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Condensed Report

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

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

Condensed Version

International Centre for Integrated Mountain Development
Kathmandu

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Abbreviations

ADB	Asian Development Bank
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
PARC	Pakistan Agricultural Research Council
PMD	Pakistan Meteorological Department
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WAPDA	Water and Power Development Authority

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Executive Summary

There is a growing recognition that countries of the Indus River Basin face major and changing threats to their water security and, therefore, to their people's critical food and energy needs. Downstream areas rely on water resources originating from glacial melt and monsoon rains in mountainous upper catchments, and the generally semiarid basin is one of the areas in the world that are most dependent on meltwater recharge. The Indus River is a lifeline for Pakistan's huge and growing population and the world's largest irrigation system fed by transboundary water. The countries in the basin are already facing water shortages. Climate and socioeconomic changes are only making it worse.

The Asian Development Bank (ADB) is tackling these vulnerabilities and risks through a variety of measures through the Promoting Climate Change Impact and Adaptation in Asia and the Pacific project (regional technical assistance 6420). This initiative supported an analytical and collective stock taking of the issues, challenges, and opportunities for water and energy projects dependent on glacial meltwater to stimulate regionally coordinated interdisciplinary research. Information from this study could prove critical for policy and decision makers to enhance their understanding of environmental risks from climate change in the Indus River Basin and help plan water resources development programs in an integrated manner to solve emerging problems.

The year-long study was implemented by the International Centre for Integrated Mountain Development (ICIMOD) in coordination with the International Union for Conservation of Nature (IUCN), and joined by experts from countries sharing the river: Afghanistan, the People's Republic of China (PRC), India, and Pakistan. It included setting up an interactive digital knowledge platform; holding a series of national, regional, and stakeholder workshops and consultations to formalize technical partnerships among institutions studying climate change; and screening for climate risks of six ADB water and energy projects in the Indus Basin.

The results—largely derived from studies of secondary information, literature reviews, and a series of intensive stakeholder consultations—show that knowledge of climate change projections have major gaps, particularly with reference to precipitation, the dynamics of glacier resources and their impact on water flows, and the economic impact of changes in the availability of water resources.

Constraints on decision making for the judicious management of water resources of the Indus River include a scarcity of automatic weather and hydrological stations in glacier areas, a lack of basin-wide and transboundary models to assess trends and provide scenarios in the water supply situation, and the absence of scientific consensus on the impact of climate change on fluctuations that show glaciers in different locations are retreating and surging. Policy environments also need to be improved.

The study therefore recommends these actions:

- Make data and information more available by creating a denser monitoring network in mountain areas, integrating data from different institutions and governments, and establishing a clearinghouse for published and unpublished information to make better informed decisions.
- Strengthen the capacity of national institutions to monitor and project climate change impacts.

This includes the technical capacity to provide climate change scenarios at the subbasin level, transboundary assessments of glacier dynamics through field-based and remote-sensing approaches, and water resources modeling of the Indus River and its tributaries.

- Make water and energy programs and projects of ADB and the Government of Pakistan adaptive to climate change in the medium and long terms by applying 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 should be field-tested.
- Organize a coordinated program that considers the complex relationship between the cryosphere, biosphere, hydrology, and human activities, using regional and global knowledge bases to improve projections of trends and their impacts on water resources.
- Create awareness among decision makers and the public of the crucial importance of adaptation to climate change in order to encourage the implementation of strategies and policies, including development of a national climate change action plan.

The consensus reached through international expert group consultations is that resource managers and decision makers require and expect the development of a favorable environment for better, integrated management of water resources on the basis of verifiable measurements and efficient uses. Stakeholders, including the regional and international scientific and management communities, agreed that a second and longer phase of work with emphasis on field verifications is necessary.

Resource managers and decision makers require and expect the development of a favorable environment for better, integrated management of water resources

1. Introduction

Climate change poses a real threat to the economies of the world. An increase in extreme weather events, including floods, droughts, forest fires, and tropical cyclones, is intensifying the vulnerability of populations in developing Asia. Water and thermal stresses, and rising sea levels add to the toll of disasters. As agricultural and aquaculture productivity declines, so does food security in many countries.

For water-dependent ecosystems and infrastructure, the overall increase in climate variability is challenging, especially for populations in semiarid areas. The situation in the Indus River Basin is particularly acute. The basin—an area shared by Afghanistan, the People's Republic of China (PRC), India, and Pakistan—provides water to millions of people. It has two broad domains as the lower basin relies on water for irrigation from upper catchments in the Western Himalayas. Here, a changing balance between temperature, precipitation, and the complex dynamics of some of the biggest glaciers in the world determines when and how much water flows downstream.

Communities in the basin are already experiencing water shortages. Climate and socioeconomic changes make it worse. Poverty, fragile natural resource–based economies, and low resilience to changing conditions mean that the adaptive capacity of human systems is low in developing countries, particularly those in Asia (Parry et al. 2007).

The Asian Development Bank (ADB) is tackling climate change vulnerabilities and risks through measures to strengthen adaptations to climate change, and mainstreaming them into ADB activities. ADB supported an analytical and collective stocktaking of the issues, challenges, and opportunities for water and energy projects in Pakistan and Afghanistan.

This report—and the expanded version—summarizes trends in increasing variability in precipitation, seasonal temperature regimes, glacial melt, and water supplies, and the risk scenarios for climate change and its possible impacts on millions of people in downstream areas.

The report aims to stimulate regionally coordinated interdisciplinary research to provide critical information for policy and decision makers to plan and design water resources development programs in an integrated manner.

Studies and consultations highlight gaps in the knowledge of climate change projections, particularly with reference to precipitation, the dynamics of glacier resources, and the economic impact of changes in the availability of water. They conclude that there is a way forward to tackle constraints on decision making for the efficient management of water resources.

2. Project Context and Background

2.1 Context

The ADB initiative, Promoting Climate Change Impact and Adaptation in Asia and the Pacific, addresses risks posed by climate change vulnerability through a variety of measures, including portfolio at-risk assessments, the screening and climate proofing of development projects, country assessments to create adaptation road maps, policy guidance to make economic sectors more resilient, and efforts to tackle social dimensions such as migration and the role of women in building community resilience.

A small grant adaptation action titled Glacial Melt and Downstream Impacts on Indus–Dependent Water Resources and Energy was implemented by the International Union for Conservation of Nature (IUCN) in collaboration with the International Centre for Integrated Mountain Development (ICIMOD) from February 2010, and joined by other international institutions. National partners included the Pakistan Meteorological Department, the Ministry Water and Energy in Afghanistan, and experts from the People's Republic of China (PRC) and India.

Project activities included the setting up of an interactive digital knowledge platform; a series of national, regional, and stakeholder consultations to formalize technical partnerships among institutions; and a thorough review of the scientific literature of climate change and its impacts in the upper and lower halves of Indus basin. Six ADB water and energy projects in the basin were screened for climate risks. A draft framework was also produced for planners to make initial assessments of potential hazards and likely risk management and adaptation options needed to ensure the viability of large-scale infrastructure investments in the face of climate change predictions. The draft framework will undergo vigorous testing and peer review before its release as a standard field manual for practitioners.

2.2 Rationale

Greater variability in precipitation and thermal regimes poses severe threats to the livelihoods of millions of people in the Indus River Basin, particularly in Pakistan, where changing weather patterns are damaging agriculture.

The basin consists of six main rivers (the Indus, Jhelum, Chenab, Ravi, Sutlej, and Kabul) originating from glaciers in the Western Himalayas; 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 forces are expected to alter river basin behavior significantly and jeopardize hydropower generation and irrigated agriculture production. 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). Lost hydropower generation may result in countries returning to fossil fuel—worsening atmospheric global warming and subsequent glacial melt.

Field observations, satellite imagery, and hydrological records have been used to investigate the reduction of the Western Himalayan glaciers, but results fail to accurately document the change and sometimes contradict climate impacts. Even with relative consensus on global warming, and recorded increases in regional temperature, uncertainties remain. Predictive downstream impacts are not sufficiently reliable to inform decision makers.

Indus Basin 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

In addition to snow and glacial melt, monsoon precipitation provides water resources for the basin. The summer monsoon caters to the peak power supply demand, fulfills the highest water demand of field crops, and provides reserves for the winter. Pakistan is an agro-based economy with more than a quarter of its land area, or 22 million hectares, used for farming. This makes it highly sensitive to a weak monsoon or mismanagement of available water resources. Per capita gross domestic product ranked Pakistan 125th in the world and wealth is distributed highly unevenly. One-quarter of its population is classified as poor.

ADB's loans and programs portfolio in the water and hydropower sectors in Pakistan and Afghanistan include the $900 million Punjabi Irrigated Agriculture Investment Program, (2006), the $400 million Sindh Water Development and Management Investment Program, and the $500 million Renewable Energy Development Sector Investment Program in Pakistan; and the upcoming $300 million Water Resource Development Project in Afghanistan.

These large-scale operations rely heavily on Indus River Basin water resources, which depend on reliable downstream glacial outflows. However, their viability in the fragile mountain ecosystems and river basins is potentially vulnerable to climate change impacts. Mountain ecosystems are subject to accelerated and unprecedented increases in water-flow patterns and downstream flooding because of irreversible glacial melt, fluctuations in temperature stressors, and altered recharge to water catchments. Impacts in river basins include runoff changes, flash floods, and siltation.

The introduction of climate adaptive measures in target watersheds would help reduce some adverse climate impacts on food production and environmental degradation, and build the resilience to withstand extreme events and climate variability.

2.3 Impact, Outcomes, and Outputs

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.

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.

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.

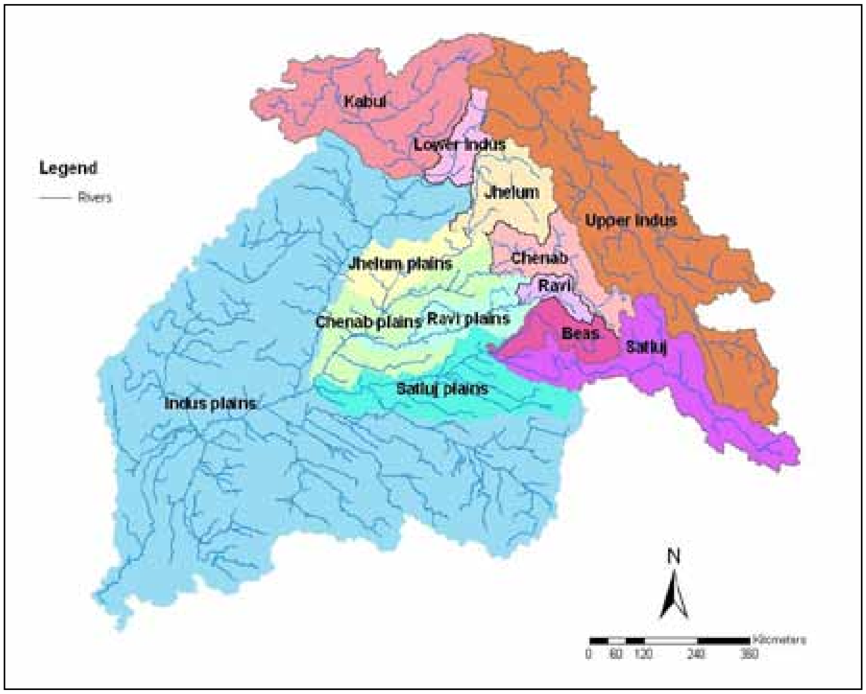
3. Climate Change in the Indus Basin: Current Understanding

3.1 The Indus Basin

The Indus River flows about 3,000 kilometers (km) through mountains, the plains of the Thar desert, and the deltaic ecosystems to the Arabian Sea, covering about 1,081,718 square kilometers (km^2), according to International Union for Conservation of Nature (IUCN) et al. (2002), forming the sixth-largest fan-shaped delta in the world (IUCN, undated). About 45% of the basin is below 1,000 meters (m) above sea level, according to Myint and Hofer (1998), and considered lowlands. That means roughly half of the basin area depends on the other upland half, which reaches as high as more than 8,000 m.

Croplands are mainly 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).

Figure 1 Indus River Basin including subbasins



Source: Own compilation.

3.2 Importance of the Indus Basin

The Indus Basin ranks among the biggest basins in terms of human dependence. The river supports a population of about 215 million people (United Nation Environment Programme [UNEP] 2008) and, according to IUCN et al. (2002), 11 large cities are in the basin: Amritsar and Hyderabad in India, and Faisalabad, Islamabad, Karachi, Lahore, Multan, Peshawar, Quetta, Rawalpindi, and Sukkur in Pakistan.

The Indus River is the primary source of water for Pakistan. Besides irrigation, the basin generates about 28% of the electricity produced in Pakistan (Archer 2003). In total, the basin is estimated to have a hydropower potential of 55,000 megawatts (MW), with 35,700 MW currently technically feasible (Fugleman and Hathaway 2009). Only 6,444 MW has been developed.

The Indus River supports a population of about 215 million people and 11 large cities are in the basin

Intensive population increases and recent climate changes mean the lower part of the basin is one of the most water-stressed areas in the world and this situation will deteriorate (Briscoe and Qatar 2005). Anomalous weather episodes may increase flooding risks and/or drought, and these pressures loom over heavily populated deltas (Parry et al. 2007).

Figure 2 The Indus Basin knowledge management platform

The Indus basin has a rich but highly fragmented knowledge base. As part of this project a knowledge platform was developed and will be continuously updated.

The database includes published and unpublished research reports, papers, and project documents, among others, related to the project objectives. The platform gives access to

(i) metadata or where possible actual hydrological, snowfall and meteorological data in summarized form for various subbasins available from various organizations;

(ii) metadata or, where possible, satellite imagery, maps, and video and so on.

The Indus Basin knowledge management platform: A screen capture

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

3.3 Physiographic Features

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

The Hindu Kush system stretches about 966 km laterally, and a median 240 km north–south. The Karakoram is a large mountain range spanning the borders between Pakistan, India, and the PRC, passing through Gilgit-Balistan (Pakistan), Latah (India), and Xinjiang (PRC). It is about 500 km, and is the most heavily glaciated part of the world outside of 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 glaciers outside the polar regions.

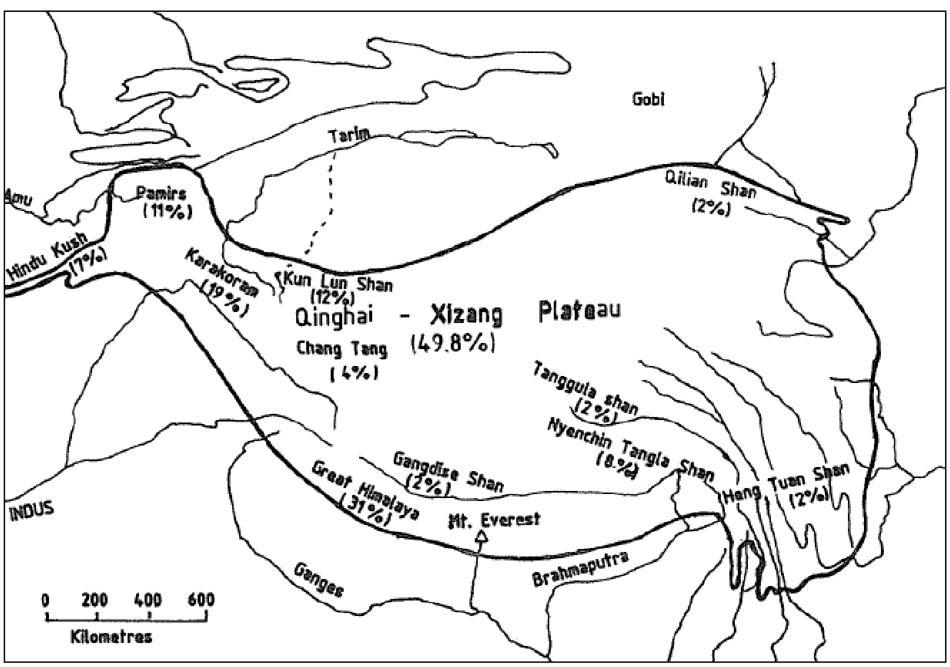
The total glacier area in the greater Himalayan region is subject to large uncertainties and problems of geographic delineation. But the reported results on glacier numbers, area, and ice volume vary greatly.

The total glacier area of the upper Indus Basin is estimated at 94,554 square kilometers

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 glacier cover for the Hindu Kush, Karakorum, and Himalaya. Collins and Hasnain (1995) reported glacier cover of 33,150 km^2 for the Himalayas, followed by the Karakorum range with 15,670 km^2. According to Hasnain (2000), 17% of the Himalayas and 37% of the Karakorum are covered by glaciers.

The inventory of glaciers in the northern areas of Pakistan described in the Pakistan Agricultural Research Council (2005) identified 5,218 glaciers with a total area of 15,040.8 km^2, or 11.7% of the total area. This includes some of the longest glaciers outside the polar region.

Figure 3 Distribution of glaciers in the Greater Himalayan Region



Note: Percentage glacier area is shown in parenthesis for various mountain systems.
Source: Lin and Xu, cited in Bahadur (1993).

Table 1 Glacier inventory in northern Pakistan

Basins	No. of glaciers	Glacier area (km^2)	Ice reserves (km^3)
Swat	233	223.55	12.22
Chitral	542	1,903.67	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.

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

3.4 The Basin 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 westerly disturbances bring winter rains in the Karakorum and the Hindu Kush.

In winter and spring, the upper basin is affected by weather systems originating from the Mediterranean or the Caspian Sea. The bulk of the snowfall derives from westerlies in the winter half of the year (Hewitt et al. 1989) and these are the biggest sources of nourishment for glaciers, which ultimately keep the Indus River system flowing in summer. Monsoon circulation in summer brings rains to the plains of Kashmir, Khyber Pakhtunkhwa, and Punjab, after striking the ridges of the Himalayas and Karakorum.

Archer (2001) notes that, overall, in winter, under the prevailing influence of the Tibetan anticyclone, more local conditions prevail. As well as global weather systems, mountain climates are also influenced by elevation; valley orientation, aspect, and slope; and the number of upwind barriers.

Based on analysis of meteorological data (1961–1990), Rasul et al. (2010) described the climatic features of the upper basin in the observation regime of the Pakistan Meteorological Department (PMD) ranging from about 1,000 m to 3,000 m. Generally, the region exhibits semiarid to arid climatic zones where winter precipitation dominates, and both summer and winter extreme temperatures occur. At elevations of 1,000 m to 1,300 m, day temperatures in summer touch over 40°C and the mercury rises to the mid-30s at 1,300 to 2,000 m. At elevations over 2,400 m it seldom reaches 35°C.

Summer monsoons make minimal contribution in the upper basin but winter precipitation is persistent from December to May, gaining its maxima in February and March. The amount of precipitation does not have any linear relationship with elevation; rather it varies with the orientation of terrain and windward exposure to the seasonal wind pattern. For instance, Dir (1,369 m) receives more than 1,400 millimeters (mm) total annual precipitation and Skardu (2,209 m) gets about 200 mm.

Studies for the wider Himalayas show the mix of precipitation changes with elevation, with rainfall dominating annual precipitation below 3,000 m, and snowfall more prevalent above 3,000 m. Snow is about 75% of precipitation at about 4,325 m, though due to lack of data the exact elevation where precipitation falls only as snow cannot be determined. The absence of stations at these altitudes proved the biggest problem for quantitative analyses of the vertical distribution of precipitation (Kolb 1994).

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 for the effective modeling of the hydrodynamic characteristics of these areas.

The entire upper basin is snow covered for some time in winter (Hewitt et al. 1989) with maximum coverage generally in March, when most of the snowfall has occurred and melting has yet to start (De Scally 1994; Singh and Kumar 1997). Below 3,500 m snowpack is usually less than 150 mm, while at 5,000 m elevation snowfall increases to about 1,500 mm. As Hewitt et al. indicate, 90% of the Indus Basin above the Tarbela reservoir may be covered by snow. Commonly more than 70% and, in poor years, less than 60% are covered by snow.

Freeze-thaw conditions are found for about 3 to 6 months below 3,000 m during October to April, 3 months in spring (April to June) and autumn (September to November) between 3,000 m and 5,500 m, while above 5,500 m freeze-thaw is observed only during summer for a few months (Hewitt 1989).

From a hydrological point of view, the upper zone is one of continuous frost (Archer 2004). The contribution to runoff is through snow avalanching and glacier flows. In the middle zone, precipitation may fall as rain or snow. During daytime the snow melts, and it partly refreezes at night. In the lower zones, where the temperature is continuously above freezing, occasional snowfall melts immediately.

3.5 Hydrology

The discharge of the Indus River and its tributaries from the Himalayas, Karakoram, and Hindu Kush largely depends heavily on runoff produced in the mountainous part of the basin through snow and glacial melt. While estimates vary greatly among different authors on the overall flow originating from the mountains, in the dry season especially it accounts for up to 100% of the total.

The discharge of the Indus River and its tributaries largely depends heavily on runoff produced in the mountainous part of the basin through snow and glacial melt

All the hydrological action, as Hewitt et al. (1989) term runoff generation, takes place in the zones above 2,500 m. Hewitt et al. (1989) estimate that more than 80% of the flow from the upper Indus River is collected in less than 20% of the basin area, essentially from zones of heavy snowfall and glaciers above 3,500 m.

Winiger et al. (2005) estimate that about 50% of the total annual runoff in the Indus River irrigation systems in Pakistan depends on snow and glacial melt from the eastern Hindu Kush, Karakoram, and Western Himalayas. According to estimates by Hewitt et al. (1989), meltwater from snow and ice 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.

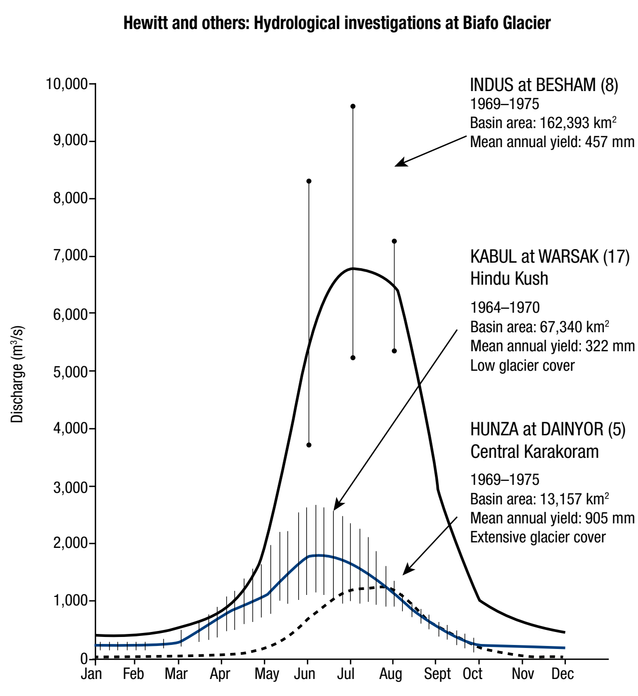
This makes the Indus River important as a "wet island" for the arid and semiarid basin areas in its lower river stretches. The contributions of the main rivers measured at the foot of the mountains are 13% from the Kabul, 37% from the Indus, 14% from the Jhelum, 15% from the Chenab, 4% from the Ravi, 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.

The Indus River is important as a "wet island" for the arid and semiarid basin areas

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 1969 to 2001 varies annually from 80% to 130% of the mean (Archer and Fowler 2005). This is due to glacial melt, which is responsible for 20–50 times higher discharge values during summer than in winter, according to Kolb (1994), who observed that variations in rivers mainly fed by glacial melt are wider than variations in rivers mainly fed by snow melt. 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 produce higher runoff at the expense of glacier storage.

Maximum discharges at all monitoring stations in the upper basin are expected between June and August, where an early peak in June indicates an influence of snow melt, and a peak in July to August shows the influence of glacial melt (Figure 4). The snow and glacial melt peaks coincide with monsoon rains in the lower parts of the basin, often masking the major role of meltwater in the basin hydrology (Hewitt et al. 1989).

Figure 4 Discharge of three Indus Basin rivers



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

By examining the relationships between climatic variables and stream flow from 19 long-term stations, Archer (2003) observed three hydrological regimes, with summer volumes governed by the following:

- **Melting of glaciers and permanent snow** (thermal control in the current summer). Catchments with these regimes are 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 same regime features in the Gilgit River and the Indus above the Shyok confluence.
- **Winter and monsoon rainfall** (precipitation control in the current season). These catchments are in the foothills and include the Khan Khwar and Siran rivers.

Hydrological regimes are governed by melting of glaciers and permanent snow, melt of seasonal snow, and winter and monsoon rainfall

Archer and Fowler (2005) found that summer runoff of snow-fed catchments is strongly linked to winter precipitation, while in predominantly glacier-fed catchments, summer runoff shows significant positive correlation with summer temperatures. On middle-altitude snow-fed catchments, runoff falls as the temperature rises, since increased temperature results in more evaporative loss and (as snow cover volume is limiting) reduced runoff. On the foothill catchments, significant correlation was found with spring (April–June) runoff, but not with summer runoff.

These results have practical consequences for flow forecasting on the Indus River. Precipitation measurements at standard valley climate stations can be used as a basis for forecasting volumes of flows originating in the upper Indus and the Astore, Swat, and Jhelum rivers, with a lead-time of 3 months or more.

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

Issue 2: Lack of basin and transboundary modeling exercises

To improve the understanding of the glacier–hydrology relationship and dynamics under climate change and to devise relevant sector-wide measures to better adapt to these challenges, a strong research base on glacial hydrology and modeling is essential. But there have been no modeling exercises for the entire Indus Basin taking into account data from all riparian countries.

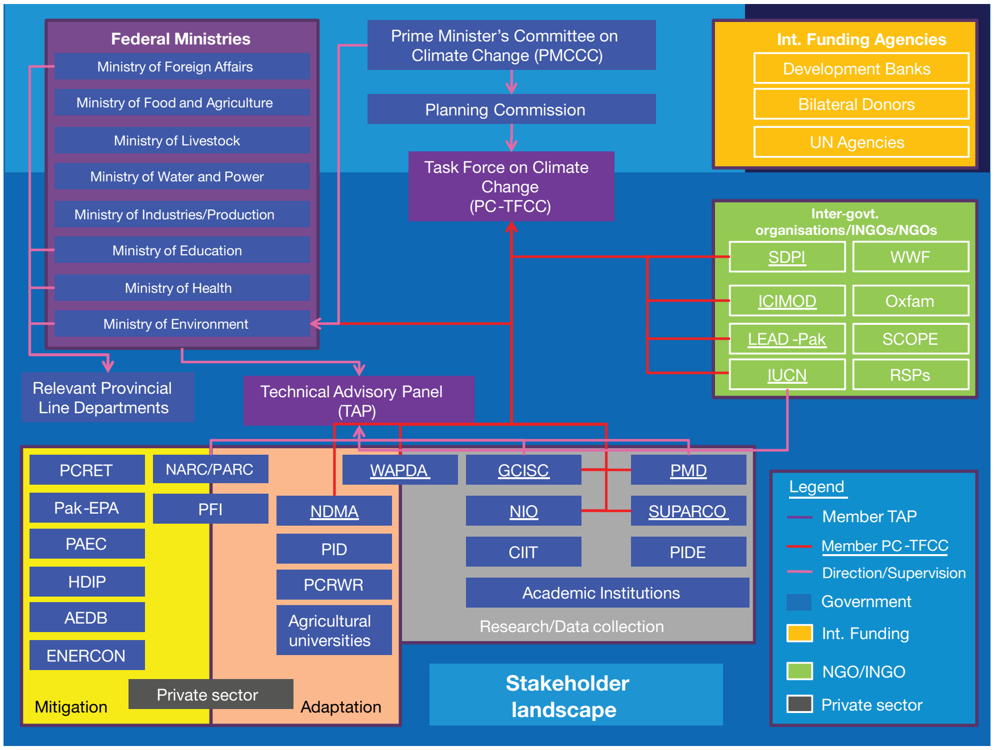
4. Institutional and Policy Landscape

4.1 Stakeholder Profile

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 5 presents a schematic overview of the different players and their relations to efforts to tackle the effects of climate change.

Some of the stakeholders attended two consultations organized in Karachi and Islamabad in 2010. Suggestions from these workshops provided proposals for activities and are fully documented in IUCN and ICIMOD (2010b).

Figure 5 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.

For example, IUCN has formulated the "National Climate Change Program" for Pakistan, with the overall objective of better equipping the country to address climate change through strengthening diplomatic efforts, the development and implementation of sound policies and action plans, strengthening of relevant institutions and interest groups and improved coordination, networking and knowledge management, and through raising awareness at all levels and improved governance in Pakistan.

Measures for preparedness against disasters and increased community resilience should also be a top priority, according to Mahmud Akhtar Cheema, the head of the IUCN Islamabad Programme Office at the consultation. Cheema also recommended mass forestation as a best solution to mitigate and adapt to climate change. Pakistan also has low forest cover (4.5%), with a deforestation rate as high as 0.2%–0.4% per annum.

Stakeholder organizations with a climate change–related mandate are presented in [[link to website]] including their potential future roles and needs.

4.2 Climate Change–Related Policies

Pakistan is committed to play an effective role in global efforts to mitigate and adapt to climate change

Pakistan has shown a very strong commitment to playing an effective role in global efforts to mitigate and adapt to climate change, taking part in the global dialogue on climate change, sustainable development, and conservation since the historic Rio Earth Summit in 1992. The country is also 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 carbon-credit incentives to investors in efforts to cut carbon emissions. Pakistan has also participated in all international climate change–related negotiations, including the Conference of Parties (COP) to the UNFCCC, the Meeting of Parties to the Kyoto Protocol, and subsidiary bodies.

A Task Force on Climate Change was set up by the Planning Commission of Pakistan in October 2008 with the view to contributing to the formulation of a climate-change policy that would assist the government in achieving sustained economic growth by appropriately addressing climate-change threats to water, food and energy security, and to recommend policy measures for promoting large-scale adaptation and mitigation efforts, raising awareness of stakeholders, and enhancing the capacities of national institutions in these endeavors.

The final report of the Task Force, issued in February 2010, describes Pakistan's vulnerability to climate change due to impacts on various socioeconomic sectors. It is hoped this report (which presents recommendations on needs for international cooperation and Pakistan's position in international negotiations on the future climate change regime) will serve as a seminal document, providing a base for further work.

The report identifies the basic parts of Pakistan's climate change policy for the near to medium term future. Salient among those are elements 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;
- Contribute to the international efforts to check climate change by controlling Pakistan's own greenhouse gas emissions to the maximum extent feasible.

5. Climate Change Impact on Climate and Water Resources

5.1 Overview

Precipitation and temperature have shown different trends in different locations of the Indus Basin, while different studies come to different conclusions. Generally, precipitation in the northern areas of Pakistan seems to have increased while temperatures have shown different trends in different seasons. There seems to be more rainfall than snow.

Studies indicate that mean annual temperature is increasing in the basin of the Kabul River. Mean rainfall has decreased slightly, mainly due to decreases in spring precipitation. This combination of factors has led to a prolonged drought in recent years.

In the Western Himalayas, decreasing annual precipitation and a warming trend overall have been observed, leading to drier conditions. However, a transboundary assessment of the trends is missing and there is no general agreement of the physical processes at work.

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 trend of decreasing flows has been noted in the Kabul River and in the lower stretches of the Indus Basin at Kotri Barrage. No conclusive answers can be stated in the case of the impact of climate change on glacier dynamics. In general, however, glacial retreat has been observed in the Himalayas and the Hindu Kush, with the exception of some glaciers in the central Karakoram. However, research is still needed to clarify whether these observations are due to internal changes in geometry of the ice or an actual increase in glacial mass.

Climate change projections have proved inconclusive. Local-scale simulation models show that in general an increase in temperature is expected and in most areas, a decrease of precipitation, but there is a considerable difference between results that are based on different scenarios, making the application of such models doubtful at present. There is a need to reduce uncertainties and increase the spatial scale for these models to be useful for planning purposes.

5.2 Observed Climate Change and Variability

Precipitation Regime

The peak for snow in the upper Indus Basin has shifted toward the end of winter in that instead of in January, heavy snow falls in February, according to Rasul et al. (2010), who used data from the meteorological network of Pakistan Meteorological Department (PMD). The dominant wet season extends from December to May reaching a March/April maxima, while the peak used to be in February/March.

On average, summer monsoonal rains in the upper Indus Basin contribute 20% to 30% of the total annual precipitation and no significant change has been observed. However, at lower elevations winter and summer precipitation occurs at about a 60:40 ratio and a little increase in monsoon share has been noticed.

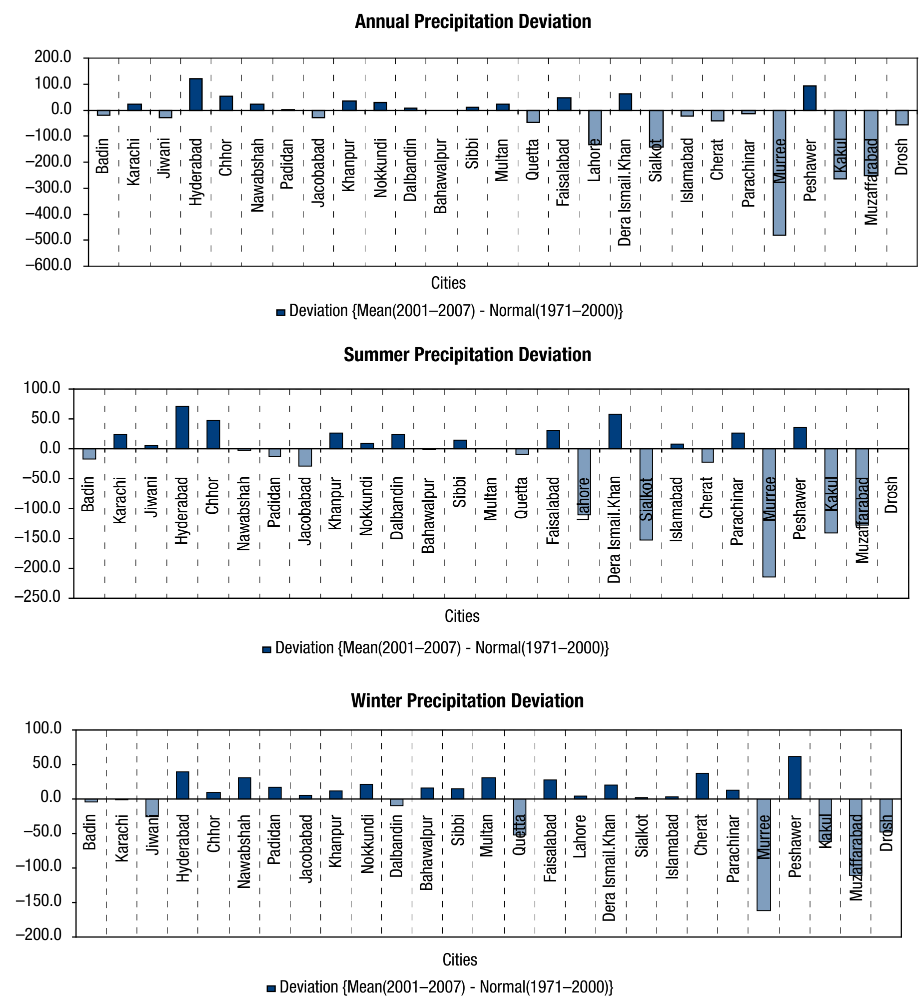
Although the rate of temperature increase in the basin during the past 50 years was greater than that in the lower (southern) parts of Pakistan, no significant increase in extreme precipitation events has been noted. However, the displacement of the snow maxima from January to February was experienced in 6 years in 2000–2010.

While Rasul et al. (2010) found no uniform trend in the area covered by snow, very heavy snow storms in early winter were recorded in 2001, 2004, and 2009. However, data produced using a Moderate Resolution Imaging Spectroradiometer found a significant shrinkage in snow cover during the winters from 2000 to 2008. This is in contrast to the other seasons and for the entire Himalayas and Tibetan Plateau, where no significant snow cover trends were identified.

PMD studies have revealed trends in the annual and seasonal precipitation regimes over the last several decades (Chaudhry et al. 2009). Figure 6 incorporates deviations from the normal (1971–2000), based on data collected at PMD stations from 1960–2007. It shows that the 1960s was much drier than more recent decades and that a low rainfall episode was broken by a wetter period from the mid-1970s until El Niño in 1998.

Summer monsoonal rains in the upper Indus Basin contribute an average 20% to 30% of the total precipitation

Figure 6 Recent deviations of annual, summer, and winter precipitation



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

Source: Rasul et al. 2010.

Under the influence of El Niño ocean current, precipitation dropped drastically throughout Pakistan, resulting in the longest and most intense drought in Pakistan's history, from the fall of 1998 to spring 2003. The rising trend since is embedded in an increased frequency of heavy downpour events.

Anomalies of annual precipitation noticed during the recent decade against the long-term average of 1971–2000 for 28 stations of Pakistan are presented in Figure 6.

The deviation of precipitation in the summer monsoon season during 2001 to 2007 is similar to the annual pattern, which depicts that the southern half has become slightly wetter and the northern half drier than its long-term average.

A seasonal trend in the upper Indus Basin is visible in the form of rising summer temperatures, but falling winter temperatures

The deviation of winter precipitation compared with the normal (1971–2000) shows some reduction in seasonal total precipitation 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. Generally, the northern half gets about five times more precipitation in winter than the south.

Archer and Fowler (2004), based on data from same sources, observed an increasing trend in winter precipitation at all stations studied, illustrating a high correlation between these different stations. The increase of precipitation during the monsoon season was particularly significant and concurs with the predictions of global climate models for the region.

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 mean and minimum summer temperatures provide a consistent trend of cooling in the region since 1961. The most striking recent change is the large increase in diurnal temperature range observed at all seasons and in the annual dataset. Fowler and Archer (2006) suggest this began in the mid-20th century. Yadav et al. (2004) attributed the increase in the diurnal temperature range since then to large-scale deforestation and land degradation, illustrating the influence of local factors on climate.

However, a seasonal trend in the upper Indus Basin is visible in the form of rising summer temperatures, but falling winter temperatures. Such a trend elaborates an increase in temperature range (not diurnal but seasonal) and symbolizes relatively clearer skies than in the past. More detailed studies based on daily temperature and cloud cover data would reveal the facts regarding changing trends.

On the basis of long-term data sets since the late 19th century from three stations in the northwestern Himalayan region, significant increasing trends in annual temperature occurred at all three (Bhutiyani et al. 2009). The estimated rates of increase varied from about 0.06°C per decade in the monsoon season to about 0.14°C per decade in winter and 0.11°C per decade in annual air temperature from 1876 to 2006.

For 1901 to 2000, Bhutiyani et al. (2007) showed different episodes of faster and slower warming, as well as some periods of cooling, but 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, while the rate of increase appears to be highest since 1991.

Chaudhry et al. (2009) used 100 years reanalysis data from the upper Indus Basin to clearly indicate a gradual rise in temperature embedded with spells of rise and fall. The last decade of 20th century was the warmest one in northern mountainous areas as shown in Figure 7, and conformed with global trends.

The first 8 years of 21st century have surpassed all trends, among them 2005 was believed to be the hottest for Pakistan, when a snow-melt flood in June created havoc in the downstream Indus.

The spread of temporal isotherms indicates that the flux of upward creeping heat is has advanced more over the eastern part (Himalaya and Karakoram) of the southern slopes than the western part comprising the Hindu Kush. Isothermic advance is skewed due to the complexities of terrain and environmental degradation, but on average the benchmark 30°C isotherm has moved 580 m above its location in the early 1980s.

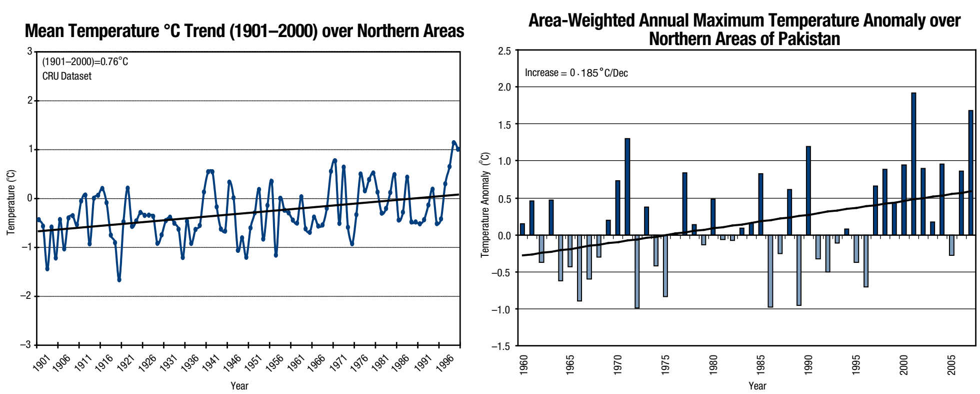
Heat waves have grouped into three categories: severe, moderate, and mild

The frequency of heat waves—a continuous stretch of persisting daytime maximum temperatures above a certain threshold for a specified time period—has increased as shown in Figure 8. They are grouped into three categories:

- **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

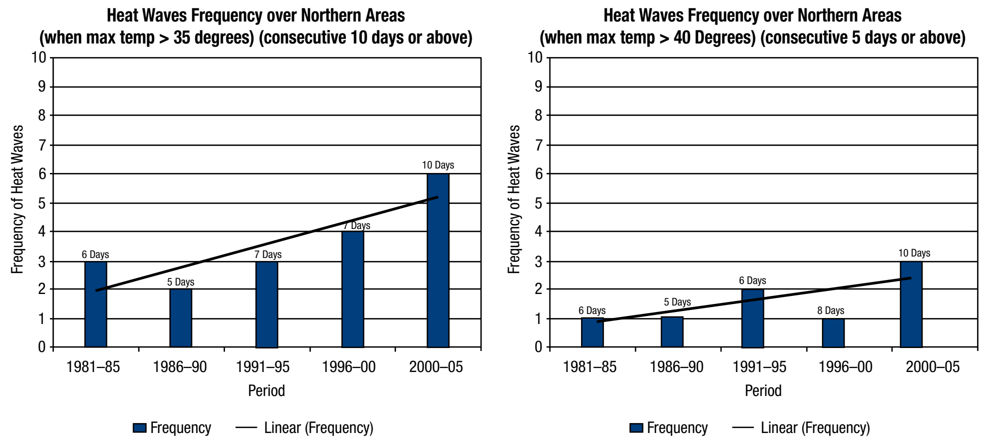
Frequency analysis of heat waves from 1981 to 2008 shows that mild stress was common even in the 1980s during May and June, but moderate and severe conditions rarely occurred. Not only was the increase in the occurrence of mild stress days significant, there was also a sharp rise in moderate and severe stress events over the past decade. Heat waves have persisted longer while their intensity and areal extent have also increased. Valley areas or shadow zones that were once unaffected are now being dominated by the heat sweep.

Figure 7 Mean temperature anomalies in Pakistan's mountainous north



°C = degree Celcius, CRU = Climate Research Unit.
The chart on the left uses the 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).

Figure 8 Changing frequency of mild, moderate, and severe heat waves



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

> Regional warming is affecting the hydrology of the upper Indus Basin due to accelerated glacial melting

5.3 Observed Impacts of Climate Change

Hydrological Regime

Given the trends observed in temperature and precipitation as shown above, changes 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 over 1961 to 2000 produced a predicted reduction of 20% in runoff, which was exceeded by actual runoff decreases on the Hunza. The absence of an equivalent decline in the Shyok can be explained by regional variations since easterly stations in the upper basin show a more positive temperature trend.

They further observed summer temperature reductions and 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 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).

Regional warming is affecting the hydrology of the upper Indus Basin due to accelerated glacial melting, Immerzeel et al. (2008) concluded after running models using daily discharge data and precipitation and snow cover parameters derived from remote sensing. 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. A significant negative winter snow cover trend was identified for the upper basin.

Rees et al. (2006) studied regional differences in the response of flow in glacier-fed Himalayan rivers to climatic warming. River flow from glacierized areas in the Himalayas is influenced both by intra-annual variations in precipitation and energy availability, and by longer-term changes in storage of water as glacial 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.

Given the difference in climate between the drier western and monsoonal eastern ends of the region, however, 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.

Ali et al. (2009) conducted a runoff modeling study under climate change scenarios using mean monthly flows for 1995–2004 in the Indus Basin. 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 challenges for winter crops, especially wheat.

Some scientists have disagreement about whether all glaciers of the Himalaya–Karakoram–Hindu Kush region are retreating

Glacier Dynamics

Trends in the long-time series of cumulative glacier-length-and-volume changes provide convincing evidence for fast climate change or sudden variability at a global scale. These effects on the cryosphere in mountain areas are most visible in the shrinkage of mountain glaciers and in reduced snow cover duration (Barry 2002).

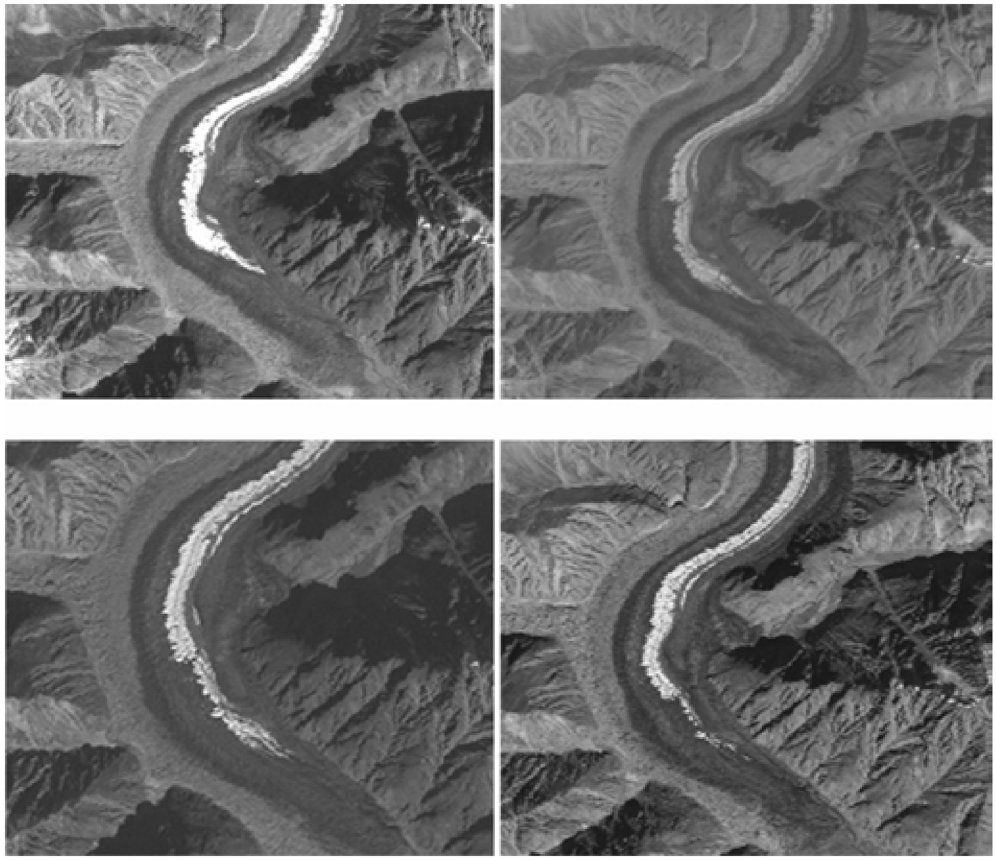
There is some disagreement among scientists about whether all glaciers of the Himalaya–Karakoram–Hindu Kush region are retreating. Most glaciers in the Himalayas have been in a general state of retreat since 1850. Those in the Trans-Himalayan grouping were either in retreat or advance from 1850 to 1880, 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 19th and early 20th centuries, the glaciers were generally advancing followed by predominant retreat during 1910–1960. Hewitt (2005) concluded that, with the exception of some short-term advances in the 1970s, observations from the 1920s to the 1990s showed most glaciers of the Karakoram shrank in line with glaciers from most parts of the world. However, in the late 1990s, many glaciers in the highest watersheds of the central Karakoram began expanding.

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 among the steepest, 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 coverage that protects the ice against melting (Hewitt 2005). Because the ice is so thick, the deeper parts of the glaciers are at or close to freezing point and they behave like temperate glaciers, leading to relatively high flow rates ranging from 100 m/yr to 1,000 m/yr (Goudie et al. 1984).

Based on simulations Kotlyakov and Lebedeva (1998) computed changes in different glacier parameters for the entire region. 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 their eastern part, will shrink.

Figure 9 Retreat of the Siachen Glacier as observed from Landsat satellite



Note: Top left image taken on 29 July 1990; top right on 18 May 2001; bottom left image from 10 September 2003; and bottom right 9 September 2006.

Source: Rasul et al. 2008.

Total glacier cover is now approaching the lowest experienced in the past 10,000 years

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 known to vary widely but the trend is increasing (Prasad et al. 2009).

Evidence of decay is illustrated in Figure 9 for the Siachen glacier, in the eastern Karakoram in Ladakh. The glacier's meltwater is the main source for the Nubra River, which drains into the Shyok River, and on to the Indus River.

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 of Water and Power Development Authority (WAPDA) stations. They found that the diumal temperature range had increased and runoff reduced. However, to carry out such study, the maximum possible data available is required, and data from three or four stations cannot be representative of such a large basin. Regarding discharge data, runoff from the upper Indus Basin finally reached Tarbela Dam and water reserves showed significant increases during the past 2 decades. Moreover, interaction of the atmosphere with the cryosphere produced a warming trend, which is gradually accelerating and incurring a reduction in ice mass.

UNEP (2009) argues that the observation of glacier termini or length alone is not enough to obtain a valid picture of the glaciers' behavior. However, since the assessment of glacial mass balances is associated with a number of logistical issues, few balances are available for the greater Himalayan region. According to Berthier et al. (2007), the glacier area monitored on average between 1977 and 1999 each year was limited to 6.8 km^2 out of about 33,000 km^2 for the Himalayan region. These authors suggest that a remote sensing–based approach for glacial mass balance assessments may help better assess glacier dynamics.

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

The glacier environment of the greater Himalayan region is still a large "blackbox" 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. Glaciers in the Himalayas seem to behave differently than in the Karakorum; while the glaciers in the Himalayas and in the Hindu Kush seem to be in retreat, a number of glaciers in the Karakorum seem to be advancing.

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—is very variable and differs from glacier to glacier.

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).

Glacial lake outburst floods pose a great risk because of their magnitude... also because of their lack of homogeneity and stationarity

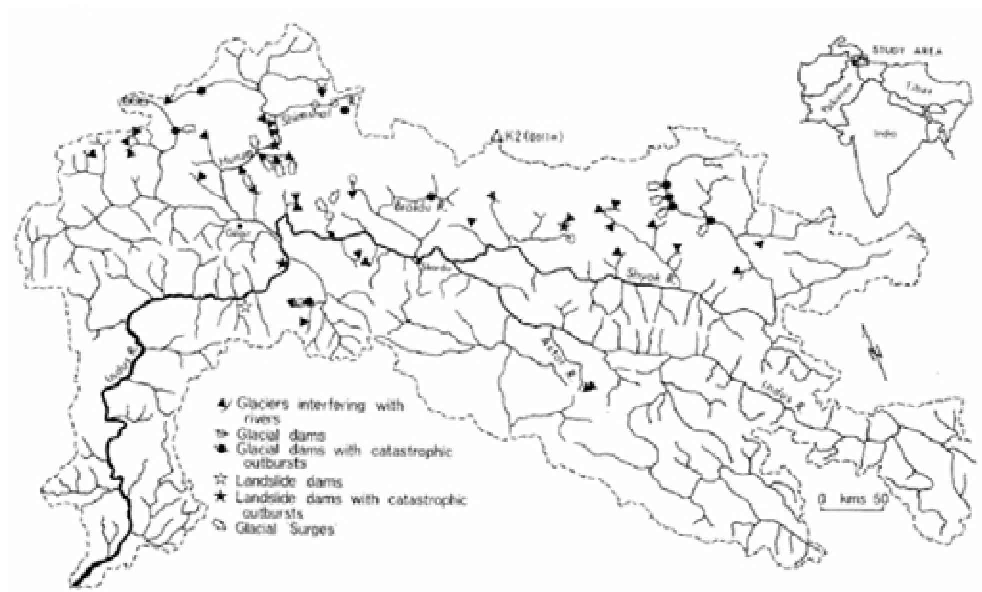
Glacial Hazards

Because of a general trend of increasing warming, snow and ice 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 of their lack of homogeneity and stationarity (Shaukat 2001).

While rare and isolated cases have been reported in other regions 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; Hewitt 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 as potentially dangerous. The details are discussed in Mool et al. (2003).

Figure 10 Distribution of glacier dams and related events



Source: Hewitt 1982.

Temperature scenarios were developed in Pakistan by downscaling 17 global circulation models for the 21st century

Glaciers in the upper Indus Basin have historically interfered with streams by damming rivers as well as through GLOFs (Hewitt 1982, 1998).

Archer (2002) discusses several events, including the last major GLOF that occurred in 1960, which originated from the Shimshal tributary valley and reportedly destroyed most of the houses and terraces in the town of Passu.

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 about 6m feet above the normal summer maximum level and destroyed the Gilgit suspension bridge. A pillar about 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.

6.4 Climate Change Projections

Climate change projections in Pakistan have generally been made on the basis of national boundaries. The country's Global Change Impact Studies Centre (GCISC) developed temperature scenarios by downscaling 17 global circulation models (GCMs) at 30-year time-steps for the 21st century. Figures 12 (a) and (b) compare the projected changes in temperature in the 2020s (representing the average value for 2010–2039), the 2050s (representing the average for 2040–2069), and the 2080s (representing the average for 2070–2099) compared with the base period (1960–1990) values over northern and southern Pakistan (separated at 31°N) corresponding to the Intergovernmental Panel on Climate Change's (IPCC) high- and medium-range A2 and A1B scenarios (Islam et al. 2009) (Figure 11).

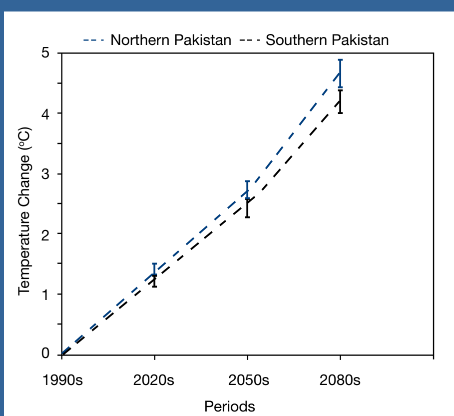
The main results are

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

The temperature increase in both parts of Pakistan at the end of the time horizon in each scenario is higher than the corresponding globally averaged temperature increase

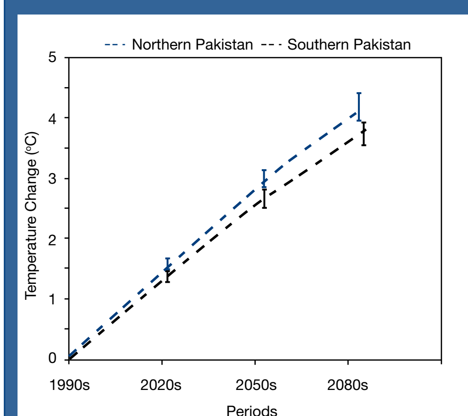
Figure 11 Temperature changes for A2 and A1B scenarios

Projected changes in average temperatures in northern and southern Pakistan for (a) the A2 scenario and (b) the A1B scenario based on 13 global circulation models



A2 Scenario: Heterogenous

The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge slowly, resulting in a 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: High growth

Rapid economic growth, a global population that peaks in mid-century and declines thereafter, with more efficient technologies rapidly introduced. 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).

GCM = global circulation model, IPCC = Integovernmental Panel on Climate Change.

Projected changes in seasonal temperature for both scenarios show that in each scenario: the temperature increases in both summer and winter will be higher in northern Pakistan than in southern Pakistan, and the temperature increases in both parts of the country will be larger in winter than in summer.

According to temperature projections for the Indus, Kabul, and Jhelum basins at the end of this century, the temperature rise in Pakistan's areas of the Indus Basin is projected to be 4.81°C for the A2 scenario and 4.29°C for A1B. Because of low changes in precipitation and large associated uncertainties, no clear-cut projection can be made for precipitation. The projected precipitation changes of the Kabul, Jhelum, and Indus river basins are not significant for either A2 or A1B scenario.

The temperature rise in Pakistan's areas of the Indus Basin is projected to be 4.81°C for the A2 scenario and 4.29°C for A1B

Islam and colleagues developed high-resolution climate change scenarios for South Asia, particularly focusing in Pakistan and applying Providing Regional Climates for Impact Studies (PRECIS), a regional climate model. Overall, the performance is better for temperature than for precipitation.

The results for projections for the three watersheds of the upper Indus, Jhelum, and Kabul rivers for 2071–2100 are shown in the following tables.

Table 2 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 3 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 large uncertainty, as was shown with the comparison of different global circulation models as well as the validation of the Providing Regional Climates for Impact Studies (PRECIS) model runs with Climate Research Unit data. In addition, downscaling work to date is based on coarse resolution, resulting in a crude overview of scenarios. It does not allow determination of the impact of climate change at a subbasin level, which is crucial for planning water resources development. The capacity for downscaling and developing regional scenarios with low uncertainties needs to be enhanced, research improved, and new initiatives supported.

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

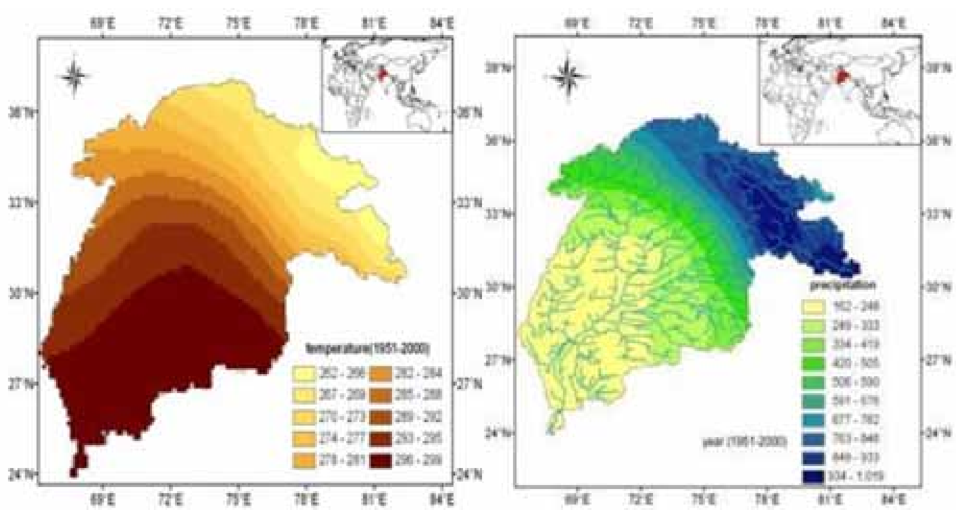
Rasul et al. (2010) attempted to develop climate change scenarios for the entire Indus Basin and at smaller time steps. Instead of depicting end of 21st century scenarios, shorter time steps could facilitate short- and medium-term planning and adaptation to climate change impacts. PMD and PRC scientists conducted a detailed study for the Indus River Basin using statistical downscaling. Daily rainfall and mean temperature data from 56 PMD stations were incorporated for the period 1951–2000 to run simulations in the process of model output validation and testing of prediction skills. Eleven simulations were completed with an equal number of GCMs and reproduced results were in close conformity with observed fields. Modeled simulations for precipitation and temperature (1951–2000) as ensemble output are presented in Figure 12.

Humid regions in the north are projected to become wetter whereas drier regions in the south will get even drier

Based on the selected scenarios A2, B1, and A1B, 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 believing that the present efforts to save the planet from further anthropogenic disasters would work. The Indus Basin scenarios for temperature and precipitation under this optimistic scenario A1B are shown in Figure 13. The basin shows little change in the 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 (drier south) and supply (wetter north), posing a challenge to water resources managers.

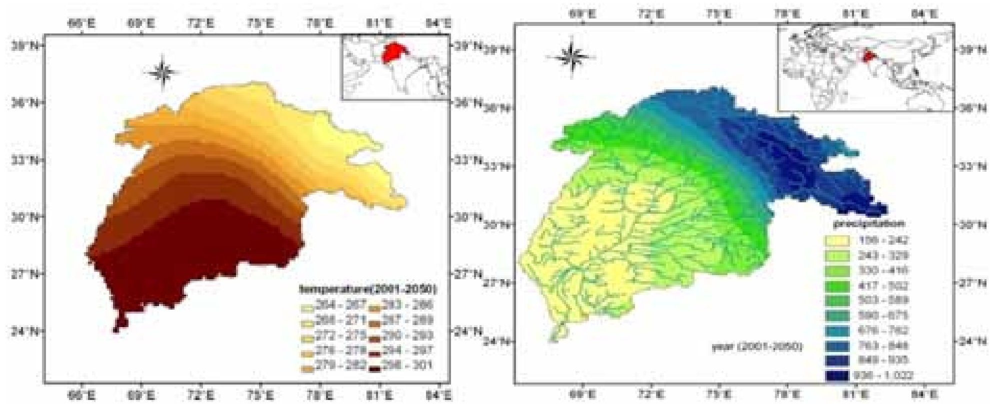
Almost the reciprocal of precipitation is projected for the temperature regime in the entire Indus Basin. In the north, precipitation is likely to increase slightly compared to the long-term average of 1951–2000, whereas temperature is projected to decrease in future projections for the period 2001–2050.

Figure 12 Ensemble reproduced precipitation and temperature over the Indus Basin, 1951–2000



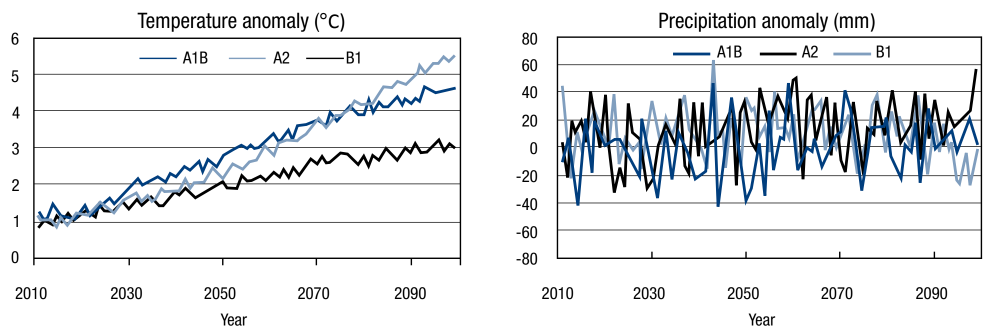
Source: Rasul et al. 2010.

Figure 13 A1B scenario for precipitation and temperature in the Indus Basin, 2001–2050



Source: Rasul et al. 2010.

Figure 14 Climate change projections for the 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.

A comparison of results based on the three different scenarios (Figure 14) indicates a great diversity in projected values of temperature, but the scenarios show an agreement in the projection of minimal change in precipitation.

The output of models was further resolved to develop local-scale scenarios for the Indus Basin with particular attention to climatic zones. Area-weighted average scenarios of temperature and rainfall are given in Table 4. According to the A2 scenario, a 2.5 mm per decade increase in rainfall is expected, and temperature may also rise about 0.5°C per decade. The B1 scenario indicates an increase of 0.25°C per decade and a projected decrease in precipitation of nearly 1 mm every 10 years. The A1B scenario indicates about 0.4°C per decade warming and an increase of nearly 2 mm of precipitation per decade.

Considering the climatic zones with similar climatic characteristics and geographical features, the whole Indus Basin was split into subregions to facilitate the formulation of policies with a clear picture of future climate at local scale (Table 5).

Table 4 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

Source: Rasul et al., in press.

Table 5 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 and 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

Source: Rasul et al., in press.

These scenarios clearly project considerably different results (Table 5). Under B1 scenario, no significant change in precipitation is projected throughout the basin with the exception of a 1.5 mm per decade decrease over the upper Indus. In contrast, 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 receive more precipitation during the monsoon season than other areas, are likely to continue the same pattern. All the scenarios under consideration 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.

6. Knowledge Issues and Gaps

Analyses of knowledge on climate change and hydrology in the Indus Basin and stakeholder workshops allowed the identification of gaps and issues in relation to climate change adaptation of the water and energy sectors, with particular reference to changes in the upland areas and their downstream impacts.

Filling these gaps will bring a better grasp of the effects of climate change, helping guide policies to protect water resources and the energy sector.

6.1 Knowledge

Based on the detailed review of literature about the state of understanding of processes in the Indus Basin on climate, hydrology, and glacial dynamics, the following knowledge shortcomings are evident.

Data and Information Availability

Sparse hydrometeorological monitoring network in mountains. The present network, including all stations of national and international organizations, does not adequately reflect the intricacies of microclimates in mountain terrain. Installation of at least 75 automatic weather stations and 35 hydrological measurement stations in target mountain areas would optimize observational demands and allow effective modeling of hydrodynamic characteristics.

Need for data integration and data access at all levels. Several national and international organizations—including Pakistan Meteorological Department (PMD), Water and Power Development Authority (WAPDA), Ev-K2-CNR, University of Bonn, and others—use their own, independent observation networks. PMD runs the largest network throughout Pakistan, sharing data with WAPDA and Ev-K2-CNR. Data from other networks or individual monitoring stations is not integrated in national datasets. The government Task Force on Climate Change has proposed setting up a national database with climate change relevant data accessible to researchers. Data access and sharing remains a pressing issue also among the riparian states.

To ensure improved knowledge about climate change issues, it is crucial to have access to reports and articles published on this subject. The Indus Basin knowledge platform is a first step in this direction to provide metadata about articles, data, and satellite imagery.

Scientific Knowledge

Inadequate downscaling capacity for regional scenarios. Precipitation projections are associated with large uncertainty, as was shown with comparisons of different models. Most of the water resource modeling exercises are spatially confined to a small and focused area, but there are no modeling exercises for the entire basin taking into account the data from all riparian countries.

Current downscaling work results in a crude overview of scenarios that does not help determine the impact of climate change at the subbasin level, which is crucial for water-resource planning.

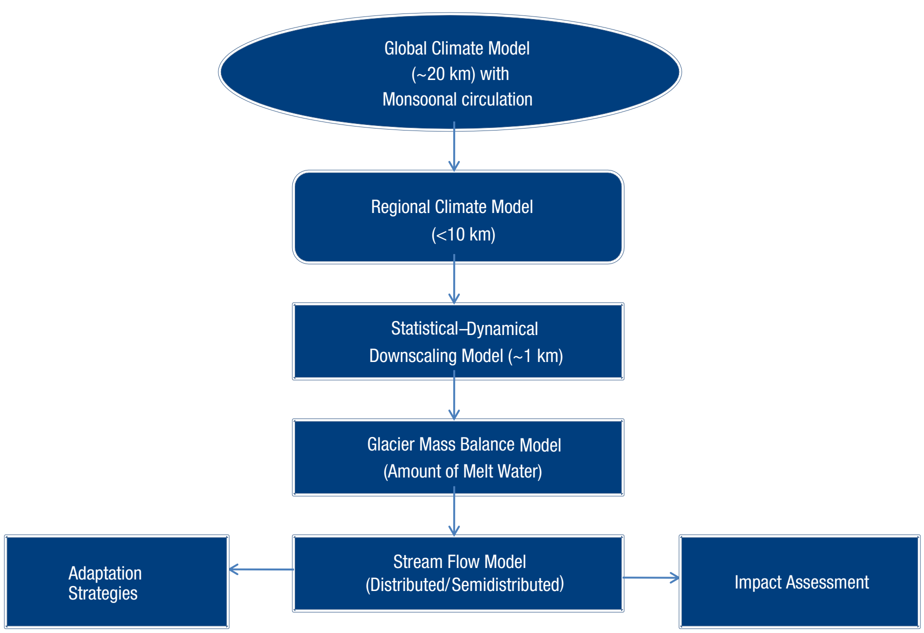
Lack of detailed knowledge of glacier resources and dynamics. The glacier environment of the greater Himalayan region is still a large "black box" as there is a lack of relevant data and large uncertainties, as shown by the great variance in assessments on glacier numbers, area, and ice volume. Whether the difference between the observed rapid retreat of glaciers in the Western Himalayas and Hindu Kush and the advance of glaciers in the Karakoram are caused by internal changes of geometry of the ice or an actual increase in glacial mass balance is still subject to clarification. Monitoring of the evolution of glaciers in the greater Himalayan region is therefore a key issue.

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

The Pakistan Agricultural Research Council (PARC), in collaboration with International Centre for Integrated Mountain Development (ICIMOD), prepared a first glacier inventory for Pakistan in 2005 to address the status of current glacier resources based on the area of the glaciers and glacier lakes, but does not deliberate on the glacial mass and balance. Without glacier mass balance information, however, no definite answer on the impact of these expanding and retreating glaciers can be made.

Lack of data on impact of glacier dynamics on water resources. A strong research base on glacial hydrology and modeling across the entire basin is essential to devise sector-specific measures for better adapting to these challenges. Data sharing between riparian countries, technical collaboration, and clear parameters for a basin water resources model that takes into account the specifics of glacial areas, snow melt, and mountain heterogenities are required. A comprehensive approach for this is shown in Figure 16.

Figure 15 Comprehensive basin-scale research



km = kilometer.
Source: ICIMOD 2010a.

Lack of data on economic impact of water resource dynamics. Information about the actual impacts of climate change on economic aspects in Pakistan is still lacking. During stakeholder workshops it was 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.

6.2 Policy, Institutions, and Capacity

Policy Environment

Climate change–related impacts are giving rise to concerns such as food security and may also be a multiplier for issues like terrorism and national security

Lack of climate change policy. A comprehensive national climate change policy has been drafted and was awaiting government cabinet approval when this report went to print.

Inadequate financial support for adaptation activities. Financial support needs to be identified by the government and multilateral bilateral donors. The UN Adaptation Fund is already accepting climate change adaptation projects. Pakistan should make the best use of the fund's available financial resources to combat the impacts of climate change.

Adaptation Capacity

Dearth of activities to promote options and action. Appropriate adaptation options need to be promoted after careful identification and selection. Adaptation options may need to be based on options applied in other countries or on traditional and indigenous knowledge. In both cases, their impacts need to be carefully studied through an enhanced research base at government agencies and local universities. Consequently, during the stakeholder workshops the following recommendations were made:

- Agriculture is likely to be badly damaged due to less available water and changing weather patterns. It is crucial to enhance the research base on more adaptive crops, adapted agricultural practices, and better water management (including construction of reservoirs and efficient distribution), and to promote alternate livelihoods.
- Climate change–related impacts are giving rise to concerns such as food security and may also be a multiplier for issues like terrorism and national security. 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 landslide-dammed rivers. For these, Pakistan should be completely prepared with adaptation strategies.
- Improved water resources management should be immediately considered. In urban areas in particular, sewage should be treated through bio-remedial measures to render it usable for agriculture. Similar concepts such as "rain-water harvesting" and "recycling of water" need to be promoted for their potential to help meet water shortages.

Absence of tools for risk management and adaptation. Tools need to be urgently developed to identify sector-wide vulnerabilities and risk management measures associated with climate change and melting glaciers. A risk management framework needs to be field-tested and adapted where necessary.

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 offers such courses at the graduate or post-graduate level. Climate change science demands a high level of professional proficiency in theory and practice. Expertise in downscaled numerical modeling is also highly desirable.

Inadequate equipment and instruments. Pakistan does not have sufficient scientific and technological capability to collect the climatological information needed 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 relevant scientific data at high spatial resolution (particularly in the remote mountain areas). PMD is striving to set up high-altitude monitoring stations to gather information on changes in glacial regions.

Weak computational capacity. PMD has been using a 16-node blade server to run High Resolution Model (HRM), Regional Climate Model version 3 (RegCM3), Statistical Down Scaling Model (SDSM), and Providing Regional Climates for Impacts Studies (PRECIS) models, while Global Change Impact Studies Centre (GCISC) is using a 16 PC cluster. Each run takes months to complete. Computer power has to be significantly enhanced to work in the regional domain to produce more realistic assessments. With greater computer capacity, dynamical and statistical downscaling can be conducted.

Institutional Arrangements

Weak interdepartmental collaboration and coordination. Links between government departments and among nongovernment organizations (NGOs) and academia must be strengthened to foster the interdisciplinary approach required for climate change activities. Improved coordination could be fostered through an interdepartmental Glacial Melt and Risk Management Committee under the National Disaster Management Authority.

Absence of transboundary collaboration and coordination. Since threats of climate change encompass South Asian countries as a whole, experts recommended that a collaborative and transboundary approach to strengthen research and implementation activities, particularly concerning glacial melt and associated downstream impacts in the Indus Basin.

Since threats of climate change encompass South Asian countries as a whole, experts recommended that a collaborative and transboundary approach to strengthen research and implementation activities

Awareness

Low public awareness of climate change. It is important to raise awareness among the general population about climate change and its impact on glacial melt and subsequent upstream–downstream impacts. Activities proposed are preparing and broadcasting a documentary film on the Indus Basin, developing educational courses, supporting climate change electronic networks, and publishing a regular newsletter and disseminating it widely. Few in Pakistan know about glaciers so study tours should be organized for policy makers as well as students.

Low institutional awareness of climate change. Limited work on glacial melt and its upstream–downstream impacts is ongoing at key national institutions such as the WAPDA, PMD, and other government ministries, according to a review of their plans. No specialized university for glaciology or mountain studies exists in Pakistan, and a higher profile is needed to advocate for inclusion of such an important subject. The NGO sector must also be strengthened to ensure momentum, especially of civil society.

These knowledge gaps and issues in the scientific and policy and institutional arenas are summarized and categorized into themes in Table 6. Specific proposals are suggested to address the issues that have been identified.

7. Conclusions and Recommendations

Actions to close the gaps and resolve the issues identified in this study (Table 6) will ease the understanding of climate change impacts on water, energy, and livelihood projects. Progress in these areas ultimately helps inform risk management planning and introduce adaptive options in infrastructure design.

The way forward involves taking the following steps:

- Make data and information more available through a denser monitoring network in the mountain areas, integration of data from different institutions and governments, and establishment of a clearinghouse for published and unpublished information to make better-informed decisions.
- Strengthen the capacity of national institutions to monitor and project climate change impacts. This includes the technical capacity to provide climate change scenarios at the subbasin level, transboundary assessments of glacier dynamics through field-based and remote-sensing approaches, and water resources modeling of the Indus River and its tributaries.
- Make water and energy programs and projects of ADB and the Government of Pakistan adaptive to climate change in the medium and long term by applying knowledge and tools to identify vulnerabilities and threats and risk management activities. The suggested screening tool may play a major role in this and therefore should be field-tested.
- Organize a coordinated program that considers the complex relationship between the cryosphere, biosphere, hydrology, and human activities, using regional and global knowledge bases to improve projections of trends and their impacts on water resources.
- Create awareness among decision makers and the public of the crucial importance of adaptation to climate change to encourage implementing strategies and policies and developing a national climate change action plan. National climate change policy needs to be supported technically and through constant consultation with stakeholders to ensure their full participation and agreement.

It is further recommended that the results of this exploratory study should forms a solid basis for a new and substantive phase of work for partners, including ADB, to formulate a long-term and cooperative results-based knowledge and development partnership in the Indus Basin.

Table 6 Summary of issues related to climate change 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.

Create awareness among decision makers and the public of the crucial importance of adaptation to climate change to encourage

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