/en/main.home.

Physiographic Features of the Indus Basin

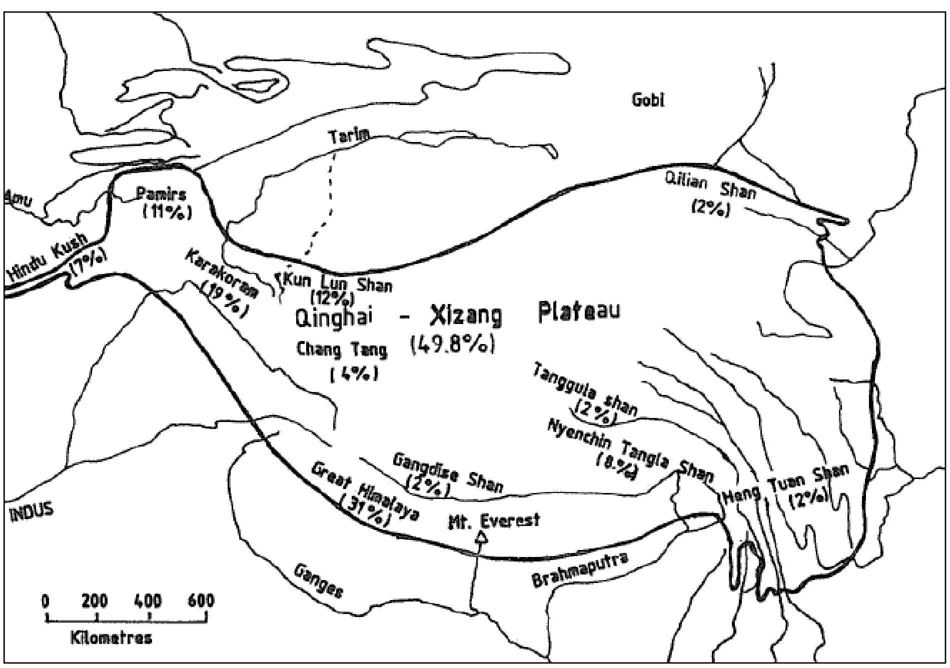
The upper Indus Basin is composed of mountainous terrains of the Hindu Kush, Karakoram, and Himalayan mountain ranges.

The Hindu Kush system stretches about 966 km laterally, and its median north–south measurement is about 240 km. Only about 600 km of the Hindu Kush system is called the Hindu Kush mountains. The rest of the system consists of numerous smaller mountain ranges. The Eastern Hindu Kush range, also known as the High Hindu Kush range, is mostly located in Northern Pakistan and in the Nuristan and Badakhshan provinces of Afghanistan.

The Karakoram is a large mountain range spanning the borders between Pakistan, India, and the PRC, located in the regions of Gilgit-Balistan (Pakistan), Ladakh (India), and Xinjiang region (PRC). It is one of the greater ranges of Asia, a part of the greater Himalaya, north of the actual Himalayan range. The range is about 500 km in length, and is the most heavily glaciated part of the world outside the polar regions (Kreutzmann 2006). The Siachen glacier at 70 km and the Biafo glacier at 63 km rank as the world's second- and third-longest non-polar glaciers.

The total glacier area in the greater Himalayan region is subject to large uncertainties and problems of geographic delineation. Bahadur (1993) estimated the total glacier area of the entire region including the Tibetan Plateau at 94,554 km^2. Figure 3 shows the contribution of glacier areas from the different mountain ranges in the region. Wagnon et al. (2007) reported 59,000 km^2 of glacier cover for the Hindu Kush, Karakoram, and Himalaya. Kotlyakov and Lebedeva (1998) indicated a glacier cover of 30,150 km^2 for the Hindu Kush Himalayas, i.e., 11% of the entire mountain range, is glacier covered. Dyurgerov and Meier (2005) report 33,050 km^2 for the Himalayas, and according to Collins and Hasnain (1995) the Himalayas has the highest glacier cover in the region. They reported a total glacier cover of 33,150 km^2 for the Himalayas followed by the Karakoram range with 15,670 km^2. Due to the smaller area of the

Figure 3 Distribution of glaciers in the Greater Himalayan Region



Note: Percentage glacier area is shown in brackets for various mountain systems.

Source: Lin and Xu, cited in Bahadur (1993).

latter range, the percentage glacier cover here is greater than in the Himalaya. According to Hasnain (2000), 17% of the Himalaya and 37% of the Karakoram are covered by glaciers. The values reported in Table 3 are in the same order of magnitude for the two different ranges.

Raina (2009) reports 7,997 glaciers in the Indus Basin with a total area of 36,431 km^2 and 1,578 glaciers in the Ganga Basin with a total area of 3,787 km^2. India's parts of three major rivers—the Indus, the Ganga, and the Brahmaputra—contain 3,538 glaciers in the Indus Basin, followed by 1,020 in the Ganga Basin and 662 in the Brahmaputra Basin (Hasnain 2000; World Wildlife Fund 2005). The part of the Indus Basin within PRC territory has a glacier cover of 1,451 km^2, with 2,033 glaciers (Li et al. 2008).

The inventory of glaciers in the Northern Areas of Pakistan described in Pakistan Agricultural Research Council's study (2005) identified 5,218 glaciers with a total area of 15,040.8 km^2, or 11.7% of the total area (Table 2). This includes some of the longest glaciers outside the polar region, including the Siachen (76 km), Hispar (61 km), Biafo (60 km), Baltoro (60 km), Batura (64 km), Yenguta (35 km), Chiantar (34 km), Trich (29 km), and Atrak (28 km) glaciers. Taking into account the glacier contributions within the territory of India and PRC, the upper Indus Basin contains about 22,000 km^2 of glaciers (Fowler and Archer 2005).

A similar inventory in Himachal Pradesh showed the largest number of glaciers in the Sutlej River Basin followed by the Chenab River Basin (Table 3). In terms of area, the glaciers in the Chenab Basin are larger followed by the glaciers of the Sutlej, and the same is true for the ice reserves.

Table 2 Glacier inventory in the Northern Area of Pakistan

Basins	**No. of Glaciers**	**Glacier area** (km^2)	**Ice Reserves** (km^3)
Swat	233	223.55	12.22
Chitral	542	1903.67	258.82
Gilgit	585	968.10	83.35
Hunza	1,050	4,677.34	808.79
Shigar	194	2,240.08	581.27
Shyok	372	3,547.84	891.80
Indus	1,098	688.00	46.38
Shingo	172	36.91	1.01
Astor	588	607.03	47.93
Jhelum	384	148.18	6.94
Total	**5,218**	**15,040.80**	**2,738.51**

km^2 = square kilometer, km^3 = cubic kilometer.
Source: Pakistan Agricultural Research Council 2005.

Table 3 Glacier inventory in Himachal Pradesh only within Indus basin

Basins	No. of glaciers	Glacier area (km^2)	Ice Reserves (km^3)
Beas	358	758.2	76.4
Ravi	198	235.2	16.9
Chenab	681	1,704.7	187.7
Sutlaj	945	1,217.7	94.5

km^2 = square kilometer, km^3 = cubic kilometers
Source: Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University, 2005.

Climate of the Indus Basin

Mountain climate

The mountain climates of the Indus Basin are influenced by the broad global circulation patterns associated with latitude, position in the continental mass, and proximity to oceans. This causes monsoon precipitation to be dominant on the southern foot slopes of the mountain ranges, while winter rains caused by westerly disturbances are bringing winter rains in the Karakoram and the Hindu Kush. The climates in these areas are dominated by a vertical component due to large elevation differences that exist in the area. Snow is an important component of the climatology.

In winter and spring, the upper Indus Basin is affected by broad-scale weather systems originating from the Mediterranean or from the area of the Caspian Sea. During the pre-monsoon season, precipitation is controlled by air mass convective storms and by monsoon systems during the summer. Wake (1987) indicates that even in the summer monsoons at least some of the higher-level precipitation also originates from westerly systems.

Overall, Archer (2001) notes that in winter, under the prevailing influence of the Tibetan anticyclone, more local conditions prevail. In addition to the influence of global weather systems, mountain climates are also influenced on the medium and local scale by elevation, valley orientation, aspect and slope, and height and the number of upwind barriers to the airflow. The bulk of the snowfall derives from westerlies during the winter half of the year (Hewitt et al. 1989). For the Nanga Parbat massif with its geographic location in the southern part of the Himalayas, the dominant source for precipitation is the monsoon (Cornwell et al. 2003). The westerly depressions during the winter season are only a secondary source.

Distinct summer and winter precipitation patterns dominate the Indus Basin's climatology. During summers, monsoon circulation (because of differential heating of sea and land and from subtropical jet stream) brings rains to the plains of Kashmir, Punjab, and Khyber Pakhtunkhwa, after striking the ridges of the Himalayas and Karakoram. Sometimes, monsoon depressions are so strong that its impacts are recorded at Biafo glacier to much higher elevations (Wake 1979). During winters, depressions flowing in the westerlies are conspicuous. Westerly air masses take moisture from the Mediterranean, Caspian, and Black seas and deliver precipitation over the HKH range, both as snowfall and rainfall. These are the biggest sources of nourishment for Hindu Kush Himalaya (HKH) glaciers in winters, which ultimately keep the Indus River system flowing in summers. Archer and Fowler (2005*)* have found teleconnections between El Niño Southern Oscillation (ENSO) and the westerly depression over the HKH and reports that the HKH has received below normal precipitation in ENSO years.

On the basis of studies in the Chenab River Basin in the Western Himalayas, Singh et al. (1995) concluded that the role of orography is very pronounced for both rainfall and snowfall, albeit more in the middle Himalayas than in the other two ranges, the outer and greater Himalayas. Seasonal and annual rainfall increases linearly with elevation in the outer Himalayas on both windward and leeward sides, except during monsoon season, when rainfall increases with elevation up to a certain height and then starts decreasing. Maximum rainfall occurs at about 1,750 millimeters (mm) at about 600 m on the windward side. In the greater Himalayas only 433 mm is observed. In the middle Himalayas, 1,159 mm, is recorded, indicating that moderate rainfall is experienced in the outer and middle Himalayas, whereas less rainfall is experienced in the greater Himalayas.

In general, monsoon rainfall is found to be dominant in the outer and middle Himalayas. It has been noted that monsoon rainfall contributes about 46% and 41% to the annual rainfall of the outer and middle Himalayas, respectively. In the greater Himalayas the contribution of pre-monsoon rainfall to annual amount was found to be a maximum of 41%. Post-monsoon rainfall contribution was always least all over the Himalayan ranges. Generally, maximum rainfall is observed in the month of July over the outer Himalayas, in March and July over the middle Himalayas, and in May over the greater Himalayas. In many northern valleys of the upper Indus Basin, only a small proportion of the annual rainfall occurs during the summer months (Archer 2002). Snow may occur at higher levels even in summer and thus not contribute to river flow directly.

According to Singh et al. (1995), snowfall starts at an elevation of about 1,300 m in the Western Himalayas, and at about 3,000 m the percentage of solid and liquid precipitation is equal. Below 3,000 m rainfall dominates annual precipitation, and above 3,000 m snowfall dominates. Snow contribution increases further with increasing elevation, reaching about 75% at about 4,325 m. Due to lack of data above this point, the exact elevation where precipitation only falls as snow cannot be determined. Missing stations at these altitudes is the biggest problem for quantitative analyses of the vertical distribution of precipitation in the study area (Kolb 1994). Singh et al. (1995) expect that above 6,000 m precipitation may only occur as snowfall. According to Hewitt and Young (1993), this already occurs at 4,800 m.

The entire upper Indus Basin is snow-covered for sometime in winter (Hewitt et al. 1989). The maximum seasonal snow cover area generally exists in March, when most of the snowfall has occurred and melting has not yet started (De Scally 1994; Singh and Kumar 1997). In areas below 3,500 m the snowpack is usually less than 150 mm, while in higher areas at 5,000 m snowfall increases to about 1,500 mm. As Hewitt et al. (1989) indicate, 90% of the Indus Basin above Tarbela reservoir may be covered by snow. Commonly more than 70% and, in poor years, less than 60% of the area above the reservoir is covered by snow.

On average, the greater Himalayas experience lower snowfall than the middle Himalayas (Singh et al. 1995).

It was found that average number of snowy days increases with elevation while the intensity decreases. Mostly maximum snowfall is experienced in the months of January and February in the middle Himalayas and in March in the greater Himalayas. Snowfall increases linearly with elevation on the windward side of the middle Himalayas and in the greater Himalayas, whereas on the leeward side of the middle Himalayas it follows the trend of rainfall. Maximum snowfall is observed at about 2,500 m elevation on the windward and at 1,800 m on the leeward side of middle Himalayas.

Temperature regimes are likewise very variable with elevation and exposition. In the valleys, temperatures can exceed 40°C occasionally and throughout the year, while exposed sites with southerly aspect can be much hotter. Goudie et al. (1984) measured up to 50°C on rock surfaces which they expect to be exceeded on a number of times. In winter, freezing conditions extend down to the valley floors of the Hunza valley.

This variability indicates that freeze-thaw conditions are found below 3,000 m for about 3 to 6 months during October to April, 3 months in each spring (April to June); and in autumn seasons (September to November) at between 3,000 m and 5,500 m, while freeze-thaw is observed only during summer at above for a few months (Hewitt et al. 1989). From a hydrological point of view the upper zone is one of continuous frost (Archer 2004). In this zone precipitation falls as snow and there is virtually no direct contribution to river runoff.

The contribution to runoff is indirectly through snow avalanching and glacier flow towards lower zones. In the middle zone, precipitation may fall as rain or snow, and frequent freeze-thaw cycles occur. During daytime snow on the ground melts, and then partially re-freezes at night. The lower zones, where temperature is continuously above freezing temperature, experience mainly rainfall and only very occasional snowfall. Any snow that falls melts immediately.

Based on analysis of meteorological normal data (1961–1990), Rasul et al. (2010) described the climatic features of upper Indus Basin in the observation regime of Pakistan Meteorological Department ranging from about 1,000 m to 3,000 m. Generally, the region exhibits semi-arid to arid zones of climate, where winter precipitation dominates and extreme temperatures occur in both summer and winter. At elevations of 1,000 m to 1,300 m, day temperatures in summer touch the 40s and the mercury rises to the mid-1930s at 1,300 m to 2,000 m. Higher elevations (over 2,400 m) seldom experience days with 35°C. The contribution of the summer monsoon is minimal but winter precipitation is persistent from December to May, gaining its maxima in February and March. The amount of precipitation does not have any relationship with elevation; rather it varies with the orientation of terrain and windward exposure to the seasonal wind pattern. For instance, Dir, which lies at 1,369 m, receives more than 1,400 mm total annual precipitation and Skardu, at the higher elevation of 2,209 m gets about 200 mm.

Hydrology of the Indus Basin

The discharge of the Indus River depends heavily on runoff produced in the mountainous part of the basin through snow and glacial melt. Estimates, however, vary greatly among different authors (Table 4).

Hydrological regimes

Discharge of the Indus River and its tributaries from the Himalayas, Karakoram, and Hindu Kush largely depends on runoff from glacier and snowmelt. While different authors agree on the importance of glacier and snowmelt, estimates differ between different rivers, and from author to author. Three distinct hydrological regimes are observed:

- Summer volume governed by melting of glaciers and permanent snow
- Melt of seasonal snow
- Winter and monsoon rainfall controlled mainly by liquid precipitation

A number of studies have applied hydrological models to subbasins of the Indus Basin. The application of comprehensive models for the runoff-generating uplands and the water-demanding lowlands is largely missing.

According to Viviroli and Weingartner (2002), 60%–100% of the flow in the Indus originates from the mountains. Especially during the dry season the flow from the mountains is extremely important and accounts for up to 100% of total flow. According to studies cited in Barnett et al. (2005), melting snow and ice contribute about 50%–60% of the summer flow in different rivers including the Sutlej and the Chenab during the seasons before and after precipitation from the summer monsoon.

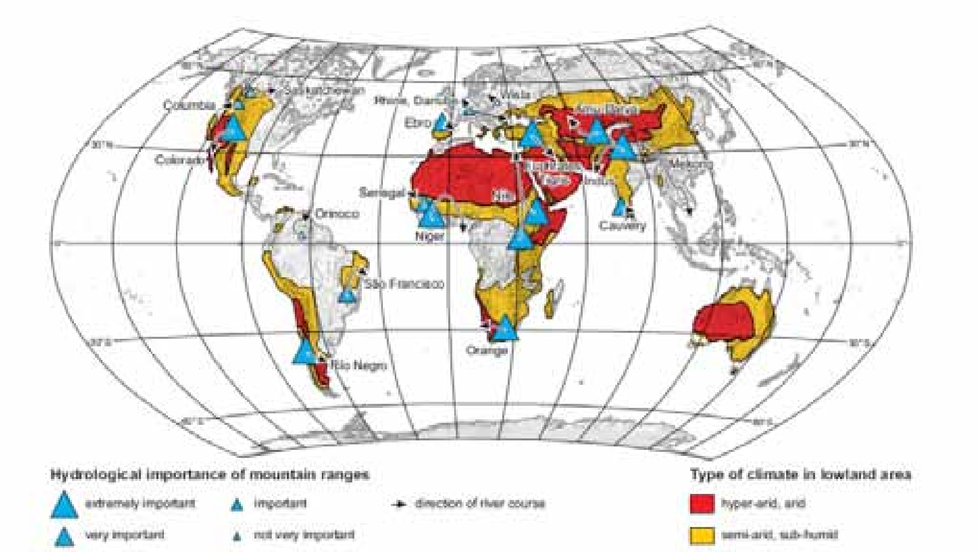
Winger et al. (2005) estimate that about 50% of total annual runoff in the Indus River irrigation systems in Pakistan is dependent on snow and glacial melt from the eastern Hindu Kush, Karakoram, and Western Himalayas. According to estimates of Hewitt et al. (1989), snow and ice meltwater supplies 75% of the flow of the Kabul River at Warsak, 80% of the Swat River, 85% of the main Indus River at Tarbela reservoir, and 65% of the Jhelum River at Mangla reservoir. Archer (2003) indicates these flows are primarily controlled by winter precipitation and energy inputs during summer.

Table 4 Estimates of snow and ice melt contribution to total flow in the Indus basin

Estimate (%)	Location	Source
85	Total runoff from high altitude belt	Krenke and Gennadyi (1998)
80–85	Indus flow at Besham	Hewitt (1998), Hewitt et al. (1989); Young and Hewitt (1990)
80	Swat River	Hewitt (1989)
~70	Annual flow of Indus without Ravi and Sutlej	Tarar (1982)
75	Kabul River at Warsak	Hewitt (1989)
70-80	Annual flow of Indus	Shah et al. (1998)
65	River Kunhar	De Scally (1994)
65	Jhelum river at Mangla	Hewitt (1989)
60–100 (100 during dry season)	Indus Flow at Kotri in comparison with Attock	Viviroli and Weingartner (2002)
59	Sutlej River at Bhakra	Singh and Jain (2002)
55	Mean annual flow of Indus, Chenab, Sutlej and Kabul	Dey and Goswami (1984)
50 or more	Indus Irrigation Scheme in Pakistan	Winiger et al. (2005)
Up to 50	Average flow	Eriksson et al. (2009)
49	Chenab River at Akhnoor	Singh et al. (1995)
40–50	Annual flow of main tributaries including Kabul, Jhelum, and Chenab	Shah et al. (1998)
35	Annual flows at Pandoh dam	Singh (2009)
35	Annual flow at Kotri in relation to flow in Besham, i.e., 17% of the total area	Collins and Hasnain (1995)

Source: Own compilation.

Figure 4 Hydrological importance of mountain ranges



Source: Viviroli et al. 2004.

Figure 4 shows the importance of the Indus River as a "wet island" for its arid and semi-arid basin areas in the lower-river stretches. The contributions of the main rivers measured at the foot of the mountains are 13% from the Kabul, 37% from the Indus, 14% from the Jhelum, 15% from the Chenab, 4% from the Ravi, 7% from the Beas, and 10% from the Sutlej (Messerli 1998). Less than 10% of the average runoff is the result of rainfall over the Indus plains.

Another measure to show that most of the flow of the Indus River originates in the Hindu Kush and the Himalayas is the specific discharge, i.e., the mean discharge divided by the basin area. During the course of flow, the river crosses the very dry areas of Punjab and Sindh provinces of Pakistan, where there are very few tributaries. As a result of this, its specific discharge is very low with a mean specific liquid runoff of only 3 $l/s*km^2$ and comparable with the other river of the region that passes through an extensive dry land area of the Loess Plateau, the Huang He in the PRC. The other rivers of the region have much higher specific discharge (Table 5).

Discharge in the Indus River and its tributaries shows high seasonal variability. Mean annual runoff estimated at 2,425 cubic meters per second (m^3/s) for the period 1969 to 2001 varies annually from 80% to 130% of the mean (Archer and Fowler 2005). These variations are due to glacial melt, which is responsible for 20–50 times higher discharge values during summer than during the winter season (Kolb 1994). Kolb observed that variations in rivers mainly fed by glacial melt are higher than variations of rivers mainly fed by snowmelt. Alford (1992) also suggests that annual variations in runoff in the Karakoram depend primarily on melting rates in summer and that a sunny summer can be expected to give higher runoff at the expense of glacier storage. Stream flow abruptly changes on a cloudy day or during snowfall, halting glacier melting.

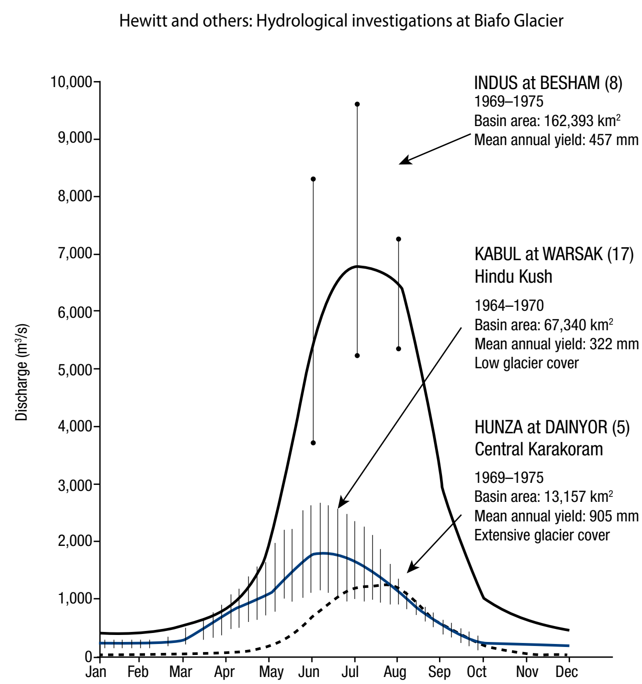
Discharge at all stations of the upper Indus Basin shows higher summer values compared to lower winter values, indicating high contributions from snow and glacial melt (Kolb 1994). Maxima at these stations are expected between June and August, where an early peak in June indicates particularly an influence of snowmelt, and a peak in July to August the influence of glacial melt (Figure 5). The snow and glacier melt peaks coincide with the monsoon influence in the lower parts of the basin, often masking the role of the major role of meltwater in the basin hydrology (Hewitt et al. 1989).

Table 5 Discharge of the main rivers in the Hindu Kush Himalaya Region

River	Mean discharge (m^3/s)	Mean specific discharge ($l/s*km^2$)
Indus[1]	3,850	3.0
Ganges[1]	15,000	14.0
Yarlungtsangpo–Brahmaputra[1]	20,000	21.3
Lancang–Mekong[1]	15,900	20.0
Nujiang–Salween[2]	4,980	18.3
Irrawaddy[2]	13,000	31.6
Huang He (Yellow River)[1]	1,365	3.1
Yangtze[1]	35,000	17.8

m^3/s = cubic meter per second.
[1] Messerli (1998), [2] Kajander (2001).
Source: Own compilation.

Figure 5 Maximum, mean and minimum monthly discharge for three Indus Basin rivers



km^2 = square kilometer, m^3/s = cubic meter per second, mm = millimeter.
Source: Young and Hewitt 1990.

Archer (2003) investigated the broad characteristics of hydrological regimes in different parts of the upper Indus Basin by developing relationships between climatic variables and stream flow from 19 long-term stations. He identified three distinct hydrological regimes with:

- Summer volumes governed by melt of glaciers and permanent snow (**thermal control in the current summer**). Catchments with these regimes are located in the high-altitude Karakoram and have a large glacierized proportion. These include the Hunza, Shigar and Shyok rivers.
- Melt of seasonal snow (**control by preceding winter and spring precipitation**). These are middle-altitude catchments south of the Karakoram including the Astore, Kunhar, and Swat rivers. The Gilgit River and the Indus above the Shyok confluence show the same regime.
- Winter and monsoon rainfall and controlled mainly by liquid precipitation (**precipitation control in current season**). These catchments are located in the foothills and include the Khan Khwar and Siran rivers.

Kolb (1994) presented four regimes for basins of the upper Indus Basin: nival–alpine, nival–glacial, glacial–nival, and glacial regimes. These regimes coincide with the two first regimes mentioned above but subdivide the second regime on the basis of the degree of influence from glacial/snowmelt. The latter regimes are governed by snow accumulation of the preceding winter months, whereas the glacial regime is driven by temperature and solar radiation conditions of the current summer.

It is shown that the daily minimum temperatures are closely correlated to the daily runoff values. Summer precipitation is not reflected as increased discharge, rather as decreased runoff because of reduced radiation and sunshine duration during these times and increased albedo (reflection) because of fresh snow on the firn (compacted snow) and glacier areas.

Singh et al. (1995) describe the river regime of Chenab River at Akhnoor. On the basis of a 10-year time series, it was concluded that 32.6% of the annual flow is observed in the pre-monsoon period (April–June) and 51.1% in the monsoon period (July–September). The source of the runoff is identified as from a combination of rain, snow, and glacial melt with the contribution from glaciers starting in June/July. The remaining runoff derives from occasional rainfall and sub-surface and groundwater flow, and occurs from October to December and January to March with 7.6% and 8.7%, respectively.

All the hydrological action, as Hewitt et al. (1989) terms runoff generation in this context, takes place in the zones above 2,500 m. Melt mainly occurs in a belt between 2,500 m and 5,500 m, above which there is high snowfall and snow accumulation, but little melting leading to large stores of snow and ice. Below 2,500 m there is little precipitation and high evaporation. According to Shah et al. (1998), this zone of meltwater origin is in the altitude belt between 3,000 m and 5,000 m. Hewitt et al. (1989) estimate that more than 80% of the flow from the upper Indus River is derived from less than 20% of the basin area, essentially from zones of heavy snowfall and glaciers above 3,500 m. Studies by Hewitt et al. showed that runoff from the Biafo glacier with an area of 0.09% of the whole upper Indus Basin, accounted for 0.9% of the total runoff.

Issue 1: Scarcity of automatic weather and hydrological stations in the glacierized areas

The present network including all stations of national and international organizations does not serve the purpose of representing the heterogeneous mountain terrain. Climate varies between valleys and mountain tops, between aspects and orientation, and between different locations. To meet the optimum observational demands, at least 75 automatic weather stations and 35 hydrological measurement stations should be installed in the mountain areas. This would allow effective modeling of the hydrodynamic characteristics of these areas.

Runoff generation and temporary retention mainly depend on the climatic variables and only to a lesser extent on vegetation and hydro–geological characteristics (Kolb 1994). However, in areas with high influence of glacial and snowmelt, high storage is achieved in snow and ice. Archer and Fowler (2005) found winter precipitation strongly correlated with summer runoff of snow-fed catchments. In contrast, they found no significant correlation in predominantly glacier-fed catchments. In these catchments summer runoff shows significant positive correlation with summer temperatures. On middle-altitude snow-fed catchments, runoff is negatively correlated with temperature as increased temperature results in increased evaporative loss and (since snow cover volume is limiting) reduced runoff. On the foothill catchments, significant correlation was found with spring (April–June) but not with summer runoff.

As Archer (2003) mentions, these results have practical consequences for flow forecasting on the Indus River. He mentioned that precipitation measurements at standard valley climate stations can be used as to forecast the volume of flow originating in the upper Indus and the Astore, Swat, and Jhelum rivers, with a lead-time of 3 months or more. However, flow originating in high altitude snowfields and glaciers of the Karakoram is little dependent on snow-covered area. Control of runoff by the energy balance, as indexed by the temperature of the current season, implies that seasonal flow forecasting from this region will be more appropriately based on statistical properties of the time series, including serial correlation. The strong serial correlation during the seasonal hydrograph recession in winter may be used as a basis for low flow forecasting. However, in many cases where monsoon rainfall occurs at valley sites there is paradoxically a decrease in river flow (Archer 2002), which is explained by the fact that rain occurs under cloudy skies with depressed temperatures and thus, a reduced glacial melt rate outweighs the rainfall inputs to the catchment.

For the Jhelum River, De Scally (1994) showed strong correlations between point measures of snow accumulation and annual discharge, especially the annual maximum of snowpack water storage and total winter precipitation. Summer precipitation on the other hand did not show any good results in estimating annual flows from this river in the Mangla dam. On the basis of the unique feature that adjacent Himalayan rivers show a high degree of correlation of concurrent flows, Dey and Goswami (1984) analyzed mean monthly concurrent flows in the Indus, Kabul, Sutlej, and Chenab rivers of the Western Himalayas during the snowmelt season, April through June, for the period 1975–1979. They then compared these results with correlations between river flow and snow cover data. They were able to show that in all the basins under study, the correlation of concurrent flows explained the variability in flow better than the model correlating snow-covered area with runoff. They, however, cautioned that this model with concurrent flows is only applicable for extension of records and filling of gaps and missing records.

A number of modeling studies have been conducted on the main Indus River or any of its tributaries including Shah et al. (1998); Singh (1998); Singh and Kumar (1997, 1998); Singh and Quick (1993); Quick and Singh (1992); Saeed et al. (2009); Jain et al. (1998, 2009); Rees and Collins (2006); Akhtar et al. (2008); Immerzeel et al. (2008); Singh and Bengtsson (2003, 2005, 2008); Singh and Jain (2003); Rathore et al. (2009); and Kulkarni et al. (2002). However, these modeling studies are generally focusing on a particular area within the entire Indus Basin and, to the knowledge of the authors, there is no comprehensive basin-wide modeling study.

Issue 2: Lack of basin and transboundary modeling excercises

Glaciers in the uplands of the Indus including the eastern and western rivers are the lifeline of Pakistan's economy. They provide water downstream thus making the country the most vulnerable to changes in glacial melt. To improve the understanding of the glacier–hydrology relationship and dynamics under climate change, hydrological modeling at different scales is crucial. A strong research base on glacial hydrology and modeling is essential to devise relevant sector-wide measures to better adapt to these challenges. Currently most water resource–modeling exercises are confined to a small and focused area, but there are none for the entire Indus Basin that take into account the data from all riparian countries. This requires data sharing among the riparian countries, transboundary technical collaboration, and the parametrization of a basin water resources model that accounts for the specificities of glacial areas, snowmelt, and mountain heterogenities in spatial characteristics and input parameters.

4.2 Climate Change Impact on Climate and Water Resources

Observed Climate Change and Variability

Precipitation and temperature have shown different trends in different locations of the Indus Basin, while various studies come to various conclusions. Precipitation in the northern areas of Pakistan seems to have increased and temperature has shown different trends in different seasons. There seems to be more rainfall than snow. In the Kabul River Basin, the indications are that mean annual temperature is increasing. Mean rainfall over the same period has decreased slightly, mainly due to a decline in spring precipitation. This combination of factors has led to a prolonged drought in recent years. In the Western Himalayas, decreasing annual precipitation and warming trend is observed overall, leading to drier conditions there. However, a transboundary assessment of the trends is missing as all analyses focus on areas within a single country. There is no general agreement on the processes.

In terms of impact of climate change on river flows, there is no indication at present of changing flows in the main stem of the upper Indus River. A decreasing trend is observed on Kabul River and in the lower stretches of the Indus Basin at Kotri Barrage. There is no conclusive answer in the case of glacier dynamics. In general, glaciers are retreating with the exception of some glaciers in the Central Karakoram.

Climate change projections are inconclusive for this scale. In general, an increase in temperature is expected along with, in most areas, a decrease of precipitation. To make these projections useful for planning purposes, there is a need to reduce the uncertainties and increase the spatial scale.

Precipitation regime

Rasul et al. (2010) analyzed the precipitation pattern based on data collected at stations of the meteorological network of Pakistan Meteorological Department (PMD) and pointed out that the dominant wet season in the upper Indus Basin extends from December to May, reaching the maxima around March–April, while in earlier years the peak used to be in February–March. From December to mid-March, precipitation falls in the form of snow and afterwards, rainfall dominates—although some spells of snowfall have been recorded until early May (up to 3,000 m above mean sea level). They have investigated that the solid precipitation maxima has shifted toward the end of winter; i.e., instead of January, heavy snow falls in February.

Strong monsoonal currents yield precipitation above elevations of 1,500 m in case of windward orientation of terrain, but such events range between two and four for the whole season. Therefore, these areas share meager rainfall during monsoon season. On average, the monsoonal contribution in the upper Indus Basin ranges from 20% to 30% of the total annual precipitation, with the exceptions of the Western Hindu Kush (Chitral) as low as 5%. No significant change in monsoonal precipitation contribution has been observed. However, at lower elevations (such as Dir and Saidu Sharif) both winter and summer precipitation occurs at about 60:40 ratio and a little increase in monsoon share has been noted. The same ratio reverses in monsoon zone comprising northeast Punjab, and upper Khyber Pakhtunkhwa.

Although the rate of increase of temperature in the upper Indus Basin during the last 50 years was greater than that in the lower parts of Pakistan, no significant increase has been noticed in extreme precipitation events. The intensity (20 mm–40 mm per day) and frequency (2–5) remained same as in the past 50 years. However, a shift in snow maxima has been observed from January to February. Six years out of this decade (2000–2010) experienced this displacement.

Rasul et al. (2010) adopted Normalized Difference Snow (NDS) Index to calculate the snow cover area in the upper Indus Basin for the last 10 years. The data was used in a snowmelt runoff model to make reliable estimates of stream flow. Areal snow cover of the winter season facilitates the scientists and engineers to evaluate the quantity of available water in summer times. Table 6 presents the snow cover area estimation study.

The results clearly indicate that the snow accumulation starts in October when temperatures drop below freezing in most of the upper Indus Basin and daytime heating loses its potential to melt fallen snow. Peak values are reached in spring until rain predominates. As the temperatures pick up their rhythm, the melting process accelerates and accumulated reserves deplete at much faster rates. The lowest snow coverage can be found in most of the cases during August and sometimes in September.

No uniform increasing or decreasing trend in areal snow cover can be seen in the upper Indus Basin. However, very heavy snow storms in early winter have been recorded in 2001, 2004, and 2009. Of all Himalayan river basins, the water resources of the Indus Basin are most dependent on snow and ice melt and large parts are snow-covered for prolonged periods of the year (Immerzeel et al. 2008). That being said, on the basis of Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover data from 2000 to 2008, a significant negative snow cover trend is found in the upper Indus Basin during winter. This is in contrast to the other seasons and for the entire Himalayas and Tibetan Plateau, where no significant snow cover trends have been identified.

PMD studies (2009) have revealed the trends in annual and seasonal patterns of precipitation regime over the past several decades. Based on meteorological data collected at PMD stations during the period 1960–2007, a time series has been drawn incorporating deviations from the normal (1971–2000) (Figure 6). It shows that the decade of 1960s was much drier than recent decades and that low rainfall continued until the mid-1970s, and was followed by a wetter period until being disrupted by El Niño in 1998.

Under the influence of the El Niño weather pattern, precipitation dropped drastically throughout Pakistan resulting to scanty rainfall both in the summer and winter seasons. That El Niño–induced

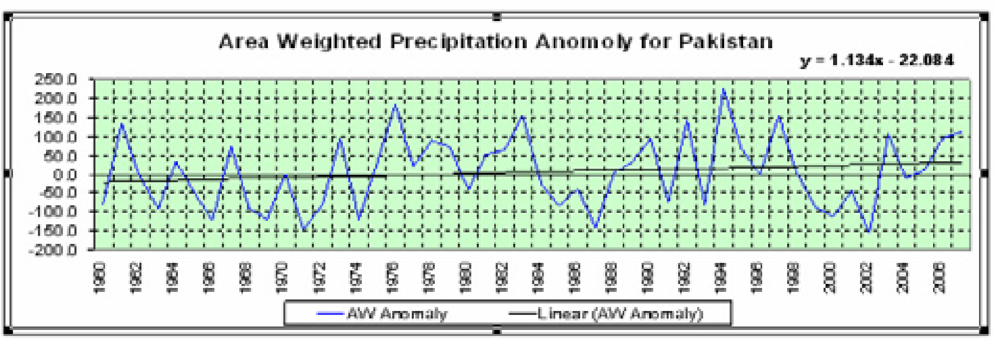
Table 6 Areal snow cover based on MODIS imagery, March 2000 to April 2010 for upper Indus Basin (square kilometer)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	NA	NA	74,532	62,157	32,840	24,004	13,088	10,452	13,496	23,677	35,975	55,244
2001	37,581	47,586	65,903	59,414	31,920	22,642	14,578	9,254	20,682	17,126	48,307	51,501
2002	56,224	63,605	66,148	68,596	52,315	31,175	13,930	10,261	20,734	18,816	28,960	35,329
2003	52,781	69,924	77,710	68,947	60,388	38,915	14,729	12,097	17,892	36,179	40,285	36,716
2004	56,363	75,231	61,734	57,831	52,948	25,129	23,165	13,493	16,807	40,441	43,448	35,835
2005	78,462	89,297	65,977	70,831	56,353	44,571	23,475	11,921	11,315	24,282	31,814	41,205
2006	44,587	71,482	63,392	67,599	43,421	26,591	12,498	11,285	13,887	11,446	32,406	53,996
2007	52,768	53,411	NA	57,154	35,905	23,940	16,696	16,763	16,712	16,926	20,087	38,662
2008	47,987	64,919	57,718	55,661	42,083	22,566	10,693	13,798	13,338	25,931	30,668	38,300
2009	50,214	66,840	66,526	60,007	55,397	34,160	21,744	19,171	16,681	22,856	44,780	45,329
2010	42,842	67,399	69,099	68,471	NA	NA	NA	NA	NA	NA	NA	NA

MODIS = Moderate Resolution Imaging Spectroradiometer, NA = no data available.

Source: Rasul et al. 2010.

Figure 6 Interannual variability and general trend of area weighted Pakistan precipitation

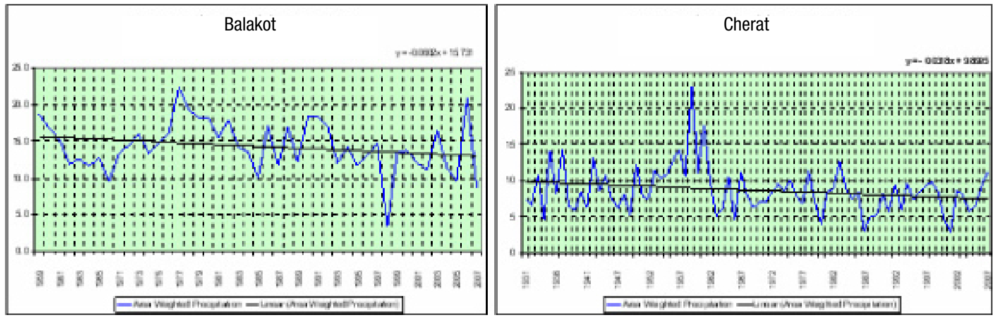


Source: Pakistan Meteorological Department 2009.

shortfall of precipitation triggered the worst drought in Pakistan's history in terms of length and intensity, from fall of 1998 to spring 2003. The rising trend since then is embedded by an increased frequency of heavy downpour events.

In Figure 7, the annual precipitation trend at two mountain stations in the upper Indus Basin are presented using PMD data from 1960 to 2007. Both show the gradual decreasing trend, except for some well-marked wetter anomaly for a few years in the 1970s. The El Niño shock wave was also felt at these stations. They both received winter and monsoon rainfall.

Figure 7 Inter-annual variability and general trend of area weighted precipitation at Cherat and Balakot



Source: Rasul et al. 2010.

Figure 8 presents the anomalies of annual precipitation noticed during the recent decade against the long-term average of 1971–2000 for 28 stations of Pakistan.

The southernmost station, Badin, is placed on the left end and latitude increases toward the right showing Drosh as the northernmost meteorological station. A slight increase can be seen in the southern half of Pakistan whereas most of the stations in the northern half show significant deficits in annual total precipitation. Similar results with an increasing deficit are shown in the case of summer precipitation in Figure 9.

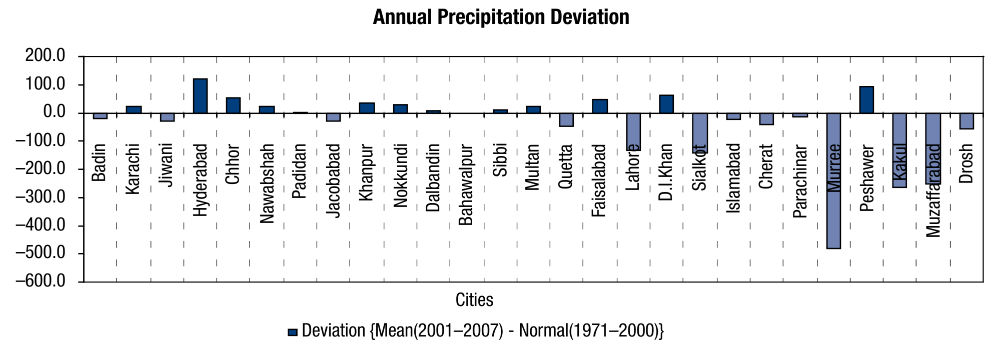
In addition to snow and glacial melt, monsoon precipitation provides the necessary water resources. Monsoon precipitation falls in summer from July to September. It not only caters to the peak power supply demands, but also fulfills the highest water demands of field crops and gathers the reserves to meet the requirements of low-flow periods in next 4–5 months. Being an agro-based economy, Pakistan is highly sensitive to any shock from a weak monsoon or mismanagement of available water resources. Deviation of precipitation in summer (monsoon season) during 2001 to 2007 has been shown in Figure 7 against the long-term average. It is more or less similar to the annual pattern, which depicts that the southern half has become slightly wetter than normal while the north has become drier than its long-term average.

Winter brings plenty of snow over the northern mountains, which melts in early summer and sustains river flows for power generation and irrigation before the onset of the summer monsoon. In addition to solid precipitation over hilly areas, winter rain-bearing systems yield substantial rainfall in sub-mountainous and low elevation plains, including arid plains of Balochistan. Generally, the northern half gets about five times more precipitation in winter than the southern half.

Figure 10 shows the deviation of winter precipitation in the recent decade compared to the norm (1971–2000). It is evident that some reduction in seasonal total precipitation has taken place over the northern hill stations in the past decade, but in general, there is no significant change countrywide. The southern half of Pakistan has shown a slight increase in rainfall. Quetta, which represents the high-elevation arid plain of Balochistan, showed a significant decrease in rainfall during the past decade, resulting to more severe droughts for winter crops, especially wheat.

A slight increase in the southern half is attributed to the strengthening of southwesterly monsoon currents from the North Arabian Sea, which has been producing more than the average precipitation in the plains of southeast Sindh province. But this increase is minimal compared to the negative water balance of those areas due to very high evaporation rates.

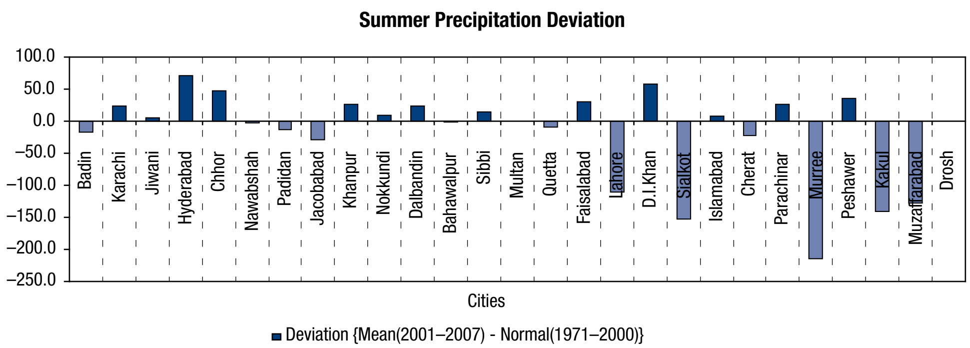
Figure 8 Deviation of annual precipitation over Pakistan in recent decade compared to normal, 1971–2000



Left end shows the southernmost station gradually rising toward north on the right.

Source: Rasul et al. 2010.

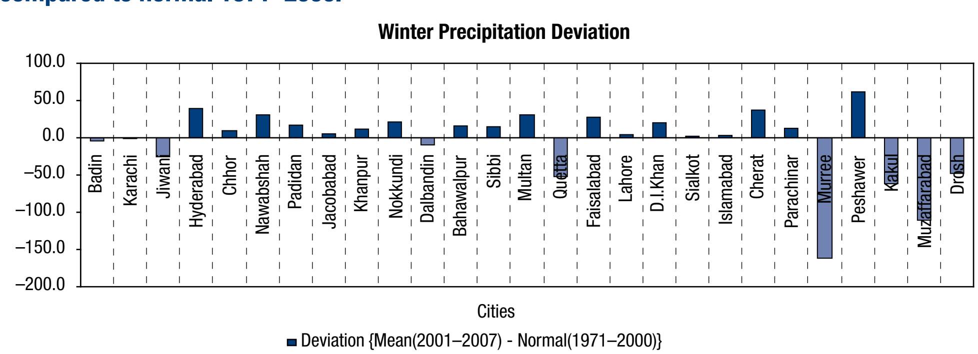
Figure 9 Deviation of summer precipitation over Pakistan in recent decade compared to normal, 1971–2000



Left end shows the southernmost station gradually rising toward north on the right.

Source: Rasul et al. 2010.

Figure 10 Deviation of winter precipitation over Pakistan in recent decade compared to normal 1971–2000.



Left end shows the southernmost station gradually rising toward north on the right.

Source: Rasul et al. 2010.

Archer and Fowler (2004), based on data from same sources, however, observed different results, which showed an increasing trend in winter precipitation at all stations studied, illustrating a high correlation between these different stations. The same, albeit only in the order of 0.2%, was shown for the Himalayas and the Hindu Kush by Sheikh et al. (2009), whereas for the Karakoram a decreasing trend of 0.2% was observed from 1951 to 2000. Sheik et al. (2009) presented an increasing trend of precipitation in the monsoon season for the three mountain ranges—Karakoram, Hindu Kush, and Himalayas—within Pakistan. The increase of precipitation during this season was particularly significant. As Archer and Fowler (2004) mention, this finding concurs with the predictions of global climate models for this region. Also increasing summer precipitation was observed since 1961 at stations north of the Himalayan divide. The reason for this eludes the explanation from the authors and it is unclear whether it is due to increased incursions of the monsoon or stronger influence of westerly airflows.

Thermal regime

Different studies have resulted to different answers on temperature trends in the region and the basin (Bhutiyani et al. 2009). Fowler and Archer (2006) have shown that mean and minimum summer temperatures provide a consistent trend of *cooling* in the period since 1961. According to the authors this characteristic is shared with northwest India and the lower-level stations in Nepal. Summer maxima on the other hand do not show a clear trend. Winter mean and maximum temperatures show statistically significant increases, while winter minima show no significant trend.

The most striking recent change is the large increase in the diurnal temperature range observed at all seasons, and in the annual dataset, suggested to have commenced in the middle of the 20th century. As the authors mention, this change is shared with much of the Indian subcontinent but is in direct contrast to most other parts of the globe, where a narrowing of the diurnal temperature range has been observed. Yadav et al. (2004) also reported temperature cooling in pre-monsoon (March to May) on the basis of observational records and reconstructions from tree rings in the Western Himalaya during the latter part of the 20th century. They attributed the increase of the diurnal temperature range to large-scale deforestation and land degradation in the area showing the higher influence of local forcing factors on climate in contrast to the general trend found in higher latitudes of the Northern Hemisphere.

Chaudhry et al. (2009) have shown a non-significant increasing trend for annual mean temperature over the mountainous areas of the upper Indus Basin in Pakistan. In Balochistan, Punjab, and Sindh, a significant increasing temperature trend of 1.15°C, 0.56°C, and 0.44°C respectively, was observed in the period from 1960 to 2007. However, a seasonal trend in the upper Indus Basin is visible, which takes the form of rising summer temperatures and falling winter temperatures. Such a trend elaborates the increase in the annual (not diurnal) temperature range and symbolizes that skies have become relatively clearer than in the past. More detailed studies based on daily temperature and cloud cover data would reveal the facts regarding these changing trends.

On the basis of long-term data sets since the late 19th century, analyses of the temperature data show significant *increasing* trends in annual temperature in all three studied stations in the northwestern Himalayan region (Bhutiyani et al. 2009). The estimated rates of increase in temperature during the study period 1876–2006 vary from about 0.06°C per decade in monsoon to about 0.14°C per decade in winter and 0.11°C per decade in annual air temperature. The negative relationships between mean air temperature in winter and snowfall amounts reveal the strong effect of rising temperatures on the decreasing snowfall component of total winter precipitation. For the period 1901 to 2000, Bhutiyani et al. (2007) showed marginally lower values than those shown above. Annual air temperature is estimated to have increased by about 0.16°C per decade, average winter temperature by 0.17°C per decade, and the monsoon temperature by 0.09°C per decade. The entire period shows different episodes of faster and slower warming, as well as some periods of cooling. The rate of increase appears to be highest since 1991. The same was shown by Klein Tank et al. (2006), who presented averaged indices of temperature extremes over all stations indicating warming of both the cold and the warm extremes of the distributions of daily minimum and maximum temperature between 1961 and 2000.

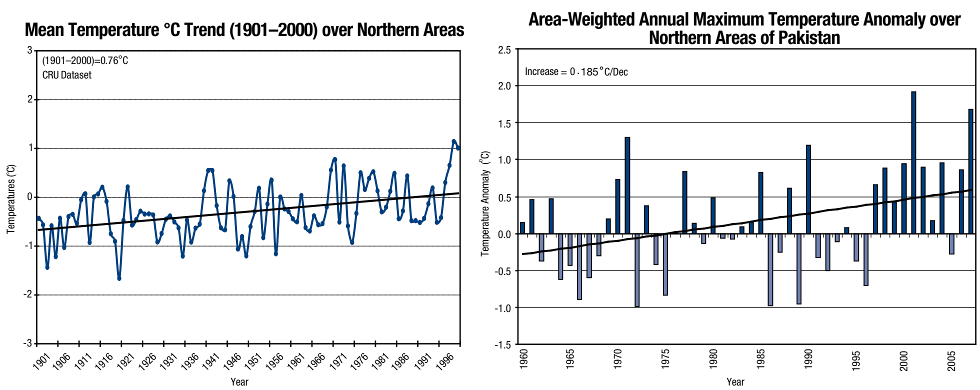
Bhutiyani et al. (2007) confirmed that the northwestern Himalayan region has “warmed” significantly during the last century at a rate higher than the global average. The rise in air temperature has been primarily due to rapid increases in the maximum as well as minimum temperatures, whereby the maximum temperature has increased more rapidly, leading to bigger diurnal temperature range.

Chaudhry et al. (2009) carried out an area-weighted analysis of the temperature trend in the upper Indus Basin using reanalysis of Climate Research Unit (CRU) data from the past 100 years. The trend clearly indicates the gradual rise, embedded with spells of rising and falling temperatures. The last decade of 20th century was the warmest one in northern mountainous areas, as shown in Figure 11 below, in conformity with global temperature trends.

Mean daily temperatures have increased in the mountainous parts of the Indus Basin shown in Figure 11 using two data sets: CRU reanalysis data (1900–2000) and PMD observed data (1960-2007). Although both data sets show an increase in temperature, a sharp increase can be noticed since mid-1990s. The data conforms to the global warming trend in the basin too, which depicted that all the 15 warmest years experienced over the globe fall in last 2 decades.

Movement of isotherms with time along the elevation revealed the fact that heat is rushing toward the peaks of this elevated complex and highly irregular terrain. To know how fast it is moving upward, the dynamics of 30°C was considered the reference indicator. In the 1980s, the changes in isothermic pattern were very slow and hardly a 35 m upward shift of reference isotherm was seen from 1981 to 1990. The warming trend increased in the 1990s. By the end of the decade, the 30°C isoline was about 300 m higher than its position in 1981 to 1985. The hottest year recorded over the globe was 1998, which co-occurred with the strongest El Niño event, in 1997–1998. This was associated with severe hygrothermal stress conditions that contributed to carrying the heat to new heights. Overall, the decade of 1990s was believed to be the warmest on record.

Figure 11 Mean temperature anomalies in Pakistan’s mountainous north



The chart on the left uses the Climate Research Unit (CRU) dataset 0.76°C during the last century. The chart on the right uses the Pakistan Meteorological Department (PMD) dataset 0.185°C per decade.

Source: New et al. (2002) and PMD (2009).

The first 8 years of 21st century have surpassed all past trends, with 2005 believed to be the hottest for Pakistan, when a snowmelt flood in June created havoc in the downstream Indus. Last pentad has completed 3 years so far (i.e., 2006, 2007, 2008 April–June period) and is showing moderate advance of warmth in the upward direction. Temporal isotherm's spread show that flux of upward-creeping heat is more over the Eastern part (Himalaya and Karakoram) of the Southern slopes than the Western part comprising the Hindu Kush. Isothermic advance is not uniform, but rather skewed due to the complexities of terrain and environmental degradation. On the average, the 30°C isotherm has now moved at 580 m above its location in early 1980s.

The frequency of heat waves, i.e., a continuous stretch of persisting daytime maximum temperatures above a certain threshold for a specified time period, has increased (Figure 12). They are grouped into three categories following the temperature range as defined below:

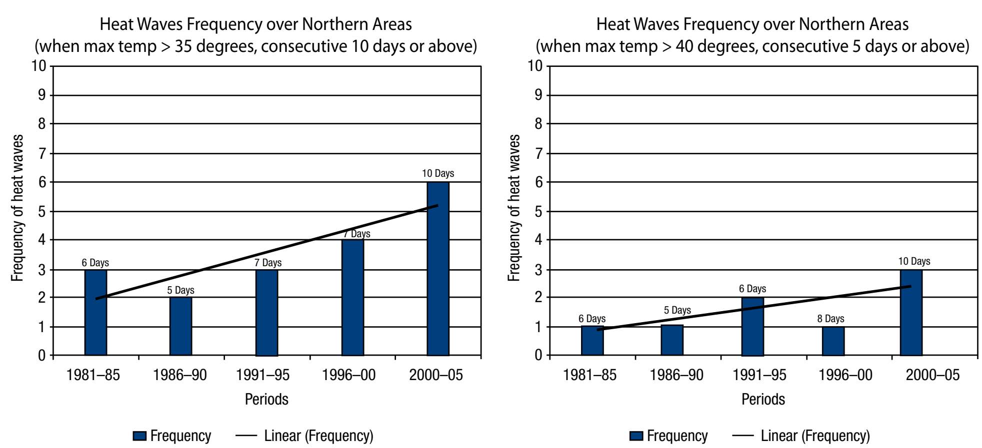
- **Severe heat wave** = 5 consecutive days with daily maximum temperature ≥ 40°C
- **Moderate heat wave** = 5 consecutive days with daily maximum temperature ≥ 35°C and < 40°C
- **Mild heat wave** = 5 consecutive days with daily maximum temperature ≥ 30°C and < 35°C

Frequency analysis of heat waves from 1981 to 2008 shows that mild stress was quite common even in 1980s during May and June, but moderate and severe stress conditions rarely occurred. A significant increase has been noticed in the occurrence of mild stress days, but also a sharp rise in moderate and severe stress events was registered during the recent decade. The longest heat wave during the respective pentad is also presented. It can be observed that the persistence of heat waves has become longer, while their intensity has increased during recent years. Similarly, their areal extent has also increased significantly. The valley areas or shadow zones appearing unaffected by increasing heat in the earlier period are dominated by the heat sweep.

Observed Impacts of Climate Change

In addition to the changing precipitation and thermal regimes, global climate change also manifests itself on the basis of impacts on the hydrodynamics and changes in the cryosphere. Rasul et al. (2008) conducted a detailed regional study on the interaction of the atmosphere and cryosphere using PMD, NCEP, CRU, and Japanese Reanalysis Project data sets. Some of the results are discussed below.

Figure 12 Changing frequency of mild, moderate, and severe heat waves



max temp = maximum temperature.
Note: This shows heat waves of 5-days duration (as bars) and their linear trend. The numbers on top of the bars indicate the longest heat waves.
Source: Rasul et al. 2008.

Hydrological regime

Given the trends observed in the temperature and precipitation as shown in the section above, trends are also expected for discharge and runoff. Fowler and Archer (2006) applied linear relationships between spring and summer temperatures and runoff in the Hunza and Shyok rivers. The observed cooling regional temperature trend produced a predicted reduction of 20% in runoff from 1961 to 2000. This predicted fall was exceeded by actual runoff decreases on the Hunza. The absence of equivalent decline in the Shyok can be explained by regional variations in temperature trend, with easterly stations in the upper Indus Basin showing more positive temperature trend.

They further observed summer temperature reductions and a positive trend in winter precipitation implying reduced ablation and increased accumulation of Karakoram glaciers. These observations are consistent with the observed thickening and expansion of glaciers in the upper Indus Basin also discussed by Hewitt (2005). In the main Indus River, Ali et al. (2009) identified neither a significant change in flow on the basis of the inflow into Tarbela (1961–2004) and at Kalabagh (1922–2002) nor of the Jhelum River measured at Mangla (1922–2004). An increasing trend was observed for the flow of Chenab measured at Marala (1922–2004) and a significant decreasing trend in the flow of Kabul River at Nowshera (1961–2004).

Immerzeel et al. (2008) used various remote-sensing products to identify spatial–temporal trends in snow cover in river basins originating in the Himalayas and adjacent Tibetan–Qinghai plateau with the aim of modeling discharge. It is shown that remote sensing allows detection of spatial–temporal patterns of snow cover across large areas in inaccessible terrain, providing useful information on a critical component of the hydrological cycle. Results show large variation in snow cover between years with an increasing trend from west to east.

Of all river basins the Indus Basin is, for its water resources, most dependent on snow and ice melt and large parts are snow covered for prolonged periods of the year. A significant negative winter snow cover trend was identified for the upper parts of the basin. A hydrological model forced with remotely sensed derived precipitation and snow cover was calibrated using daily discharges from 2000 to 2005. Stream flow in the upper Indus Basin can be predicted with a high degree of accuracy. From the analysis it is concluded that there are indications regional warming is affecting the hydrology of the upper Indus Basin due to accelerated glacial melting during the simulation period. This warming may be associated with global changes in air temperature resulting from anthropogenic forcing. This conclusion is primarily based on the observation that the average annual precipitation over a 5-year period is less than the observed stream flow and supported by positive temperature trends in all seasons.

Rees and Collins (2006) studied the regional differences in the response of flow in glacier-fed Himalayan rivers to climatic warming. River flow from glacierized areas in the Himalaya is influenced both by intra-annual variations in precipitation and energy availability, and by longer-term changes in storage of water as glacier ice. High specific discharge from ice melt often dominates flow for considerable distances downstream, particularly where other sources of runoff are limited, providing a major water resource. Should Himalayan glaciers continue to retreat rapidly, water shortages might be widespread within a few decades. Details of the model are compiled in Rees and Collins (2004).

However, given the difference in climate between the drier western and monsoonal eastern ends of the region, future warming is unlikely to affect river flow uniformly throughout. A simple temperature index–based hydro–glaciological model, in which glacier dimensions are allowed to decline through time, has been developed with a view to assessing, in data-sparse areas, by how much and when climate warming will reduce Himalayan glacier dimensions and affect downstream river flows. Two glaciers having the same initial geometries were located (one each) in the headwaters of two identical nests of hypothetical catchments, representing contrasting climates in the west and east of the region.

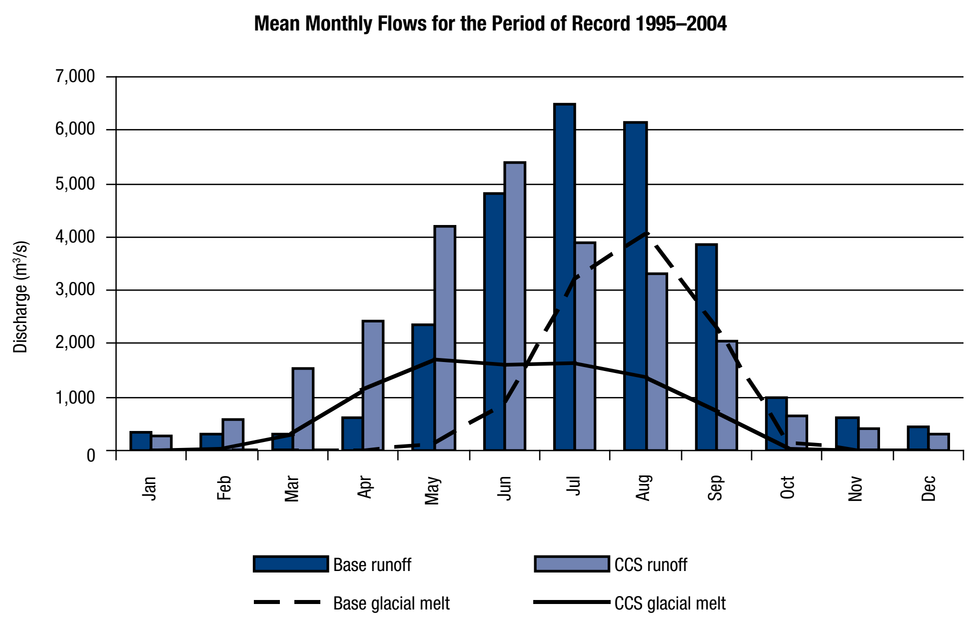
The hypothetical catchments were nested such that percentage ice cover declined with increasing basin area. Model parameters were validated against available but limited mass-balance and river flow measurements. The model was applied for 150 years from an arbitrary start date (1990), first with standard-period (1961–1990) climate data (New et al. 2002) and then with application of a 0.06°C per year transient climatic warming scenario. Under this warming scenario, Himalayan rivers fed by large glaciers descending through considerable elevation range will respond in a broadly similar manner, except that summer snowfall in the east will suppress the rate of initial flow increase, delay peak discharge, and postpone eventual disappearance of the ice. Impacts of declining glacier area on river flow will be greater in smaller and more highly glacierized basins in both the west and east, and in the west, where precipitation is scarce, for considerable distances downstream.

Ali et al. (2009) conducted a runoff modeling study under climate change scenarios using mean monthly flows for the period 1995-2004 in the Indus basin (Figure 13). They assumed a uniform increase of +3°C throughout the year and a reduction of glacier area by 50%. The results indicate that current peak volume of meltwater in July and August will be available at least 2 months earlier. The shift of melting peak will leave the post-monsoon season with depleting reservoirs and hence posing the challenges for Rabi (winter crop, especially wheat) sowing as it matches with dry season.

Glacier dynamics

The study of the interaction between the cryosphere and atmosphere is an appropriate approach to assess the dynamic behavior of glacial fluctuations (Kaser 2001; Wagnon et al. 2007). Trends in a long time series of cumulative glacier-length and volume changes provide convincing evidence for fast climate change or sudden variability at a global scale. The effect of global climate change on the cryosphere in mountain areas are most visibly manifested in the shrinkage of mountain glaciers and in reduced snow cover duration (Barry 2002).

Figure 13 Comparison of base and projected flows in the upper Indus Basin in the wake of climate change



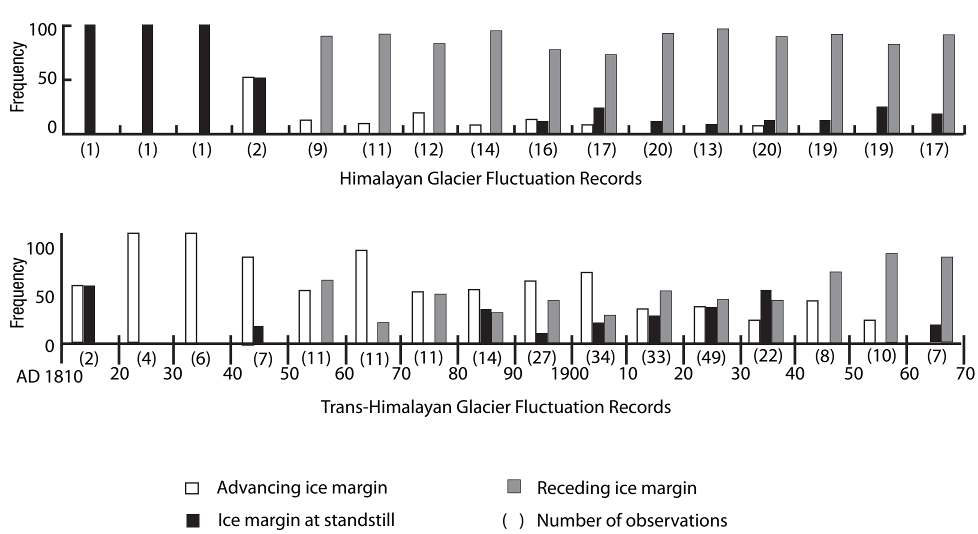
CCS = Climate Change Scenario, m^3/s = cubic meter per second.
Source: Ali et al. 2009.

There is some disagreement among the scientists whether all glaciers of the Himalaya–Karakoram–Hindu Kush region are retreating. Mayewski and Jeschke (1979) used termini movements as the sole indication of advance or retreat of glaciers in the region. They drew their information from about 112 different glaciers in the existing literature and discussed glacier dynamics from as early as 1812. They showed that records of glacier fluctuations in the Himalayas differ from those of glaciers in the Trans-Himalayas (Figure 14): most glaciers in the Himalayas have been in a general state of retreat since 1850. Those in the Trans-Himalayan grouping were either in retreat or advance from 1850 to 1880, reflected near-equivalent influences of retreat, standstill, and advance regimes from 1880 to 1940, and have retreated since 1940.

Goudie et al. (1984) found historical records of glacier fluctuations in the Himalayas and the Karakoram indicating that in the late nineteenth and early twentieth centuries, the glaciers were generally advancing, followed by predominant retreat during 1910–1960. Hewitt (2005) concluded that most glaciers of the Karakoram Himalaya were also observed to diminish from the 1920s to the early 1990s in line with the glaciers from most parts of the world. This is with the exception of some short-term advances in the 1970s. However, in the late 1990s, many glaciers located in the highest watersheds of the central Karakoram began expanding (Figure 15). These glaciers originate above 7,000 m with negative annual mean temperatures and have elevation ranges of over 4,500 m, some descending as low as 2,300 m with subtropical conditions (Goudie et al. 1984). In addition to these unprecedented elevation differences, these glaciers are also among the steepest in the world, causing them to be glaciologically complex. Possible reasons for this contrary behavior are increased precipitation, a local trend of decreasing temperatures, particularly in summer (Fowler and Archer 2006), or the influence of thick debris cover, which protects the ice against melting (Hewitt 2005; see also section below). Due to the great thickness of ice, deeper parts of the glaciers are at or close to 0ºC and behave like temperate glaciers leading to relatively high flow rates ranging from 100 m to 1,000 m per year (Goudie et al. 1984).

The glaciers in the Indian part of the Himalayas have been retreating since the earliest recording began around the middle of the 19th century (Raina 2009). They exhibited an average annual retreat of

Figure 14 Glacier activity frequencies



Source: Mayewski and Jeschke 1979.

about 5 m up to the late 1950s. Retreat of the glaciers in the central and eastern Himalayas increased many fold in the mid-1970s and 1980s, but then slowed down and came to a standstill in the 1990s and early 21st century. The Kumdan glaciers in the upper Shyok valley showed exceptional behavior with their periodic fluctuations. Raina (2009) identified a gradual decrease of cumulative negative mass balance values from the glaciers in the northwest to the glaciers in the northeast. On the basis of published records, Bhambri and Bolch (2009) suggest that glaciers of India longer than 15 km retreat at a rate of more than 20 m a year with few exceptions (e.g., Miyar and Gangotri glaciers). Furthermore they observed an acceleration of this recession compared with previous observations as well as maximum recession rates in the Parbati, Chenab, and Baspa basins.

Glacier cover has also decreased in the adjacent areas on the Tibetan plateau and the mountain regions of the PRC, as compiled by Li et al. (2008). According to these authors the Himalayan glaciers and the glaciers in the Qilian and Tianshan mountains have shrank significantly, about 5% to 10% in the last 30 years. On the Tibetan Plateau they shrank at a slower pace, but have picked up in the recent past so that all glaciers in the PRC's mountains are decreasing in size. According to He and Zhang (2003), the temperate glaciers in the region have been retreating continuously throughout the 20th century, with an increased rate of retreat after the 1980s.

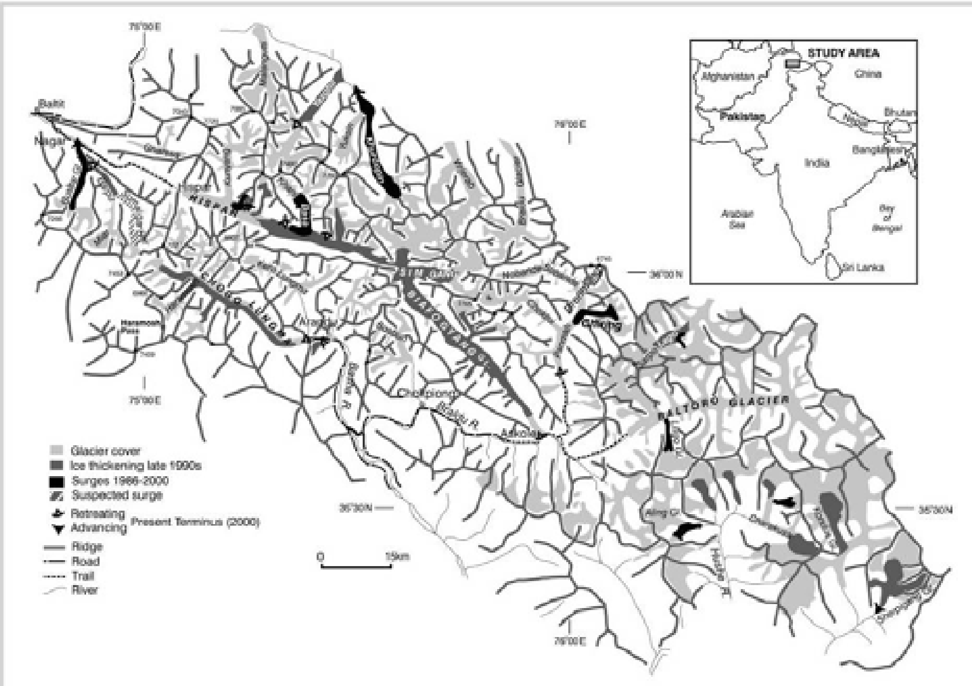
The glacier mass balance assessments by Berthier et al. (2007) showed glaciers of the Spiti–Lahaul region experienced rapid ice losses from 1999 to 2004. These losses were observed to be at least twice higher than the average mass balance between 1977 and 1999, as reflected in Dyurgerov and Meier (2005).

Based on simulations, Kotlyakov and Lebedeva (1998) computed changes in different glacier parameters for the entire region (Table 7). In summary, their results indicate that glacier-covered areas in the Hindu Kush, Hindu Raj, and Naga Parbat massifs will expand, while the glaciers in the Himalayas, especially in the eastern part, will shrink. This is shown by the increase in the altitude of the equilibrium line in the case of the Himalayas overall, and the decrease of equilibrium line altitude in the western part of the mountain range.

Glacier cover has decreased rapidly in recent years, and total cover is now approaching the lowest experienced in the past 10,000 years (Farooqi et al. 2005). The annual rate of retreat is however known to vary widely but with an increasing trend (Prasad et al. 2009). Different authors have reported on changes on different glaciers in the Indus Basin:

- Based on satellite data Kulkarni et al. (2005) reported a 97 m **retreat** from 2000 to 2001 compared to 22 m from 1998 to 2000 of the Parbati glacier located in the western Himalayas. Between 1990 and 2001, a decrease of 578 m occurred.
- From 1962 to 2001, Kulkarni et al. (2007) observed an overall 21% **decline** in the glacial area of 466 glaciers in the Himalayan basins of Baspa, Parbati and Chenab rivers. However, the number of glaciers has increased due to fragmentation.
- Wagnon et al. (2007) present annual specific mass balances of Chhota Shigri Glacier for 4 consecutive years from 2002 to 2006. The balances are often **sharply negative**, with –1.4, –1.2, +0.1 and –1.4 meter water equivalent (m w.e.) in 2002/03, 2003/04, 2004/05, and 2005/06, respectively. The authors however warn that neither any general trend in the mass balance nor any conclusion concerning local climate change can be derived from this too-short observation period. For the same glacier Kumar et al. (2007) reported a variation of the equilibrium line altitude in the 17 years from 4,650 m in year 1987 to 5,180 m in 2004, i.e., an average rate of upward shifting by 31 m/year.
- There is controversy about the dynamics of Siachen glacier. Upadhyay (2009) reported an advance of 700 m from 1862 to 1909, followed by a retreat of about the same amount between 1929 and 1958. Currently the **snout is at rest** and the authors expect no dramatic changes are

Figure 15 Observed changes in glacier cover in the central Karakoram Himalaya in the period 1997–2002 and surges since 1986



Source: Hewitt, 2005

Table 7 Changing glacierization conditions early in the 21st century

Mountain country	Glacier Glaciological levels, m glacier : glacier heads : termini:	Change by early 21st century Δ X, : Δ t, °C mm/year % :sum- :win- mer : ter	Equilibrium line altitude, m ELA a : b :	Ablation A, mm/year : a : b :	Δ ELA, m	Δ A, mm/year
Hindu Kush	5,000- : 3,200- 6,500 : 4,000	10-15: -0.5 : -0.5	3,500- : 3,280- 5,200 : 5,050	8,000- 9,200- 1,600 : 1,750	-220 -150	1200 150
Hindu Raj	6,400 : 3,600- : 4,000	10 : -0.5 :0.0	3,800- : 3,580- 4,800 : 4,600	6,450- : 7,100- 2,600 : 2,900	-220 -200	650 300
Nanga Parbat	6,500 : 2,900-: 3,670	5 : -0.5 : 0.0	4,200- : 4,000- 5,200 : 5,100	7,400- : 7,800- 3,200 : 3,340	-200 -100	400 140
Western Himalayas	: 3,300- 6,500 : 5,000	: : -5 : -0.5 : 0.5	4,500- : 4,450- 5,000 : 4,950	5,100- : 4,850- 3,400 : 3,230	-50 -50	-250 -170
Central Himalayas	: 3,700- 6,500 : 5,000	: : -5 : 0.0 : 1.0	5,000- : 5,070- 5,500 : 5,550	3,100- : 2,950- 1,700 : 1,600	70 50	-150 -100
High Himalayas	6700 : 4,500- : 5,500	-5 : 0.5 : 1.0	4,500- : 4,720- 5,800 : 5,920	4,400- : 4,180- 750 : 650	250 120	-220 -100
Eastern Himalayas	: 2,900- 6,500 : 4,000	: : -5 : 0.5 :0.75	4,500- : 4,720- 5,200 : 5,350	4,400- : 4,180- 2,200 : 1,900	220 150	-220 -300

[a] Current value.

[b] Anticipated value early in the 21st century.

Source: Kotlyakov and Lebedeva 1998.

expected according to the author. Ganjoo and Koul (2009) reported a retreat of 8–10 m from 1995 to 2008, which they say represents stagnant behavior. They further argue that the Siachen glacier is not affected by global warming.

- The study of glacier mass balances of 19 glaciers in the Baspa basin, a tributary of Sutlej river, by Kulkarni et al. (2004) suggests a **loss** of 0.2347 km^3 of glacial ice in 2001 and 2002. It was further shown that four glaciers located in lower altitude zones have no accumulation area and are therefore expected to face terminal retreat due to a lack in the formation of new ice.
- Fluctuations of the Raikot glacier, Nanga Parbat massif, over the past 70 years are characterized by retreat between the 1930s and 1950s, a marked advance between the 1950s and 1980s, and a relatively **stable situation** after 1992 (Schmidt and Nuesser 2009).
- The monitored glaciers in India and Nepal had continuous negative mass balances since their first assessments (Dyurgerov and Meier 2005) and continued to **reduce** since that last comprehensive assessment, as shown in World Glacier Monitoring Service.

Some more findings about the dynamics of glaciers were tabulated by UNEP (2009) and are shown below in Table 8.

Evidence of decay is also presented in Figure 16 for the Siachen glacier. The glacier is located in the eastern Karakoram Range in Ladakh. Meltwater from the glacier is the main source of Nubra River flow, which drains into Shyok River and in turn joins the Indus River.

The decay estimates calculated by remote sensing techniques show that Siachen Glacier has reduced by 1.9 km in longitudinal extent from 1989 to 2006. The evaluation puts the thinning of ice mass at 17% during the same period.

Fowler and Archer (2006) attempted to study the complex behavior of this part of cryosphere using hydrometeorological parameters and claimed that the glaciers of upper Indus Basin region are thickening and expanding based on meteorological data from some PMD stations and hydrological data collected at Water and Power Development Authority (WAPDA) stations. They found that the diurnal temperature range has increased and runoff reduced. However, in carrying out such study over such a large and complex terrain, data from three or four stations data cannot be representative. Also, cloud cover over most of the stations (included in their study) increased when comparing meteorological norms from 1931 to 1960 with those of 1961 to 1990. Logically, the diurnal temperature range could not increase, as clear skies would be the basic requirement for that to occur. Regarding discharge data, runoff from the upper basin finally reached Tarbela Dam and water reserves have increased significantly during the past 2 decades. Moreover, the interacting atmosphere and cryosphere have shown a warming trend, which is gradually accelerating the reduction in ice mass.

UNEP (2009) argues that observation of glacier termini or length alone does not provide enough information to obtain a valid picture of glaciers' behavior. UNEP suggests that all main glacial parameters including length, area, volume, mass, and thickness need to be taken into account. Glacier mass balances are widely considered to represent a glacier's health. However, the assessment of glacial mass balances is associated with a number of logistical issues. For this reason very few glacier mass balances are available for the greater Himalayan region including eight glaciers in India and three in Nepal with mass balances measured for at least one year (Dyurgerov and Meier 2005). According to Berthier et al. (2007) the glacier area monitored on average between 1977 and 1999 each year is limited to 6.8 km^2 out of about 33,000 km^2 in total for the Himalayan region. These authors therefore suggest a remote sensing–based approach for glacial mass balance assessments, which may help produce a better assessment of real glacier dynamics for the poorly sampled greater Himalayan region.

Table 8 Other evidences of Himalaya's glacial retreat and advance

Glacier or Location	Period	Receding	Source	Method of Measurement
Bara Shigri glacier, Himachal Pradesh	1997–1995	650m **retreat** of snout; 36.1 m/yr average retreat of glacier	Cruz et al. (2007)	Maps and field observation
Batal Glacier, Chenab Basin	1980–2006	**Receded** by about 25.7 m each year	TNN (2007)	National Institute of Hydrology
Chhatru Glacier, Chenab Basin	1980–2006	**Receded** 1,400 m–54 m a year	TNN (2007)	National Institute of Hydrology
Baturat Glacier, Pakistan	1992–2000	A **decrease** of about 17 km^2	Munir (2008)	Comparison of Landsat images of Batura glacier for October 1992 and October 2000. Although accurate changes in glacier extent cannot be assessed without baseline information, these efforts have been made to analyze future changes in glaciated area.
Beaskund Glaciers, Beas Basin	1980–2006	**Shrunk** to half	TNN (2007)	National Institute of Hydrology
Chota Shigri Glacier, Himachal Pradesh	1989–1995	60m **retreat** of Snout; 6.7 m/yr average retreat of glacier	Cruz et al. (2007)	Maps and field observation
Triloknath Glacier, Himachal Pradesh	1969–1995	400 m **retreat** of snout; 15.4 m a year average retreat of glacier	Cruz et al. (2007)	Maps and field observation

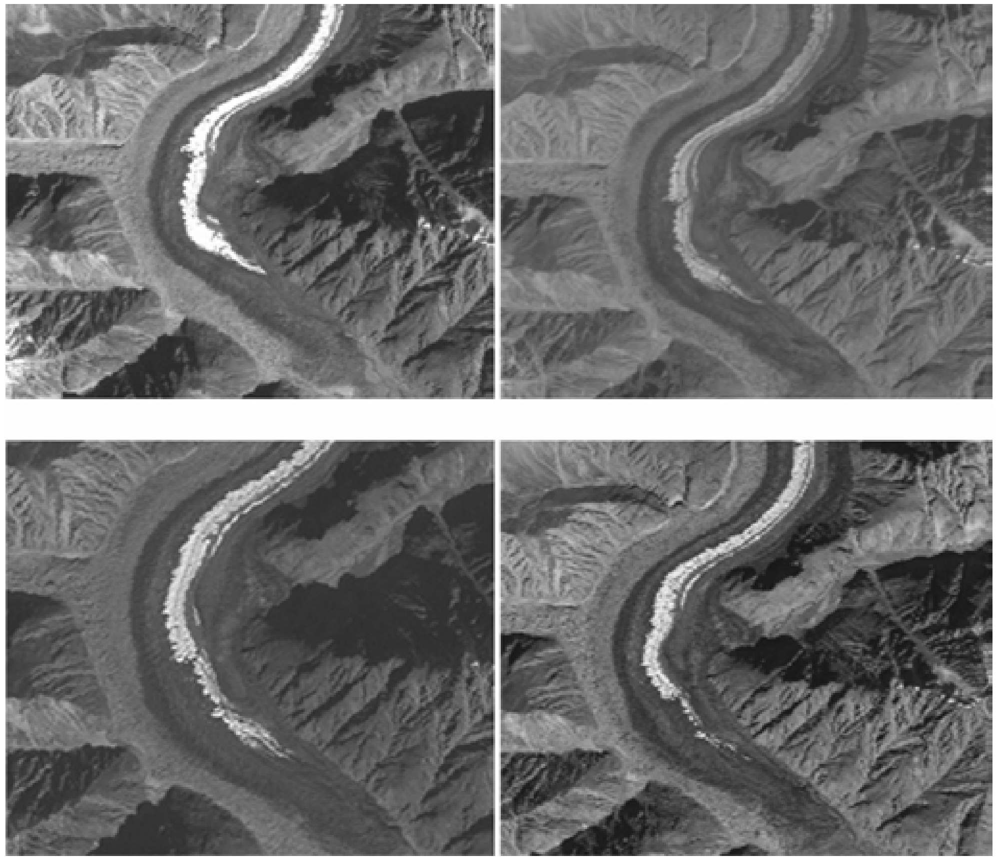
km^2 = square kilometer, m/yr = meter per year.

Source: Adapted from UNEP (2009).

Glacial hazards

Of the entities in the natural ecosystem, snow and ice are the most sensitive to any change in thermodynamic regime. Due to a general trend of increasing warming, these frozen water reserves have started melting at an accelerated rate, giving rise to the formation of new glacial lakes and producing local flooding due to their outburst. In the northern areas of Pakistan glacial lake outburst floods (GLOFs) pose a great risk, not only because of their magnitude but also because they are neither homogeneous nor stationary, according to Shaukat (2003), who reported floods in association with glacial lakes.

Figure 16 Retreat of the Siachen Glacier observed from Landsat satellite at different times



Top left: 29 July 1990, top right: 18 May 2001, bottom left: 10 September 2003, bottom right: 9 September 2006.
Source: Rasul et al. 2008.

While rare and isolated cases have been reported, in other parts of the world, there have been a substantial number of these catastrophic events in the Karakoram Himalaya and neighboring ranges (Hewitt 1982). In the upper Indus River system, 35 destructive GLOF events were recorded in the 200 years to 2003 (Hewitt 1982, 1998; Mool et al. 2003). A GLOF from the Shyok area in August 1929 in the Indus River system extended 1,300 km downstream to Attock and had a discharge greater than 15,000 m^3/s. In a case study of the Astor catchment in the northern part of the Indus Basin, the same authors identified several potentially dangerous glacial lakes. In total 126 glacial lakes were identified in this basin, among them 9 lakes that were identified as potentially dangerous. The details are discussed in Mool et al. (2003).

Glaciers in the upper Indus Basin have historically interfered with streams by damming rivers as well as through GLOFs (Hewitt 1982, 1998). Figure 17 compiles the different dams (both glacial as well as landslide) as reported by Hewitt (1982). Eighteen dams are caused by a total of 30 surging glaciers across major headwater streams of the basin.

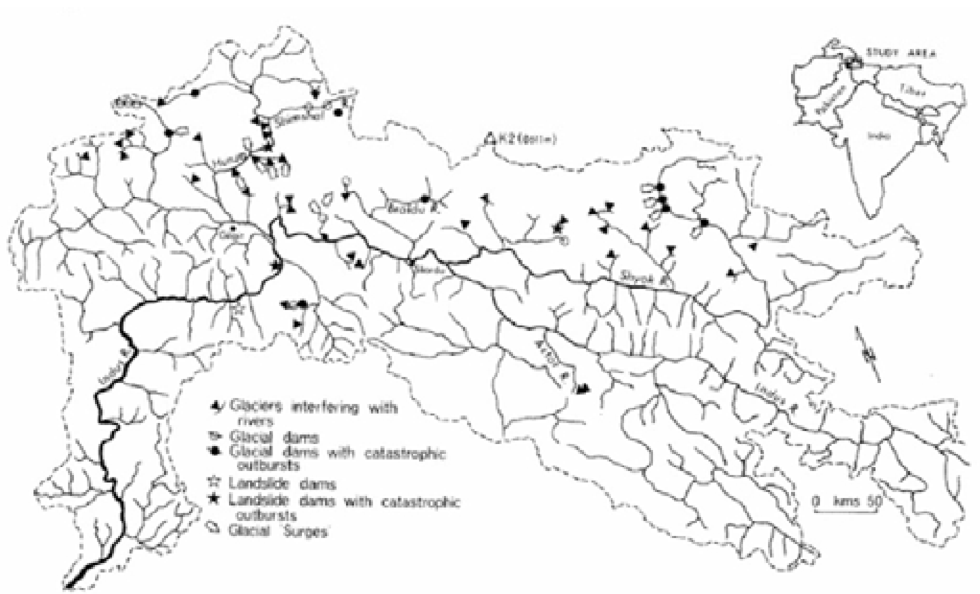
Archer (2002) discusses several events including the last major GLOF that occurred in 1960 originating from the Shimshal tributary valley and reportedly caused the destruction of most of the houses and terraces in the town of Passu. Other major GLOFs occurred from Shimshal in 1833, 1884, 1893, 1905, 1906, 1907, 1927, and 1942, while minor floods from the same source occurred in 1980 and 2000.

Issue 3: Shortage of basin-wide data on glacier status and dynamics

The glacier environment of the greater Himalayan region is still a large "black box" as there is a lack of relevant data and large uncertainties in the assessments as shown by the great variance of reported results on glacier numbers, area, and ice volume. In addition, glaciers in the Himalayas seem to behave differently than in the Karakoram; while the glaciers in the Himalayas and in the Hindu Kush seem to retreat, a number of glaciers in the Karakoram seem to advance. However, whether these changes are due to internal changes of geometry of the ice or actual increase in glacial mass balance, changes are still subject to research and clarification. The influence of debris cover—many glaciers in the region are debris covered—are very variable and differ from glacier to glacier.

Monitoring of the evolution of the glaciers in the greater Himalayan region is therefore a key issue as their melting may: (i) negatively affect regional water supply in the next decades (Barnett et al. 2005), (ii) significantly contribute to ongoing sea-level rise (Kaser et al. 2006), and/or (iii) increase natural hazards linked to glaciers (especially glacial lake outburst floods) (Mool et al. 2001).

Figure 17 Distribution of glacier dams and related events



Source: Hewitt 1982.

The record at Attock has been used to determine the magnitude of abrupt increases in flow arising from some events. The assessed increase in flow was 2,975 m^3/s in 1905 and 3,550 m^3/s in 1906. Given the attenuation over several hundred kilometers of channel length, the magnitude of the flow in the Hunza was probably at least double these figures, and thus much larger than any gauged flow.

Major GLOFs are also reported to have occurred on the Ishkoman tributary in 1844, 1865, 1893, and 1905. The 1905 flood has passed into the folklore of Gilgit as the damaging floodwaters rose 20 feet above the normal summer maximum level and destroyed the Gilgit suspension bridge. A pillar approximately 10 m above normal summer maximum level exists near Gakuch There is said to have been a second pillar but this was not found and it has probably been destroyed. Some reports suggest that the 1893 flood rose even higher in Gilgit, and the discharge increase assessed for this flood at Attock was 4,250 m^3/s. There have been a number of recent floods arising from GLOFs on small tributaries in addition to the one at Sosat noted above in 1995. These include Khalti in 1980, Gulogah in the Ishkoman valley in 1984, and Khankui in 1999. While these floods and accompanying debris flows caused serious damage at the site, there were again no reported floods at Gilgit.

Climate Change Projections for the Indus Basin

Up-to-date climate change projections in Pakistan were generally made on the basis of the national boundaries. The Global Change Impact Studies Centre developed temperature scenarios by downscaling 17 global circulation models (GCMs) at 30 years time steps for the 21st century. Figure 18 (a) and (b) compare the projected changes in temperature in 2020s (representing average value for the period 2010–2039), 2050s (representing the average for 2040–2069), and 2080s (representing average for 2070–2099) compared to the base period (1960–1990) values over northern and southern Pakistan (separated at 31°N) corresponding to the IPCC high- and medium-range A2 and A1B[1] scenarios respectively (Islam et al. 2009).

The main results are as follows:

- As expected, the temperature increase throughout the time horizon in northern Pakistan as well as in southern Pakistan is higher in A2 scenario than in A1B scenario.
- In each scenario the temperature increase in northern Pakistan is larger than that in southern Pakistan, in line with IPCC global scenarios which show higher temperature increases over Central Asia than over Southern Asia.
- The temperature increase in both northern and southern Pakistan at the end of the time horizon in each scenario is higher than the corresponding globally averaged temperature increase. For the A2 scenario, the projected temperature increases in the 2080s are 4.67°C in northern Pakistan and 4.22°C in the south, compared to a 3.4°C average global temperature increase for 2090–2099 relative to 1980–1999. For the A1B scenario, the corresponding values are 4.12°C, 3.73°C, and 2.8°C. The current annual average temperatures for northern and southern Pakistan are about 19°C and 24°C respectively.

For Pakistan as a whole the temperature increases in the 2020s, 2050s and 2080s are 1.31°C, 2.54°C, and 4.38°C in A2 scenario, and 1.45°C, 2.75°C, and 3.87°C in the A1B scenario. Projected changes in seasonal temperature for A2 and A1B scenarios show that in each scenario (i) the temperature increases in both summer and winter will be higher in northern Pakistan than in southern Pakistan, and (ii) the temperature increases in both northern and southern Pakistan will be larger in winter than in summer.

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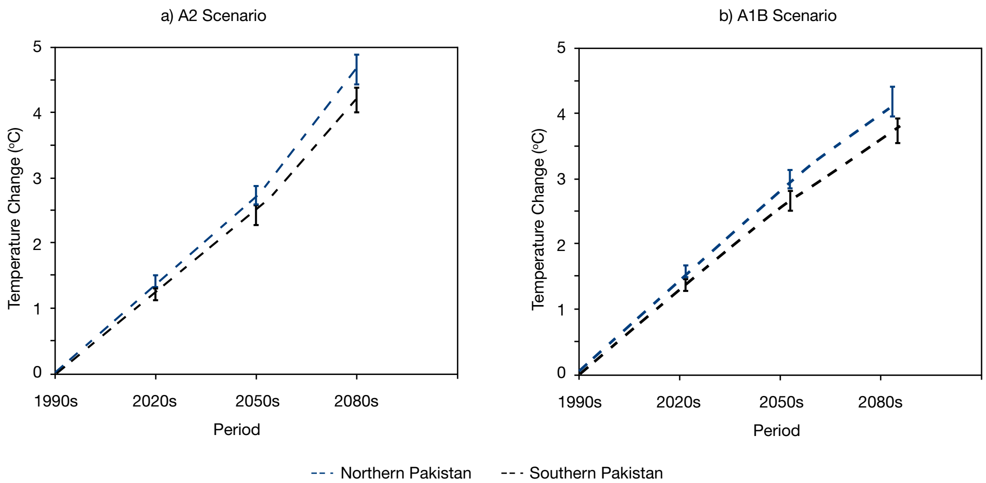
[1] A2 Scenario: this scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines. A1B Scenario: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income, balanced use of fossil and non-fossil energy sources (IPCC 2000).

Figure 18: Projected changes in average temperature of Northern and Southern Pakistan based on ensemble of 13 global circulation models



Source: Syed et al. 2009.

Temperature projections for the Indus, Kabul, and Jhelum basins, applying 17 GCMs, are presented in Table 9 (Islam et al. 2009). According to these projections, at the end of this century, the temperature change in Pakistan's areas of the Indus Basin is projected to be 4.81ºC for the A2 scenario and 4.29ºC for A1B. Projected precipitation changes are listed in Table 10. Due to low changes in precipitation and large uncertainties associated with them, no clear-cut projection can be made for precipitation. The projected precipitation changes in the basins of the Kabul, Jhelum, and Indus rivers are not significant for both A2 and A1B scenarios.

Islam et al. (2009) developed high-resolution climate change scenarios for South Asia particularly focusing on Pakistan by applying the Providing Regional Climates for Impact Studies (PRECIS) regional climate model. The model is nested within the Hadley Centre Coupled Model version 3 (HadAM3P) GCM to simulate the baseline (1961–1990) climatology for 2071–2100 under a Special Report on Emissions Scenarios' (SRES) A2 scenario. PRECIS was first validated with observed CRU data sets, which showed that the simulated baseline climate compared quite well in the case of surface air temperature over South Asia, but showed large biases in the case of precipitation. Overall, the performance of the model is better for temperature than for precipitation.

The simulated climate change in 2080s for A2 scenario shows that summer precipitation will increase over the monsoon belt of South Asia and winter precipitation will increase over northern parts of Pakistan. In contrast, precipitation is projected to decrease over southern parts of Pakistan. The rise of winter temperature in Pakistan will be more than that of summer temperatures. The results for projections for the three watersheds of the upper Indus, Jhelum, and Kabul rivers for the period 2071–2100 are shown in Table 11 and 12.

Both summer and winter temperature changes over the upper Indus Basin will be lower than those of other basins. Temperatures during winter will trend slightly lower than in summer in the upper Indus Basin and be higher for Jhelum and Kabul river basins. Similarly, the precipitation trend of the upper Indus Basin is positive in summer and negative in winter. The precipitation trend of the other two basins is higher in winter than for the summer.

Table 9 Projected temperature change over Kabul, Jhelum, and Indus rivers

Global Circulation Models	A2 scenario			A1B scenario		
	2020s	2050s	2080s	2020s	2050s	2080s
UKMO-HadCM3	1.26	2.76	4.96	1.40	3.15	4.41
PCM-NCAR	0.92	1.77	3.27	1.17	2.14	2.92
CCSM3-NCAR	1.94	3.22	5.29	1.92	3.49	4.07
MRI-CGCM2.3.2	1.09	2.29	3.80	1.50	2.62	3.63
ECHAMS/MPI-OM	1.15	2.66	5.41	1.47	3.40	5.27
MIROC3.2 (hires)	2.04	3.64	5.56	1.89	3.79	5.37
IPSL-CM4	1.28	2.71	4.80	1.51	2.89	4.38
INM-CM3.0	2.12	3.52	5.46	2.17	3.63	4.42
GISS_ER	1.58	2.73	4.46	1.54	2.74	3.92
GFDL-CM2.1	1.76	3.19	5.46	1.82	3.54	4.69
GFDL_Cm2.0	1.82	3.65	6.03	2.05	3.74	5.17
CSIRO-MK3.0	1.20	2.15	3.71	1.15	2.01	3.05
CNRM-CM3	1.15	2.48	4.34	1.42	2.60	3.62
GISS_AOM	–	–	–	1.17	2.56	3.25
GISS_EH	–	–	–	1.65	2.69	3.91
FGOALS-g1.0	–	–	–	0.92	2.23	3.35
MIROC3.2 (medres)	–	–	–	2.76	5.07	7.58
$(x \pm \Delta X)$	1.48±0.11	2.83±0.16	4.81±0.23	1.62±0.11	3.08±0.19	4.29±0.27

– = no data available.
Source: Islam et al. 2009.

Rasul et al. (2010) attempted to develop climate change scenarios for the entire Indus Basin and at smaller time steps. Shorter time steps instead of depicting end of the 21st century scenarios could facilitate short- and medium-term planning and adaptation to climate change impacts. PMD and PRC scientists conducted a detailed study for the basin using statistical downscaling. IPCC emission scenarios (SRES 2007) were used in the study. Daily rainfall and mean temperature data from 56 PMD stations were incorporated for the 1951–2000 period to run the simulations in order to validate model outputs and test prediction skills. Eleven simulations were completed with an equal number of GCMs and reproduced results were in close conformity with observed result in the field. Modeled simulations for precipitation and temperature (1951–2000) are presented in Figure 19.

Based on A2, B1, and A1B scenarios, projections were made for both temperature and precipitation on different temporal and spatial scales. The A1B scenario is generally known for its optimism about the behavior of world community and the belief that present efforts to save Earth from further anthropogenic disasters will work. The Indus Basin scenarios for temperature and precipitation

Table 10 Projected precipitation changes over Kabul, Jhelum, and Indus river

Global circulation models	A2 scenario			A1B scenario		
	2020s	2050s	2080s	2020s	2050s	2080s
UKMO-HadCM3	9.76	16.39	5.92	7.22	0.62	7.22
PCM-NCAR	1.79	3.35	0.63	–2.98	–0.71	1.45
CCSM3-NCAR	2.09	8.56	12.81	4.87	4.47	9.40
MRI-CGCM2.3.2	11.19	13.65	13.19	–0.63	9.07	10.18
ECHAMS/MPI-OM	–1.94	0.64	–1.33	–1.66	–12.10	–8.96
MIROC3.2 (hires)	2.90	–1.51	11.60	2.44	–2.13	–1.30
IPSL-CM4	–1.47	–0.40	–1.97	1.11	–6.94	–4.93
INM-CM3.0	–10.24	–10.03	–17.96	–11.78	–13.00	–22.22
GISS_ER	0.63	0.91	–3.17	–0.35	0.56	–2.85
GFDL-CM2.1	–2.88	–2.28	–8.26	–5.36	–5.56	–5.10
GFDL_Cm2.0	–6.14	–7.51	–14.51	–3.93	–8.24	–8.16
CSIRO-MK3.0	3.96	3.20	6.75	–1.73	–0.53	5.75
CNRM-CM3	1.46	–0.13	2.30	–0.41	1.48	3.49
GISS_AOM	–	–	–	–0.45	2.07	9.44
GISS_EH	–	–	–	–0.59	3.33	–1.16
FGOALS-g1.0	–	–	–	–1.94	0.51	–5.13
MIROC3.2 (medres)	–	–	–	6.56	11.37	18.44
(x±ΔX)	0.85±1.61	1.91±2.07	0.46±2.74	-0.57±1.09	-0.93±1.61	0.33±2.31

– = no data available.
Source: Islam et al. 2009.

Table 11 Projected temperature changes (°C), 2071–2100

Watershed regions	Annual	Summer	Winter
Upper Indus basin	4.58	2.66	2.54
Jhelum river basin	4.67	4.12	5.32
Kabul river basin	5.00	4.79	5.46

Source: Islam et al. 2009.

Table 12 Projected precipitation changes (%), 2071–2100

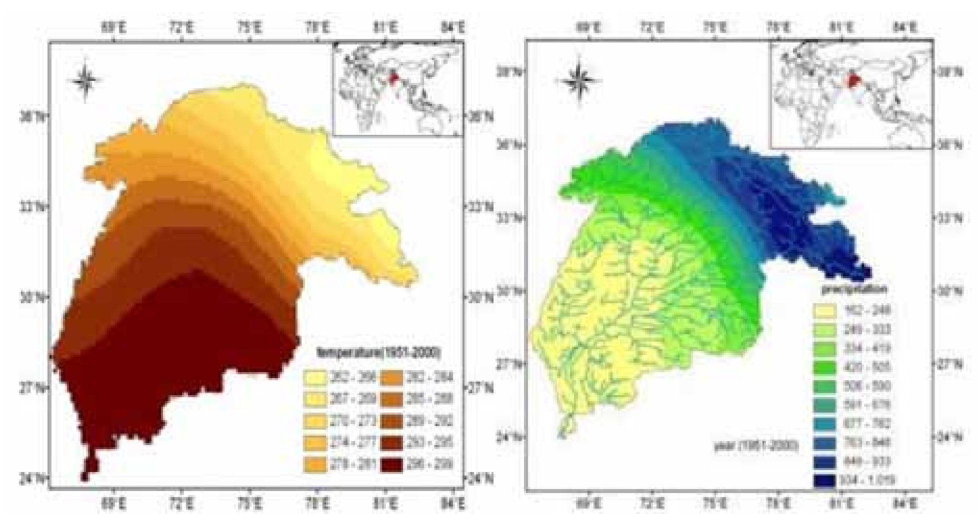
Watershed regions	Annual	Summer	Winter
Upper Indus basin	19.62	14.83	–4.33
Jhelum river basin	5.58	5.20	20.05
Kabul river basin	4.26	2.54	16.20

Source: Islam et al. 2009.

Issue 4: Large uncertainties in precipitation projections

The precipitation projections are associated with a large uncertainty, as was shown with the comparison of different GCMs as well as the validation of the PRECIS model runs with CRU data. In addition, downscaling work to date is based on coarse resolution, which results in a crude overview of the future scenarios. It does not allow determination of the impact of climate change at a subbasin level, which is crucial for planning of water resources development. The capacity for downscaling and developing regional scenarios with low uncertainties needs to be enhanced, along with improvements to research and support for new initiatives.

Figure 19 Ensemble reproduced precipitation and temperature over the Indus Basin, 1951–2000



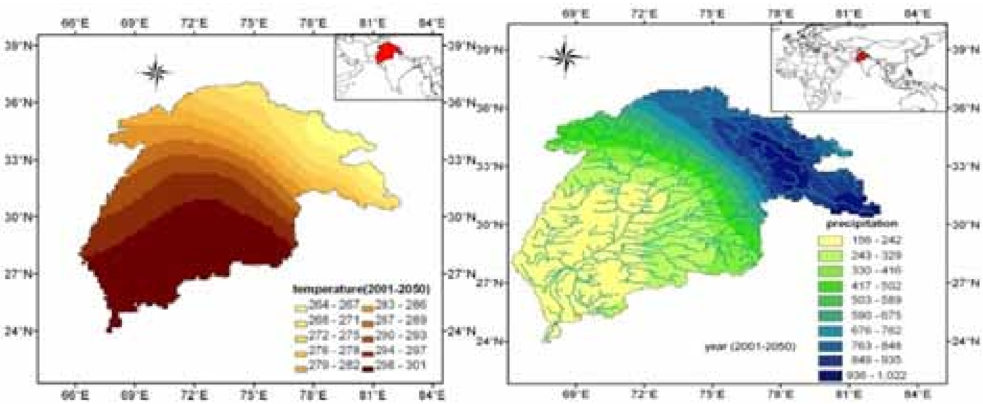
Source: Rasul et al. 2010.

developed with this A1B scenario are shown in Figure 20. The basin shows little change in future precipitation regime (2001–2050) as compared to the baseline (1951–2000). However, it may be noticed that already humid regions in the north are projected to become wetter, whereas drier regions in the south will get even drier. This may generate a strong gradient between demand (in the drier south) and supply (from the wetter north) posing a challenge to water resources managers.

Projections show the temperature regime trending in almost the direct opposite of precipitation. In the north of the Indus Basin precipitation is likely to increase slightly, compared to the long-term average of 1951–2000, whereas temperature is projected to decrease in projections for 2001–2050.

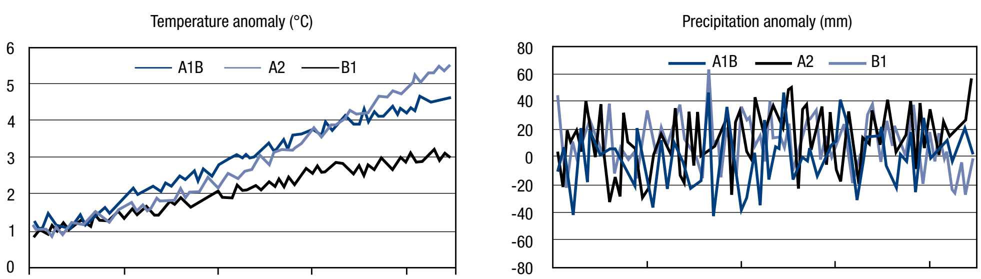
Comparison of the results from the three different scenarios (Figure 21) indicates a great diversity in projected values of temperature, but they show an agreement in projecting minimal change in precipitation.

Figure 20 A1B scenario for precipitation and temperature in Indus Basin, 2001–2050



Source: Rasul et al. 2010.

Figure 21 Climate change projections for Indus Basin, 2011–2100



mm = millimeter.
Note: Both temperature and precipitation anomalies are at time steps of 20 years for the three scenarios. (A1B, A2, and B1).
Source: Rasul et al. 2010.

The output of models was further resolved to develop local-scale scenarios for the Indus Basin with particular attention paid to climatic zones. Area-weighted average scenarios of temperature and rainfall are given in Table 13. According to the A2 scenario, an increase in rainfall at a rate of about 2.5 mm per decade is expected, whereas temperature may also rise by about 0.5°C per decade. The B1 scenario indicates half this rate of increase, at 0.25°C per decade, and precipitation is projected to decrease at nearly 1 mm per 10 years. A1B Scenario indicates about 0.4°C warming and an increase of nearly 2 mm of precipitation every decade.

Considering the climatic zones with similar characteristics and geographical features, the whole Indus Basin was split into subregions to facilitate the formulation of policies with a clear picture of future climates at the local scale (Table 14). The results of these projections show that there is a considerable difference in the results between different scenarios. While under B1 scenario precipitation is projected to experience no significant change throughout the basin with the exception of the upper Indus, where a decrease of 1.5 mm per decade is predicted, the two other scenarios predict a considerable increase in precipitation over the mountainous and sub-mountainous areas and a decrease in large areas of the plains. Northern Punjab and southeastern parts of Sindh, which presently receive more precipitation

Table 13 Linear trends in the Indus Basin, 2011–2099

	Precipitation (mm/10 years)			**Temperature** (°C/10 years)		
Scenario	A2	A1B	B1	A2	A1B	B1
Change	2.48	1.91	–0.78	0.53	0.43	0.25

mm = millimeter.
Source: Rasul et al., in press.

Table 14 Linear trends across climatic zones, 2011–2099

	Precipitation (mm/10 years)			**Temperature** (°C/10 years)		
Region	**A2**	**A1B**	**B1**	**A2**	**A1B**	**B1**
Upper Indus	4.8	2.7	–1.5	0.79	0.65	0.35
Northern Punjab, Upper Khyber Pakhtunkhwa	8.1	6.10	–0.10	0.02	–0.35	–0.03
Central/Southern Punjab, Lower Khyber Pakhtunkhwa	–3.1	–1.97	–0.50	0.71	0.63	0.07
High Balochistan	2.14	1.33	–0.18	0.36	0.29	0.09
South–Eastern Sindh	7.3	5.2	–0.01	0.03	–0.21	0.10
Sind, Lower Balochistan	–2.87	–1.13	–0.09	0.55	0.59	0.07

mm = millimeter.
Source: Rasul et al., in press.

during monsoon season than other areas, are likely to continue the same pattern. All the scenarios show a warming trend in the entire Indus plains with some discrepancy in Northern Punjab/upper Khyber Pakhtunkhwa, where A1B and B1 scenarios predict a cooling.

4.3 Knowledge Issues and Gaps

Based on the detailed literature review of the available knowledge in the Indus basin on climate, hydrology, climate change and impact of climate change, it has become evident that the following gaps exist:

- **Scarcity of automatic weather and hydrological stations in the glacierized areas.** The present network including all stations of national and international organizations does not serve the purpose of representing the heterogeneous mountain terrain. Climate varies between valleys and mountain tops, between aspects and orientation, and between different locations. To meet the optimum observational demands, at least 75 automatic weather stations and 35 hydrological measurement stations should be installed in the mountain areas. This would allow effective modeling of the hydrodynamic characteristics or these areas.
- **Lack of basin and transboundary modeling excercises.** Glaciers in the uplands of the Indus including the eastern and western rivers are the lifeline of Pakistan's economy. They provide water downstream thus making the country the most vulnerable to changes in glacial melt. In

order to improve the understanding of the glacier–hydrology relationship and dynamics under climate change, hydrological modeling at different scales is crucial. A strong research base on glacial hydrology and modeling is essential to devise relevant sector-wide measures for better adapting to these challenges. Currently, most of the water resource–modeling exercises are confined spatially to a small and focused area, but there are no modeling exercises for the entire Indus Basin that take data from all riparian countries into account. This requires data sharing among the riparian countries, transboundary technical collaboration, and the parametrization of a basin water resources model that accounts for the specificities of glacial areas, snowmelt, and mountain heterogenities and input parameters.

- **Shortage of basin-wide data on glacier status and dynamics.** The glacier environment of the greater Himalayan region is still a large "black box." There is a lack of relevant data and large uncertainties in assessments, as shown by the great variance of reported results on glacier numbers, area and ice volume. In addition, glaciers in the Himalayas seem to behave differently than in the Karakoram; while the glaciers in the Himalayas and in the Hindu Kush seem to be in retreat, a number of glaciers in the Karakoram seem to be advancing. However, whether these changes are due to internal changes of geometry of the ice or an actual increase in the glacial mass balance is still subject to research and clarification. The influence of debris cover—many glaciers in the region are debris covered—is very variable and differs from glacier to glacier. Monitoring of the evolution of the glaciers in the greater Himalayan region is therefore a key issue as their melting may (i) negatively affect regional water supply in the next decades (Barnett et al. 2005), (ii) significantly contribute to ongoing sea level rise (Kaser et al. 2006), and/or (iii) increase natural hazards linked to glaciers (especially glacial lake outburst floods) (Mool et al. 2001).
- **Large uncertainties in precipitation projections.** The precipitation projections are associated with a large uncertainty—as was shown with the comparison of different GCMs as well as the validation of the PRECIS model runs with CRU data. In addition, downscaling work to date is based on coarse resolution, which results in a crude overview of the future scenarios. It does not allow the determination of the impact of climate change at a subbasin level, which is crucial for planning of water resources development. The capacity for downscaling and developing regional scenarios with low uncertainties needs to be enhanced, research needs to be improved, and new initiatives need to be supported.

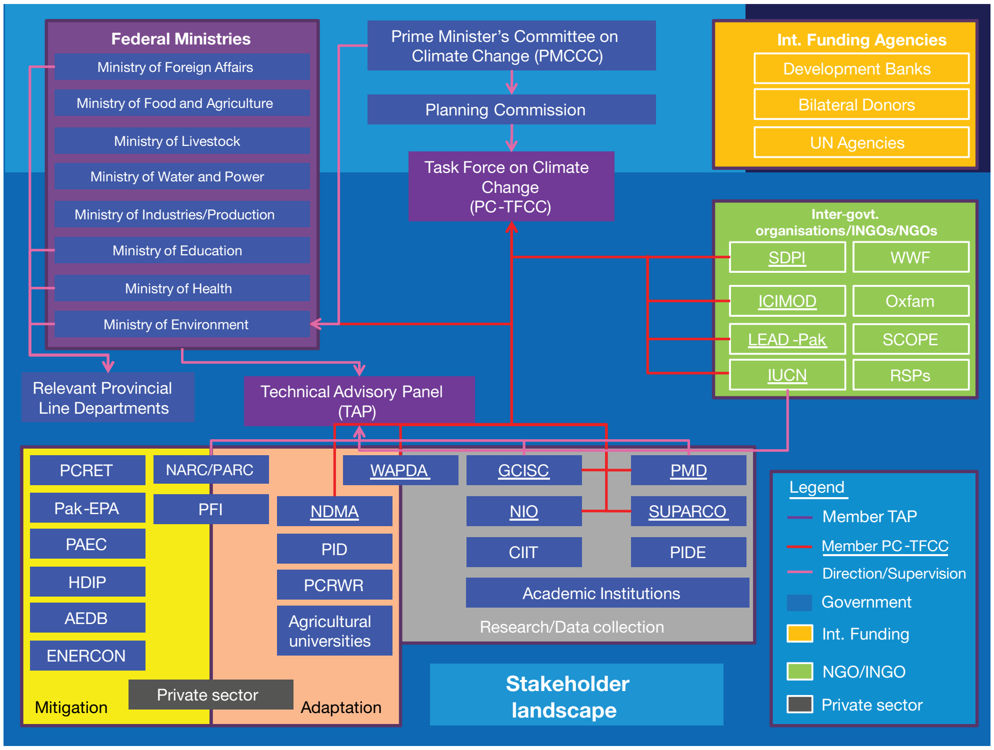
Proposed actions to address these issues are recommended in the concluding chapter.

5. The Institutional Landscape

The International Union for Conservation of Nature Pakistan (IUCN-Pakistan) has compiled a detailed list of institutions as part of this project. IUCN and ICIMOD (2010b) discuss the institutional landscape for activities related to climate change in Pakistan. Figure 22 presents a schematic overview of the different players and their relations in the context of climate change efforts.

Selected stakeholders were invited for two consultations organized in Karachi and Islamabad in 2010. During these consultations proposals for future activities and requirements were made and are documented in IUCN and ICIMOD (2010b).

Figure 22 The institutional landscape



AEDB = Alternative Energy Development Board, CIIT = COMSATS Institute of Information Technology, ENERCON = National Energy Conservation Centre, GCISC = Global Change Impact Studies Centre, HDIP = Hydrocarbon Development Institute of Pakistan, ICIMOD = International Centre for Integrated Mountain Development, INGO = international nongovernment organization, IUCN = International Union for Conservation of Nature, LEAD-Pak = Leadership for Environment and Development Pakistan, NARC = National Agricultural Research Centre, NDMA = National Disaster Management Authority, NIO = National Institute of Oceanography, PAEC = Pakistan Atomic Energy Commission, Pak-EPA = Pakistan Environmental Protection Agency, PARC = Pakistan Agricultural Research Council, PCRET = Pakistan Council for Renewable Energy Technology, PCRWR = Pakistan Council for Research in Water Resources, PFI = Pakistan Forest Institute, PID = Press Information Department, PIDE = Pakistan Institute of Development Economics, PMD = Pakistan Meteorological Department, RSPs = Rural Support Programmes, SCOPE = Society for Conservation and Protection of Environment, SDPI = Sustainable Development Policy Institute, SUPARCO = Space and Upper Atmosphere Research Commission, WAPDA = Water and Power Development Authority, WWF = World Wildlife Fund.

Source: ICIMOD.

5.1 Profile of Stakeholders

In the Table 15 below, organizations with a climate change related mandate are presented, alongside their potential future roles and needs. Further details about the different stakeholders can be obtained from IUCN and ICIMOD (2010b).

Table 15 Organizations with climate change–related mandates

No	Organization	Climate change–related mandate	Potential future role/needs
		National	
A.	**MINISTRY OF ENVIRONMENT**	• Focal institution for climate change • Designated national authority for CDM • Custodian of national environmental policy and other relevant policies • Focal point for IPCC	• Strong policy influence including formulation and implementation • Technical capacity to deal with the subject required • Institutional strengthening required for policy formulation and implementation • Further linkages development required
1.	**Environment Wing**	• Focal institution for climate change • Designated national authority for CDM • Custodian of national environmental policy • Focal point for IPCC, CDM Executive Board	• Strong policy influence including formulation and implementation • Technical capacity to deal with the subject required • Institutional strengthening required • Further linkages development required • Technical support required for formulation of climate change policy, NAPA, and national CDM operational strategy
2.	**Global Change Impact Studies Centre**	• Key institution to conduct research on climate change impacts • Technical backstopping to overview, plan, and monitor adaptation programs in Pakistan and region • Strong role in policy and technical advice • Strong role in technical advice for intentional negotiations	• Strong potential role of conduct modeling-based research on glaciers at national as well as regional levels • Further institutional strengthening required • More autonomy required under recent administrative changes • Sufficient financial resources required to upscale the current work being done • Mechanisms required for improved access to research outputs
3.	**National Energy Conservation Centre**	• Focal institution to plan and implement energy conservation measures at national level	• Institutional reforms required with must strengthened linkages with line agencies and other related ministries and departments at federal and provincial levels • Capacity development, particularly in supporting climate change mitigation measures in Pakistan and formulation and implementation of CDM projects • Potential role in policy advice must be focused

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Table 15 continued

No	Organization	Climate change–related mandate	Potential future role/needs
4.	**Pakistan Environmental Protection Agency**	• Custodian of Pakistan Environmental Protection Act • Strong linkages, particularly with private sector • Role in tackling ambient pollution	• Capacity for law enforcement needs to be enhanced • Institutional strengthening required • Potential role in policy advice needs strengthening
5.	**Forestry Wing**	• Custodian of Pakistan Forest Policy • Focal institution for UNCCD and CBD • Role in mitigation (sink enhancement)	• Capacity for policy implementation needs to be enhanced • Institutional strengthening required • Potential role in policy advice needs focus • Financial resources for implementation of mitigation/sink enhancement projects
6.	**Pakistan Forest Institute, Peshawar**	• Key institution for research and training of forest discipline	• Institutional strengthening required • Financial support required to undertake research • Administrative reforms required
7.	**Zoological Survey Department**	• Key institution to undertake wildlife surveys	• Institutional strengthening • Linkages with other research institutions • Potential role in support research on habitat analysis and species status
B.	**PLANNING COMMISSION**	• Focal institution to support policy planning and future visions in Pakistan • Hub for planning activities and custodian of all relevant polices in Pakistan • Very strong role in policy support and implementation of activities	• Linkages with all relevant institutions must be strengthened • Potential role in formulation and implementation of sectoral policies
1.	**Pakistan Institute for Development Economics**	• Key institution to undertake research, particularly for economic perspective • Potential role in technical advice	• Linkages with all relevant institutions must be strengthened • Diversify research activities covering economic and social aspects
C.	**MINISTRY OF FOOD, AGRICULTURE AND LIVESTOCK**	• Key ministry to formulate and implement agriculture-related policies, action plans • Mandate of undertaking research on agriculture and all allied disciplines • Implementation of ground activities • Key potential role in policy advice and support implementations • Role in supporting mitigation and adaptation activities	• Capacity to focus on climate change needs to be strengthened • Relevant policies must integrate the subject of climate change • Further strengthening of research activities • Strengthened linkages with all relevant partners

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Table 15 continued

No	Organization	Climate change–related mandate	Potential future role/needs
1.	**Pakistan Agricultural Research Council**	• Mandate of undertaking research on agriculture and all allied disciplines • Implementation of ground activities • Key potential role in policy advice and support implementations • Role in supporting mitigation and adaptation activities	• Mechanism required for improved access to research information • Research in relation to climate change needs more focus • Improved linkages with other research institutions • Role in supporting adoption must be improved • Further capacity building
a.	**Water Resources Research Institute**	• Mandate of undertaking research on water-related issues • Implementation of ground activities • Key potential role in policy advice and support implementations • Role in supporting adaptation activities	• Strong potential role of conduct modeling-based research on glaciers at national as well as regional levels • Mechanism required for improved access to research information • Research in relation to climate change needs more focus • Improved linkages with other research institutions • Role in supporting adoption must be improved
D.	**MINISTRY FOR WATER AND POWER**	• Mandate of formulation and implementation of water and power–related polices and regulations • Mandate of research in allied disciplines	• Climate change–related mandate to be initiated • Potential role in supporting mitigation and adaptation must be strengthened
1.	**Federal Flood Commission**	• Mandate of flood forecast and monitoring • Potential role in adaptation and mitigation and disaster risk reduction	• Strong potential role of conduct modeling–based research on glaciers • Climate change–related mandate to be initiated • Potential role in supporting and adaptation must be strengthened • Linkages must be developed with other relevant institutions
2.	**Water and Power Development Authority**	• Mandate of implementation of to water and power–related polices • Potential role in mitigation	• Reasonable potential role of conduct modeling-based research on glaciers • Climate change–related mandate to be initiated • Potential role in supporting and mitigation must be strengthened • Linkages must be developed with other relevant institutions • Additional support to conduct research particularly in water resources
3.	**Pakistan Electric Power Company**	• Mandate of development and promotion of electric power	• Potential role in mitigation to be enhanced

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Table 15 continued

No	Organization	Climate change–related mandate	Potential future role/needs
4.	**Private Power Infrastructure Board**	• Mandate of development of power-related infrastructure	• Potential role in mitigation to be enhanced
5.	**Alternative Energy Development Board**	• Mandate of promotion of alternate energy in Pakistan • Role in mitigation through CDM	• Potential role in mitigation to be enhanced • Further institutional strengthening required • Role in policy support needs more focus
E.	**MINISTRY FOR SCIENCE AND TECHNOLOGY**	• Mandate of promoting scientific research on the subject • Mandate of providing technological guidance and advice	• Potential role in mitigation to be enhanced
1.	**Pakistan Council for Research on Water Resources**	• Mandate of conducting scientific research on water resources	• Strong potential role of conduct modeling-based research on glaciers at national as well as regional levels • Potential climate change mandate to be brought in focus • Research linkages needs strengthening • Role in policy support needs more focus • Research linkages needs strengthening • Mechanism for improved access to scientific resource required
2.	**Pakistan Council of Renewable Energy Technologies**	• Mandate of introduction and promotion of renewable energy technologies in Pakistan	• Potential climate change mandate to be brought in focus. Particularly, supporting mitigation activities/ CDM
3.	**National Institute for Oceanography**	• Key institution to undertake research in climate change related impact of oceans and related phenomenon • Potential role in technical advice for adaptation and disaster risk reduction	• Climate change–related mandate to be focused • Strengthening of research linkages • Mechanism of improved access to scientific and research information required • Role in policy advice needs strengthening
F.	**MINISTRY OF PETROLEUM AND NATURAL RESOURCES**	• Role in development of petroleum resources	• Climate change–related mandate to be focused
1.	**Hydrocarbon Development Institute of Pakistan**	• Role in development of hydrocarbons as alternate and clean fuel • Potential role in mitigation	• Climate change–related mandate to be focused
G.	**MINISTRY OF DEFENSE**	• No direct role	

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Table 15 continued

No	Organization	Climate change–related mandate	Potential future role/needs
1.	**Pakistan Meteorological Department**	• Key institution to undertake research on climatology and other allied disciplines • Climate change forecasting • Technical advice	• More financial resources to broaden research base required • Role in supporting climate change policy needs to be focused more • Further scientific linkages required
2.	**Pakistan Space and Upper Atmosphere Research Commission**	• Key institution to undertake research on climatology in relation to upper atmosphere • Role in technical advice	• Strong potential role of conduct modeling-based research on glaciers • Climate change–related mandate to be focused • Mechanism for improved access to scientific information • Strengthened linkages with relevant partners
H.	**NATIONAL DISASTER MANAGEMENT AUTHORITY, PRIME MINISTER'S SECRETARIAT**	• Focal institution to manage natural and man-made disasters • Strong policy influence for adaptation and disaster risk reduction	• Climate change–related mandate to be focused • Capacity for deployment of early warning system needs to be enhanced • Potential role in supporting adoption activities
		International	
A.	**UNITED NATIONS DEVELOPMENT PROGRAMME**	• Mandate of achieving greater impact in contributing to national development plans and priorities • Potential role in accessing funding resources • Potential role in promoting international linkages	• More focus on mobilizing donor support for adaptation measure in Pakistan
B.	**WORLD BANK**	• Largest sources of funding and knowledge • Role in project funding and advisory services	• More resources and activities in Pakistan must be made available
C.	**ASIAN DEVELOPMENT BANK**	• Key finance institution • Mission is to help its developing member countries reduce poverty and improve the quality of life	• More resources and activities in Pakistan • Project support aiming at adaptation
D.	**IUCN (INTERNATIONAL UNION FOR CONSERVATION OF NATURE) - PAKISTAN**	• Largest global Union, with diverse portfolio • Climate change is a thematic priority area • Pioneer in climate change activities in Pakistan • Role in policy advice, support in policy formulation • Role in strengthening diplomatic efforts • Role in mobilizing stakeholders • Strong role in technical advice	• More financial resources are required • Strong convening mandate must be harnessed to initiate policy development process in Pakistan

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Table 15 continued

No	Organization	Climate change–related mandate	Potential future role/needs
E.	**INTERNATIONAL CENTRE FOR INTEGRATED MOUNTAIN DEVELOPMENT**	• Regional knowledge development and learning center • Support regional transboundary programs through partnership • Strong networking • Role in implementation of adaptation measures (particularly in mountain ecosystems) • Research mandate	• More financial resources are required
F.	**WORLD WIDE FUND FOR NATURE, PAKISTAN**	• Mandate of conservation of natural resources and degradation of environment • Integrate the environmental principles with other policies across the government and private sectors • Potential role in design and implementation of adaptation activities	• Climate change mandate needs to be focused • More resources needs to be provided to initiate projects aiming and natural resources conservation, ecosystem protection, and building community resilience
G.	**OXFAM GB**	• Mandate of working directly with communities • Role in responding to emergencies • Potential role in building community resilience and climate change adaptation	• More resources needs to be provided to initiate projects aiming and natural resources conservation, ecosystem protection, and building community resilience • Role in policy advice needs strengthening • More partnership building required
H.	**LEAD PAKISTAN**	• Mandate to create, strengthen, and support networks of people and institutions promoting change toward sustainable development • Leadership development • Role in advocacy and partnership devotement	• More resources needs to be provided to initiate related projects climate change • More focus of leadership development • Active participation in advocacy campaigns
I.	**ASIANICS AGRO DEVELOPMENT INTERNATIONAL**	• Expertise in research on climate change and allied disciplines including agriculture, forestry, and economics • Collaboration and partnership with international and national partners • Strong role in policy and technical advice	• More resources needs to be provided to initiate projects aiming and natural resources conservation, ecosystem protection, and building community resilience • Role in policy advice needs strengthening • More partnership building required
J.	**WINROCK INTERNATIONAL**	• Role in agriculture, natural resources management, clean energy, and leadership development • Role in mitigation through design and implementation of CDM projects	• Advisory role to be focused • More focus of CDM-related activities

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Table 15 continued

No	Organization	Climate change–related mandate	Potential future role/needs
K.	**SUSTAINABLE DEVELOPMENT POLICY INSTITUTE**	• Mandate for providing expertise for policy analysis and development, policy intervention, and policy and program advisory services • Advocacy campaigns and consultations • Role in policy advice	• More resources needs to be provided to initiate projects for policy support • Advisory role to be focused • Important role for policy support could be harnessed

CBD = Convention in Biological Diversity, CDM = Clean Development Mechanism, IPCC = Intergovernmental Panel on Climate Change, NAPA = National Adaptation Programme of Action, UNCCD = United Nations Convention to Combat Desertification.
Source: IUCN and ICIMOD. 2010a.

5.2 Climate Change–Related Policies

In order to be a progressive nation, safeguard its ecological integrity, and ensure sustainable development, Pakistan has shown a very strong commitment to play an effective role in global efforts to mitigate and adapt to climate change. Pakistan has been actively participating in the global dialogue since the historic Rio Earth Summit in 1992. The country has also effectively contributed to global dialogue on climate change, sustainable development, and conservation, and is a signatory to a number of conventions and protocols, including the United Nations Framework Convention on Climate Change (UNFCCC).

Pakistan entered into Kyoto Protocol on 11 January 2005 and has since become eligible to benefit from carbon-financing opportunities under the Clean Development Mechanism (CDM). Pakistan formulated the National Operational Strategy for CDM in February 2006, which offers tremendous incentives to investors to generate carbon credits for reducing carbon emission from potential sectors. Pakistan has also participated in all international climate change–related negotiations, including the Conference of Parties (COP) to UNFCCC, Meeting of Parties (MOP) to the Kyoto Protocol, and meetings of subsidiary bodies.

A Task Force on Climate Change was set up by the Planning Commission of Pakistan in October 2008 with the view to (i) take stock of country's situation in relation to climate change; (ii) contribute to the formulation of a climate change policy that would assist the government in achieving sustained economic growth by appropriately addressing climate change threats so as to ensure water security, food security, and energy security of the country; (iii) recommend policy measures for promoting large-scale adaptation and mitigation efforts, raising awareness of various stakeholders; and (iv) enhance the capacities of relevant national institutions.

The final report of the Task Force was issued in February 2010. It describes Pakistan's vulnerability to climate change due to impacts on various socioeconomic sectors and recommends a number of adaptation and mitigation measures based on the initial assessment of different sectors, and it reviews the country's implicit ongoing and planned responses. The report also provides recommendations on issues such as much-needed capacity building, needs for international cooperation, and Pakistan's position in international negotiations on the future climate change regime.

The report identifies the basic elements of Pakistan's climate change policy for the near to medium term. Salient among those are efforts to

- assist the government for sustainable economic growth by appropriately addressing the challenges posed by climate change, in particular the threats to Pakistan's water, food, and energy security; and
- contribute to the international bid to check climate change by controlling Pakistan's own greenhouse gas emissions to the maximum extent feasible.

A national climate change policy was under Cabinet consideration at the time this report went to press.

6. Risk Screening of the Government of Pakistan–ADB Water and Energy Portfolio

For further details refer to Supplementary Report: ICIMOD (2010b) Climate Risk Screening of the ADB Water and Energy Portfolio in the Indus Basin. Report prepared for ADB Project Glacial Melt and Downstream Impacts on Indus Dependent Water Resources and Energy. Kathmandu.

6.1 The Approach

As part of this study, current ADB projects in the Indus Basin in Afghanistan and Pakistan were screened for potential climate change impacts and associated risks. After a rapid desk screening selected projects were reviewed in more detail with visits to project implementing partners and project management units. The screening was concerned with the associated climate risks faced by the project and expected in the future as an impact of climate change. It looked into the current level of risk management preparedness and attempted to identify further adaptation options to be considered.

Prior to the screening process, different methodologies proposed by a variety of institutions (UNEP 2008; Klein et al. 2007; Gigli and Agrawala 2007; Burton and van Aalst 2004) were reviewed and assessed (ICIMOD 2010b). The method applied in this study is largely based on the ORCHID (Opportunities and Risks of Climate Change and Disasters) approach's steps 1 to 6 (Tanner et al. 2007). Steps 7 and 8 of the original ORCHID approach are not included as they are based on actual implementation of the selected measures.

Overall, the process was divided into two major sets of steps: first, a set on desk screening, and second, field screening steps. Field screening was only undertaken in case the projects were climate sensitive or had opportunities for further risk management and/or adaptation. For further details refer to ICIMOD (2010b).

Desk Screening

Step 1: **General project information.** On the basis of the Report and Recommendation of the President to the Board of Directors (RPP) a general introduction and understanding of the project was presented in the format shown below.

Step 2: **Identification of potential climate hazards and stresses.** On the basis of the geographical location and the type of project, its exposure to different climate hazards and stresses was assessed according to the template shown below. The assessment was based on a review of the available published and unpublished literature. Hazards and stresses that were generally included in this assessment are riverine floods, flash floods, riverbank erosion, drought, cyclone/storm surge, heat waves/cold spells, sea-level rise, and groundwater salinity (Tanner et al. 2007). This assessment also included landslides/mudslides, glacial hazards and flow reduction as additional hazards with particular relevance in mountainous areas.

Step 3: **Vulnerabilities.** According to the type of project, its vulnerability was assessed based on variations in climate with particular focus on the project's objectives.

Step 4: **Existing risk management.** An assessment of possible interventions that may be considered and were discussed in the RPP is provided here.

Step 5: **Recommendations.** On the basis of information gathered above, final recommendations were made about the climate sensitivity of the intervention and the opportunities to reduce risks. In addition practical and operational factors were included in this assessment.

Field Screening

Prior to the actual field screening, it was important to update the desk screening results and verify the desk assessment. The field screening itself involved three steps, i.e. the identification of risk management options followed by a detailed assessment of the different options to gain a better handle on the possible options to be implemented. The result of the process is a summary table of different scores for different options.

Step 6: **Identification of risk management options.** On the basis of the interviews and meetings with the project implementation partners as well as on the basis of documents received about the project, planned and potential risk management options were identified. The result of this was a list of options divided into existing and additional options for different risks.

Step 7: **Scoring of risk management options.** Each risk management option identified above was scored on the basis of the score list shown below. The projects were classified into three different groups:

- Strategic changes (SC)—these are measures that involve changes in the implementation strategy of the project;
- Structural measures (ST)—these are changes that involve the setup or construction of physical structures such as dams, embankments, etc.;
- Non-structural measures (NS)—these are measures that involve the implementation of management changes.

Step 8: **Risk management options summary.** Finally, the different options were compared in a summary table and recommendations were made.

6.2 The Results

In the course of this assessment six projects from the water and energy portfolio in Afghanistan and Pakistan, for which documents were available, were assessed based on a modified ORCHID methodology (Table 16).

Table 16 Projects included in the screening process

Projects	Country
001-2010: Punjab Irrigated Agricultural Investment Program (37231)	Pakistan
002-2010: Renewable Energy Development Sector Investment Program (34339)	Pakistan
003-2010: New Bong Escape Hydropower Project (38928)	Pakistan
004-2010: Water Resources Development Investment Program (42091)	Afghanistan
005-2010: Power Transmission Enhancement Investment Program (37192)	Pakistan
006-2010: Energy Sector Development Investment Program (42094)	Afghanistan

Source: Own compilation.

In terms of risk assessment, it is evident that water availability is the main issue for all field-screened projects. However, the risk to impacts of climate change as well as the opportunities for risk management options varies. In the case of the Punjab Irrigated Agricultural Investment Program, particularly the Lower Bari Doab Canal Project, a number of risk management options are already being planned as in this case there is a high opportunity to reduce risk. In the case of the other two programs, the Renewable Energy Development Sector Investment Program, particularly the part involving the Punjab Power Development Company, and the New Bong Escape Hydropower project, very few additional options are available as they are both quite climate robust as long as the irrigation management from Mangla reservoir remains unchanged. As such the projects are more vulnerable to political decisions about water releases to different provinces and canal systems than to climate change. In addition, the life cycle of these hydropower projects is 40 to 50 years, within which water flows are expected to increase due to increased glacial melt (Rees and Collins 2006).

In terms of risk management, current on-farm management options seem to provide a best bet for agricultural projects as they not only address problems associated with climate change, but also with increasing population, and balanced costs, prior knowledge, and direct benefits. Both groundwater management and institutional reforms are associated with new approaches that still need to be verified in reality in the context of irrigation water management in Punjab. But both these options also seem robust. In order to address flood risks, the options are clear with a change in the design of the structures for floods of higher-return periods. However, as the impact of climate change in relation to floods is very uncertain, the risk of overdesigning and expanding the costs is very high.

To make more robust assessments, uncertainties related to the impact of climate change on water resources, climate, and glaciers need to be reduced. This calls for a comprehensive research effort to better understand the interaction between climate change, the local climate, its impact on glaciers, and their influence on water availability, but also on disasters. Therefore, more efforts need to be made in climate downscaling, glacier mass balance assessments, and the hydrological modeling of glacier and snowmelt. For further details refer to ICIMOD (2010b).

Table 17 Assessment of ADB portfolio after field screening

Project	Rec. 1	Rec. 2	Rec. 3	Remarks
001-2010: Punjab Irrigated Agricultural Investment Program (37231)	X			• The project is particularly affected by the looming water crisis. There is no water running in the Ravi River and the water supply in the canals has reduced in the last 10 years. • The project includes several adaptation options in on-farm water management, groundwater management, and institutional reforms. • In terms of flooding there is a large uncertainty because of the influence of Thein dam in India. The design of the structures is based on the assumption that Thein Dam will have a beneficial impact on floods of high magnitude. For this reason the design floods are reduced and currently only the 1:50 years flood is being considered for the design of the barrage. • Overall, it is clear, that the main issue for this project is water availability followed far behind by riverine and flash floods.
002-2010: Renewable Energy Development Sector Investment Program (34339)			X	• Risks associated with the planned power stations are far lower than previously expected on the basis of the desk-screening process. • All power stations are located on existing irrigation canals. The potential for extraordinary and large floods as well as flash floods is therefore very small. • Landslide hazards do not apply as they have virtually no impact on the canal systems (except increased sediment loads, which is however controlled by the automatic closure of canal intakes in case of high sediment concentrations in the water). • Glacial hazards do not apply. • The main risk is reduction in flow in the canals because of lower water availability. But also this risk is much smaller than expected as water for irrigation purposes is part of the lifeline for Punjab and is managed centrally. • In addition it is important to mention that the design life of these power stations is about 40 to 50 years. As a private operator, Punjab Power Development, Ltd. does not plan beyond this. • As such the projects are more dependent on political decisions than on climate change within their life cycle. For this reason the assessment was changed to "Low climate sensitivity/opportunities for reducing risks."
003-2010: New Bong Escape Hydropower Project (38928)			X	• On the basis of the desk screening the project produced a medium climate sensitivity rating, which seems to be the right assessment. • Options for risk management are tied to the decisions made on Mangla Reservoir. • While during the desk screening the main impact from climate change seemed to be water availability, it was shown during the field screening that the main issue is flash floods in Jabbar Nullah (Sustainable Solutions Pvt. Ltd. 2009). • Water availability is regulated by the upstream Mangla Reservoir, and flows for this project are highly regulated. • Currently the Mangla Reservoir is being raised, which will increase the storage and regulation capacity and therefore increase the benefits for this project. Within the project's life cycle, no reduction in water availability for this project is expected from climate change, rather an increase may be experienced due to increasing glacial melt. • Flash floods are being catered for through the appropriate design.

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Table 17 continued

Project	Rec. 1	Rec. 2	Rec. 3	Remarks
004-2010: Water Resources Development Investment Program (42091)				No field screening undertaken
005-2010: Power Transmission Enhancement Investment Program (37192)				No field screening undertaken
006-2010: Energy Sector Development Investment Program (42094)				No field screening undertaken

Rec. = Recommendations:
1 Significant climate sensitivity / opportunities for reducing risks
2 Some climate sensitivity / opportunities for reducing risks
3 Low climate sensitivity / opportunities for reducing risks

Source: Own compilation.

7. Conclusions and Recommendations

Based on the findings of knowledge gap analyses and stakeholder workshops organized in Karachi and Islamabad (IUCN and ICIMOD 2010b), different issues in relation to climate change adaptation of the water and energy sectors were identified with particular reference to the upland areas and the downstream impacts of changes in these areas. The issues are summarized in Table 18 and discussed in more detail in the section below.

7.1 Policy Environment

Progress on national climate change policy: To date, a comprehensive national climate change policy has been drafted and is awaiting the approval of the Government of Pakistan's Cabinet when this report went to print. ADB has supported this process with the integration of a climate change adaptation road map in the Task Force's broader climate change report.

7.2 Inadequate Financial Support for Adaptation Activities

Financial support needs to be identified by the Government and multi-/bilateral donors. During the workshop it was advised that the UN Adaptation Fund is already operational and is accepting projects aimed at climate change adaptation. It was therefore recommended that Pakistan make best use of available financial resources under the Fund to combat the impacts of climate change.

7.3 Data and Information Availability

Sparse Hydrometeorological Monitoring Network in Mountain Areas

The present network, including all stations of national and international organizations, does not serve the purpose of representing the heterogeneous mountain terrain. Climate varies between valleys and mountain tops, between aspects and orientation, and between different locations. To meet the optimum observational demands, at least 75 automatic weather stations and 35 hydrological measurement stations should be installed in target mountain areas. This would allow effective modeling of the hydrodynamic characteristics or these areas.

Need For Integration of Data from Different Institutions

There are several national and international organizations—including Pakistan Meteorological Department (PMD), Water and Power Development Authority (WAPDA), Ev-K2-CNR, University of Bonn/Germany, and others—involved in hydrometeorological data collection using their own, independent observation networks. PMD runs the largest network throughout Pakistan. It works in close collaboration and through data-sharing protocols with WAPDA and Ev-K2-CNR. Other networks or individual monitoring stations have been operational in the mountain areas, but the data is not integrated in national data sets. In a recent report of the Task Force on Climate Change, it was proposed that a national database be set up with climate change data accessible to the research community.

Table 18 Summary of climate change-related issues in mountain areas

Issues	Policy environment	Data and information availability	Scientific knowledge	Adaptation capacity	Technical capacity	Institutional arrangements	Awareness
Missing climate change policy	X						
Financial support for adaptation activities	X						
Density of hydrometeorological monitoring network in mountain areas		X					
Data integration of data from different institutions		X					
Data access at national and transboundary levels		X					
Access to published and unpublished information		X					
Downscaling of climate change scenarios			X				
Detailed knowledge of glacier resources and dynamics			X				
Impact of glacier dynamics on water resources			X				
Economic impact of water resources dynamics			X				
Promotion of appropriate adaptation options				X			
Tools for risk management and adaptation				X			
Lack of trained human resources					X		
Adequate equipment and instruments					X		
Computation capacity					X		
Interdepartmental collaboration and coordination						X	
Transboundary collaboration and coordination						X	
Awareness of climate change in the general population							X
Awareness of climate change at different institutional levels							X

Source: ICIMOD.

Need for Data Access at National and Transboundary Levels

Data access and sharing remains a pressing issue both nationally among different departments and line agencies and also among the riparian states. Relevant organizations, particularly in the public sector, must be supported to provide easy access to relevant information and data. Protocols need to be established to allow transboundary data access.

Need for Access to Published and Unpublished Information

To ensure better and improved knowledge about climate change issues, it is crucial to have access to reports and published articles on this subject. The Indus Basin knowledge platform is a first step in this direction to provide metadata about articles, data, and satellite imagery. However, access to full text articles and reports has to be envisaged in future for any researcher, planner, or policy maker to take advantage of this platform.

7.4 Scientific Knowledge

Inadequate Downscaling Capacity for Developing Regional Scenarios with Low Uncertainties

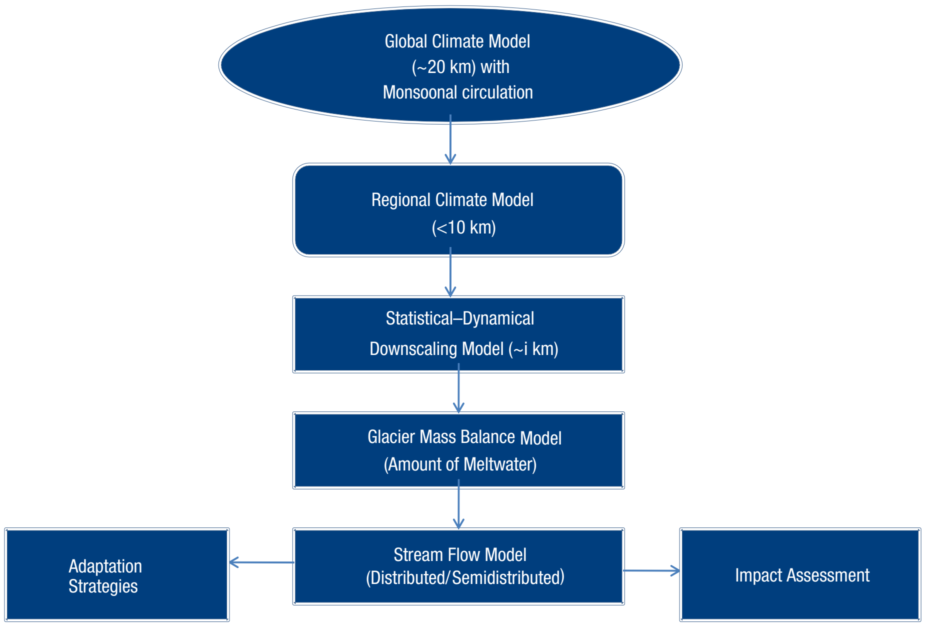
The precipitation projections are associated with a large uncertainty, as was shown with the comparison of different global circulation models and by running CRU data to validate the Providing Regional Climate for Impact Studies (PRECIS) model. In addition, current downscaling work is based on coarse resolution, which results in a crude overview of future scenarios. It does not help to determine the impact of climate change at a subbasin level that is crucial for planning of water resources development. The capacity for downscaling and developing regional scenarios with low uncertainties needs to be improved, and research needs to be enhanced and new initiatives supported.

Lack of Detailed Knowledge of Glacier Resources and Dynamics

The glacier environment of the greater Himalayan region is still a large "black box" as there is a lack of relevant data and large uncertainties in the assessments as shown by the great variance of reported results on glacier numbers, area, and ice volume. In addition, glaciers in the Himalayas seem to behave differently than those in the Karakoram; while the glaciers in the Himalayas and in the Hindu Kush seem to be in retreat, a number of glaciers in the Karakoram seem to be advancing. However, whether these changes are due to internal changes of geometry of the ice or actual increase in glacial mass balance is still subject to research and clarification. The influence of debris cover—many glaciers in the region are debris covered—are quite variable and differ from glacier to glacier. Monitoring of the evolution of glaciers in the greater Himalayan region is therefore a key issue as their melting may (i) negatively affect regional water supply in the next decades (Barnett et al. 2005), (ii) significantly contribute to ongoing sea-level rise (Kaser et al. 2006), and/or (iii) increase natural hazards linked to glaciers (especially glacial lake outburst floods) (Mool et al. 2001).

Pakistan Agricultural Research Council, in collaboration with ICIMOD, prepared a first glacier inventory for Pakistan in 2005, which has been widely referred to. This inventory addresses the status of glacier resources based on the area of the glaciers and determines glacier lakes, but does not deliberate on the glacial mass and the glacier mass balance. As shown above, the behavior of glaciers in the Karakoram differs from other areas in the region in form of rapid expansion, while glaciers in the other areas of the Western Himalayas and the Hindu Kush, are in rapid recession. Without glacier mass balance information, however, no definite answer on the impact of these expanding and retreating glaciers can be made. It is therefore suggested to initiate a new glacier inventory, including both glacier cover as well as glacier mass balance, applying remote sensing techniques with rigorous

Figure 23 Comprehensive basin-scale research



km = kilometer.
Source: ICIMOD 2010a.

ground truthing. In addition to the areas within Pakistan, it is crucial to also get an understanding of the glacier status and dynamics in other riparian countries of the Indus River.

Lack of Data on Impact of Glacier Dynamics on Water Resources

Glaciers in the uplands of the Indus, including the eastern and western rivers are the lifelines of Pakistan's economy. They provide water downstream thus making the country the most vulnerable to changes in glacial melt. To improve the understanding of the glacier–hydrology relationship and dynamics under climate change, it is crucial to perform hydrological modeling at different scales. A strong research base on glacial hydrology and modeling is essential to devise relevant sector-wise measures for better adapting to these challenges. Currently most water resource–modeling exercises are confined to small and focused areas, but there are no modeling exercises for the entire basin taking into account the data from all riparian countries. This requires data sharing among riparian countries, transboundary technical collaboration, and the parametrization of a basin water resources model that accounts for the specificities of glacial areas, snowmelt, and mountain heterogenities and input parameters. A comprehensive modeling approach (as shown in Figure 23) integrating different disciplines and sectors is necessary to provide relevant guidance to decision and policy makers.

Lack of Data on Economic Impact of Water Resource Dynamics

There is still a lack of information about the actual impacts of climate change on the economy in Pakistan. During the stakeholder workshops it was very strongly recommended that high-quality research on the economic impacts of climate change and water management needs to be conducted and new risk management initiatives supported.

7.5 Adaptation Capacity

Dearth of Activities to Promote Adaptation Strategies, Options, and Actions

To increase the adaptation capacity of a nation, appropriate adaptation options need to be promoted after careful identification and selection. Adaptation options may be from options applied in other countries, or they may be based on traditional and indigenous knowledge. In both cases, the options need to be assessed and their impacts carefully studied. For this reason an enhanced research base is required at government agencies and at local universities. Consequently, during the stakeholder workshops the following recommendations were made:

- The agriculture sector is likely to be badly damaged due to less water availability and changing weather patterns. For this sector, it is crucial to enhance the research base on more adaptive crops, adapted agricultural practices, better water management (including construction of reservoirs and efficient distribution), and promoting alternate livelihoods.
- Changes in rates of glacial melt in the Indus Basin may have tremendous downstream impacts increasing the risks of riverine floods and outburst floods from glacial lakes and rivers dammed by landslides after the collapse of destabilized slopes.
- Climate change–related impacts are giving rise to issues like food security concerns and may also be a multiplier for issues like terrorism and national security threats. Pakistan should be completely prepared for this with appropriate adaptation strategies.

It was recommended that improved water resources management be immediately considered. Particularly in urban areas, sewage should be treated through bio-remedial measures, to render waste products useful for agriculture. Similar concepts like rainwater harvesting and water recycling, which have the potential to help in meeting the shortages, need to be promoted.

Absence of Tools for Risk Management and Adaptation

Tools urgently need to be developed to identify sector-wide vulnerabilities and risk management measures associated with climate change and melting glaciers. During Phase 1 a risk management framework was proposed, which needs to be field tested and adapted where necessary.

7.5 Technical Capacity

Lack of Climate Change Adaptation Capacity

There is an acute shortage of well-trained staff who understand climate change science and the dynamics of the climate system. None of the national universities offer such courses at the graduate or post-graduate level. Climate change science demands a high level of professional proficiency in theory and practice. In addition, expertise in downscaled numerical modeling is highly desirable. There is a dire need to train the staff of PMD, Global Change Impact Studies Centre (GCISC), and National Agriculture Research Centre on downscaled numerical modeling and climate system dynamics at International organizations that play leading roles in climate change science.

Inadequate Equipment and Instruments

Pakistan does not have sufficient scientific and technological capability for the collection of climatologically information, to monitor and predict associated changes in the climate system and to regularly update glacier mass balances. The available technical facilities are not sufficient to obtain all the relevant scientific data and present scenarios at high spatial resolution (particularly in the remote mountain areas). PMD is striving to set up high-altitude monitoring stations to gather information of changes happening in the glacial regions of the country. WAPDA is setting up a Glacier

Research and Monitoring Centre, which needs support with equipment and instruments to provide a relevant service.

Weak computational capacity

Presently PMD has been using a 16 nodes blade server to run High-resolution Regional Model (HRM), Regional Climate Model (RegCM3), Statistical Downscaling Model (SDSM), and PRECIS models, whereas GCISC is using a 16 PC cluster. Each run takes months to be completed in a limited domain, and at a larger time step. Computer power has to be significantly enhanced to work in the regional domain to reduce the bias at finer time steps in order to produce more realistic assessments. With enhanced computer capacity, dynamical and statistical downscaling can be conducted.

7.7 Institutional Arrangements

Weak Interdepartmental Collaboration and Coordination

Interdepartmental collaboration and coordination among government departments and coordination among nongovernment organizations (NGOs) and academia needs considerable strengthening. Climate change activities demand an inter-disciplinary approach relying upon multiple stakeholders. This coordination could be fostered through an interdepartmental committee (Glacial Melt and Risk Management Committee) under the National Disaster Management Authority.

Lack of Transboundary Collaboration and Coordination

Since the threats of climate change encompass South Asian countries as a whole, experts recommended that a collaborative and transboundary approach should be adopted to strengthen research and implementation activities, particularly in areas of mutual interest, like glacial melt and associated downstream impacts in the Indus Basin. It was also recommended that efforts must be enhanced to adopt a shared approach to deal with the multitude of challenges associated with climate change. Coalitions with other regional and international bodies must be built to benefit from the high-quality expertise available at the global level.

7.8 Awareness

Low Awareness Level of Climate Change in the General Population

It is important to continuously raise awareness about climate change and its impact on glacial melt and subsequent upstream–downstream impacts to the general population. The activities proposed are (i) the preparation of a documentary film on the Indus Basin and its wide broadcasting on public and private TV channels; (ii) development of curricula for high schools, colleges, and universities; (iii) support to the climate change electronic networks; and (iv) regular publication of newsletter and its wider dissemination. Only a few people in Pakistan know about glaciers, therefore, it is important to organize glacier study tours for the key policy makers as well as college and university students.

Low Awareness of Climate Change at Different Institutional Levels

A quick review of the work plans of key national institutions, such as WAPDA, PMD, Ministry of Food and Agriculture, Ministry of Water and Power, Ministry of Science and Technology, etc., would indicate that there is limited ongoing work on glacial melt and its upstream–downstream impacts. There is no specialized university where glaciology or mountain studies are taught. Therefore, it is important to create awareness (using the above-mentioned instruments) and advocate for the inclusion of such an important subject in the work plans of these key institutions. There is also a need to strengthen the NGO sector to ensure the momentum, especially at the level of civil society.

8. The Way Forward

On the basis of issues identified above the following recommendations emerge for the way forward:

- **The capacity of relevant national institutions needs to be strengthened** to adequately monitor and project the impacts of climate change. This includes the technical capacity to provide downscaled climate change scenarios to subbasin level, the transboundary assessment of glacier dynamics (particularly glacier mass balances and impact on meltwater flow) through field-based and remote-sensing approaches, and water resources modeling of the Indus River and its tributaries. Capacity building is understood in terms of human resources development through training and education, the setting up of required geo–spatial analysis and computational capacity at relevant line agencies, and instrument and equipment support for adequate field investigation and monitoring.
- **Appropriate adaptation options suitable for climate proofing and risk management** for the water and energy sectors at different locations in the Indus Basin need to be identified through an enhanced and collaborative research program, pilot studies, and integrated planning approaches. Collaborative research demands the integration of different disciplines and the participation by relevant research organizations. The national research organizations require technical and funding support. It is suggested that the latter can be organized through a competitive research grant system.
- Given the complexity of problems related to the connectedness of cryosphere, biosphere, hydrology, and human activities, there is also a need to **organize future activities in a coordinated and programmatic manner,** bringing in the regional and global knowledge base to improve the scenario analysis and projection of future trends and impacts on water resources.
- Water and energy programs and projects of ADB and the Government of Pakistan need to be made **climate adaptive and proofed through the application of suitable knowledge and tools** to identify vulnerabilities and threats and risk management activities with the help of the medium- and long-term adaptation options identified above. The suggested screening tool and the framework may play a major role in this and therefore need field testing and subsequent adaptation in policies, programs, and plans.
- To provide a **favorable environment for the implementation of climate change adaptation activities**, awareness creation of the public at large and policy and decision makers is of crucial importance. The development of climate change policy and a national climate change action plan needs to be supported technically and through a constant stakeholder consultation and policy dialogue to ensure full participation and agreement of all relevant stakeholders.

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