THE VULNERABILITY OF PAKISTAN'S WATER SECTOR TO THE IMPACTS OF CLIMATE CHANGE:

IDENTIFICATION OF GAPS AND RECOMMENDATIONS FOR ACTION

AGENZIA ITALIANA PER LA COOPERAZIONE ALLO SVILUPPO

CCRD

IISD International Institute for Sustainable Development

UNDP Pakistan

THE VULNERABILITY OF PAKISTAN'S WATER SECTOR TO THE IMPACTS OF CLIMATE CHANGE:

IDENTIFICATION OF GAPS AND RECOMMENDATIONS FOR ACTION

Contents

Acknowledgements

This report was prepared by Jo-Ellen Parry, Dr. Hisham Osman and Anika Terton of the International Institute for Sustainable Development, Canada (www.iisd.org), Dr. Saeed A. Asad and Dr. Toqeer Ahmed of the Centre for Climate Research and Development (www.ccrd.edu.pk) at COMSATS Institute of Information Technology Islamabad, Pakistan.

The project team would like to thank the many individuals from federal and provincial government departments, research institutes, academic organizations, non-governmental organizations and independent consultants who provided their time and expertise to the project.

We thank Ministry of Climate Change and the Ministry of Water and Power for their guidance and support during implementation of the project and special thanks to the Italian Agency for Development Cooperation for their financial support to the project.

Acronyms

GDP	Gross Domestic Product
GOP	Government of Pakistan
HKH	Hindu Kush-Karakoram-Himalaya
KP	Khyber Pakhtunkhwa
MoCC	Ministry of Climate Change
MW	megawatt
NCCP	National Climate Change Policy
NGO	non-governmental organization
NTDC	National Transmission and Despatch Company
PPIB	Private Power and Infrastructure Board
RCP	Representative Concentration Pathway
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WHO	World Health Organization

Executive Summary

Concern has been growing in recent years regarding the potential impact of climate change on Pakistan's already stressed water resources. Rising temperatures, increasing saltwater intrusion in coastal areas, a growing threat of glacier lake outburst floods, more intense rainfall, and changes in monsoon and winter rainfall patterns are just some of the ways in which climate change is expected to affect Pakistan's hydrologic resources. These risks amplify an already problematic situation given that Pakistan is among the most water-stressed countries in the world. Per capita access to surface and groundwater sources is expected to continue to decline in the decades ahead, driven largely by rapid population growth and urbanization.

Of particular concern is the potential for climate change to affect water flows within the Indus Basin. The majority of Pakistan's water is provided through the Indus River and its tributaries, which are fed primarily by snow and ice melt in the Hindu Kush-Karakoram-Himalaya mountains. Any change in water flow in the Indus basin will have significant implications for food security in Pakistan given that 90 per cent of total agricultural production occurs on arable land supported by the Indus Basin Irrigation System (Qureshi, 2011). Indus basin water flows also play a critical role in meeting domestic and municipal water supply needs, as well as supporting the country's energy production, manufacturing and industrial processes.

While the potential for climate change to jeopardize the country's efforts to increase its water, energy and food security has been acknowledged by the Government of Pakistan, there remains uncertainty regarding how changing climatic conditions are or could adversely affect the country's critical water resources (GOP, 2012). This uncertainty impedes Pakistan's capacity to move forward on planning and implementing adaptation response strategies. Compiling existing research related to climate change and water in Pakistan and systematically identifying priority research needs in this area would be a step toward enhancing the country's capacity to prepare for the impacts of climate change.

The research project, The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of Gaps and Recommendations for Action, was launched by the Ministry of Climate Change (MoCC) and the United Nations Development Programme (UNDP) in July 2015 in response to this situation. The project's goal was to analyze how climate change could adversely affect the availability of water resources in the Indus basin, and therefore limit the country's future economic and social development. It also sought to identify significant research gaps and capacity barriers limiting Pakistan's ability to more completely understand its vulnerability to climate change and take actions that would enhance its resilience. The project further aimed to increase comprehension by the people of Pakistan regarding how climate change could alter the future availability of water resources in the Indus basin. Outcomes of the project are expected to improve decision-making capacity within government ministries, research institutes and the general public in relation to water resources management in a changing climate.

Implementation of the project was guided by a detailed research methodology that consisted of five main components:

- *Key informant analysis* to identify who is doing what in the area of climate change and hydrology in Pakistan.
- *Water supply analysis* to synthesize the current state of knowledge regarding how water flows in the Indus basin may or may not change in the future, based on a systematic review of existing literature.
- *Water demand analysis* to summarize current projections regarding how water use rates by different sectors will change under different scenarios in the years leading to 2050.
- *Policy analysis* to assess the implications of future changes in water supply and demand for three key sectors—energy, agriculture and health—and to identify interventions that could address identified research and capacity gaps.
- *Outreach and communication* to share project outcomes and raise public awareness of climate change and its potential implications for Pakistan's long-term economic and social development.

The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change project was implemented under the leadership of the MoCC in partnership with UNDP-Pakistan, the Centre for Climate Research and Development at COMSATS Institute of Information Technology Islamabad, Pakistan, and the International Institute for Sustainable Development, Canada. Funding for the project was provided by the Overseas Technical Unit of the Italian Embassy in Pakistan.

MAIN OBSERVATIONS

The following main observations emerged through implementation of the project's five components:

- **Climate change impacts on water flows in the Indus basin will be limited in the near term.** The systematic review of existing research on how climate change may affect the hydrological regime of the Indus Basin found a limited number of comprehensive studies encompassing this issue. Almost consistent agreement emerged from these studies that climate change will only have a limited impact on total annual volumes of water flow stemming from the glacial and nival (snow melt) regimes in the near and medium terms. The impact of climate change in the period before 2050 is more likely to be reflected in changes in the timing of peak flows and increased variability in flow levels, primarily due to greater unpredictability in the rainfall (monsoon) regime.
- **Large knowledge gaps remain regarding the impact of climate change on the Indus basin's hydrological regime.** The systematic review also made evident the continuing lack of knowledge regarding the physical processes that shape the hydrological regime of the Upper Indus basin. Limited research has been conducted in this topographically and climatologically complex region from which about 60 per cent of water flow in the

Indus basin originates. Thus, there is no clear understanding of the relationship between the glacial and nival regimes, how they respond to current climate conditions and how they might change in the future. In part this situation stems from a lack of data due to the limited number of hydrometeorological monitoring stations established in the Upper Indus basin. As well, current climate models are unable to adequately reflect the complexity of the region. Greater understanding of the hydrological regime in the Upper Indus basin is required to inform estimates of future water availability.

- **Strong action is needed to reduce growing water demand.** A comparison of five water demand scenarios, each of which took into consideration factors such as population growth, urbanization rates, economic growth and potential changes in agricultural practices, clearly demonstrates the likelihood of a growing water demand by 2050. The analysis demonstrates the potential for significant reductions in water demand in the near-term simply through the implementation of improved irrigation efficiency. It also highlighted the risk associated with rising temperatures, which will further increase water needs by the agricultural sector—which remains the dominant source of water demand in the country (at almost 90 per cent) under all scenarios. The analysis reiterates the conclusions of other studies that Pakistan faces a growing and significant risk of increasing water scarcity on a per-capita basis unless strong water demand management practices are introduced in the near term.
- **Understanding of water demand is limited.** A very limited number of studies of water demand in Pakistan have been published. There is an absence of water demand information at the subnational level and for particular industries. As well, projections have generally relied on the use of simple linear regression models. A better understanding of current and projected water demand patterns, and how they may be influenced by climate change, is needed to inform water management decisions and sector-based planning.
- **Agriculture faces significant climate change-related challenges.** The agriculture sector is expected to experience significant adverse impacts due to greater competition for water as temperatures increase and the population expands. Key issues were identified as being: the potential for significant declines in the production of cash crops such as wheat, rice, sugarcane, cotton and maize; the need to shift cropping patterns and crop rotations due to reduced water availability; and a decline in livestock production due to greater stress on rangelands. Targeted interventions are needed to reduce the risk climate change poses for future food security, such as increasing uptake of efficient irrigation technologies, introducing new crop varieties, regulating groundwater use to stop over-exploitation, encouraging rain and flood water harvesting, and developing more climate-resilient livestock varieties.
- **Energy production will be affected by climate change's impacts on water resources.** Pakistan's expanding thermal power production is highly dependent on water for steam production and cooling, and sensitive to temperature increases. These installations may face greater competition for water resources to meet its growing needs as the climate changes. As well, run-of-the-river hydroelectric power installations may be affected by

greater variability in water flows, while large-scale hydropower plants are unlikely to be significantly affected in the near to medium terms. Greater analysis is needed to better understand the potential for trade-offs between energy sector water needs and those of other sectors, particularly the agricultural sector.

- **Climate change impacts on the health of Pakistanis is not understood.** Research conducted through this study highlighted the general absence of knowledge regarding how the health of Pakistanis will be affected by climate change, such as through future changes in water quality and the presence of water-borne diseases. A greater risk of negative health outcomes due to poor water quality is likely as the frequency of heavy rainfall events, floods and droughts increases with climate change. Moreover, it is well recognized that climate change will influence the occurrence of water-borne and water-related diseases such as malaria and cholera. However, understanding of the role of climate change in influencing future disease patterns in Pakistan is quite limited.
- **A limited number of researchers are engaged on issues related to climate change.** A survey of 77 experts from 42 organizations found that the majority of ongoing climate change-related research is linked to the biophysical impacts of climate change (e.g., glaciology, hydrology) and in the fields of agriculture and irrigation. Less research is being undertaken in areas such as human health, gender and poverty-related impacts. The surveyed experts also identified a number of areas in which key research questions remain to be answered. Many highlighted needs related to reducing water demand, such as effective ways to raise public awareness regarding the need to engage in water conservation, the potential for household-level rain water harvesting and the benefits of high-efficiency irrigation systems. Other areas identified as requiring the immediate attention of policy-makers were the revision of water pricing policies, updating the academic curricula regarding sustainable development in a changing climate and strengthening the country's watershed monitoring networks.
- **Researchers face data access, financial, human resource and technology barriers.** A majority of researchers and research managers stated that they are facing challenging barriers, including: accessing high-quality, reliable data at a limited cost; financial constraints; an absence of human resources training in specific areas of knowledge; and an inability to access scientific tools for on-site data recording. The absence of a central repository for water data was cited as a major impediment for scientists wanting to initiate studies addressing the biophysical and socioeconomic impacts of climate change on water resources. Researchers also were found to require additional resources for capacity building and enhanced cooperation among the different organizations working in this field.

PRIORITY AREAS FOR ACTION

Taking into account these observations, "road maps" or action plans for four priority gaps or barriers were developed. These areas were chosen based on how strongly the issue impeded efforts to understand and respond to the vulnerability of the Indus basin's water resources to climate change, and the potential for a clearly definable action to be taken in response. The actions prioritized for implementation are to:

- *Accelerate uptake of sustainable irrigation practices by smallholder farmers:* Increase smallholder farmers' capacity to adopt more efficient irrigation technologies and better land management practices in order to improve the efficiency of water use within the agriculture sector and increase the climate resiliency of the Indus Basin Irrigation System.
- *Strengthen post-secondary education in the area of climate change:* Develop curriculum, capacity-building programs and exchange programs at the post-secondary level to increase the number of individuals entering the work force that have the interest and training needed to engage in impact, vulnerability and adaptation research and action.
- *Establish a central repository of water data and analysis:* Establish a centralized, open access data portal through which researchers, scientists, academics and decision-makers can access standardized surface and groundwater metadata sets, visualizations and related analysis regarding hydrologic conditions in a changing climate.
- *Modernize Pakistan's streamflow monitoring network:* Strengthen streamflow monitoring in the Upper and Lower Indus basins to ensure the accurate and timely collection of data that can be reliably used to inform decision-making in sectors such as agriculture, energy, health and disaster risk management.

RECOMMENDATIONS

The research conducted as part of the Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change project highlighted the need to increase capacity in Pakistan to anticipate and minimize climate change's impact on water resources in the Indus basin by: deepening knowledge and action on water demand and ways in which to promote more efficient water use; strengthening research capacity in the area of climate change adaptation; and increasing efforts to fill critical hydrometeorological data gaps. The following recommendations address these needs:

1. Research-focused actions:

- Establish a dedicated water demand research program to better understand future sector demands, potential trade-offs between different water users, specific costing for different water uses and actual water-use patterns.
- Establish a centralized, open-access water data portal that provides access to standardized surface and groundwater metadata sets, visualizations and related analysis regarding hydrologic conditions in a changing climate.
- Promote research on the socioeconomic impacts of climate change, particularly in the areas of climate-smart agricultural practices, water quality and human health implications, energy performance impacts, and potential economic costs.
- Investigate appropriate water pricing policies that will promote more efficient water use and sustainable management of water infrastructure.

2. Policy-related actions:

- Strengthen climate change education at the post-secondary level to build capacity to undertake research and action to reduce vulnerability to climate change impacts.
- Establish a centralized federal water authority responsible for regulating and monitoring surface and groundwater use in Pakistan.
- Increase the role of government in the promotion of water demand reduction strategies.
- Increase consideration of the implications of growing water demand and the impacts of climate change in energy planning.

3. Implementation-focused actions:

- Accelerate the uptake of highly efficient irrigation technologies and sustainable land management practices by smallholders.
- Implement Integrated Water Resource Management in a priority watershed of the Indus basin to advance efforts to achieve equitable, sustainable and efficient management of Pakistan's limited water resources.

4. Infrastructure-focused actions:

- Strengthen streamflow monitoring in the Upper and Lower Indus basins.
- Install more hydrometeorological stations in the Upper Indus basin to better meet optimum observational demands and amplified research regarding the region's physical processes and how they are affected by climate change.

5. Climate change adaptation actions:

- Undertake provincial-level vulnerability assessments to fully understand how climate change will affect their water resources and the associated socioeconomic consequences of these changes, as well as identify priority climate risk management strategies.
- Foster the development of a climate change community of practice in Pakistan.

1. Introduction

Access to a safe and reliable water supply is recognized as an urgent concern for the people of Pakistan. Water availability per person is low and decreasing in Pakistan, with the country ranked as among the most water stressed in the world and expected to be classified as "water scarce" in the coming years. This situation has negative implications for the millions of Pakistanis who depend on irrigated agriculture for their livelihoods and food security. It has adverse implications for energy production given the role of water in thermal and hydroelectric power production; for domestic and industrial supplies in Pakistan's rapidly expanding urban centres; and for critical ecosystem services such as those provided by wetlands and mangroves.

Within this context there is growing concern about the potential impacts of climate change on Pakistan's water resources, particularly those within the Indus Basin. Rising temperatures spurring higher evaporation rates, rising seas leading to greater saltwater intrusion in coastal areas, more glacial melt increasing the threat of glacier lake outburst floods, and the potential for more intense rainfall and changes in monsoon and winter rainfall patterns are just some of the potential impacts of climate change on the Pakistan's hydrologic resources. These impacts are expected to negatively affect sectors such as agriculture, energy, health, manufacturing, and the provision of domestic and municipal water supplies.

While there is increasing awareness of the potential for climate change to enhance existing water scarcity concerns in Pakistan, uncertainty remains regarding the degree to which this change may occur and its potential implications for different sectors. As acknowledged in Pakistan's National Climate Change Policy (NCCP), Pakistan does not have a comprehensive evaluation of how changing climatic conditions are or could adversely affect its critical water resources and how to act to reduce its vulnerability to this risk (GOP, 2012). In particular, the NCCP draws attention to the absence of a compilation of existing research related to climate change and water in Pakistan, and the systematic identification of priority research needs in this area.

In response to this situation the research project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action" was formally launched in July 2015. Developed by the Ministry of Climate Change (MoCC) and the United Nations Development Programme (UNDP), the project was initiated to provide analysis regarding how climate change is or could adversely affect the availability of water resources in the Indus River basin, and therefore limit the country's future economic and social development. More specifically, its objectives were to:

- Develop a fuller picture of current knowledge regarding the exposure of Pakistan's water resources to the impacts of climate change and the potential socio-economic ramifications of these impacts.
- Identify priority research gaps and barriers to be overcome to fill these gaps.
- Present options to enhance understanding of and capacity to respond to the vulnerability

of Pakistan's water resources to climate change through revised or new policies, research programs and other initiatives.

- Increase comprehension by the people of Pakistan regarding how climate change could alter the future availability of water resources.

By completing this analysis, the project aimed to improve decision-making capacity within government ministries, research institutes, and the general public in relation to water resources management in a changing climate. Knowledge gained through implementation of the project also was expected to contribute to future efforts to develop a comprehensive vulnerability assessment of Pakistan's water sector and prepare a National Water Sector Adaptation Plan. The project was implemented under the leadership of the MoCC, in partnership with the UNDP-Pakistan, the Centre for Climate Research and Development at COMSATS Institute of Information Technology Islamabad, Pakistan, and the International Institute for Sustainable Development, Canada. Funding for the project was provided by the Overseas Technical Unit of the Italian Embassy in Pakistan.

This report captures the main messages and key deliverables from the project. It begins by providing an overview of the methodology used to implement the project's five main components: key informant analysis, water supply analysis, water demand analysis, policy analysis, and outreach and communication. Outcomes of these components are then presented, beginning with a summary of a systematic review of existing research regarding the projected changes in water availability in the Indus River Basin due to climate change. The potential socio-economic implications of these changes are presented in section 3. Specific analysis is provided regarding the growing gap between water supply and demand in the country, and its potential implications for the development of Pakistan's electricity sector, the well-being of the economically critical agriculture sector, and for water quality and human health. Section 4 presents outcomes of a key informant survey that gathered information regarding the type of climate change research currently underway in Pakistan and priority areas for research-related interventions that emerged from this study. Guidance is presented in section 6 regarding possible strategies for overcoming observed priority research gaps or barriers that must be overcome for Pakistan to more fully understand the vulnerability of its water sector. The report concludes with recommendations regarding how the Government of Pakistan (GOP) could move forward to enhance in-country capacity to better understand the vulnerability of its water resources to the impacts of climate change and develop strategies for reducing this risk.

2. Research Methodology

A detailed research methodology was developed to guide implementation of the project's planned components and ensure achievement of its objectives. The methodology clarified the scope of research to be undertaken and clearly defined the roles and responsibilities of the project's partner organizations. The methodology document served to ensure that there was a common understanding of what the project would and would not achieve, along with key deliverables and milestones toward project completion. Drafted in the fall of 2015, the research methodology was reviewed within the project implementation team prior to being presented at a meeting of the project's Expert Working Group in November 2015 for review and endorsement. Revisions were subsequently made in light of feedback from the Expert Working Group and the final version of the project's research methodology completed in early December 2015.

The research methodology consists of five main components, each of which builds on the previous step:

i. *Key informant analysis* – which aimed to identify who is doing what in the area of climate change and hydrology in Pakistan.

ii. *Water supply analysis* – the most significant portion of the project, this component involved preparing a synthesis of the current state of knowledge regarding how water flow levels in the Indus River Basin may or may not change in the future, based on a systematic review of existing literature.

iii. *Water demand analysis* – which aimed to summarize current understanding of projected changes in water demand in Pakistan, providing a basis of comparison with projected changes in water supply.

iv. *Policy analysis* – research was undertaken to answer two primary questions:

   o What are the implications of a changing climate for three key sectors—energy, agriculture and health—based on the outcomes of the water supply and demand assessments?

   o What are the main research gaps related to the projected changes in water supply and what interventions are needed to address these gaps and strengthen capacity?

v. *Outreach and communication* – publication of research results and sharing of project outcomes through key events such as a national symposium.

Further information regarding the methodology used to complete each of these research components is provided in the remainder of this section.

Key informant survey. The first step in the research methodology was implementation of a key informant survey to inform the subsequent research components focused on water supply, water demand and policy analysis. In particular, the aim was to identify who in Pakistan is undertaken research within the climate change and water nexus, and the focus of this research. It further sought to clarify key gaps and barriers to conducting research on the climate-water nexus in Pakistan from the perspective of the key informants. Through completion of the key informant survey, the project also sought to identify grey literature that could inform other components of the planned research, and key stakeholders with whom to communicate the project's outcomes.

To conduct the survey, an interview protocol was drafted consisting of key questions regarding the profile of the respondent, the type of research they were engaged in, and key findings of the research (published and unpublished) that they have completed. The draft protocol was tested in October 2015 and revised in light of lessons gained through this experience as well as feedback from the Expert Working Group. The survey was then undertaken between December 2015 and February 2016, with interviews being conducted in-person by members of the CCRD project team. All interview responses were recorded and uploaded using SurveyMonkey into a common database. In total 77 experts from 42 organizations were interviewed. The responses collected were subsequently analyzed qualitatively and quantitatively to draw out and verify conclusions. A synopsis of findings from the key informant survey is provided in section 5 and the full report from this research component is provided in Annex 1.

Water supply analysis. The objective of this portion of the project was to document the current state of knowledge regarding how climate change will alter hydrological flows in the Indus River Basin due to factors such as glacial retreat, changes in monsoon patterns, and changes in winter precipitation patterns. Systematic Review methodology was selected for conducting this research. This methodology is increasingly being used in the field of climate change research, particularly when reviewing, synthesizing or tracking existing knowledge related to a particular question. Its key feature is the explicit use of standardized criteria to guide the identification and selection of documents and information to be included in the review—helping to ensure that this process is less ad hoc and less open to research bias.

Following the parameters set for compliance with the systematic review approach, literature for use in the analysis was identified between mid-December 2015 and mid-January 2016. Peer-reviewed literature that meet established criteria was identified by searching three online databases: Web of Science (formerly Web of Knowledge), Scopus and Google Scholar. Grey literature was identified primarily through a general web search, while keeping in mind the inclusion and exclusion criteria established by the project. After compiling an initial list of references, the inclusion and the exclusion criteria were again applied to create a shortlist of particularly relevant sources that contained a total of 27 peer reviewed and grey literature sources. These sources were then carefully reviewed with respect to their key messages, the rigour of the methodology used in the studies, and identified research barriers and knowledge gaps. A summary of the outcomes of this assessment is presented in section 3 and the full report is provided in Appendix 2.

Water demand analysis. The third research component of the project focused on gaining a macro-level understanding of projected changes in water demand in Pakistan. The aim of this analysis was to present a synthesis of existing research regarding potential water demand in Pakistan in the coming decades under different scenarios. Relevant peer-reviewed and grey literature was identified through a general search using Google as well as the three online databases used in the water supply analysis. The analysis sought take into consideration factors such as population growth, urbanization, economic development, and potential changes in agriculture practices. Findings from this research component primarily informed the policy analysis component of the project.

Policy analysis. The policy analysis component primarily assessed the potential research, socio-economic and policy-related implications of the project's prior findings. It specifically aimed to answer two main questions: (1) What are the implications of a changing climate for Pakistan's future water security and for three key sectors: energy, agriculture and water quality / human health?; and (2) What are the main research gaps and research barriers influencing current understanding of the potential vulnerability of Pakistan's water resources to climate change, and what interventions are needed to help fill these gaps?

To help provide a response to the first question, analysis was undertaken with respect to the following themes:

A. *Energy production:* The energy component focused on potential scenarios for future thermal and hydroelectric power production, based on existing government sources, and the extent to which climate change impacts may or may not have implications for these plans.
B. *Agriculture production:* A review of existing literature assessed the extent to which research on this topic has been completed and the key messages that are emerged, giving particular attention to changes associated with potential increases or decreases in water availability.
C. *Water quality and human health:* Initial attention was given to current expectations regarding how water quality and the incidence of water-related diseases could be affected by climate change based on existing research.

A summary of findings from analysis on each of these topics is provided in section 4.

To address the second question within the project's policy component, outcomes of the key informant survey and water supply and demand studies were assessed to identify barriers to gaining a more robust understanding of the potential implications of climate change for Pakistan's hydrologic system and the socio-economic consequences of these impacts. Taking into consideration identified selection criteria, a short list of priority research barriers was identified. For each of these shortlisted barriers, a practical action plan or "road map" was created that outlines how the identified gaps could be filled and knowledge generated to improve decision-making capacity related to the future management of Pakistan's water resources. Section 6 provides a synopsis of these roadmaps, which are presented in full in Appendix 7.

Outreach and communication. Specific activities were undertaken to achieve the project's objective of increasing comprehension by the people of Pakistan regarding how climate change could alter the future availability of water resources. In particular, a one-day national symposium was held in May 2016 to share the project's findings with researchers and policy makers. The symposium also aimed to provide an opportunity for Pakistani researchers working in the water resources and climate change fields to share their research on projected changes in water supply and water demand, along with the potential socio-economic implications of these changes and possible solutions. Presentations were selected through a competitive call for abstracts. As well, invitations were extended to prominent experts in the climate change and water fields to be keynote speakers. More than 130 participants from a cross-section of regions and sectors attended the symposium, the outcomes of which are presented in Appendix 8.

3. Water Availability Assessment

The Water Supply Analysis component of the project aimed to provide a synthesis of the current state of knowledge regarding how future water flows in the Indus Basin may change in the face of climate change. To set the research in context, the assessment began by providing a synthesis of the current "anatomy" of the hydrologic regime of the Indus Basin and historic climate trends in the region. Outcomes of a systematic review of secondary sources—both peer-reviewed publications and grey literature—regarding projected changes in water flow in the Indus Basin due to climate change was then presented. Through this review commonly cited barriers to gaining a fuller understanding of the potential implications of climate change for water flow in the Indus River basin were also identified.

3.1 HYDROLOGY OF THE INDUS BASIN

A good understanding of the hydrological processes that determine river flow in the Indus Basin is required to assess how climate change will impact this system. The basin's hydrology is determined by the combined influence of three very distinct regimes and their responses to climatic conditions: the glacial regime, the nival (snowmelt) regime, and the rainfall regime. The glacial regime generates about 25 to 35 percent of water flow in the Indus River (Immerzeel et al., 2010; Mukhopadhyay & Dutta, 2010; Savoskul & Smakhtin, 2013). Its flow patterns are characterized by large variation in responses due to the inherently diverse topography and climate of the region (Archer et al., 2010; Asian Development Bank, 2010; Miller et al., 2012). Runoff rates in the glacial regime are positively correlated with summer temperatures (i.e. higher temperatures leads to greater runoff) and negatively correlated with summer precipitation levels. The latter relationship may be due to rainfall clouds reducing the concurrent heat energy input for ice melt and the consequence increase in albedo from new snow cover.

The nival regime generates about 35 to 40 percent of total water flow in the Indus Basin (Immerzeel et al., 2010; Mukhopadhyay & Dutta, 2010; Savoskul & Smakhtin, 2013), which arises from the melting of snow that fell during the preceding winter plus spring precipitation. In contrast to the glacial regime, a consistently negative relationship between runoff and temperature has been reported for the nival regime (Yu et al., 2013; Archer & Fowler, 2008). This reduced in runoff as temperatures rise has been attributed to greater evaporative losses at higher temperatures (Archer et al., 2010; Singh & Bengtsson, 2005). The

Figure 1. Map of the Indus Basin

rainfall regime is largely dependent on variations in the timing and intensity of the Indian monsoon, which is the primary factor influencing runoff in the southern foothills of the Himalayas and the Indus Plains (Archer et al., 2010; Yu et al., 2013). The rainfall regime is the main cause of lowland flooding as it produces more intense runoff.

As highlighted, flow patterns in the glacial, nival and rainfall regimes are influenced by a combination of factors including physical factors (altitude and topography), timing, and climatic conditions. A key driver of the whole system is winter precipitation, which shapes the glacial and nival regimes by nourishing glacial areas and determines the accumulation of snow cover. Changes in temperatures and precipitation patterns are the main variables that influence changes in the Indus Basin's hydrological regime as they in turn determine factors such as seasonal extremes, evapotranspiration rates, glacier volumes, and rates of snow and glacier melt.

While the above description provides a general picture of the factors influencing hydrologic patterns in the Indus Basin, it is important to keep in mind that a limited number of studies of the hydrology of the Upper Indus Basin have been completed. While the hydrology of the southern portion of the Indus Basin is well studied, hydrologic patterns in the Upper Indus Basin have been described as a "black box," with current understanding of climate patterns, local hydrology and glacier behaviour in the Upper Indus Basin is based on limited analysis using a limited data base (Yu et al., 2013).

3.2 HISTORIC CLIMATE AND HYDROLOGY TRENDS

Pakistan's climate is beginning to change in response to the global process of climate change. Studies of historical temperature datasets show a statistically significant warming trend over all of Pakistan, with mean annual temperatures reported to have increased by 0.6°C between 1900 and 1999 (Sheikh et al., 2009). Regional differences have been observed, with the northern portion of Pakistan experiencing an overall warming trend over the past 50 years while some parts of the lower Indus Basin have cooled. At the same time, temperatures in the Upper Indus Basin show contrasting trends between winter and summer, with average and maximum winter temperatures showing a statistically significant increase (0.1 to 0.55°C per decade), while average and minimum summer temperatures showed consistent cooling. Winter warming has been confined to lower altitudes while summer cooling is greater at higher elevations (Fowler & Archer, 2006).

Existing annual and decadal variability in precipitation levels within Pakistan due to factors such as variable in monsoon patterns make it more challenging to detect emerging precipitation trends spurred by global climate change. Available studies for Pakistan as a whole suggest that there has been an increase in annual and seasonal precipitation in the past 30 to 50 years, although large differences between regions and seasons have been observed. There has been a strong trend toward increasing precipitation levels in the Upper Indus, Punjab and northern Baluchistan plateau, while the western Baluchistan plateau and particularly the coastal belt has experienced declining precipitation levels (Yu et al., 2013). Within the Indus Basin available studies are less consistent in terms of observed changes but generally suggest that there has been an increase in winter precipitation levels in the

Upper Indus Basin since the 1960s (Fowler & Archer, 2005; Khattak et al, 2011; Nepal et al., 2015). They also suggest that there has been an increase in rainfall intensity, with more rain falling in fewer rainy days, across the basin (Shrestha et al, 2015; Singh et al., 2011). However, uncertainty remains regarding historical trends, particularly given the limited number of studies and meteorological data available in the upper portion of the Indus basin.

Little research has been published to date on how hydrological patterns have or have not changed in recent decades due to the observed increases in winter temperatures and declining summer temperatures in the Upper Indus Basin and the variable trends in precipitation levels. However, it is reported that gauge data from hydrological stations along the Indus River and three of its tributaries document a decline in river flow in the kharif season (April to August) (Khan, 2016) and a 5 percent overall decline in total water supply between 1962 and 2012 (Qiu, 2016). This reported trend is consistent with the observed decline in spring and summer temperatures, which would reduce the rate of ice and snow melt in the Upper Indus Basin that is critical to downstream water flow. Further research is required, though, to better assess historical trends in available hydrological data.

3.3 PROJECTED CHANGES IN THE CLIMATE AND HYDROLOGICAL REGIME IN THE INDUS BASIN

Climate projections suggest that temperatures in the Indus Basin will continue to rise in the coming decades—in both the summer and winter—and that there remains significant uncertainty regarding changes in precipitation, particularly with respect to winter precipitation, as available projections are inconsistent with respect to changes on a seasonal and spatial basis. How each of the glacial, nival and rainfall regimes respond to these climatic changes will determine the future hydrology of the Indus Basin. As runoff in the glacial regime is positively correlated to summer temperatures, higher summer temperatures are expected to lead to higher rates of runoff (Yu et al., 2013; Singh & Bengtsson, 2005; Archer & Fowler, 2008). However, it is difficult to predict the extent or timing of this increase over the long-term given the uncertainties associated with climate projections, the topographical complexity of the Upper Indus Basin, and the absence of a comprehensive inventory of glaciers within in the basin. Most of the current studies available focus on changes in small areas that are then extrapolated to present a regional overview.

Nival regime changes are of particular interest when trying to assess the potential consequences of climate change for future hydrological patterns in the Indus Basin as it comprises the greater portion of consistent downstream water flow (Archer et al., 2010; Laghari et al., 2012). A higher rate of winter precipitation, which would be consistent with historical trends, could lead to higher levels of summer runoff (Archer & Fowler, 2008; Laghari et al., 2012; Yu et al., 2013). However, as winter precipitation projections from different models contradict one another and are associated with great uncertainty, it is challenging to anticipate how runoff rates from this regime might change in the future.

With respect to changes in the rainfall regime, most climate models predict that monsoon rainfall will increase in most parts of Pakistan. An increase in inter-annual and intra-seasonal variability is also projected. Collectively these changes point to a greater risk of flooding during the monsoon season in the coming decades (World Bank, 2013). Overall, significant uncertainty remains regarding not only how each of the glacial, nival and rainfall regimes will be affected by climate change but also with respect to the interplay between them and therefore the collective outcome of these changes.

A limited number of studies have been conducted that assess future changes in water flow in the Indus Basin as a whole, both in the near and longer term. The three studies examined as part of this review all concluded that the volume of water flow in the Indus Basin will not change significantly prior to 2050 as decreases in glacial melt runoff will be compensated by runoff generated from increasing monsoon rainfall (Laghari et al., 2012; Shrestha et al., 2015; Yu et al., 2013). While no significant change in total flow volume is projected, modelling results by Yu et al. (2013) show that the main impact of climate change prior to 2050 will be a shift in the timing of peak flow to slightly earlier in the year. Immerzeel et al. (2009) also projects that there will be a shift in the timing of peak flows in the Indus Basin, with modeling results suggesting that peak flow will occur three to four weeks earlier compared to a baseline of recorded flows between 2001 and 2005 in which peak runoff occurred in weeks 26 and 27 of the calendar year (June/July) (Immerzeel et al., 2009).

In the long-term, available models suggest that water flow in the Indus Basin will decline with the loss of glaciers in the Hindu Kush-Karakoram-Himalaya (HKH) ranges. Modelling by Immerzeel et al. (2009), for example, found that a 50 percent decrease in glacial cover due to the temperature increases would result in a decrease in glacier runoff of only 22 percent. However, the total runoff in the basin would increase by 7 percent under this scenario as glacial melt losses would be offset by significant increases (by 53 percent) in rainfall concentrated in the period between June to August. In contrast, the discharge drops significantly for the scenario in which there is complete loss of glaciers in the area. These results are in agreement with the outcomes of a detailed modeling of climate change impacts in the Upper Indus Basin by Akhtar et al. (2008), which found increases in discharge for models that assume 50 to 100 percent glacier coverage, but substantial reductions when there is a complete loss of glacier coverage.

3.4 DISCUSSION

The systematic review generally concluded that current evidence suggests that climate change will have a relatively low impact on overall annual discharge in the Indus Basin in the near-term (i.e. prior to 2050). However, there may be a shift in peak flows to earlier in the year. The review also highlighted a number of gaps and areas for building capacity to enhance understanding in Pakistan of climate change's impact on future water flows in the Indus Basin:

- *Hydro-meteorological monitoring network and data availability*. In general, mountainous regions are required to be equipped with more weather stations than the flat regions to have a good representation of the mountain climate heterogeneity (Fowler & Archer, 2005). The current density in the Upper Indus Basin represents one gauge for precipitation per 5,000 square kilometers, which falls short of the one gauge per 250 square kilometers recommended by the World Meteorological Organization (1994). The Asian Development Bank (2010) concluded that in order to meet the optimum observational demands, at least 75 automatic weather stations and 35 hydrological monitoring stations must be installed in the high elevation areas of the Upper Indus Basin. Moreover, the predominance of monitoring stations in the valley floor creates bias in the monitoring network of the Upper Indus Basin. It is therefore essential to establish a dense network to capture the seasonal variations across the basin, supported by a joint program to manage, maintain and operate the hydro-meteorological monitoring network and data.

- *Large uncertainties in precipitation projections and hydrological models.* Large uncertainties remain regarding precipitation projections for the Indus River Basin. While winter precipitation is a key driver of the whole basin's hydrologic regime, its future projections are the most uncertain compared to other climate indicators. Moreover, most of the current downscaling work is produced from high coarse resolution models, which generate a crude overview of the future scenarios. It is therefore very difficult to determine the impact of climate change at the sub-basin level, which is very important for water resource development planning. In addition, current understanding and representation of the different hydrological regimes of the Indus Basin is not yet well understood and associated with large uncertainties. Better quantification of the hydrological processes within the basin's three regimes at different scales and obtaining better and higher resolution winter precipitation projections would be essential steps toward obtaining a more detailed and comprehensive picture of future water availability in the Indus Basin.
- *Lack of comprehensive glacial data and understanding of its physical processes.* Many studies report that the glaciers of the HKH are not very well understood and remain a "black box." Most scientific research on Himalayan glaciers has focused on isolated data or individual perception that does not provide an objective or systematic assessment of the evidence base or true understanding of ongoing physical changes. As the glacial and nival regimes contribute about 60 percent of the discharge in the Indus Basin, monitoring the evolution of glacial cover in the Karakoram range and the HKH mountains more generally is required to better inform estimates of future water availability and provide early warning of risks such as glacial lake outburst floods.
- *Strengthen research capacity within Pakistan.* Only about 15 percent of the publications identified for inclusion in the analysis was based on research conducted by Pakistani researchers. Of these, most were produced by the Pakistan Meteorological Department. However, these studies were focused more on historical trend analysis; future climate projections using multiple models and the current RCP scenarios remain to be completed. Greater capacity needs to be built within Pakistan's government and academic research institutes to be able to undertake these and other studies, and to publish research results.

The full report from this study is provided in Appendix 2 of this report.

4. Implications for Changes in Water Availability

The volume and timing of water flowing within the Indus River has a critical influence on a wide variety of economic and social activities in Pakistan. Consequently, any future changes in flow patterns in the Indus River—either in terms of increases or decreases or changes in peak flow patterns—has implications for variety of sectors. These potential implications were explored with respect to three key sectors:

- Energy production, with a focus on the prospects for electricity generation from thermal power and hydroelectric power production.
- Agriculture, which is the main user of water resources in Pakistan and highly sensitive to changes in hydrological and climatic conditions, particularly given the essential role of irrigation in agricultural production and food security.
- Health, given the potential influence of climate change on water quality and water-borne diseases.

While these sectors are sensitive to changes in water availability, they are influenced by, and contributors to, Pakistan's current rising levels of water demand and growing water scarcity per person. Climate change also is expected to influence future water demand, furthering the challenges facing these sectors. As such attention is first given to understanding projected changes in water demand in Pakistan prior to discussions regarding the implications of climate change for water use by the energy, agriculture and health sectors.

4.1 WATER DEMAND IMPLICATIONS

The Water Demand Analysis component of the project aimed to provide a macro-level synthesis of projected changes in water demand in Pakistan by 2050 under five different scenarios, taking into consideration factors such as population growth, urbanization, economic development and potential changes in agricultural practices. The analysis was based on a review of secondary sources identified through a general web search, drawing on studies that discussed current and/or future water demand in Pakistan's agricultural, industrial and municipal sectors. Outcomes of the analysis were then compared to findings from the water availability study to inform the development of recommendations related to water, climate change and the energy, agriculture and health sectors.

Water demand is usually categorized in terms of its use by three main sectors: agriculture, municipal and industrial. Looking back over the past five decades, it is clear that water demand within each of these sectors has grown, with the greatest increase in absolute terms occurring in the agricultural sector while the municipal sector experienced the greatest proportional rate of increase—rising by 629 percent between 1975 and 2008 (see Table 1). In Pakistan, the agricultural sector has always been the primary water user, responsible for about 90 percent of water withdrawals. Much of this water is used within the Indus Basin Irrigation System, one of the largest canal irrigation systems in the world, spreading over 14.87 million hectares of the flat plains of the Indus Valley (FAO, 2011).

Table 1. Historical water demands by sector.

Year	Agriculture (km3/year)	Industry (km3/year)	Municipal water (km3/year)	Total water withdrawal (km3/year)
1975	150.3	1.534	1.534	153.4
1991	150.6	2.5	2.5	155.6
2000	162.7	3.47	6.39	172.6
2008	172.4	1.4	9.65	183.5

Source: FAO (n.d.)

Historic and future water demand in Pakistan is highly influenced by the country's population growth rate, which census data shows reached its highest point in the 1970s (3.77 percent in the 1972 census) and has since declined to about 2.7 percent based on the last census completed in 1998 (Amir & Habib, 2015). Estimates suggest that Pakistan's total population reached about 189 million people in 2015, and could reach 245 million people in 2030 and 309 million people in 2050 (United Nations, 2015). As total renewable water availability in the country is relatively stagnant at 246.8 cubic kilometres (FAO, n.d.), this rise in population and associated water demand has led to a steady decline in per capita water availability. Based on the United Nation's estimate of Pakistan's population in 2015, per capita water availability was just less than 1,000 cubic metres per person, classifying the country as water scarce.

Estimates of future water demand for five different scenarios were calculated based on a number of assumptions regarding anticipated changes in Pakistan's rate of population growth, urbanization, industrial water withdrawals, and agricultural water withdrawals. Specifically, these assumptions were that:

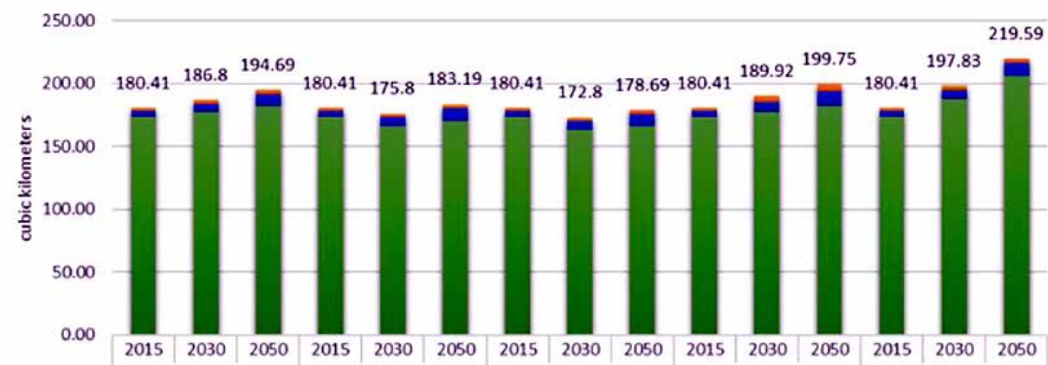
- The proportion of Pakistanis living in urban centre reached 38.8 percent in 2015 and will increase to 46.6 percent in 2030 and 57.5 percent in 2050 (United Nations, 2015).
- Water use in rural areas averages 45 litres per capita per day and in urban areas averages 120 litres per capita per day. These use rates in combination with the above projected changes in total and urban population in 2015, 2030 and 2050 was used to create a baseline for municipal water withdrawals.
- Industrial water use is directly associated with the industrial Gross Domestic Product (GDP) growth rate. As the relationship between water used and industrial GDP growth rate in Pakistan is unclear due to paucity of available data, demand levels were estimated under for low, medium and high rates of economic development based on case study analysis conducted by Suttinon et al. (2009) in Thailand.
- Agricultural water withdrawals will primarily be influenced by changes in irrigation efficiency, which is currently about 30 percent, as the country's net sown area (and

associated total irrigated area) is relatively stagnant (Amir & Habib, 2015; Bhatti et al., 2009; Qureshi, 2011).

Using this information, five water demand projection scenarios were developed:

1. *Business-as-usual scenario:* This baseline scenario assumed that the United Nations' population projections (total and proportion living in urban areas) are realized, rates of rural and urban water use per capita per day remain unchanged, a medium level of economic growth occurs (leading to an industrial GDP growth rate of 6.9 percent), and irrigation efficiency remains at 30 percent. Any potential impacts of climate change were not considered.
2. *Moderate water demand management scenario:* Under this scenario, all assumptions within the baseline scenario remained constant with the exception of an assumed increase in irrigation efficiency (the average delivery ratio) from 30 percent to 37 percent, which could be achieved by applying more sustainable irrigation methods such as sprinkler or drip irrigation.
3. *Strong water demand management scenario:* In this scenario irrigation efficiency is increased from 30 percent to 45 percent, while all other factors remain constant.
4. *Above business-as-usual scenario with exceeded extrapolation of current water demands:* This scenario projects water demand will be greater than the baseline, business-as-usual scenario due to a higher level of economic growth (leading to an industrial GDP growth rate of 9.7 percent) and an increase in population 15 percent greater than the United Nations' estimate. All other factors remained constant.
5. *Climate change impact scenario:* The scenario assumes that temperatures increase by 3°C, which would lead to an increase in agricultural water requirements of 6 percent by 2025 and 12 to 15 percent by 2050 according to research conducted by Amir and Habib (2015). All other factors remain the same.

Outcomes of the analysis are presented in Figure 2, which demonstrates that under the baseline, business-as-usual scenario total water demand will increase by about 15 cubic kilometers by 2050, when total water demand will be 195.2 cubic kilometers. A much more significant rate of growth is projected to occur under the climate change impact scenario, in which total water demand increases to 219.6 cubic kilometers in 2050. In contrast, significant reductions in water demand could be achieved in the near-term solely through efforts to improve irrigation efficiency. The impact of these measures links to the continuing role of the agricultural sector as the largest source of water demand under all scenarios. It may be anticipated that additional reductions in water demand could be achieved through implementation of a broader array of water demand management initiatives in the agricultural, industrial and municipal sectors.



	Business as usual scenario			Moderate demand management scenario			Strong demand management scenario			Business as usual scenario with exceeded extrapolation			Climate change scenario		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
Industry	2.30	2.65	2.73	2.30	2.65	2.73	2.30	2.65	2.73	2.30	4.70	5.80	2.30	2.65	2.73
Municipalities	5.11	7.15	9.96	5.11	7.15	9.96	5.11	7.15	9.96	5.11	8.22	11.45	5.11	7.58	10.66
Agriculture	173.00	177.00	182.00	173.00	166.00	170.50	173.00	163.00	166.00	173.00	177.00	182.50	173.00	187.60	206.20
Total	180.41	186.8	194.69	180.41	175.8	183.19	180.41	172.8	178.69	180.41	189.92	199.75	180.41	197.83	219.59

Agriculture   Municipalities   Industry   Total

Figure 2. Comparison of five water demand scenarios against a baseline period of 2015

Taking into account experiences gained through conducting this assessment, a number of general observations can be made regarding the nature and availability of literature related to water demand in Pakistan:

- A very limited number of studies have been conducted that address various types of water demand in Pakistan, an observation made as well by Amir and Habib (2015) in their similar study.
- Most of the available studies are high level and use data "aggregated" to the national level. Thus they lack detail regarding the implications of increasing water demand for different regions of Pakistan. Moreover, the literature lacks information about industrial water demands and potential trade-offs between irrigation needs and hydropower generation.
- Most of the future projections of water demand are based on simple linear regression models, which is mainly attributed to the limited availability of time series data.

The study clearly exposed the potential for a significant increase in water demand in Pakistan due to climate change and population growth, and the potential for water demand management measures to help reduce this level of future demand. In the absence of these measures, water demand will increasingly approach Pakistan's total renewable water availability (currently 246.8 cubic kilometres [FAO, n.d.]). Pakistan must invest more in scientific research to better understand the impact of climate change on water demand, particularly in the agricultural sector.

4.2 ENERGY DEVELOPMENT IMPLICATIONS

The implications for Pakistan's energy sector resulting from altered trends in water supply and demand due to climate change was explored through the project. Energy access is a significant concern in Pakistan as the country faces power outages, cuts and rotational load shedding. This situation stems from a growing gap between energy supply and demand. The policies of successive governments have led to high power production costs, tariffs on electric utility rates that are below the level sufficient to recover costs, and consequently limited development of the energy sector. Attempts to restructure and liberalize the electricity market in Pakistan have been difficult, resulting in sub-marginal electricity tariffs, unpaid bills, and power shortages. Additionally, the country is dealing with an inefficient power transmission and distribution system that currently records losses of 23 to 25 percent due to poor infrastructure, mismanagement and theft (Private Power and Infrastructure Board [PPIB], 2013). At the same time, energy demand is continuing to increase due to population growth, urbanization and industrial development. According to National Transmission and Despatch Company (NTDC), electricity consumption is set to continue to increase at a rate of about 8 percent each year (NTDC, 2011).

In response, the Government of Pakistan has developed a power policy to support the current and future energy needs of the country that sets key targets in terms of the demand-supply gap, affordability, efficiency, financial viability and governance of the system (PPIB, 2013). Amongst these are key commitments to the development of thermal and hydroelectric power. As the production of both of these sources of energy is sensitive to climatic conditions and water availability, specific analysis was conducted regarding how thermal power and hydroelectric power production and its future development could be affected by climate change.

Thermal power generation currently stands at about 13,670 megawatts (MW) and generates about 65 percent of Pakistan's current electricity. However, a number of plans for expansion of the sector are currently in development to further increase the electricity production. In light of the discovery of one of the world's largest coal deposits, the Thar coalfield, in 1991, Pakistan is adding to its one existing coal-fired power plant by constructing and proposing 11 new projects. Data provided by the Planning Commission of Pakistan indicates that 24 more independent power producer plants will be added by 2025 (Q. Sabir, personal communication, May 13, 2016), which could substantially add to the country's power generation capacity.

Thermal power production is sensitive to climate change due to two primary factors: its high dependence on water for steam production and subsequently for cooling the steam; and temperature increases. Analysis from the systematic review of studies on projected changes in water flow in the Indus River completed as part of this project indicates that availability will not change significantly in the short and mid-term (2050) although there could be a shift in the timing of the peak flow to earlier in the year—potentially by three to four weeks in the longer term (Immerzeel et al., 2009; Yu et al., 2013). Changes in water supply are therefore unlikely to significantly affect current thermal power plant developments. However, these utilities are likely to be affected to projected increases in air temperature, which will decrease the efficiency of the thermal conversion process and result in a loss of production or electrical output (Makky & Kalash, 2013). In turn this will lead to an increase in water demand by the energy sector, leading to increased competition with other sectors such as agriculture. However, it appears that national planning for power generation does not fully account for how climate change might influence the issue of long-term competition for water resources in the country. Such considerations could influence decisions regarding whether or not there is a need to retrofit cooling systems or switch to more efficient cooling methods.

Pakistan has significant hydropower development potential and is interested in facilitating private sector investment in hydropower generation so at to address its current energy gap and thereby support achievement of the country's socio-economic development objectives. While total installed hydropower capacity was 6,720 MW as of 2010, the total potential capacity is about 60,000 MW. Almost all of this potential lies in Khyber Pakhtunkhwa, Gilgit-Baltistan, Punjab and Azad Jammu and Kashmir (PPIB, 2011); 75 percent of all hydropower potential in Pakistan is contained in the Indus River Basin (Qureshi & Akintug, 2014). Under Pakistan's Integrated Energy Plan 2009-2022, the government has mandated an increase in hydropower production to 17,392 MW by the year 2022-2023 "at any cost" (Ministry of Finance, 2009). Based on the projects that are currently being implemented (mostly small hydel projects) along with the ones under consideration, the total hydel capacity can be expected to potentially grow to 42,765 MW by the year 2030 (International Institute for Sustainable Development, forthcoming).

Depending on the expected lifespan of newly constructed dams, the loss of glaciers beyond the middle of this century and its potential impacts on water flows in the Indus River could potentially affect water supplies and hydroelectric generation capacities. In the medium-term (2050), however, reduced availability of water supply in the Indus River basin does not appear to be a significant threat to large hydropower installations. Changes in the timing and variation of daily water flows though could have a greater impact on run-of-the-river hydroelectric projects.

What could be of concern is the potential for conflicting shifts in peak energy demand and water run-off, given that hydropower reservoirs are an important source of irrigation water. Projections suggest that there could be a shift in the timing of peak run-off, which could significantly increase between weeks 14 and 25 of the calendar year (Immerzeel et al., 2009). This time period coincides with the onset of the growing season for kharif crops and therefore is a critical period for irrigation. Should energy demand also shift to earlier in the year in response to rising temperatures (and therefore greater cooling needs), competition for water could increase. Greater analysis is needed to better understand the potential for growing trade-offs between irrigation and energy generation, as well as careful assessment of the need for changes in water allocation rules.

Future energy development processes will need to take into consideration the inter-relationship between climate change, energy production and water supply and demand. Better management practices and conservation initiatives will be required to address trade-offs and promote synergies, particularly with respect to management of competing demands for water from a finite supply. As such it appears that there is a need to:

- Integrate water demand projections into the planning and development of new thermal power plants and consider the most efficient cooling methods to reduce the amount of water used in the cooling process.
- Increase promotion of water and energy conservation strategies through regulations and incentives, recognizing the interdependencies of both resources across sectors and regions.
- Review current water allocation rules to take into potential shifts in run-off patterns and peak flows.

The full brief on Pakistan's energy sector and how it might be affected to changes in climatic conditions is provided in Appendix 4.

4.3 AGRICULTURE IMPLICATIONS

Agricultural production in Pakistan is intimately linked to the availability of water in the Indus River and its tributaries that feed the Indus Basin Irrigation System and enable crop growth in the largely arid and semi-arid Indus Plains. Land irrigated by the Indus Basin Irrigation System generates about 90 percent of Pakistan's total agricultural production. Pakistan's agriculture sector is also a critical source of local livelihoods; about 67 percent of rural Pakistanis are economically dependent on agriculture in one way or the other (Maqbool & Bashir, 2009). Agriculture also generates approximately 22 percent of Pakistan's GDP and 70 percent of its export earnings (FAO, 2015).

While the Indus Basin is richly endowed with land and water resources, agricultural production within this region is challenged by a variable climate and hydrology, the impact of natural hazards like floods and earthquakes, concerns regarding the sustainability of agricultural production, and continued undernourishment of about 20 percent of the population (FAO, 2016). An equally large concern is the Indus Basin's increasingly inadequate and aging water infrastructure, particularly its limited water storage capacity due to too few reservoirs and the sedimentation of existing reservoirs. The Indus River Irrigation System is also characterized by large inefficiencies at the canal, watercourse and field levels, due in part to poor management and low water rates that do not generate sufficient funds to cover existing operation and maintenance costs. In addition to these difficulties, Pakistan is experiencing a decline in per capita water availability as its population increases and economy grows. Water demand in the agriculture sector is projected to increase much more than in other sectors to meet the growing food requirement needs of an expanding population (Amir & Habib, 2015).

Climate change is an additional stressor on this already challenged system—leading to agriculture being identified as perhaps the sector more vulnerable to changing climate risks. The sector is expected to be affected by an anticipated rise in mean temperatures on an annual and seasonal basis, changing precipitation patterns, the potential for more frequent and intense extreme weather events such as floods and droughts, and by changes in the growing season. Of particular concern is the potential impact of a changing climate on water flows in the Indus Basin given the implication for irrigated agriculture. The Indus Basin and its tributaries are largely fed by the melting of glacial and annual snowfall in the HKH mountain ranges, which provides between 50 and 70 percent of the basin's water flow (Yu et al., 2013). Altered melt patterns in the HKH ranges along with potential changes in monsoon patterns could result in changes in the spatial and temporal distribution of water resources on an annual and inter-annual basis (GOP, 2012)—with subsequent implications for irrigated agriculture and livestock production. At present it is anticipated that total water flows in the Indus Basin in the near-term (i.e. before 2050) will remain relatively stable, although there could be an increase in flows due to higher run-off as temperatures warm and a shift in the timing of peak water flow to earlier in the year (Immerzeel et al., 2009).

These climatic changes will bring both risks and opportunities for Pakistan's agriculture sector. Potential impacts include: declines in water availability, which would lead to shifts in crop rotations and alter sowing and harvesting patterns in the coming two to three decades; a reduction in the production of the country's main cash crops; reduced cereal production in southern Pakistan of up to 20 percent while minor improvements may be experience in the northern belt; and a potential decline in livestock production of up to 30 percent due to greater stress on rangelands due to longer droughts and greater competition for limited resources as people and animals migrate to riverine areas. At the same time there is the potential for elevated temperatures to speed up crop growth and for yields to increase due to a longer and hotter summer season (GOP, 2012).

Climate change will disproportionally impact agricultural production across the country. In Punjab and Sindh, limited capacity to store water could take a toll on about 20 to 25 percent of cultivable land, rendering it unfit for agriculture. As well, it has been projected that a 4°C increase in temperatures and 3 percent rise in precipitation by 2080 could result in a loss in agricultural productivity of up to 13 percent in these two provinces (Dehlavi et al., 2014). Similar results have been generated by Yu et al. (2013), who suggest that more adverse change could potentially be experienced in Sindh. More positively, in Pakistan's northern foothills, wheat, maize and rice yields could increase due to longer and hotter summer seasons (Rasul & Ahmed, 2012).

The potential implications for the country's main cash crops has been the focus of most of the (relatively limited) research completed to date on climate change and agriculture in Pakistan. These studies have identified potential climate risks for specific crops:

- Wheat: A decrease of 8-10 percent in wheat yields may occur. The population will need to reduce its dependence on wheat and shift to use of coarse grains such as barley, sorghum, millets, oats and coarse rice (Janjua et al., 2010).
- Rice: Production may be reduced by up to 20 percent compared with current figures (Tariq et al., 2014).
- Maize: Maize yield will be substantially decreased as temperatures increase up to 1.8oC in central areas of Punjab. If the current scenario of a consistent increase in temperatures continues, the commodity yield may decrease by 20 percent beyond 2050 (Khaliq, 2008).
- Cotton and sugarcane: Cotton (Raza & Ahmed, 2015) and sugarcane (Zhao, 2015)

production would be severely impacted by changing rainfall patterns, rising temperatures and declining supplies of surface water. The negative impacts of temperature on cotton production are more striking for Sindh. It has been projected that a 1°C rise in temperature during the vegetative and flowering stages of growth would reduce yield by 24.14 percent and 8 percent respectively (Raza & Ahmed, 2015).

Overall available research suggests the potential for water-intensive crops to be most affected by climate change, resulting in significant reductions in crop yields.

Livestock production, which generates half of the agriculture sector's current contribution to GDP, will also be affected by a changing climate. Direct effects of climate change on livestock may result in lowered milk and meat production and reduced reproductive capacity as temperatures rise. Risks such as climate-related disease epidemics may also increase. Decreased nutritional quality and palatability of forage plants due to increasing concentration of carbon dioxide, competition for land between fodder and staple crops, and increased water requirements present further impacts. The vulnerability of the livestock sector to climate change is particularly high because it depends largely on grazing on rangelands whose capacity for adaptation is very low (GOP, 2013a).

To enhance food and water security, a number of actions could be taken to address the challenges Pakistan's agriculture sector is facing due to climate change, including:

- Introduce new varieties of crops which are high yielding and less water intensive.
- Regulate groundwater usage to stop over exploitation and encourage rain and flood water harvesting along with enhanced water storage capacity.
- Initiate water conservation technologies such as drip or sprinkler irrigation methods in selected areas and promote raised bed technology, which could reduce by 50 percent the need for irrigation water while increasing crop productivity.
- Implement waste water recycling in urban settings.
- Up-scale land leveling, which enables 30 percent water saving with corresponding increases in productivity.
- Develop and introduce better varieties of livestock that have higher capacity to produce milk and meat, are less prone to heat stress, and are more drought tolerant.

A fuller brief on the vulnerability of Pakistan's agriculture sector to climate change is provided in Appendix 5 of this report.

4.4 WATER QUALITY AND HEALTH IMPLICATIONS

A further critical impact of climate change is expected to be on water quality and the presence of water-borne diseases such as malaria and cholera. Water quality in Pakistan is increasingly being negatively impacted by factors such as population growth, agricultural contaminants, environmental degradation, and the intensification of water use to meet rapidly growing demands for agricultural production, urbanization and industrialization. These stressors interact with factors like temperature, humidity, extreme events and changing in rainfall pattern to influence the occurrence of water-related and water-borne pathogens and diseases. Analysis therefore was completed as part of the project that reflected on potential changes in the quality of water available to Pakistanis, potential changes in the incidence of water-related diseases due to climate change, and potential actions to reduce these risks.

Climate change is likely to impact water quality and the presence of water-borne diseases through two principle means:

- *Temperature increases:* Water quality parameters, including acidity levels, oxygen and nutrient levels, are particularly sensitive to increasing water temperatures, which influences the blooms of various planktonic species that are directly or indirectly hazardous to human health. Thus, increasing water temperatures will likely mean an increase in water-borne bacteria and harmful algal toxins. It can also lead to potential increases in vector-related diseases such as malaria, dengue fever, dengue hemorrhagic fever, chikungunya, yellow fever and filariasis. Clear evidence is available, for example, on the effect of temperature on the risk of a cholera outbreak. Studies have shown that rising temperatures leads to plankton blooms that, under suitable conditions, are followed by increases in the reported cases of cholera (Hunter, 2003).
- *Precipitation changes:* Climate change may lead to changes in monsoon rainfall patterns and other variations in precipitation levels that could lead to greater frequency of heavy rainfall events and more extreme events like floods and droughts that have a direct impact on water quality and water-borne and water-related diseases. Heavy rainfall events such as those that occur during the monsoon season lead to water abundance and quality deterioration because storm water runoff carries pathogens and dissolved organic pollutants into surface and groundwater sources, resulting in high counts of indicator bacteria as well as potential pathogens in drinking water. Flooding and heavy rainfalls, particularly in urban areas, also cause large amounts of contaminants to be transported from industrial and agricultural areas to rivers, further deteriorating water quality. In contrast, drought conditions not only reduce water supply, they also impair water quality as contaminants become more concentrated in the declining supply of surface and ground water. Moreover, droughts conditions can force residents to use contaminated sources of water for drinking and other uses. Reportedly, vegetables and crops have been irrigated with wastewater, due to the unavailability of treated water. Consequently, vegetables and crops are polluted with pesticides, heavy metals and other pollutants.

Thus, climate change coupled with poor socio-economic conditions could exacerbate deteriorating water quality and changing vector parameters, rapidly increasing the number of people exposed to a high risk of water pollution, related diseases and health impacts. Moreover, as decreasing water quality will reduce the amount of water available for consumption, this process will likely compound Pakistan's future water demand challenges along with population expansion and economic growth.

Both malaria and cholera appear to be on an upward trend in Pakistan and, while there is limited information currently available about climate change's link to the occurrence of these diseases in the context of Pakistan, international research suggests the potential for greater prevalence of these diseases in the future. Temporal variations in the occurrence of malaria is strongly associated with climatological variables like temperature and average rainfall (Ahmad et al., 2015), with data confirming that the transmission of malaria in Pakistan mainly occurs in the post-monsoon season (September-November) every year. With changing rainfall patterns and increases in temperature due to climate change, the population density and geographic distribution of malaria carrying mosquito species will be changed and likely could increase. However, an increase in the occurrence of malaria will not occur under all conditions. For example, floods can have a negative effect on the density of mosquito populations because floods may wash or destroy their eggs and larvae.

Between 2005 and 1992, not a single case of cholera in Pakistan was reported to the World Health Organization (WHO) (Naseer & Jamali, 2014). However, by 2014, 1,218 cholera cases were reported by Pakistan and it remains a public health problem related to water contamination in the country (WHO, 2015). The deterioration of water quality after floods—the occurrence of which may increase in Pakistan with climate change—and the unavailability of clean drinking water can increase the risk of cholera and other water-related diseases. The importance of providing basic health care facilities in affected flood areas and infrastructure will be key to preventing and treating diseases such as cholera.

While the risk of climate change for human health and, to a lesser extent, water quality has been identified and examined in detail in different regions of the world, this study found that very little if any research has been published to date on the potential impact of climate change on water quality and the presence of water-borne diseases in Pakistan. This presents a sizeable gap in current understanding of the potential risk climate change poses for Pakistanis—particularly given that increases in health risks has been identified as one of the main climate change threats facing Pakistan (GOP, 2012). As climate change progresses, it will become more important to monitor the annual outbreak of the diseases in Pakistan and to enhance research on the likely impacts of climate change on water- and vector-borne parasites, along with their control under changing climatic conditions.

Based on the above findings, the following recommendations emerged from the project regarding actions that could be taken by the Government of Pakistan:

- Given the large research gap regarding the relationship between climate change impacts and changes in water quality and water-borne diseases, it is highly recommended that greater research be conducted on potential water quality scenarios under changing climatic conditions and possible adaptive measures to reduce or avoid future impacts on water quality.
- Given the important influence of water quality on human health, now and under changing climatic conditions, greater emphasis should be put on the adoption of sustainable agriculture practices, improved wastewater treatment, industrial design and other measures to minimize water pollution.
- Few studies have been conducted in Pakistan to assess the quality of water in rivers. Such studies should be conducted to provide a baseline against which to compare future studies regarding the impact of climate change on bacteriological water quality.
- Water quality should be monitored during regular time intervals, especially pre- and post-

extreme weather events and natural disasters. It is recommended that water quality and climate change be included in future water policies at the national and provincial levels.

- More research is needed on the potential impact of climate change on the abundance and distribution of water- and vector-borne parasites, such as malaria, dengue fever and cholera, as well as strategies for their control under changing climatic conditions. Such action could reduce the future incidence of these diseases.
- Investment is needed in the health care system, particularly in flood affected areas, to increase its capacity to manage the expected increase in the occurrence of water- and vector-borne diseases associated with changing climatic conditions.
- Health campaigns and other awareness raising efforts that use modern techniques and local languages are needed to inform those most at risk of the best strategies to control malaria and cholera.

The full policy brief for this study is provided in Appendix 6.

5. Climate Change Research Context in Pakistan

As described in section 2, a key informant survey was undertaken between December 2015 and February 2016 that aimed to identify the Pakistani researchers and institutions engaged in climate change and water research. It also sought to identify the type of research being undertaken regarding the biophysical impacts of climate change on Pakistan's hydrological system and the potential socio-economic consequences of these changes. Another aim of the survey was to identify key research gaps and barriers from the perspective of Pakistani researchers. Participants were also asked to identify their recent research papers as part of the grey literature data collection process. The responses collected were subsequently analyzed qualitatively and quantitatively to draw out and verify the conclusions. The following section presents the main results of the survey of 77 key informants from a total of 42 organizations engaged in water and climate change-related studies.

5.1 PROFILE OF KEY INFORMANTS

Of the 77 respondents (70 men, 6 women), approximately 60 percent of key informants had a background in the sciences, followed by those specialized in engineering (27 percent); 10 percent identified themselves as social scientists. Regardless of gender or the field of specialization, more than 93 percent of the key informants were either master or higher degree holders in their respective fields of expertise.

Research areas of the key informants surveyed are depicted in Figure 3. Data analysis indicates that the greatest number of people (18 percent) interviewed were working in the field of hydrology, followed by those from related disciplines such as irrigation (11

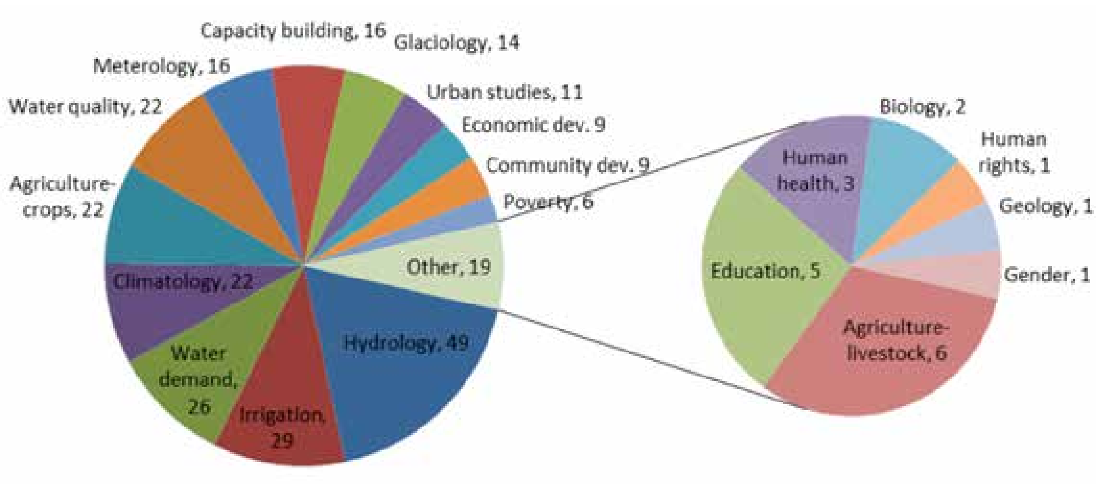


Figure 3. Percentage of respondents engaged in the identified fields of research

percent) and water demand (10 percent). Scientists engaged with assignments in the fields of climatology, agricultural crops and water quality constituted 8 percent of each of these disciplines, whereas representation from the remaining identified areas of specialization was approximately 6 percent. Further, the analysis indicated that researchers working with climate change-related studies generally engage in a mix of biophysical and socio-economic research, but those engaged in biophysical research are more likely to focus primarily in this area, devoting 51 percent to 75 percent of their time to this aspect.

5.2 SURVEY RESULTS

Results from the data collected through the key informant survey is presented below. The subsequent discussion identifies significant barriers and gaps to conducting research that address the biophysical and socio-economic impacts of climate change on water resources in Pakistan as identified by the survey participants.

Research Areas. The main objectives of climate change-related research being undertaken by a majority of the key informants and/or their organizations included: on-farm water management to enhance agricultural productivity; development of water resources; and cryosphere monitoring. Others were involved in research related to water conservation and improving water storage for small-scale hydropower generation. Approximately 3 percent of all those interviewed were engaged in monitoring surface and ground water quality while a negligible number of candidates pursued studies related to climate change adaptation measures.

Research Barriers. When respondents were asked about the major challenges to conducting studies regarding the biophysical and socio-economic impacts of climate change on water resources, a majority identified data access as the single factor which has most affected their research initiatives. Moreover, the same interview participants were doubtful about the quality of available data—an additional area of concern. Approximately 91 percent of the interviewees and their respective organizations were facing financial issues which was further exacerbated by the fact that already underfinanced individuals and organizations are being asked to pay high fees to purchase data needed for research. One out of five respondents documented a lack of human resources and particularly trained personnel for specific projects such as data collection as a major impediment to work on climate change-water nexus projects.

A considerable number of key informants (17 percent) reported the non-availability of scientific equipment for on-site data recording as a challenging issue. Twelve percent of respondents reporting other obstacles to engage in water-related research. Security concerns were identified among these obstacles, particularly with respect to undertaking research in Khyber Pakhtunkhwa (KP) and Baluchistan province, as well as along the Indus River and its tributaries near the Afghanistan border.

Knowledge Gaps. Survey respondents were requested to highlight the main research questions or knowledge gaps that they believe remain to be addressed regarding the biophysical and/or socio-economic impacts of climate change on water resources of Pakistan. A significant number of participants noted that climate change is a rather new phenomenon in Pakistan, that it is not well understood, and that it has not received the necessary attention at the research and policy levels. Interview participants proposed that the inclusion of climate change-related courses in the curriculum at least of higher education institutions may improve the situation.

Several key informants recognized that basic studies are lacking, leading to a lack of clarity regarding whether glaciers are retreating at a faster rate compared with the previous three decades. Interviewees linked the absence of a central data repository to the non-existence of such reports. Capacity building of farmers, the revision of water pricing, rainwater harvesting and water conservation were identified as themes that remain to be researched and legislated to combat the country's growing water stress. It was emphasized that farmers' reluctance to adopt new water-saving technologies and the inability of the national government to implement regulations are core issues to be addressed. Respondents representing provincial irrigation departments in Punjab and Sindh underlined that farmers' involvement should be sought to adopt high efficiency irrigation systems given their potential to save 50 percent of irrigation water compared with conventional flood irrigation methods. It was also cited that peoples' attitudes toward water needs to be addressed, as non-judicious use of water by households has very serious repercussions and is contributing to the growing demand for this natural resource.

A very critical knowledge gap shared by an interview participant was that credible watershed data does not exist. No work has been carried out on watershed network studies, and most of the watershed forecasting is done using non-established procedures—a practice that has resulted in incorrect data. Non-coordinated responses amongst all stakeholders to extreme weather events such as floods was presented as another challenge. Furthermore, it was observed that groundwater contamination and over mining concerns are missing altogether in most studies conducted within the climate change and water nexus.

5.3 OBSERVATIONS AND DISCUSSIONS

Data access, quality and cost were observed to be the most serious concerns facing the research community involved in climate change and water related studies in Pakistan. this problem may be addressed by establishing a databank at the federal level that encompasses all data from projects related to hydrology and climate change, and by strengthening the network amongst researchers and data holding organizations. Data quality may be improved by capacity building as it was observed that most organizations are understaffed and face issues related to the availability of trained personnel. Moreover, the use of state of the art techniques and equipment (e.g. early warning system) for on-site data recording may further improve the situation.

Security concerns limiting or preventing data collection and site visits to remote areas, such as those bordering Afghanistan and the tribal areas of KP and Baluchistan provinces, was identified as being a severe challenge. This problem has increased scientists' dependence on other organizations to collect data, rather than recording information themselves firsthand. A further challenge is the limited attention federal and provincial governments have given to climate change-water nexus studies in the past and their lack of willingness to prioritize this type of research. Given all of these challenges it is perhaps not surprising that no notable progress has been made in advancing hydrological studies with reference to climate change in the last decade.

Many research questions remain to be answered on an urgent basis, such as effective ways to overcome the current lack of public awareness regarding the need for and ways to engaged in water conservation such as rain water harvesting and the adoption of high efficiency irrigation systems. To address these issues, it has been recommended that a water resource regulatory authority be formulated after necessary legislation has been enacted. This authority should be given the task of revising water pricing policies and regulations in consultation with stakeholders. Water pricing, along with public education campaigns, may encourage people to make more judicious use of water.

Another area seeking urgent attention is groundwater, which has largely been ignored in the national water policy of Pakistan. Due to the non-existence of a designated regulatory body, this natural resource has been over-mined as the supply of surface water has decreased. Parallel with these research and policy shortcomings, negligible work has been conducted on adaptation strategies to cope with water-related extreme events triggered by climate change. Additionally, the impact of climate change on water quality and its consequent influences on human health has not yet been studied. It is highly recommended that such research be undertaken.

To conclude, a limited number of organizations and experts are studying hydrology with respect to climate change, particularly in relation to its socio-economic implications, and are facing challenging barriers related to data access, finance, human resources and technology availability. The key informant survey demonstrates that researchers need additional resources for capacity building, easy access to reliable data, and enhanced cooperation among different organizations working in this field. It further identifies critical gaps of climate change-water related research that need to be prioritized both at the research and policy levels.

6. Options for Addressing Priority Research Gaps or Barriers

Insight into some of the gaps and barriers that currently impede understanding of the vulnerability of the Indus River Basin's water resources to climate change was gained through the feedback provided by surveyed key informants and the literature review completed within the water availability study. From this list of gaps and barriers, four priority needs were selected taking into consideration criteria such as: the extent to which it addresses an identified research-related gap or barrier; how strongly it emerged as an urgent need through the project's activities; and whether it could be addressed through clearly definable actions that would attract the interest of international donors.

For each of the shortlisted priority needs, a "road map" or action plan for filling the identified gap or barrier has been elaborated. These road maps provide a general description of the main elements of the prioritized action, a rationale for its selection, expected results from its implementation, possible implementation challenges, potential partners, and a general timeline and estimated costs. They are intended to provide sufficient information regarding the specific elements of the proposed initiative to enable the Government of Pakistan to engage in discussions with potential funders. The content of each road map was informed by desk-based research that looked at similar actions in other developing countries, as well as feedback received through in-country consultations with relevant experts.

The actions prioritized for implementation are to:

- Accelerate uptake of sustainable irrigation practices by smallholder farmers
- Strengthen post-secondary education in the area of climate change
- Establish a central repository of water data and analysis
- Modernize Pakistan's streamflow monitoring network

Summary descriptions of road maps for these priority options are provided in the pages that follow. Full descriptions of each road map are provided in Appendix 7.

6.1 ACCELERATE UPTAKE OF SUSTAINABLE IRRIGATION PRACTICES BY SMALLHOLDER FARMERS

Pakistan has experienced a steady decline in its water availability per capita over the past 50 years, driven by greater demand spurred by population growth, urbanization and economic expansion. The greatest demand for water comes from the agriculture sector - a situation that will remain unchanged in the coming decades. As demand increases while total water availability remains on average constant, competition for this finite resource is expected to grow. This situation puts greater pressure on Pakistan to improve the efficiency of its irrigation system. At present only about 30 percent of water flowing through the Indus

Basin Irrigation System is delivered to farms and it is not uncommon for farmers at the tail end of the system to not receive water (GOP, 2013a). Climate change will place additional pressure on this faltering system by, at a minimum, increasing evapotranspiration rates as temperatures rise and exposing the system to greater risk of damage by extreme weather events. The need to upgrade, extend and improve the efficiency of Pakistan's irrigation system is widely recognized as a key priority for the country. In response a number of initiatives are underway that seek to improve the functioning of the Indus River Basin System. As noted by interviewed experts, though, considerable effort remains to be undertaken to increase the uptake of high efficiency irrigation systems by small landholding farmers.

This action therefore aims to increase the number of smallholder farmers adopting more efficient irrigation technologies and better land management practices. An integrated and holistic approach is planned that will promote the development of an irrigation system that is economically, socially and environmentally sustainable. As such it will put in place well-designed incentive structures that encourage the provision of appropriate technologies at prices smallholders can afford, engagement of the private sector in financing and manufacturing high efficiency irrigation systems, use of more sustainable land practices, and direct involvement of farmers in the management of local irrigation systems. Collectively these actions are intended to reverse current trends of groundwater depletion, soil erosion, waterlogging, and soil subsidence and salinization, while also increasing the climate resilience of smallholder farmers and the Indus Basin Irrigation System as a whole.

The proposed main elements of a strategy for developing an integrated program that will achieve these objectives are:

- *Landscape analysis* to identify the range of actors involved in efforts to improve Pakistan's irrigation systems and understand their current and planned activities focused on the needs of smallholder farmers. This information will provide a baseline against which to develop a new initiative that complements ongoing and planned initiatives, and avoids duplication.
- *Best practices review* to deepen knowledge regarding the most effective strategies for enabling smallholder farmers to adopt sustainable irrigation and land management practices, drawing upon lessons gained through past efforts in Pakistan and other South Asian countries facing similar challenges.
- *Identification of priority needs* to ensure development of a program that targets particularly vulnerable smallholder farmers in areas not supported through other initiatives. Priorities will be assessed against economic, social and environmental criteria and take into consideration federal and provincial government policies and plans, expert analysis, farmers' knowledge, and outcomes of the landscape assessment and best practices review.
- *Detailed design of targeted program*. A full proposal for a multi-year program of action that addresses the priority needs identified will be developed and reviewed in a participatory manner. Elements of the program are expected to focus on supporting farmers by introducing sustainable financing strategies, holding farmer field schools, and forming

farmers' councils. It will also provide complementary support to strengthen the capacity of the private sector, provincial government officials, and research institutes and academia.

The planned irrigation program is expected to improve the socio-economic conditions of smallholders, increase crop productivity per drop of water used, reduce smallholders' vulnerability to climate variability and change, and better protect fertile land against erosion, waterlogging and salinization.

Lead partners to be engaged within this initiative would be provincial departments responsible for irrigation, agriculture and finance as well as local irrigation and drainage authorities. Additional support would be provided by relevant federal government departments, research organizations, local private sector suppliers, local large landowners, and non-governmental organizations (NGOs). It is expected that the project would be implemented through three phases: a one year to 18-month design phase (approximate cost of US$300,000 to US$350,000; a four to five-year pilot phase (approximate cost of US$2.0 to $4.0 million, depending on the scope of planned activities); and a four to five-year upscaling phase (approximate cost of US$4.0 to $8.0 million depending on the scope of interventions).

6.2 STRENGTHEN POST-SECONDARY EDUCATION IN THE AREA OF CLIMATE CHANGE

Limited numbers of people engaged in research and action related to the direct and indirect impacts of climate change on Pakistan's hydrological regime was identified as a fundamental barrier to informed planning and decision-making by governments, the private sector and civil society. Researchers currently engaged in this field cited the absence of required human resources as a barrier to implementing the research that they are undertaking. Perhaps more revealing is the limited amount of peer-reviewed and grey literature related to climate change and hydrology identified through this research that had been produced by Pakistani researchers. It was observed that research being produced and shared publicly is largely emerging from national and international NGOs. The GOP also has identified the need to address the absence of sufficient numbers of climate change experts, scientists, modellers and technologists as part of the NCCP (GOP, 2012).

While several factors contribute to this situation, a specific identified gap was the limited amount of quality education at the post-secondary level pertaining to climate change - its drivers, potential manifestations and the possible implications for different regions, sectors and people. Climate courses have been developed as part of the 2014 version of the Higher Education Commission's environmental sciences curriculum. Tailored course work on climate change is needed in other field of research, such as engineering and health. As well, no post-secondary education institution in Pakistan currently offers an associated degree program at the Masters level that would provide an in-depth examination of the linkages between climate change and different sciences and social sciences disciplines. As such the objective of this road map is to increase the number of post-secondary graduates entering into the work force that have a committed interest in climate change and the training needed to engage in impact-, vulnerability- and adaptation-related research and action.

Strengthening post-secondary education in Pakistan will require efforts that address multiple needs, such as: development of tailored curriculum in priority scientific and social disciplines; improving the capacity of instructors to deliver in-depth and up-to-date climate change-related knowledge; and creating opportunities for students to engage in research and action in this field. Main elements of a strategy for meeting these needs could include:

1. *Stakeholder analysis and engagement*, which would include identification of stakeholders within and outside of government who should be involved in shaping the content of this program. A stocktaking of existing priorities and initiatives would also be undertaken to identify existing climate change-related training, programs and initiatives being implemented at the post-secondary level and efforts to strengthen education and training institutions more generally.
2. *Assessment of learning needs*, to gain a deeper understanding of the knowledge and technical skills required by employers in key sectors to ensure that education programs produce graduates with capacities desired in the work place.
3. *Assessment of delivery capacities* that looks at the existing expertise and teaching capacity of knowledge providers such as professors and instructors and assesses required learning and skills development needs.
4. *Development of an action plan* designed to address priority gaps between identified learning needs and delivery capacities. The plan's content should be focused on addressing individual learning needs as well as strengthening the capacity of learning institutions. Potential elements of this plan could be: further development of curricula and courses both for students and instructors; encouragement of professional development opportunities; establishment of a competitive grants program; and additional linkages with international research institutions. The action plan should be developed though a multi-stakeholder process to ensure its continued relevance to both post-secondary education institutions and potential employers in government and the private sector.

Outcomes arising from implementation of this action are expected to include improved capacity to undertake climate change-related research that can inform future adaptation policies and programs, and greater generation of knowledge regarding climate change-related risks, vulnerabilities and risk reduction strategies.

Key partners to be involved in implementation of this actions are expected to be the MoCC, the Higher Education Commission of Pakistan, sectoral ministries, government research institutions, universities, technical training institutes and NGOs. In implementing this action, efforts would need to be made to ensure complementarity with existing initiatives such as US-Pakistan Centre for Advanced Studies project funded by the United States Agency for International Development and the activities of the Climate Change Centre at the University of Agriculture, Peshawar funded by the Swiss Agency for Development and Cooperation. Implementation of the first steps in this action could take place over a period of 18 to 24 months, and it is estimated that it would cost between US$1.0 and $2.0 million, depending on the scope of work undertaken.

6.3 ESTABLISH A CENTRAL REPOSITORY OF WATER DATA AND ANALYSIS

An inability to access robust and reliable water-related data at little or no cost was identified by Pakistani researchers as being a significant barrier to their climate change related work. Difficulties are being experienced in terms of accessing what data is available regarding glacial fluctuations, river flows and ground water levels, in part due to the high cost that can be associated with purchasing it. Concerns regarding the quality of the data being provided also were raised. Additional challenges are being experienced in terms of finding published and unpublished technical reports, research papers and policy analyses on climate change and water issues in Pakistan. These barriers impede the capacity of researchers to undertake the analysis needed to inform water use planning and the development of adaptation plans at the provincial and federal levels.

In response, it is proposed that the federal government establish a centralized, open access data portal through which researchers, scientists, academics and decision makers can access standardized surface and ground water metadata sets, visualizations (maps, graphs, tables), and a curated library of technical reports, research papers, and policy assessments pertaining to climate change and water issues in Pakistan. This proposal is consistent with past recommendations, such as the Task Force on Climate Change, NCCP, and framework for implementation of the NCCP. The Task Force on Climate Change, for example, called for the establishment of a national data bank that would provide access to the hydrological, climatological and agro-meteorological data required to inform decision-making in a changing climate (GOP, 2010). Creation of the portal should be informed by a deep understanding of the needs of its intended users so as to avoid the pitfalls that have been experienced with past online climate change knowledge platforms (Hammill et al., 2013).

It is expected that the main elements associated with creation of the planned water portal would be:

- *Best practices review* to glean from the experience and expertise of foreign national and sub-national governments as well as international institutes that have established open data water portals.
- *Mapping of existing data sources and materials* to identify potential content for the water portal, as well as gain a detailed understanding of the collection, quality control and management practice associated with different data sets. Discussions with data holders also would be initiated to secure their involvement in establishment of the data portal.
- *Stakeholder consultations* to gain a clear picture of issues such as the type of water-related data and derived products researchers would like to see provided through the portal, the desired format for its delivery, and potential barriers to accessing the platform.
- *Development of protocols for data quality, access and usage*, such as quality control and quality assurance protocols, to ensure that the data provided through the portal meets international standards. Data access and use protocols would also be established to ensure respect for existing copyrights, intellectual property rights and data agreements.
- *Design, review, creation and launch of planned data portal* through a participatory process

and drawing on knowledge gained through the best practices review and stakeholder consultations.

- *Capacity building* to ensure the presence of sufficient technical, managerial and knowledge management skills to ensure the effective operation of the water portal.

Establishment of a water portal that provides access to reliable data suitable for the needs of researchers within Pakistan is expected to improve the quality of research undertaken in the country and to provide greater access to the information needed for informed decision-making.

Lead partners to be engaged in the development, launch and operation of the water data portal are expected to be the Ministry of Science and Technology and its associated Pakistan Council of Research in Water Resources, the MoCC, the Ministry of Water and Power, and the Pakistan Meteorological Department. Key input would be expected from provincial governments, federal and provincial research institutions, NGOs and international research organizations. The estimated time required to establish the water portal is two years, at an approximate cost of US$ 3.0 to 4.0 million.

6.4 MODERNIZE PAKISTAN'S STREAMFLOW MONITORING NETWORK

A number of data gaps currently impede understanding of past, ongoing and projected future changes in water flow in the Indus Basin due to climate change. Many of these knowledge gaps could be addressed by strengthening Pakistan's existing network of river and stream gauges and enhance its hydrological monitoring network. As noted in Pakistan's Framework for Implementation of National Climate Change Policy (GOP, 2013b), strengthening this network would improve the national flood warning system as well as capacity to understand the future hydrology of the Indus Basin in a changing climate. The need for better watershed data was also emphasised by surveyed researchers, along with the need to strengthen human and technical capacity to collect, analyse and develop forecasts using globally established procedures. Studies by international organizations and researchers have highlighted similar needs. Of particular concern is the absence of an adequate streamflow network in the Upper Indus Basin, but a lack of monitoring stations in main, branch and distribution channels of the Indus Basin Irrigation System has also been cited as an impediment to efficient water allocation practices (Alford et al., 2016; Archer et al., 2010; Briscoe & Qamar, 2007).

The objective of this action therefore is to improve streamflow monitoring in the Upper and Lower Indus Basins to ensure that accurate and timely data is collected for use in decision-making related to agriculture, energy, health, disaster risk management and other sectors. The main elements of an initiative that aims to achieve this objective would be:

- *Completion of a needs assessment* to determine how the existing streamflow monitoring network needs to be improved in light of factors such as international standards and the growing requirement for data that can inform climate change research and modelling. The assessment will also identify institutional and human resource capacity gaps that should be filled.

- *Development of a detailed strategic implementation plan* to address shortcoming in the current monitoring network, taking into account outcomes of the needs assessment. The plan will identify a strategic, stage-by-stage process for improving the monitoring network over time. Central questions expected to be addressed within the plan include: where efforts will be prioritized, the types of instruments to be used, and the locations in which they will be placed. Issues related to the management and maintenance of the system will also be addressed, such as training and institutional strengthening commitments, equipment maintenance strategies, and processes for data access, synthesis, digitization, analysis, storage and sharing.
- *Undertaking capacity building activities* in areas such as data collection and management, operation of different monitoring stations, and the use of specific technologies. Training as research assistants and technicians could also be provided to villagers in high altitude locations near the monitoring stations.
- *Strengthening information dissemination processes* to make reliable data more available to researchers and decision-makers. Implementation of this work element could be linked to efforts to establish an open-access water data portal (as described in section 6.3).

The expected outcome of efforts to enhance streamflow monitoring in the Indus River Basin would be greater capacity to identify changes in run-off volumes, prepare near-term flow forecasts, and develop more reliable projections of future hydrological conditions. This information in turn would enable the creation of more robust vulnerable assessments and stronger adaptation plans.

Key partners in implementing this action would include the MoCC, the Ministry of Water and Power, the Water and Power Development Authority, the Pakistan Meteorological Department, the Indus River System Authority and the National Disaster Management Authority. Additional implementation partners would include national and international researchers as well as multilateral organizations involved in research and activities in the Upper Indus Basin such as the World Bank and International Centre for Integrated Mountain Development. The initial assessment and planning phase would be completed over a period of 12 to 18 months, at an estimated cost of US$2.0 to 3.0 million. The timeline and cost of subsequent phases of work would be determined in the planning phase.

7. Recommendations

Research completed through "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change" project has provided greater clarity regarding current scientific understanding of how the climatic changes Pakistan is projected to experience over the remainder of this century could affect Indus Basin water flows in the near-, medium- and longer term. It has also provided new insight into the type of climate change adaptation research that is being undertaken by Pakistani research institutes, government departments, universities and NGOs. Significant data gaps and barriers to understanding the risks climate change poses for Pakistan have been identified, along with areas in which greater research, analysis and knowledge sharing is required.

Collectively, the project's findings have clarified three priority areas in which the Government of Pakistan needs to take action to increase its capacity to anticipate and minimize the impacts of climate change on hydrological resources within the Indus Basin:

- *Deepen knowledge and action on water demand and ways to promote more efficient water use.* With current estimates suggesting that Pakistan is already a water stressed country on a per capita basis, priority attention needs to be given to accelerating efforts to promote the use of water efficient technologies and practices. At the same time there is a need to more fully understand water demand drivers and trends, and for this knowledge to inform water allocations. In the absence of these actions, Pakistan can anticipate growing conflict between water users, less capacity to adapt to climate change, and difficulties achieving its water, energy and food security goals.
- *Strengthen research capacity in the area of climate change adaptation.* Limited research is currently being undertaken in Pakistan specifically in the area of climate change—its potential manifestations, possible impacts, current vulnerabilities and effective adaptation strategies. While there is limited research across all issues, particular gaps exist regarding the potential socio-economic impacts of climate change and the development of appropriate climate risk reduction strategies. Additionally, there is a need to foster a culture of data and knowledge sharing within Pakistan's research community. The absence of available analysis and sharing of what research is conducted limits the capacity of Pakistan to effectively assess its vulnerability to climate change and engage in robust adaptation planning.
- *Increase efforts to fill critical hydrometeorological data gaps.* A well-known critical barrier to understanding the potential impacts of climate change on water flows in the Indus Basin is the limited availability of hydrometeorological data, particularly in the Upper Indus Basin. Targeted efforts are needed to improve the volume and quality of data available to researchers and decision-makers by installing new hydrometeorological stations and strengthening existing monitoring networks. In parallel, there is a need to increase the amount of research being undertaken in the Upper Indus Basin and the capacity of Pakistani researchers to participate in these opportunities.

Research completed through "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change" project has provided greater clarity regarding current scientific understanding of how the climatic changes Pakistan is projected to experience over the remainder of this century could affect Indus Basin water flows in the near-, medium- and longer term. It has also provided new insight into the type of climate change adaptation research that is being undertaken by Pakistani research institutes, government departments, universities and NGOs. Significant data gaps and barriers to understanding the risks climate change poses for Pakistan have been identified, along with areas in which greater research, analysis and knowledge sharing is required.

Collectively, the project's findings have clarified three priority areas in which the Government of Pakistan needs to take action to increase its capacity to anticipate and minimize the impacts of climate change on hydrological resources within the Indus Basin:

- *Deepen knowledge and action on water demand and ways to promote more efficient water use.* With current estimates suggesting that Pakistan is already a water stressed country on a per capita basis, priority attention needs to be given to accelerating efforts to promote the use of water efficient technologies and practices. At the same time there is a need to more fully understand water demand drivers and trends, and for this knowledge to inform water allocations. In the absence of these actions, Pakistan can anticipate growing conflict between water users, less capacity to adapt to climate change, and difficulties achieving its water, energy and food security goals.
- *Strengthen research capacity in the area of climate change adaptation.* Limited research is currently being undertaken in Pakistan specifically in the area of climate change—its potential manifestations, possible impacts, current vulnerabilities and effective adaptation strategies. While there is limited research across all issues, particular gaps exist regarding the potential socio-economic impacts of climate change and the development of appropriate climate risk reduction strategies. Additionally, there is a need to foster a culture of data and knowledge sharing within Pakistan's research community. The absence of available analysis and sharing of what research is conducted limits the capacity of Pakistan to effectively assess its vulnerability to climate change and engage in robust adaptation planning.
- *Increase efforts to fill critical hydrometeorological data gaps.* A well-known critical barrier to understanding the potential impacts of climate change on water flows in the Indus Basin is the limited availability of hydrometeorological data, particularly in the Upper Indus Basin. Targeted efforts are needed to improve the volume and quality of data available to researchers and decision-makers by installing new hydrometeorological stations and strengthening existing monitoring networks. In parallel, there is a need to increase the amount of research being undertaken in the Upper Indus Basin and the capacity of Pakistani researchers to participate in these opportunities.

To address these needs the following recommendations are made:

1. Research-focused actions:

- Establish a dedicated water demand research program. As noted in this study and others, "water demand is a subject that has not been sufficiently studied in Pakistan" (Amir & Habib, 2015: p.2). There is a general absence of water demand data and analysis, and existing data is "aggregated" to the national level, limiting capacity to track and anticipate changes in water demand in different regions of the country. The absence of this sub-national information impedes capacity to undertake water demand forecasting and design locally relevant water conservation strategies for different sectors. A large water demand research program is therefore needed on an urgent basis to better understand issues such as sector demands, potential trade-offs between different water users, specific costing for different water uses, actual water use patterns, and policy gaps.
- Establish a centralized, open-access water data portal. As described in section 6.3, there is a need for a user-driven portal through which researchers, scientists, academics and decision makers can access standardized surface and ground water metadata sets, visualizations, and related analysis of hydrologic conditions in a changing climate. This data could be augmented by improved access to historical climate trends and downscaled multi-modal climate projections using the most recent internationally agreed upon scenarios. Greater access to this information would help inform decision making and improve the quality of research conducted within Pakistan.
- Promote research on the socio-economic impacts of climate change. Significant gaps were observed with respect to the amount of research being undertaken that looks at the socio-economic impacts of climate change. While some research has been done within the agriculture sector, more is needed given this sector's economic importance and existing food security concerns. More attention also needs to be given to other critical sectors, such as the potential impacts of climate change on water quality and human health. Other areas that could be prioritized include the potential economic costs of climate change, its gendered impacts, how it may affect energy performance, and the potential of climate change to aggravate existing social tensions and conflicts.
- Investigate appropriate water pricing policies. The need to revise water pricing policies to promote more efficient use of water resources and recover sufficient funds to enable consistent investment in water infrastructure emerged as a consistent message throughout the project. Further research is needed to identify strategies for reforming existing water subsidies that are driving unsustainable practices and modifying pricing systems in a manner that protects the rural and urban poor. Research could also be undertaken on how to communicate to the public the level of subsidies being provided, the benefits of reforming this system, and how subsidy reform might be achieved.

2. Policy-related actions:

- Strengthen climate change education at the post-secondary level. As outlined in section 6.2, improving the level and quality of climate change-focused education at the post-secondary level is required to improve climate change research and action in Pakistan. Addressing this barrier will require: the creation of new curricula; building the capacity of education planners, curriculum developers and teaching staff; and increasing the number of academic exchanges between Pakistani and developed countries research institutes and universities with strong teaching and research programs in the areas of climate change and water.

- Establish a centralized federal water authority. An observed barrier to addressing Pakistan's growing per capita water scarcity and implementing water conservation practices is the absence of a centralized agency with the capacity and authority to coordinate and enforce improved water management practices. The mandate of existing agencies, such as the Indus River System Authority, is limited and does not meet current needs arising from a changing social and climatic environment. The envisioned federal water authority would be responsible for regulating and monitoring surface and ground water use in Pakistan. Among other possibilities, it could be given the tasks of: revising existing water policies and regulations; monitoring water use, availability and quality; reviewing water tariffs for domestic and commercial utilities; and promoting water conservation practices and water saving technologies. The authority's mandate should be developed through consultations with a diversity of stakeholders and legislation passed to enact its establishment.
- Increase the role of government in promoting water demand reduction strategies. Reflecting the risks arising from growing per capita water scarcity, provincial governments should play a leadership role in promoting water conservation by the agricultural, industrial, municipal and domestic sectors. This should include greater investment in programs that: promote water conservation practices such as flood and rainwater harvesting, as well as the use of high efficiency irrigation systems; improve the maintenance of irrigation canals; promote the breeding and cultivation of less water intensive crops; implement waste water recycling in urban areas; and install more efficient thermal cooling systems. Governments should also introduce water pricing policies that better reflect the real-cost of water usage.
- Increase consideration of water-related issues in energy planning. Greater consideration should be given to the impact of energy developments on water demand when planning new power generation infrastructure. As competition for water increases with rising demand, the need to account for potential conflicts and trade-offs between sectors will become increasingly important. So too will the need to understand and seek to optimize potential co-benefits arising from energy developments, such as the possible role of hydro dams in water retention, irrigation and flood protection. As well, the potential impacts of climate change on new energy infrastructure (e.g., higher temperatures, more variable rainfall) should be taken into consideration during the assessment and planning process.

3. Implementation-focused actions:

- Accelerate sustainable irrigation practices by smallholders. As described in section 6.1, there is a need to increase the number of smallholder farmers adopting high-efficiency irrigation systems. An integrated approach is needed to enable farmers to overcome existing barriers to the use of these systems while also building an irrigation system that is economically, socially and environmentally sustainable. A multi-year program of activity is urgently needed that brings together efforts to improve incentive structures, engage the private sector, promote sustainable land use practices, build capacity within government departments, and strengthen linkages with the research community.

- Implement Integrated Water Resource Management in a priority watershed of the Indus Basin. Effective management of water resources requires decision-making and action at a watershed scale. Too often, however, decisions that influence water flow, storage and quality are made in Pakistan on a sector-by-sector basis in an uncoordinated and fragmented manner. This has led to the loss of ecosystem services, unsustainable use, and negative economic and social outcomes. Integrated Water Resources Management addresses these challenges by promoting a holistic, coordinated and participatory approach to the development and management of water, land and related resources. To promote expanded application of this internationally recognized cross-sector approach in Pakistan, a program of action should be implemented in a selected sub-catchment of the Indus Basin. This initiative would advance efforts to achieve equitable, sustainable and efficient management of Pakistan's limited water resources—while also supporting adaptation to climate change.

4. Infrastructure-focused actions:

- Strengthen streamflow monitoring in the Upper and Lower Indus Basins. As outlined in section 6.4, a more comprehensive and modern streamflow monitoring network is required to address existing data gaps. This information becomes more important as demand for a finite supply of water grows and the risk of over-extraction increases. The existing network of river and stream flow gauges needs to be improved to prepare more reliable near-term flow forecasts, inform flood risk assessments, enhance monitoring of long-term trends in water flow patterns, and develop more reliable projections of future hydrological conditions. The network should also be enhanced to better monitor water quality and fish stocks. Along with the installation of improved physical infrastructure, further capacity building is needed to ensure the quality, timeliness and sharing of available data.
- Install more hydrometeorological stations in the Upper Indus Basin. Fundamental questions remain to be answered regarding how climate change has begun to impact the glacial, nival and snowmelt regimes of the HKH. In part this is because insufficient data is currently available to analyze ongoing climatic changes in the Upper Indus Basin at elevations above 1,000 metres, and particularly between 2,000 and 5,000 metres above sea level. A denser network of stations is needed to capture the heterogeneity of mountain climates. These investments should be complemented by amplified research regarding the region's physical processes and greater capacity to model projected changes in key climate parameters and their potential biophysical impacts at the sub-basin level.

5. Climate change adaptation actions:

- Undertake provincial-level vulnerability assessments for the water sector. Building on outcomes of this study, assessments of the vulnerability of each province in Pakistan to the impacts of climate change on their water resources should be undertaken. Key steps in this assessment would be to: (1) understand the existing and anticipated situation in a province regarding its water availability and demand, giving particular attention to existing drivers of water-related stress and exposure to climate-related risks; (2) understand the socio-economic situation in each province and the inter-linkages between water availability and economic, social and ecological well-being; (3) develop climate change projections for each province and assess the risk associated with different climatic impacts on the water sector and the potential associated socio-economic consequences; (4) identify, assess and prioritize the feasibility of implementing different options for ameliorating the impacts of key climate risks; and (5) develop provincial adaptation plans for the water sector that will guide the implementation of prioritized climate risk management strategies.
- Foster the development of a climate change community of practice in Pakistan. While institutions—in government, academia and civil society—are undertaking research on the implications of climate change for water resources, there is little collaboration and coordination between these groups. Limited sharing of research findings and lessons learned through the implementation of climate adaptation strategies is presently occurring in Pakistan, restricting the potential generation of new ideas and development of informed policies and strategies. Efforts to improve collaboration between research institutes, academia, government departments and NGOs engaged in climate change research and action is needed. This objective could be achieved by hosting regular national and regional workshops and conferences that provide an opportunity for discussion and debate, as well as by creating online knowledge sharing opportunities.

References

Ahmad, S.S., Aziz, N., Butt, A., Shabbir, R. & Erum, S. (2015). Spatio-temporal surveillance of water based infectious disease (malaria) in Rawalpindi, Pakistan using geostatistical modeling techniques. Environmental Monitoring and Assessment. 187:555. DOI: 10.1007/s10661-015-4779-9.

Akhtar, M., Ahmad, N., & Booij, M. J. (2008). The impact of climate change on the water resources of Hindukush–Karakorum–Himalaya region under different glacier coverage scenarios. Journal of hydrology, 355(1), 148-163.

Alford, D., Archer, D., Bookhagen, B., Grabs, W., Halvorson, S., Hewitt, K., Immerzeel, W., Kamp, U. & Krumwiede, B. (2016). Monitoring of Glaciers, Climate, and Runoff in the Hindu Kush-Himalaya Mountains. Washington, D.C.: World Bank Group. Report No.67668-SAS. Retrieved from http://documents.worldbank.org/curated/en/2016/03/26048237/monitoring-glaciers-climate-runoff-hindu-kush-himalaya-mountains

Amir, P. & Habib, Z. (2015). Estimating the impacts of climate change on sectoral water demand in Pakistan. Action on Climate Today.

Archer, D. R., & Fowler, H. J. (2008). Using meteorological data to forecast seasonal runoff on the River Jhelum, Pakistan. Journal of Hydrology, 361(1), 10–23.

Archer, D. R., Forsythe, N., Fowler, H. J., & Shah, S. M. (2010). Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions. Hydrology and Earth System Sciences, 14(8), 1669–1680. http://doi.org/10.5194/hess-14-1669-2010

Asia Development Bank. (2010). Islamic Republic of Pakistan: Glacial Melt and Downstream Impacts on Indus Dependent Water Resources and Energy.

Bhatti, A. M., Suttinon, P., & Nasu, S. (2009). Agriculture water demand management in Pakistan: a review and perspective. Society for Social Management Systems, 9(172), 1-7.

Briscoe, J. & Qamar, U. (2007). Pakistan's Water Economy Running Dry. Karachi: Oxford University Press. Commissioned by World Bank.

Dehlavi, A., Groom, B. & Gorst, A. (2014). The Determinants, Impact and Cost Effectiveness of Climate Change Adaptation in the Indus Ecoregion: Micro Econometric Study. Lahore University of Management Studies, World Wide Fund for Nature – Pakistan and London School of Economics. Retrieved from: http://www.pide.org.pk/psde/pdf/AGM30/papers/The%20Determinants_Impact%20and%20Cost%20Effectiveness.pdf

Food and Agriculture Organization of the United Nations (FAO). (no date). AQUASTAT Home [web site]. Retrieved from http://www.fao.org/nr/water/aquastat/main/index.stm

Food and Agriculture Organization of the United Nations (FAO). (2011). Indus basin. Retrieved from http://www.fao.org/nr/water/aquastat/basins/indus/index.stm

Food and Agriculture Organization of the United Nations (FAO). (2015). Women in Agriculture in Pakistan. Retrieved from http://www.fao.org/3/a-i4330e.pdf

Food and Agriculture Organization of the United Nations (FAO). (2016). FAOSTAT. Country Profiles. Pakistan. Retrieved from http://faostat3.fao.org/home/E

Fowler, H. J., & Archer, D. R. (2005). Hydro-climatological variability in the Upper Indus Basin and implications for water resources. Regional Hydrological Impacts of Climatic Change—Impact Assessment and Decision Making, 295, 131-138.

Fowler, H. J., & Archer, D. R. (2006). Conflicting signals of climatic change in the Upper Indus Basin. Journal of Climate, 19(17), 4276–4293.

Government of Pakistan (GOP). (2010). Task Force on Climate Change: Final Report. Islamabad: Planning Commission.

Government of Pakistan (GOP). (2012). National Climate Change Policy. Islamabad: Ministry of Climate Change.

Government of Pakistan (GOP). (2013a). Agriculture and Food Security Policy (Draft). Islamabad: Ministry of National Food Security and Research.

Government of Pakistan (GOP). (2013b). Framework for Implementation of Climate Change Policy (2014-2030). Islamabad: Climate Change Division.

Government of Pakistan (2014). Vision 2025: One Nation – One Vision. Islamabad: Ministry of Planning, Development & Reform. Retrieved from http://pakistan2025.org/wp-content/uploads/2014/08/Pakistan-Vision-2025.pdf

Hammill, A., Harvey, B. & Echeverria, D. (2013). Understanding Needs, Meeting Demands: A user-oriented analysis of online knowledge broker platforms for climate change and development. Winnipeg: International Institute for Sustainable Development. Retrieved from http://www.iisd.org/library/understanding-needs-meeting-demands-user-oriented-analysis-online-knowledge-broker-platforms

Hunter, P.R. (2003). Climate change and waterborne and vector-borne disease. Journal of Applied Microbiology 94. 37S-46S. http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2672.94.s1.5.x/pdf

Immerzeel, W.W., Droogers, P., de Jong, S.M. & Bierkens, M.F.P. (2009). Large-scale monitoring of snow cover and runoff simulations in Himalayan river basins using remote sensing. Remote Sensing of Environment. 113 (2009): 40-49.

Immerzeel, W. W., Van Beek, L. P. & Bierkens, M. F. (2010). Climate change will affect the Asian water towers. Science, 328(5984), 1382-1385.

International Institute for Sustainable Development (IISD). (forthcoming). Low-Carbon Scenarios Analysis for Pakistan.

Janjua, P.Z, Samad, G., Khan, N. U. & Nasir, M. (2010). Impact of climate change on wheat production: A case study of Pakistan. The Pakistan Development Review. 799-822.

Khaliq, T. (2008). Modeling the impact of climate change on maize (Zea mays L.) productivity in the Punjab. Dissertation, University of Agriculture Faisalabad, Pakistan.

Khan, A. (2016). Glacier Monitoring: WAPDA's initiative in the Upper Indus Basin. Presented at the International Conference on Climate and Environmental Change Impacts on the Indus Basin Waters, Kathmandu, Nepal, 17-18 February 2016.

Khattak, M. S., Babel, M. S., & Sharif, M. (2011). Hydro-meteorological trends in the upper Indus River basin in Pakistan. Climate research, 46(2), 103-119.

Laghari, A. N., Vanham, D., & Rauch, W. (2012). The Indus basin in the framework of current and future water resources management. Hydrology and Earth System Sciences, 16(4), 1063-1083.

Makky, M. & Kalash, H. (2013). Potential Risks of Climate Change on Thermal Power Plants. Retrieved from https://www.researchgate.net/publication/236174007_Potential_Risks_of_Climate_Change_on_Thermal_Power_Plants

Maqbool, A. & Bashir, M. (2009). Rural Development in Pakistan: Issues and Future Strategies. Conference proceedings "Agriculture: Challenges, Opportunities and Option under Free Trade Regime. Retrieved from https://www.researchgate.net/publication/216413804_Rural_Development_in_Pakistan_Issues_and_Future_Strategies

Miller, J. D., Immerzeel, W. W., & Rees, G. (2012). Climate change impacts on glacier hydrology and river discharge in the Hindu Kush-Himalayas: a synthesis of the scientific basis. Mountain Research and Development, 32(4), 461-467.

Ministry of Finance. (2009). Integrated Energy Plan 2009-2022. Report to Expert Energy Group. Government of Pakistan. Retrieved from http://www.pc.gov.pk/hot%20links/integrated_energy_plan2009-22.pdf

Mukhopadhyay, B., & Dutta, A. (2010). A stream water availability model of Upper Indus Basin based on a topologic model and global climatic datasets. Water resources management, 24(15), 4403-4443.

Naseer, M. & Jamali, T. (2014). Epidemiology, determinants and dynamics of cholera in Pakistan: gaps and prospects for future research. J. Coll. Phy. Surg. Pak. 24(11):855-60.

National Transmission and Despatch Company (NTDC). (2011). Electricity Demand Forecast based on Multiple Regression Analysis. Period 2011 to 2035. Retrieved from http://www.ntdc.com.pk/EDF20112035.pdf

Nepal, S. & Shrestha, A. B. (2015). Impact of climate change on the hydrological regime of the Indus, Ganges and Brahmaputra river basins: a review of the literature. International Journal of Water Resources Development, 31(2), 201-218.

Private Power and Infrastructure Board (PPIB). (2011). Hydropower Resources in Pakistan. Government of Pakistan. Retrieved from http://www.ppib.gov.pk/HYDRO.pdf

Private Power and Infrastructure Board (PPIB). (2013). National Power Policy 2013. Government of Pakistan. Retrieved from http://www.ppib.gov.pk/National%20Power%20Policy%202013.pdf

Qiu, J. (2016). Stressed Indus River threatens Pakistan's water supplies. Nature News and Comment. Retrieved from http://www.nature.com/news/stressed-indus-river-threatens-pakistan-s-water-supplies-1.20180

Qureshi, A. S. (2011). Water management in the Indus basin in Pakistan: Challenges and opportunities. Mountain Research and Development, 31(3), 252–260.

Qureshi, F.U. & Akıntuğ, B. (2014). Hydropower Potential in Pakistan. Retrieved from https://www.researchgate.net/publication/268224059_Hydropower_Potential_in_Pakistan

Rasul, G. & Ahmed, B. (2012). Climate change in Pakistan. Pakistan Meteorological Department.

Raza, A. & Ahmad, M. (2015). Analyzing the impact of climate change on cotton productivity in Punjab and Sindh, Pakistan. Climate change Working Paper Series (no.9). Retrieved from http://www.pide.org.pk/pdf/Climate_Change_9.pdf

Savoskul, O. S. & Smakhtin, V. (2013). Glacier systems and seasonal snow cover in six major Asian river basins: Hydrological role under changing climate (Vol. 150). International Water Management Institute.

Sheikh, M. M., Manzoor, N., Adnan, M., Ashraf, J., & Khan, A. M. (2009). Climate profile and past climate changes in Pakistan. GCISE report No. RR-01, Islamabad.

Shrestha, A., Agrawal, N., Alfthan, B., Bajracharya, S., Maréchal, J., van Oort, B. (Eds.). (2015). The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins. ICIMOD, GRID-Arendal and CICERO, Kathmandu, Nepal.

Singh, P. & Bengtsson, L. (2005). Impact of warmer climate on melt and evaporation for the rainfed, snowfed and glacierfed basins in the Himalayan region. Journal of Hydrology, 300(1), 140-154.

Singh, S. P., Bassignana-Khadka, I., Karky, B. S., & Sharma, E. (2011). Climate change in the Hindu Kush-Himalayas: the state of current knowledge. International Centre for Integrated Mountain Development.

Suttinon, P., Bhatti, A. M., & Nasu, S. (2009). Industrial and household water demand management: a case study of Pakistan.

Tariq, A., Tabasam, N., Bakhsh, K., Ashfaq, M. & Hassan, S. (2014). Food security in the context of climate change in Pakistan. Pakistan Journal of Commerce and Social Sciences. 8(2): 540-550.

United Nations. Department of Economic. (2015). World Population Prospects: The 2015 Revision. United Nations Publications.

World Bank. (2013). Turn Down the Heat: Climate extremes, regional impacts and the case for resilience. A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. Washington: World Bank. Retrieved from http://documents.worldbank.org/curated/en/2013/06/17862361/turn-down-heat-climate-extremes-regional-impacts-case-resilience-full-report

World Health Organization (WHO). (2015). Weekly epidemiological record: Cholera 2014. 90: 517-544

World Meteorological Organisation (1994). Guide to Hydrological Practices. WMO-164, 5th edition. Geneva: World Meteorological Organization.

Yu, W., Yang, Y., Savitsky, A., Alford, D., Brown, C., Wescoat, J., Debowicz, D., & Robinson, S. (2013). Executive Summary. In The Indus Basin of Pakistan: The Impacts of Climate Risks on Water and Agriculture. Washington, DC: World Bank.

Zhao, D. & Li, Y.R. (2015). Climate change and sugarcane production: Potential impact and mitigation strategies. International Journal of Agronomy. Retrieved from http://dx.doi.org/10.1155/2015/547386

Appendix 1:

Key Informant Survey Report

The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action

Author: Dr. Saeed A. Asad, Centre for Climate Research and Development

Reviewer: Jo-Ellen Parry, International Institute for Sustainable Development

Table of Contents

Acknowledgement

The Key Informant survey was conducted in-person by members of project team from the Centre for Climate Research and Development that included Dr. Saeed A. Asad, Dr. Toqeer Ahmed and Dr. Amir H. Malik.

Research Team

From IISD, Canada: (www.iisd.org)

1. Jo-Ellen Parry
2. Hisham Osman
3. Anika Terton

From CCRD, COMSATS IIT, Islamabad: (www.ccrd.edu.pk)

1. Dr. Toqeer Ahmed
2. Dr. Saeed A. Asad
3. Prof. Dr. Amir H. Malik
4. Ms. Asma Shabbir
5. Ms. Sara Gilani

Executive Summary

The project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action" was launched in July 2015 in Islamabad. Prime objective of this project was to conduct a systematic review of current understanding of the potential changes in Pakistan's hydrological regime due to climate change, identify critical knowledge gaps, and prioritize the means by which these gaps might be filled on an urgent basis. Another objective of this project was to present options for enhancing understanding of and capacity to respond to the vulnerability of Pakistan's water resources to climate change through revised or new policies, research programs and other interventions. Developed by the Ministry of Climate Change and the United Nations Development Programme, the project is being implemented jointly by the Centre for Climate Research and Development at COMSATS Institute of Information Technology Islamabad, and the International Institute for Sustainable Development, Canada.

The project's objectives were achieved through implementation of a research methodology consisting of five main components: (1) a key informant analysis intended to identify who is doing what in the area of climate change and hydrology in Pakistan; (2) water supply

analysis to synthesize knowledge regarding how water flow levels in the Indus River Basin may or may not change in the future; (3) analysis looking at projected changes in water demand; (4) policy analysis to assess potential impacts on health, agriculture and energy, as well as identify the main research gaps and interventions/investments to fill these gaps and; (5) outreach and communication of the project's outcomes via conference/symposium.

As a first step of the research methodology, a key informant survey was conducted to inform the subsequent research components focused on water supply, water demand and policy analysis. The specific aims of the key informant survey were to identify the type of research being undertaken on the biophysical impacts of climate change on Pakistan's hydrological system, the potential socio-economic consequences of these changes and who is undertaking this research. Along with these, other aims of this survey were to identify key gaps and barriers in the research on the biophysical impacts of climate change on Pakistan's hydrological system, so as to inform the policy analysis component of the project. For this purpose, an interview protocol was drafted consisting of key questions regarding the profile of the respondent(s), the type of research they were engaged in or managing, and key findings of the research they have completed. Interviews were conducted from a total of 42 organizations and 77 experts engaged in water and climate change-related studies. The responses collected were subsequently analysed qualitatively and quantitatively to draw out and verify the conclusions.

The analysis indicated that researchers working with climate change-related studies generally engage in mix of biophysical and socio-economic research, but those engaged in biophysical research are more likely to focus primarily in this area thereby devoting 51% to 75% of their time to this aspect. Looking in to the barriers faced by researchers working on climate and water related projects; majority of the respondents indicated data access and its quality being the major bottlenecks affecting their research initiatives. About 91% of the interviewees/organizations were facing financial issues. One out of five respondents documented lack of trained human resources for specific projects as the major impediment to work on climate change-water nexus projects. Significant number of interviewees reported the non-availability of scientific equipment for on-site data recording as a challenging issue to work on their research plans. Respondents reporting other obstacles to take up water-related projects constituted 12% of total number of individuals being interviewed. Security concerns in Khyber Pakhtunkhwa and Baluchistan provinces were peaked at the top of the list among those hardships.

As identified by the interviewees, priority areas that remain to be addressed regarding the biophysical and/or socio-economic impacts of climate change on water resources of Pakistan included; lack of basic knowledge about climate change and its consequences where climate change being a new phenomenon in Pakistan is not quite understood and has never been taken seriously, both at the research as well as policy levels. Moreover, the absence of central body/repository to collect the data related to water projects and glacier fluctuation/runoff was increasing the hardships of researchers engaged in such studies. Among others, capacity building of farmers, revision of water pricing, rainwater harvesting and water conservation were identified as key questions lacking the attention of researchers and policy makers. A considerable numbers of survey participants indicated that credible information on watershed data does not exist and most of the forecasting regarding watershed is done whilst using wrong variables. Non-coordinated response amongst all stakeholders in response to climate triggered extreme weather events such as floods is also a challenge. Groundwater contamination and over mining concerns are missing altogether in most studies conducted on the climate change-water nexus.

To conclude, a limited number of organizations/experts are studying the hydrology with reference to climate change and are facing challenging barriers such as accessing quality data, financial constraints, non-availability of scientific tools, and lack of trained human resources. Researchers need additional resources for capacity building, easy access to data and enhanced cooperation among different organizations working in this field. Other areas of concerns such as; lack of public awareness regarding water conservation and rain water harvesting at the household scale, and convincing farmers to adopt high efficiency irrigation systems (sprinkler, drip) need to be addressed on priority basis. Other areas seeking immediate attention are the revision of water pricing and updating the academic curricula to address ways to engage in sustainable development in a changing climate. These gaps need to be prioritized both at research as well as policy level, as climate change-water related research has largely been ignored until recently.

1. Introduction

The research project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of Gaps and Recommendations for Action" jointly developed by the Ministry of Climate Change (MoCC) and the United Nations Development Programme (UNDP) was formally launched on July 02, 2015, in Islamabad. The project responds to the Government of Pakistan's acknowledged need to better understand the vulnerability of its water resources to the impacts of climate change. This need was enunciated in the country's National Climate Change Policy and subsequent framework for implementation of the same. Each identifies the absence of an evaluation of how climate change is or could adversely affect the availability of surface water resources as a limit to adaptation planning in Pakistan. It also strives to address the existing uncertainty regarding how availability of water flows in the Indus River Basin will change in the future given existing factors such as the Karakoram anomaly.

The primary objectives of the project are completion of a systematic review of current understanding of the potential changes in Pakistan's hydrological regime due to climate change, identification of critical knowledge gaps, and provision of recommendations on how to fill these gaps on an urgent basis. In completing this analysis, the project aims to improve decision-making capacity within government ministries, research institutes, and the general public in relation to water resources management in a changing climate. The project was being implemented under the leadership of the MoCC, in partnership with UNDP, by the Centre for Climate Research and Development (CCRD) at COMSATS Institute of Information Technology Islamabad, Pakistan, and the International Institute for Sustainable Development (IISD), Canada.

A detailed research methodology was prepared to guide the project towards achievement of its objectives. It consists of five main components: (1) a key informant analysis intended to identify who is doing what in the area of climate change and hydrology in Pakistan; (2) water supply analysis to synthesize knowledge regarding how water flow levels in the Indus River Basin may or may not change in the future; (3) analysis looking at projected changes in water demand; (4) policy analysis to assess potential impacts on health, agriculture and energy, as well as identify the main research gaps and interventions/investments to fill these gaps and; (5) outreach and communication of the project's outcomes.

Consistent with this methodology, the first step in the project's research methodology was to conduct a key informant survey designed to inform subsequent research components focused on water supply, water demand and policy analysis. The specific aims of the key informant survey were to:

- Identify the type of research being undertaken on the biophysical impacts of climate change on Pakistan's hydrological system, and on the potential socio-economic consequences of these changes; and who is undertaking this research within different research institutes located within and outside of Pakistan.

- Gather information to support implementation of other components of the research methodology, mainly with respect to identification of climate and water-related research organizations and sources of grey literature to support implementation of the water supply analysis component of the project.
- Identification of gaps in the research on the biophysical impacts of climate change on Pakistan's hydrological system, which will inform the policy analysis component of the project.
- Identification of key organizations and individuals in Pakistan's research and policy communities with whom to communicate the project's outcomes.

This report presents the outcomes of a survey of 77 key informants undertaken as part of "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change" project. The sections below first present the methodology used to develop and implement the survey, and then the main survey results. The report concludes by analysing the implications of the research findings.

2. Research Methodology

The process by which the key informant survey was designed, reviewed, revised, finalized and implemented is presented in the paragraphs below. This is followed by a presentation of the profile of the individuals who were surveyed.

2.1. Methodology to develop and implement the key informant survey

In support of the key informant survey, an interview protocol was developed by the IISD and CCRD research teams in consultation with UNDP in October 2015. The protocol drafted consisted of key questions regarding the profile of the respondent(s), the type of research they were engaged in or managing, key research findings they have completed (published and unpublished) spanning over a time frame between January 2005 and September 2015. An initial list of key informants was also prepared.

After several rounds of modifications by the research teams, a final draft of the protocol was piloted through five interviews conducted in-person with representatives from different types of organizations (e.g. academia, government and NGOs) based within Pakistan. The protocol was then modified according to the suggestions of the interviewees and the observations of the CCRD research team. The revised protocol was then presented to the Expert Working Group (EWG) established as an advisory forum for the project in November 2015, to ensure that key concerns and questions were addressed in the survey and that all relevant informants had been identified. The final version was provided to UNDP and MoCC in November 2015 and converted into a Survey Monkey form for use in online data compilation. A copy of the final version of the key informant survey is provided in Annex A. After the interview protocol was finalized, a list of possible national and international research organizations, government departments and academic institutions to be engaged in interviews was developed by CCRD in consultation with IISD as provided in Annex B.

In late November, CCRD sent the organizations/individuals listed in "Annex B" an invitation by courier or email to participate in the survey. When no response to these invitations was received, appointments were made with key informants via telephone calls and interviews were conducted in-person by the CCRD project team to record the responses/data collection. Interviews were conducted with a total of 77 experts from 42 organizations, as some interviews involved more than one respondent from the same organization/institute. Interviews were only conducted with people engaged in water and climate change related studies. A list of individuals interviewed and their respective organizations appears as an "Annex C" of this report.

Interviews data were compiled by entering all surveys into the shared database using the Survey Monkey form. Depending on the nature of the questions originally asked, the data collected was subsequently analysed either quantitatively through basic statistical analysis or qualitatively using qualitative content analysis to draw out and verify the conclusions.

2.2. Profiles of the respondents

As captured in Table 1, female respondents constituted 8% of the total population interviewed. Of the 77 respondents, 31 persons had a dual role in their current position as both a researcher as well as a manager of research projects, 27 interviewees had a research managerial role, while the remaining 19 were primarily engaged in research activities/ assignments. Approximately, 60% of key informants had a background in one of the sciences, followed by those specialized in engineering (27%) while 10% of total respondents were social scientists. Regardless of gender or the field of specialization, more than 93% of the key informants were either master or higher degree holders in their respective subjects. Although the majority of interviewees (64%) had been working in their fields of specialization over the last two decades, 70% of whole sample size were working in their current positions as a researcher/manager for five years or less.

Table 1: Profiles and other attributes of the 77 key informants interviewed

Gender	Age (yrs)		Qualification		Academic Background		Time in Current Position (yrs)		Total Professional experience (yrs)	
Male: 71	≤ 25	0	Secondary school	0	Sciences	46	0-5	54	0-5	07
Female: 6	26 -35	14	Post- secondary	0	Social Sciences	08	06 - 10	17	06 - 10	10
	36 - 54	41	Bachelor	05	Engineering	21	11 - 15	03	11 - 15	04
	55 ≥	22	Master	34	Business	01	16 - 20	01	16 -20	06
			PhD	31	Others	01	≥20	02	≥20	50
			Post Doc	07						

3. Survey Results

The following results are based on the analysis of information shared by the interview participants. The analysis presents the data collected with respect to the research areas of the key informants surveyed, and the focus of current research. The analysis also identifies the significant barriers and research gaps to conduct studies addressing the biophysical and socio-economic impacts of climate change on water resources.

3.1 Research Areas

Research areas of the key informants surveyed are depicted in Figure 1. Data analysis indicates that a greatest number of people (18%) interviewed were working in the field of hydrology, followed by those from allied disciplines such as irrigation (11%) and water demand (10%). Scientists engaged with assignments in the fields of climatology, agricultural crops and water quality constituted 8% for each of these disciplines, whereas representation from remaining specializations was ≤ 6% as illustrated in the Figure 1.

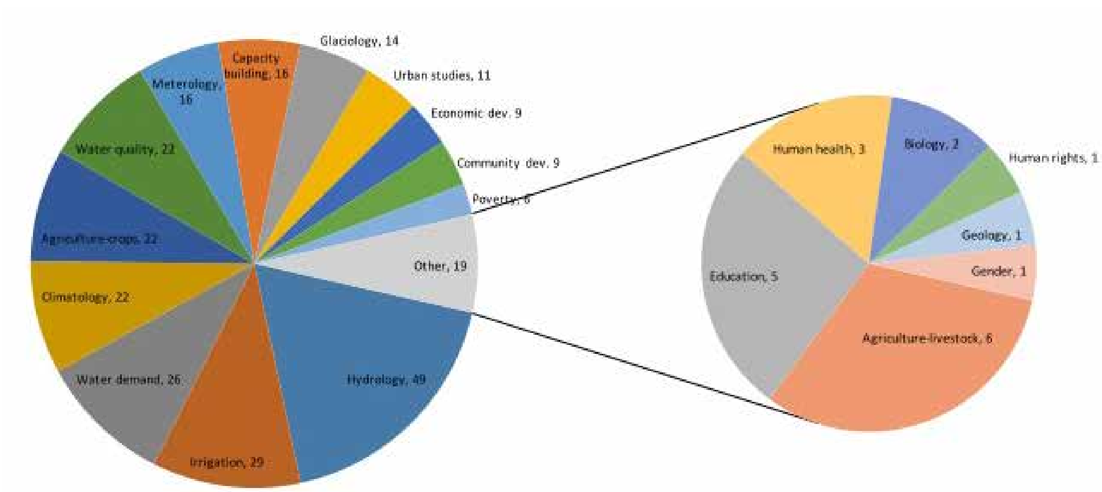


Figure 1: Research areas of the respondents. Different colours represent the percent of individuals from respective backgrounds. Most of the interviewees had expertise or were working in more than one area of research.

3.2. Focus, objectives and methodology for research undertaken by respondents

Interview candidates were asked to mark themselves on a continuum scale (0-100%) in terms of their degree of focus on the biophysical or socio-economic impacts of climate change on water resources. Analysis revealed that 25 persons among the key informants focussed from 51-75% their research activities on studying the biophysical impacts of climate change whilst 17 interviewees have the same degree of focus in evaluating the socio-economic impacts of climate change on water resources (see Figure 2). In contrast, 26 candidates expressed that the limelight of their research may be scaled from 26-50% with reference to socio-economic impacts, whereas on the same continuum scale, 18 experts were involved in investigating the biophysical impacts 26-50% of their time. While looking into the data, 18 individuals were committing 76-99% of their to exploring the socio-economic impacts of climate change, compared with 16 key informants studying the biophysical impacts of climate change on water resources at the same extent of focus. Overall these results suggest that researchers engaged in climate change-related studies generally engage in mix of biophysical and socio-economic research, but that those engaged in biophysical research are more likely to focus primarily in this area and are thereby devoting 51% to 75% of their time to this aspect area.

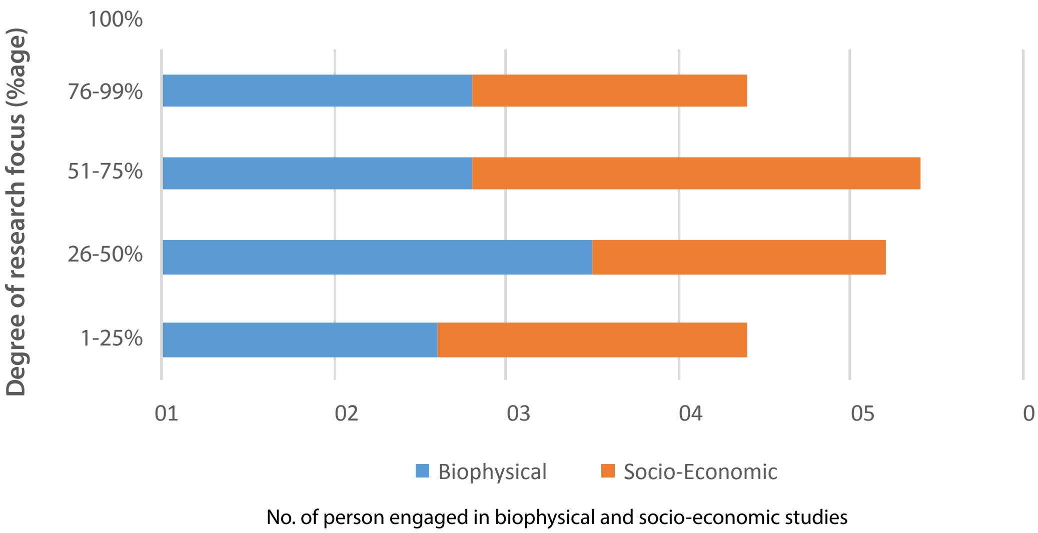


Figure 2: Degree to which key informants' research is focused on the (a) biophysical and (b) socio-economic impacts of climate change on water resources.

The main objectives of the climate change-related research being undertaken by a majority of the key informants and/or their organizations included; on-farm water management to enhance agricultural productivity, development of water resources, cryosphere monitoring, and suggesting adaptation measures during extreme events such as floods and cloud bursts. Various others were involved in research related to water conservation and improving water storage for small-scale hydropower generation. Approximately 3% of all those interviewed were working with the monitoring of surface and ground water quality whilst negligible numbers of candidates were engaged in studies related to adaptation measures that could be implemented in reference to climate change triggered extreme events such as floods and droughts.

Different research methods ranging from statistical analysis to remote sensing, field surveys and questionnaires were being applied by the respondents in their research endeavors. More than 30% were using remote sensing for glacial fluctuation/melting and runoff studies. Those applying questionnaires, survey forms and statistical analyses techniques constituted 20% of the total number of key informants. These techniques were used by researchers to study cropping patterns, precipitation trends for best agricultural practices, and sustainable use of water resources. Respondents associated with policy analysis and water quality testing constituted 2% and 10% respectively of total sample size. Surprisingly, 15 (19%) of the respondents did not disclose the research methodology adopted and one out of four respondents did not share the time frame of their research initiatives. Of those that did share the temporal extent of their research, the time span of research carried out by them extended from less than a year to over a decade, where about 15% of the individuals were at the infancy stage of their research projects focused on the biophysical and socio-economic impacts of climate change on water resources.

3.3. Research Barriers

In the interview protocol, research barriers were grouped in to five categories as; technical, human resource, financial, data access and any other. When respondents were asked about the major challenges to conduct studies regarding the biophysical and socio-economic impacts of climate change on water resources, a majority of those identified data access as the single factor which has most affected their research initiatives. Moreover, these interview participants were doubtful about the quality of available data. Approximately 91% of the interviewees/organizations were facing financial issues and this was further highlighted in that already underfinanced individuals/organizations engaged in such studies are being asked to pay high amounts of money to purchase the data for research. One out of five respondents documented a lack of human resources and particularly trained personnel for specific projects as the major impediment to work on climate change-water nexus projects. This shortcoming was further explained by an interviewee who reported "their department bought equipment about two years ago for monitoring the water supply at farm level, but due to lack of trained personal that equipment was not even tried and tested since its procurement". Contrary to this observation, a considerable number of key informants (17%) reported the non-availability of scientific equipment for on-site data recording as a challenging issue. Respondents reporting other obstacles to the take up of water-related research projects constituted 12% of total number of individuals being interviewed. Among those hardships, security concerns were peaked at the top of the list, particularly in Khyber Pakhtunkhwa (KP) province, along the Indus River and its tributaries near the Afghanistan border, and in Baluchistan.

3.4. Knowledge gaps

Survey respondents were requested to highlight the main research questions or knowledge gaps that they believe remain to be addressed regarding the biophysical and/or socio-economic impacts of climate change on water resources of Pakistan. A significant number of participants noted that since climate change is a new phenomenon in Pakistan it is not quite understood and has never been taken seriously, both at the research as well as policy levels. They proposed that inclusion of climate change-related courses in the curriculum at least at higher education institutions may improve the situation.

Several key informants recognized that basic studies to establish whether glaciers are liquefying/retreating at a faster rate compared with the last three decades are lacking. They pointed out that no such report exists to clarify this uncertainty, which they linked to the absence of central data repository to collect the glacier fluctuation and runoff data.

Capacity building of farmers, the revision of water pricing, rainwater harvesting and water conservation were identified as themes that remain to be researched and legislated to combat the water stress scenario faced by the country. Respondents representing provincial irrigation departments from Punjab and Sindh underlined that farmers' involvement should be sought to adopt high efficiency irrigation systems to save 50% of irrigation water compared with conventional methods of flood irrigation. It was further emphasized that farmers' reluctance to adopt new technologies and the inability of government at the national level to implement regulations at farmers' scale are core issues to be addressed. It was also cited that people's attitude towards water needed to be addressed, as non-judicious use of water by households has very serious repercussions and is contributing to the widening gap between demand and supply of this natural resource.

A very critical knowledge gap shared by an interview participant was that credible information on watershed data does not exist, that no work has been carried out on watershed network studies, and that most of the watershed forecasting is done whilst using wrong variables resulting in wrong projections regarding drought and floods occurrence. Other priority research areas identified by respondents as lacking attention included:

- Migration attributed to climate change and the consequent increased burden on groundwater use in the areas to which the migrants move.
- Groundwater contamination and over mining concerns are missing altogether in most studies conducted on the climate change-water nexus.
- Non-coordinated response from all stakeholders towards climate triggered extreme events such as floods, and the building of reservoirs to store flood water as this may help to cope with the reality of declining water resources.

It was pointed out by an interviewee that physical interventions to divert the Indus tributaries (Neelum River for example) for hydropower generation would have serious implications on future water availability in the Indus River system.

3.5. Socio-economic consequences of biophysical impacts of climate change

Respondents studying the biophysical impacts of climate change on water resources were asked to identify any potential socio-economic consequences that might arise from these impacts. A majority of the respondents expressed that the occurrence of extreme weather events such as drought and floods were intertwined with the biophysical impacts of climate change and have increased the vulnerability of communities and resulted in compromised food security. Corollary to the biophysical impacts of climate are significant shifts in cropping patterns that have been forecasted to increase crop water requirement by 20% until 2050, while decreasing yield to the same degree could affect 80% of peasants and result in compromised food security. One interviewee observed that a decreased supply of surface water is evident from the increasing dependence on groundwater, which has resulted in over mining and groundwater contamination. According to him, development of water reservoirs is ultimately required to ensure the socio-economic development of the country. Contrary to this perspective, a few respondents noted that, based on their observations, crop yield in Pakistan has increased due to increased supply of water, leading to improving livelihoods and ensuring food security and poverty reduction.

3.6. Literature and knowledge sharing

Guidance from the survey participants was sought regarding the provision/recommendation of literature geographically focused on the Indus River basin that emphasized the projected impacts of climate change on; water flow and demand, water quality, human health, hydroelectric power production, and agriculture. According to the responses, 80% (63) of the participants have completed or are currently working on the research projects in the water-climate change nexus while the remaining 20% noted that they have not carried out any investigation encompassing this criterion as they were performing the administrative/ managerial duties. Regarding the provision of literature, 78% agreed to provide, but despite several reminders only 17 key informants provided the same. Most of the literature was provided by representatives of NGOs and multinational organizations. Negligible no. of reports or other literature was provided by government departments. A list of articles/ reports provided by the respondents is attached as "Annex D" of this report.

4. Observations and Discussions

This study aimed to get the opinions of key experts regarding research related to the potential impacts of climate change on Pakistan's water sector. Moreover, their observations regarding barriers to conducting studies on the climate change-water nexus and knowledge gaps that need to be addressed on a priority basis were collected through the survey. Extracted from the responses of the key informants, major findings and discussions are presented below.

Data access and its quality were observed to be the most serious concerns faced by the research community involved in climate change and water related studies in Pakistan. On top of this, the demand of huge sums of money to buy data for research purposes was another issue given that respondents stated that more than 90% of their organizations are under-financed. Data access problem may be addressed by establishing a databank at the federal level that encompasses all data from projects related to hydrology and climate change, and by strengthening the networking amongst researchers and data holding organizations (the Pakistan Meteorological Department and Water and Power Development Authority for example). Data quality may be improved by capacity building of organizations as it was observed that most of the organizations were understaffed and facing issues related to trained human resources for data collection. Moreover, the use of state of the art techniques/equipment (e.g. early warning system) for on-site data recording may further improve the scenario.

Limited or no access to remote areas due to security reasons, such as those bordering Afghanistan and tribal areas in KP and Baluchistan provinces, was identified as being a most severe challenge for researchers to collect data and site visits. This problem has increased the scientists' dependence on other organizations regarding data collection and they have to rely on whatever data is available, rather than recording firsthand information by themselves.

Apart from quite a few, well-resourced organizations, more than 90% of institutions are facing financial challenges to initiate climate change and water related studies. Unfortunately, the major chunk of allocated funds is utilized to pay supporting staff salaries, many of whom are only inducted due to political influence on recruitment processes otherwise they would not be needed at the institutions. Eradication of political interference in the organizations working in the areas of water and climate change sectors is required to maintain a technical versus support staff balance for efficient work, and to divert maximum funds to research activities rather than paying salaries for non-technical human resources.

Given these challenges is it is perhaps not surprising that notable progress has not been made in hydrological studies with reference to climate change in the last decade. Along with other obstacles, this might be because less experienced persons are available in the job market, which is evident from the data stating that many among the interview participants were in the first five years of their current assignments. This is not recognized as a very exhaustive time span for hydrology and climate change studies. Another reason could be the limited attention by federal and provincial governments to climate change-water nexus studies in the past and a lack of willingness to prioritize research in the climate change-hydrology nexus in the near future. Studies on the watershed network of different basins have not been carried out using established procedures worldwide and thus correct data regarding these watersheds is not available. Informants indicated that any projections made on the basis of such data may have serious repercussions on watershed flood forecasting and management.

Key questions that remain unaddressed so far at the research and policy levels were highlighted by the respondents. For example, a water resource regulatory authority needs to be formulated after necessary legislation has been enacted. This authority should be given the task of revising water pricing policies and regulations in consultation with stakeholders. Water pricing, along with public education campaigns, may encourage people to make more judicious use of water.

Most of the water in the Indus River is diverted towards agriculture and farmers irrigate their crops by conventional methods of flood irrigation requiring 40-60% more water compared with high efficiency irrigation methods such as sprinkler or drip irrigation. Most of the farmers with small land holdings are not even aware of these technologies. Apart from that unknowing by key stakeholders, initial installation cost of these systems causes reluctance among the peasant community. Installation cost issues may be addressed if government (federal and/or provincial) shares the expenses to ease up the farming community to reap the long term benefits.

Research on water pollution triggered by climate change has not attracted the attention of researchers and policy makers so far. Extreme events such as drought and floods impact human health and agricultural commodities both in quantitative as well as qualitative terms. Consecutive occurrence of floods since 2010 has resulted in an alarming increase of infectious diseases. For instance, an increase in mould after extensive flooding has been observed in flood affected areas . Similarly, outburst of dengue fever in recent past has been attributed to the climatic changes, particularly stagnant polluted flood water providing suitable niche for the mosquitoes that transmit this disease to breed . This situation has panicked the country as a whole and is getting worse with every passing year.

Another area seeking urgent attention is groundwater resources which have largely been ignored in the national water policy of Pakistan. Due to the non-existence of a designated regulatory body, this natural resource has been over-mined because of decreased supply of surface water. Empirical studies noted that around 50 million acre feet of ground water are extracted annually for agricultural, domestic and commercial utilities. This huge amount of extraction of underground water demands equal importance to be given in the National Water Policy. Parallel with these research and policy shortcomings, negligible work has been conducted on adaptation strategies to cope with water-related extreme events triggered by climate change.

Surface water resources are depleting due to urbanization and increases in temperature, especially in Sindh and Baluchistan provinces. There is a strong need to assess the impact of drought conditions on human and animals' lives. Additionally, the impact of climate change on water quality has not been studied yet. Therefore, it is highly recommended to study the impacts of changing climate on water quality and its consequent influences on human health in future projects. In some parts of Pakistan, especially in Sindh and Baluchistan, water scarcity is forcing people to use the polluted and wastewater for irrigation purposes, ultimately affecting human health.

To many in Pakistan, climate change is a new phenomenon and its implications on various sectors are less studied and far less understood. In part this is because our academic curriculum does not contain enough information on the subject. This situation demands a revision to the curriculum of higher/technical institutes through the inclusion of teaching and practical modules regarding climate change-water studies and sustainable development in the changing climate. Basic knowledge regarding climate change's implications on water resources also needs to be disseminated through public seminars and media.

5. Conclusions

From the current study it was concluded that only a limited number of organizations/experts are involved in studies around climate change-hydrology nexus and these researchers are facing challenging barriers such as accessing quality data, financial constraints and a lack of trained human resources, along with the non-availability of scientific tools. The non-existence of a water resource regulatory authority and a central databank were major impediments for scientists wanting to initiate studies addressing the biophysical and socio-economic impacts of climate change on water resources. Researchers require additional resources for capacity building, easy access to data and enhanced cooperation among different organizations working in this field. These barriers need to be addressed at the policy level, as climate change-related research has largely been ignored until recently due to a lack of political will and commitment.

Many research questions remain to be answered on an urgent basis, such as; effective ways to overcome the current lack of public awareness regarding water conservation and the potential to engage in rain water harvesting at the household scale, and to convince farmers to adopt high efficiency irrigation systems (sprinkler, drip etc.) rather than conventional methods of irrigation. So far, no serious efforts have been made to investigate the watershed monitoring networks which has most often resulted in wrong water flow projections. Other areas seeking immediate attention by policy makers are the revision of water pricing and updating the academic curricula to address way to engage in sustainable development in a changing climate.

Annex A: Interview protocol

The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action

Thank you for taking the time to participate in this survey.

It is being conducted as part of the project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action," which was formally launched in Islamabad in July 2015. The main focus of the project is to:

- Complete a systematic review of current understanding of the potential changes in Pakistan's hydrological regime due to climate change;
- Identify critical knowledge gaps, and;
- Prioritize the means by which these gaps might be filled on an urgent basis.

By completing this analysis, the project aims to improve decision-making capacity within government ministries, research institutes, and the general public in relation to water resources management in a changing climate.

The purpose of this survey is to identify the types of research being undertaken on the bio-physical impacts of climate change on Pakistan's hydrological system, and on the potential socio-economic consequences of these changes. It also seeks to understand who is undertaking this research within different institutions and organizations located within and outside of Pakistan.

We expect the results of this survey to inform other components of the research project, and facilitate the collection of grey literature from institutions engaged in research on water and climate change issues in Pakistan.

Please focus your answers on the primary context in which you work. All information provided in response to this survey will be kept anonymous.

SECTION 1: PERSONAL PROFILE

1. Name (for internal use only):

2. Age: ☐ 25 and under ☐26-35 ☐36-54 ☐55 and over

3. Sex: ☐ Female ☐Male

4. Organization: ______________________________

____

5. Position (for internal use only):

____

6. Time in current position

☐ 0-5 years ☐6-10 years ☐11-15 years ☐16-20 years ☐>20 years

7. Qualification:

☐ Secondary school ☐ Post-secondary diploma ☐ Bachelor degree

☐ Masters ☐ PhD ☐ Post-doctoral studies

8. Academic or technical background:

☐ Sciences. Specialization: ______________________________

☐ Social Sciences. Specialization: ______________________________

☐ Engineering. Specialization: ______________________________

☐ Business. Specialization: ______________________________

☐ Other (please specify): ______________________________

9. Years of professional work experience:

☐ 0-5 years ☐6-10 years ☐11-15 years ☐16-20 years ☐>20 years

SECTION 2: RESEARCH AREA

1. What is your role with respect to the research on the implications of climate change for Pakistan's water resources being undertaken within your organization?

☐ Researcher ☐ Manager/ supervisor of research?

2. What is the focus of the research being undertaken by yourself or those that you supervise in relation to the projected bio-physical or socio-economic impacts of climate change on water resources? (Please tick all boxes that apply).

☐ Meteorology	☐ Climatology	☐ Geology
☐ Glaciology	☐ Hydrology	☐ Biology
☐ Water demand	☐ Water quality	☐ Agriculture – crops
☐ Agriculture - Livestock	☐ Irrigation	☐ Human health
☐ Education	☐ Capacity building	☐ Gender
☐ Human rights	☐ Urban studies	☐ Community development
☐ Poverty	☐ Economic development	☐ Other (please specify):

3. On a continuum, where would you place the research being conducted by you or your organization on the scales below in terms of its degree of focus on the bio-physical and/or socio-economic impacts of climate change on water resources (please tick one box per scale)?

Bio-physical:	☐ 0%	☐ 1-25%	☐ 26-50%	☐ 51-75%	☐ 76-99%	☐ 100%
Socio-economic:	☐ 0%	☐ 1-25%	☐ 26-50%	☐ 51-75%	☐ 76-99%	☐ 100%

4. What was the primary objective or key issues being addressed in the current research being conducted by you or your organization?

5. What methodology is being applied within this research? (If you or your organization is engaged in more than one climate change and water related research initiatives, please identify each project and the methodology being used in it.)

6. What is the timeframe of this research? (If you or your organization is engaged in more than one climate change and water related research initiatives, please identify each project and its timeframe.)

Supplemental question: If the respondent works in the area of the biophysical impacts of climate change:

7. Has the study identified any potential socio-economic consequences of these changes? If so, please describe:

SECTION 3: OBSERVATIONS

1. Based on your experience, what do you see as being the most significant barriers to building the research and knowledge base regarding the bio-physical and socio-economic impacts of climate change on water resources in Pakistan? (These could be technical, human resources or financial barriers, but also could be challenges such as poor coordination between research initiatives or problems accessing data sets.)

Please identify barriers related to any of the following categories:

☐ Technical. Please describe:

☐ Human resources. Please describe:

☐ Financial. Please describe:

☐ Data access. Please describe:

☐ Other. Please describe:

2. What do you see as being the most significant knowledge gaps, or research questions that remain to be answered, regarding the potential biophysical and/or socio-economic impacts of climate change on water resources of Pakistan?

SECTION 4: LITERATURE RECOMMENDATIONS

As noted previously, a principal objective of our study is to complete a systematic review of existing research to understand the current state of knowledge regarding the potential impacts of climate change on Pakistan's hydrological regime.

We are also seeking to understand the current state of knowledge regarding how climate change might impact water quality, human health, agriculture, and hydroelectric power production.

As part of this study we therefore want to identify peer reviewed and grey literature sources that meet the following criteria:

i. Journal articles, technical reports, books, book chapters or conference proceedings published from January 1, 2005 to date.

ii. Focus on projected impacts of climate change (i.e. how things might change in the future) in relation to:

- o Water flow in the Indus River Basin
- o Water demand
- o Water quality
- o Human health
- o Agriculture
- o Hydroelectric Power Production

iii. Are geographically focused on the Indus River Basin (including changes in the HKH region that will affect Pakistan)

1. Have you completed any studies that meet these criteria?

   ☐ Yes ☐ No

2. If yes, could you please list up to three (3) publications that you feel best meet these criteria, and would be of benefit to our study, at the end of this survey?

   ☐ Yes ☐ No

3. If yes, would be able to provide us with copies of these publications?

   ☐ Yes ☐ No

SECTION 5: INTERVIEW CLOSURE

1. Are there any other comments that you would like to make?

2. While all of the information you have provided us will be kept anonymous, we would like to recognize your participation in this survey in the acknowledgements section of our final report. Do you agree to have your name and organization's name included within this list?

   ☐ Yes ☐ No

In closing, the interviewers should:

- Invite the interviewee to be in touch should they have any follow-up information to provide or which to clarify any of their statements
- Remind the interviewee of how their information will be used.

Addendum: List of resources

Please list below up to three publications (peer reviewed or grey literature) produced by yourself or your organization that you feel best meet the criteria outlined in Section 4 of this survey and the objectives of our research.

1	
2	
3	

Annex B: Initial list of institutions to be engaged in the survey

Based on an initial review conducted by CCRD, the following list of key organizations and external experts who could be engaged in the planned research, particularly the key informant survey, was compiled.

Federal Government Ministries and Authorities	
1	Project Management and Policy Implementation Unit, Ministry of Water and Power, Government of Pakistan/PMPIU/WCAP
2	Ministry of Water and Power, Government of Pakistan/MoWP
3	Clean Development Mechanism/Ministry of Climate Change, Pakistan/CDM, MoCC
4	Climate Finance Unit, Ministry of Climate Change/CFU, MoCC
5	Federal Water Management Cell, Ministry of National Food Security & Research/FWMC, MoNFSR
6	Pakistan Environmental Protection Agency/ PAK-EPA
7	Federal Flood Commission, Ministry of Water & Power/FFC, MoWP
8	Indus River System Authority/IRSA
9	Pakistan Water and Power Development Authority/WAPDA
10	Pakistan Meteorological Department/PMD
11	National Disaster Management Authority/NDMA
12	National Engineering Services Pakistan/NESPAK
13	Pakistan Poverty Alleviation Fund/PPAF
14	Pakistan Council of Research in Water Resources, Government of Pakistan/PCRWR
15	Pakistan Agricultural Research Council, Ministry of National Food Security & Research/PARC, MoNFSR
16	Agriculture Policy Institute, Ministry of National Food Security & Research/API, MoNFSR
17	Nuclear Institute for Food and Agriculture/NIFA, Peshawar
18	Climate Change, Alternate Energy and Water Resources Institute/CAEWRI, PARC, NARC
19	Baluchistan Agricultural Research and Development Centre/BARDC, PARC, NARC
Provincial Governments	
20	Inland Water Transport Development Company, Government of Punjab/IWTDC
21	Punjab Irrigation & Drainage Authority/PIDA
22	Irrigation Department, Government of Khyber Pakhtunkhwa/ID, KPK
23	Federally Administered Tribal Areas (FATA)Development Authority/(FATA)DA
24	Planning & Development Department/AJK
25	Barani Agricultural Research Institute/BARI, Chakwal, Punjab
26	Agricultural Research Institute, Sariab/ARI
27	Irrigation Department, Government of Sindh
28	Agriculture Department, Government of Baluchistan

(Government) Research Institutes and Universities	
29	Centre of Excellence in Water Resources Engineering/CEWRE, Univ. of Engineering and Technology, Lahore
30	Water Management Research Centre, University of Agriculture Faisalabad/WMRC, UAF, Faisalabad
31	USAID- funded Pakistan Centers for Advanced Studies in Water, Mehran Univ. of Engineering and Technology, Jamshoro, Sindh
32	Global Change Impact Studies Centre/GCISC
33	Integrated Mountain Area Research Centre, Karakorum International University
34	National University of Sciences and Technology
35	National Institute of Oceanography, University of Karachi
UN and Intergovernmental Organizations	
36	World Food Program/WFP
37	United Nations Educational, Scientific and Cultural Organization/UNESCO
National and International NGOs and Research Programs/Individuals	
38	Sustainable Development Policy Institute/SDPI
39	International Centre for Integrated Mountain Development/ICIMOD
40	International Union for Conservation of Nature/IUCN
41	World Wide Fund/WWF
42	International Water Management Issues/IWMI
43	LEAD-Pakistan
44	Ev-K2-CNR
45	Pakistan Water Partnership
46	Aga Khan Rural Support Programme
47	Danial Hashmi, Water and Power Development Authority, Lahore
48	Ms. Zaighum Habib, Independent consultant, Islamabad

Annex C: Respondents and their respective organizations

List of respondents along with their respective organizations interviewed as a part of key informant survey. Responses from these interviewees were also uploaded on Survey Monkey to develop an online data base.

Sr. No	**Organizations** Names of respective interviewees are provided in Italics under each organization
	Federal Government Ministries and Authorities
1	National Disaster Management Authority (NDMA), Islamabad *Respondents; Ahmad Kamal, S. I. Alam*
2	Pakistan Meteorological Department (PMD), Islamabad *Respondent; Muhammad Afzaal*
3	Pakistan Council for Research in Water Resources (PCRWR), Islamabad *Respondent; Dr. Sheikh*
4	Climate Change, Alternate Energy & Water Resources Institute (CAEWRI), Pakistan Agriculture Research Council (PARC), National Agriculture Research Council (NARC), Islamabad *Respondents; Dr. B. Ahmed, Dr. M. Ashraf*
5	Water and Power Development Authority (WAPDA), Lahore *Respondents; M. S. Kamboh, M. A. Sheikh, Dr. Basharat, Danial Hashmi, Muhammad Nawaz, I. A. Kaukab*
6	Pakistan Environmental Protection Agency (Pak-EPA), Islamabad *Respondent; Zia ul Islam*
7	Indus River System Authority (IRSA) Islamabad *Respondent; Raqib Khan*
8	Federal Water Management Cell (FWMC), Islamabad *Respondent; Tahir Anwar*
9	Ministry of Climate Change, Islamabad *Respondent; Irfan Tariq*
10	Punjab Irrigation Department, Lahore *Respondent; Dr. Javed*
11	Irrigation Research Institute (IRI), Government of Punjab *Respondent; G. Z. Hussain*
12	Planning and Development Department, Azad Jammu & Kashmir *Respondents; Dr. Ahmad, Muhammad Bashir, Dr. Khan, M. T. Khan, S. R. Shah*
13	Barani Agricultural Research Institute (BARI) Chakwal *Respondent; Dr. Subhani*
14	Irrigation Department, Government of Sindh *Respondent; Ayub Sumroo*
15	Forest Department, Azad Jammu & Kashmir (AJK) *Respondents; R. T. Maqsood, S. G. Shah*
16	Private Power Cell, Azad Jammu & Kashmir (AJK) *Respondent; N.Z. Gillani*

17	Department of Agriculture, Azad Jammu & Kashmir (AJK) *Respondents; Dr. Butt, Mohammad Shafique*
18	Department of Irrigation and Small Dams, Azad Jammu & Kashmir (AJK) *Respondent; Basharat Hussain*
19	Federally Administered Tribal Areas (FATA) Development Authority *Respondent; Aqiq Bangesh*
20	Irrigation Division, Khyber Pakhtunkhwa (KP), Peshawar *Respondent; Zahoor Muhammad*
21	Pakistan Meteorological Department, Khyber Pakhtunkhwa (KP), Peshawar *Respondent; M.A. Shah*
22	Irrigation Department, Government of Baluchistan (GoB), Quetta *Respondents; Sher Afghan, Shakeel Azam, Arif Ali, S. Z. Shah*
Research Institutes/ Academia	
23	University of Agriculture Faisalabad *Respondents; Dr. Hussain, Dr. Baksh, Dr. Farooq, Dr. Khaliq, Dr. Cheem, Dr. Alam*
24	Center of Excellence in Water Resources Engineering, University of Engineering and Technology (UET), Lahore *Respondents; Dr. Shakir, Dr. Nabi*
25	International Islamic University (IIUI) Islamabad *Respondent; Dr. Irfan*
26	University of Karachi, Karachi *Respondent; Dr. Jillani*
27	Water Management Training Institute (WMTI), Lahore *Respondent; Dr. Ahmad*
28	U.S. Pakistan Center for Advanced Studies in Water (USPCASW), Mehran University of Engineering and Technology (MuET), Jamshoro *Respondents; Dr. Siyal, Dr. Maher, Dr. Kori, Waqas Ahmed, Rakshanda*
29	NED University of Engineering and Technology, Karachi *Respondents; Dr. Mustafa, Dr. Ahmed*
30	Climate Change Center (CCC), Agriculture University Peshawar *Respondent; Dr. Jawed*
31	Karakoram International University (KIU), Gilgit *Respondents; Poonam Almas, Dostdar Hussain, Dr. Nafees*
32	National Institute of Oceanography (NiO), Karachi *Respondent; Dr. Inam*
33	Comsats Institute of Information Technology (CIIT) *Respondents; Dr. Tahir, Dr. Ahmed*
34	Global Change Impact Studies Center (GCISC), Islamabad *Respondents; Dr. Hashmi, Arif Goheer*
35	National University of Science and Technology (NUST), Islamabad *Respondents; Dr. Iqbal, Dr. Baig*
36	Pakistan Forest Institute (PFI), Peshawar *Respondent; Ahmad Zameer*
Non-Governmental Organizations/ Private Sector /Individuals	
37	Sustainable Policy Development Institute (SDPI), Islamabad *Respondents; Dr. Saeed, Sadia Ishfaq*
38	International Union for Conservation of Nature (IUCN), Islamabad *Respondent; Dr. Majeed*

39	Leadership for Environment and Development (LEAD), Pakistan *Respondents; Usman Mirza, Ayesha Asad*
40	World Wide Fund for Nature (WWF), Lahore *Respondent; Sohail Naqvi*
41	International Water Management Institute (IWMI), Lahore *Respondent; A. A. Shah*
42	International Center for Integrated Mountain Development (ICIMOD), Islamabad *Respondent; M. Muddasir*
43	Independent consultant, Islamabad *Dr. Zaighum Habib*

Annex D: List of literature provided/ recommended by the key informants

1. Recommendations for water policy reforms Worldwide Fund for Nature (WWF), (2012).
2. Ali Akhtar., Environment, natural resources, and agriculture. (2013). Indus Basin Floods: Mechanism, Impacts and Management. The Asian Development Bank (ADB).
3. Ali Hasnain Syed. (2012). Climate Change and its Realities for Pakistan. Worldwide Fund for Nature (WWF)
4. Anwar, S., Yu, B., & Nabi, G. (2012). Application of weather generator for environmental parameters estimation for upper Indus basin. Soil & Environment, 31(1).
5. Cheema., & Pawar. (2015). Bridging the Divide: Trans-boundary Science & policy Interaction in the Indus Basin. Stimson Environmental Security Program: Visiting Fellows Report.
6. Chevallier, P., Arnaud, Y., & Ahmad, B. (2011). Snow covers dynamics and hydrological regime of the Hunza River basin, Karakoram Range, Northern Pakistan. Hydrology and Earth System Sciences, 15(7), 2259-2274.
7. Democratic friends of Pakistan. (2010). Task Force on climate Change. Planning commission of Pakistan
8. Engr. Asrar-ul-Haq., Muhammad Aamir Khan., & Muhammad Hasnain Khan. (2012). Water resources management in Pakistan: the challenges, climate change implications and way forward. Centenary Celebration (1912 – 2012).
9. Inam, A., Clift, P. D., Giosan, L., Tabrez, A. R., Tahir, M., Rabbani, M. M., & Danish, M. (2007). The geographic, geological and oceanographic setting of the Indus River. Large rivers: geomorphology and management, 333-345.
10. Iqbal, M. M., & Arif, M. (2010). Climate-change aspersions on food security of Pakistan. A Journal of Science for Development, 15.
11. Jawad Ali., Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED) Department for International Development (DFID). (2014). Climate Change and adaptation - farmer's experience from rainfed areas of Pakistan.
12. Jawad Ali., Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED) Department for International Development (DFID). (2014). Climate scenarios 2011-2040 districts Haripur, Swabi, Attock and Chakwal Pakistan.
13. Karim, R., Nafees, M. A., Khan, T., Khan, M. Z., Wafi, S., & Ali, S. (2014). Studies in assessment of environmental degradation and tourism in the Karakoram Mountain Ranges using water quality characterization. Journal of Biodiversity and Environmental Sciences (JBES), 5(2), 260-267.
14. Mirza Hamid Hasan. (2014). Policy Briefings – II: Water Policy & Institutions in Pakistan. International Union for Conservation of Nature (IUCN)

15. Nabi, G., Latif, M., & Azhar, A. H. (2011). The role of environmental parameter (degree day) of snowmelt runoff simulation. Soil & Environment,30 (1).
16. Nafees, M. A., Ahmed, K., Ali, S., Karim, R., & Khan, T. (2014). Bacteriological analysis of drinking water sources in CKNP region of Gilgit–Baltistan, Pakistan. International Journal of Biosciences (IJB), 5(4), 54-59.
17. Nafees, M. A., Ahmed, K., Ali, S., Karim, R., & Khan, T. (2014). Bacteriological analysis of drinking water sources in CKNP region of Gilgit–Baltistan, Pakistan. International Journal of Biosciences (IJB), 5(4), 54-59.
18. National Water policy draft.
19. Pervaiz Amir & Zaighum Habib. (2015). Estimating the impacts of climate change on sectoral water demand in Pakistan. ACT Report
20. Pervaiz Amir., Simi Kamal & Khalid Mohtadulah. (2012). Development of Integrated River Basin Management for Indus Basin. Worldwide Fund for Nature (WWF)
21. Raqib Khan. (2015). Development of GIS/MIS centre and decision support the system to enhance the capacity of Indus River System Authority. Indus River System Authority (IRSA)
22. Report FY 2012: Climate Change in Pakistan, Climate Change in Pakistan Focused on Sindh Province
23. Shah, S. H. H., Vervoort, R. W., Suweis, S., Guswa, A. J., Rinaldo, A. S. E. A. T. M., & van der Zee, S. E. A. T. M. (2011). Stochastic modeling of salt accumulation in the root zone due to capillary flux from brackish groundwater. Water Resources Research, 47(9).
24. Shahid Ahmad., (2013). Indus water Treaty and Water Cooperation for managing apportioned rivers. International Union for Conservation of Nature (IUCN).
25. Tahir, A. A., Chevallier, P., Arnaud, Y., Ashraf, M., & Bhatti, M. T. (2015). Snow cover trend and hydrological characteristics of the Astore River basin (Western Himalayas) and its comparison to the Hunza basin (Karakoram region). Science of the Total Environment, 505, 748-761.
26. Tahir, A. A., Chevallier, P., Arnaud, Y., Neppel, L., & Ahmad, B. (2011). Modeling snowmelt-runoff under climate scenarios in the Hunza River basin, Karakoram Range, Northern Pakistan. Journal of Hydrology, 409(1), 104-117.
27. Van der Zee, S. E. A. T. M., Shah, S. H. H., & Vervoort, R. W. (2014). Root zone salinity and sodicity under seasonal rainfall due to feedback of decreasing hydraulic conductivity. Water Resources Research, 50(12), 9432-9446.
28. Van der Zee, S. E. A. T. M., Shah, S. H. H., Van Uffelen, C. G. R., Raats, P. A., & Dal Ferro, N. (2010). Soil sodicity as a result of periodical drought. Agricultural water management, 97(1), 41-49.
29. Waqas Ahmad. (2014). Thesis: GIS and systems support in water infrastructure projects for Hyderabad, hydro informatics: How technology can help in water resources planning.

30. Winston Yu & Yi-Chen Yang., The Indus Basin of Pakistan. (2013). The Current Water and Agriculture, Context, Challenges and Policies. International Bank for Reconstruction and Development.

31. Yaseen, M., Rientjes, T., Nabi, G., & Latif, M. (2014). Assessment of recent temperature trends in Mangla watershed. Journal of Himalayan Earth Science, 47(1).

32. Zhu, T., Ringler, C., Iqbal, M. M., Sulser, T. B., & Goheer, M. A. (2013). Climate change impacts and adaptation options for water and food in Pakistan: scenario analysis using an integrated global water and food projections model. Water International, 38(5), 651-669.

Appendix 2: Water Availability Study

Water supply in the Indus Basin under changing climatic conditions: An analysis of current research

The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change Project

Prepared by: Hisham Osman, International Institute for Sustainable Development

Table of Contents

Acronyms

CRU	Climatic Research Unit
FAO	Food and Agriculture Organization of the United Nations
HKH	Hindu Kush-Karakoram-Himalaya
PMD	Pakistan Meteorological Department
UIB	Upper Indus Basin
UNFCCC	United Nations Framework Convention on Climate Change

1.0. Introduction

Flowing out of the Hindu Kush, Karakoram and Himalaya mountain ranges through dry plains to the Arabian Sea, the Indus River and its tributaries are central to water, energy and food security in Pakistan. The Indus Basin is Pakistan's primary source of fresh surface water and actively replenishes its ground water resources. Its rivers are the main source of Pakistan's hydropower production (Laghari et al., 2012) and their water plays an essential role in thermal power generation. The Indus River is also critical to agricultural production—a mainstay of the national economy. As the climate of the Indus River plains is largely arid and semi-arid, about 90 percent of agricultural production is grown on 18 million hectares of irrigated lands; nearly 80 percent of the country's irrigation water comes through the Indus River Irrigation System, the largest contiguous irrigation system in the world (Yu et al., 2013).

Given the importance of the Indus River system to Pakistan's economy, ecology and society, any changes that affect its water flows are of critical interest to the nation. This sensitivity is augmented by Pakistan's growing degree of water stress as per capita water availability has declined to an estimated 1,017 cubic meters per person (International Monetary Fund, 2015), largely due to rapid population growth and knock-on impacts such as greater agricultural water demand to meet rising food production needs. Various studies project that Pakistan will soon become classified as "water scarce" as per capita availability falls below 1,000 cubic meters per person, and could become the most water stressed country in South Asia by 2040 (World Resources Institute, 2015).

Particular concern has been expressed regarding how climate change will impact future water flows in the Indus Basin. As water flow in the basin is derived primarily from the melting of snow and glacial ice in the western Hindu Kush-Karakoram-Himalaya (HKH) region, its flow regime is sensitive to temperature and precipitation changes that affect the accumulation of snow and ablation of glaciers in the Upper Indus Basin (Fowler & Archer, 2005; Archer et al., 2010; Immerzeel et al., 2010; Yu et al., 2013; Shrestha et al., 2015). However, the complexity of geographic, cryospheric, hydrologic and atmospheric factors that influence the Indus Basin's hydrological regime make it challenging to anticipate climate change's impact on future water flows. In particular, there is uncertainty regarding current and future changes in the Karakoram range's glacial regime; while glaciers in most of the Himalayas have been observed to be retreating to varying degrees, some in the Karakoram have been found to be either advancing or stable (Kilroy, 2015; Khan & Pervaiz, 2012; World Bank, 2013). This uncertainty regarding future water flows in the Indus Basin makes it more challenging to assess the vulnerability of Pakistan to climate change and engage in robust adaptation planning. Gaining better awareness of the risk climate change poses for Pakistan's water resources has therefore been prioritized in its National Climate Change Policy and subsequent framework for implementation of this policy.

As a contribution toward gaining a fuller understanding of the vulnerability of Pakistan's water resources to the impacts of climate change, this paper provides a synthesis of the current state of knowledge regarding how water flow levels in the Indus Basin are projected to change in the coming decades. It provides an overview of the Indus Basin's hydrological regime before examining current and projected temperature and precipitation conditions expected to drive changes in this hydrological regime. The outcomes of a systematic review of recent research on how climate change will alter hydrologic flows in the Indus Basin is then presented. It looks at current understanding of how factors such as glacial retreat, changes in monsoon patterns, and changes in winter precipitation patterns may affect the hydrology of the Indus Basin in the near and longer terms. The potential implications of the findings from the systematic review are then discussed prior to presentation of the research conclusions.

This paper was prepared as part of the project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action" (2015–2016) led by the Pakistan Ministry of Climate Change and implemented in partnership with the United Nations Development Programme, the Centre for Climate Research and Development at COMSATS Institute of Information Technology, Islamabad, and the International Institute for Sustainable Development. Funding for this project was provided by the Overseas Technical Unit of the Italian Embassy in Pakistan.

2.0. Methodology

To assess the current state of research and knowledge regarding how climate change will alter hydrologic flows in the Indus Basin, a structured review of secondary sources—both peer-reviewed publications and grey literature—was undertaken. Systematic review methodology was selected for use in conducting this structure review. Systematic review methodology has been defined as "a focused review of the literature that seeks to answer a specific research question using a set of standardised techniques and explicitly outlined and reproducible methods" (Berrang-Ford, Pearce & Ford, 2015: p.756). Widely used for decades in the health sciences field, systematic review methodology is increasingly being used in the field of climate change research, particularly when reviewing, synthesizing or tracking existing knowledge related to a particular research question. Its key feature is the explicit use of standardized criteria to guide the identification and selection of documents and information to be included in the review—helping to ensure that this process is less ad hoc and less open to researcher bias (Berrang-Ford, Pearce & Ford, 2015).

The specific parameters used in the systematic review of available literature on projected changes to the Indus River hydrological regime were selected by the research team and reviewed by an external advisory group comprised of Pakistani experts from relevant fields of knowledge. The parameters selected for use in the systematic review to ensure an unbiased process for identifying a comprehensive literature sample were:

i. Source of literature to be reviewed: Peer review literature (accessed using Web of Science, Scopus and Google Scholar) and grey literature published by Pakistan-based organizations (government departments, research institutes, universities, NGOs) and international organizations.

ii. Types of literature: Journal articles, technical reports, books, book chapters and conference proceedings.

iii. Publication timeframe: Sources published between January 1, 2005, and September 30, 2015.

iv. Keywords: The following research terms were used to identify literature for inclusion in the study, using three categories – place names, generic terms and biophysical terms:

   a. ("Pakistan" OR "Himalaya*" OR "Karakoram" OR "Karakorum" OR "Hindu Kush" OR "Tibetan Plateau" OR "Indus" OR "Jhelum" OR "Chenab" OR "Ravi" OR "Beas" OR "Sutlej") AND

   b. ("global warming" OR "climate change") AND

   c. ("precipitation" OR "temperature" OR "runoff" OR "snow" OR "glacier*" OR "glacial melt" OR "monsoon" OR "flood*" OR "drought").

v. Language: English

Prior to finalizing the above parameters, test searches were conducted in October 2015 using different keyword combinations. The outcomes of these searches were validated against references contained in known publications such as Yu et al. (2013) and Archer et al. (2010). The formal search was performed between mid-December 2015 and mid-January 2016. Peer reviewed literature was identified by searching Web of Science, Scopus and Google Scholar and grey literature through a general internet search using the designated keywords. A snowballing technique subsequently was used to identify additional relevant sources that involved reviewing the references contained in the literature identified through the online search.

After compiling an initial list of references, additional inclusion and exclusion criteria were applied to ensure that the literature list only included publications dealing with impacts occurring or predicted to occur due, at least partially, to post-industrial climate change and impacts that are biophysical in nature. The outcome of this process was the creation of a shortlist of publications for review which contained a total of 27 sources: 22 per peer reviewed publications and five grey literature sources. These identified literature sources are listed in Annex 1 of this report. The majority of the shortlisted publications documented research conducted by international institutes; research conducted by Pakistan-based researchers accounted for only about 15 percent of the total number of selected publications.

Additional research drawing on a range of literature sources was conducted to set the content of the shortlisted publications into context. This research was used to develop a synthesis about the "anatomy" of the hydrologic regime of the Upper Indus Basin, and current understanding of how the regime responses to changes in the climatic drivers. It also was used to gain insight into historic climate trends in the Indus Basin. Available literature was analysed as well to develop a synthesis of projected changes in the regions temperature and precipitation regimes. A general understanding was also gained regarding the results from different global circulation models to quantify the range of uncertainty associated with the different climate change projections. Collectively the hydrologic regime and climate information was used to inform conclusions regarding how climate change could affect runoff in the Indus Basin and also to identify the main barriers and gaps related to research within this field of knowledge.

3.0 Hydrology of the Indus Basin

The Indus Basin encompasses a total area of about 1.12 million square kilometers, portions of which fall within the territorial boundaries of four countries: Pakistan (47 percent), India (39 percent), China (8 percent) and Afghanistan (6 percent) (see Figure 1). Within Pakistan the basin covers about 65 percent of the country's total territory, including all of the provinces of Khyber Pakhtunkhwa and Punjab, most of Sindh, and the eastern part of Balochistan (Food and Agriculture Organization [FAO], 2011). The HKH mountain ranges of its upper reaches run approximately in an arc that extends from the west and north (the Hindu Kush and Karakoram mountains) to the south and east (the main Himalaya mountain chain). Commonly known at the "third pole", the HKH region has the highest concentration of snow and glaciers outside the polar region (Bajracharya et al., 2015) and the basin contains some of the highest mountains in the world (including K2). Forty percent of the total basin area (1,137,819 square kilometres) lies at an elevation higher than 2,000 meters above sea level (Harrington et al., 2009; Babel and Wahid, 2008; Laghari et al., 2012).

The Indus River has a total length of approximately 2,900 kilometres, making it the twelfth largest river in the world (FAO, 2011). Originating in the Tibetan Plateau, in its upper reaches it is fed in part by catchments of the Shyok, Shigar, Hunza, Gilgit and Astore rivers (Yu et al., 2013). In its lower reaches, the Indus River is fed by two main tributaries: the Kabul River flowing in from the western side and the Panjnad River flowing in from the eastern side. The Panjnad River itself is the confluence of five significant rivers: the Jhelum, Chenab, Ravi, Beas and Sutlej. Use of these rivers is governed by the Indus Water Treaty signed in 1960 by India and Pakistan. Under this treaty, all of the waters in the eastern tributaries of Sultej, Beas and Ravi are allocated to India for unrestricted use until they finally enter Pakistan. Waters in the western tributaries of Jhelum and Chenab are allocated for unrestricted use by Pakistan (FAO, 2011). On average, approximately 180 cubic kilometres of water enters the basin on an annual basis, of which around 125 cubic kilometres is diverted annually into the Indus Basin Irrigation System (Yu et al., 2013).

Although the flow characteristics of the rivers within the Indus Basin differ, generally their hydrographs start to rise in the April to June period as a result of snow melt in the Upper Indus Basin and monsoon rains in the basin's lower portion. Approximately 60 percent of total mean annual river flow is derived from the headwaters of the Indus River, of which about 80 percent enters into the system between June and September (Yu

Figure 1. Map of the Indus Basin

et al., 2013). Peak flows usually happen in the period between July and August. During the winter or rabi season (October to December) runoff into the basin is low—about one-tenth of summer flow—because of limited ice and snow melt (Kahlown & Majeed, 2003).

A good understanding of the hydrological regimes that determine river flow in the Indus Basin is required to assess how climate change will impact this system. The basin's hydrology is determined by the combined influence of three very distinct regimes and their responses to climatic conditions (Archer et al., 2010; Immerzeel et al., 2010; Sharif et al., 2013; Laghari et al., 2012; Reggiani et al., 2015):

- **A glacial regime.** About 25 to 35 percent of water flow in the Indus River is derived from glacial melt (Immerzeel et al., 2010; Mukhopadhyay & Dutta, 2010; Savoskul & Smakhtin, 2013). This water flows into the tributaries of high altitude catchments such as the Hunza and Shyok in the Karakoram and Hindu Kush mountains (Sharif et al., 2013). The regime's flow patterns are characterized by large variation in responses due to the inherently diverse topography and climate of the region (Archer et al., 2010; ADB, 2010; Miller et al., 2012). Many studies report that there is a significant positive relationship between summer temperatures and runoff rates (Yu et al., 2013; Singh & Bengtsson, 2005; Archer and Fowler, 2008). Annual water flow from the glacial regime is therefore highly dependent on summer temperature and solar radiation conditions in the current year. At the same time, it also has been observed that there is a significant negative relationship between summer precipitation and monthly streamflow on a seasonal and maximum basis (Yu et al., 2013; Archer and Fowler, 2008). The main explanation provided for this negative relationship is that rainfall clouds reduce the concurrent heat energy input for ice melt and consequently this increases albedo from new snow cover.
- **A nival (or snowmelt) regime.** At middle altitudes (above 2,500 metres [FAO, 2011]), flow is predominately dependent on the melting of snow that fell during the preceding winter plus spring precipitation. As the area of winter snow cover is an order of magnitude greater than the area of the perennial snow and ice (Frenken & Spottorno, 2012), the nival regime generates the greatest portion of water flow in the Indus River (Archer et al., 2010; Laghari et al., 2012). Its contribution to total water flow has been estimated as being 35 to 40 percent (Immerzeel et al., 2010; Mukhopadhyay & Dutta, 2010; Savoskul & Smakhtin, 2013).

  In contrast to the glacial regime, a consistently negative relationship between runoff and temperature has been reported for the nival regime—both for the coexisting summer temperature and prior season temperature (Yu et al., 2013; Archer and Fowler, 2008). This negative relationship between temperature and runoff may be attributed to greater evaporative losses from snow cover at higher temperatures, which leads to a reduction in runoff (Archer et al., 2010; Singh & Bengtsson, 2005). Thus, while higher temperatures increase the amount of runoff from glacial regime, it reduces the amount of flow from the nival regime, and vice versa.
- **A rainfall regime.** In the southern foothills of the Himalayas and the Indus plains to the south, the basin's hydrologic regime is mainly controlled by runoff from rainfall that occurs primarily in the monsoon season (Archer et al., 2010; Yu et al., 2013). The literature

reports that the contribution of the rainfall regime to the total flow of the Indus River is less than the combined flow from the nival and glacial regimes, generating about 40 percent of total flows (Gebre & Ludwig, 2014; Immerzeel et al., 2010). The rainfall regime is the main cause of lowland flooding as it produces more intense runoff. For example, the catastrophic floods that took place in 2010 and affected more than 20 million people occurred largely as a result of the heavy rainfall that occurred during that year's monsoon (Laghari et al., 2012; Lau & Kim, 2012; Archer et al., 2010).

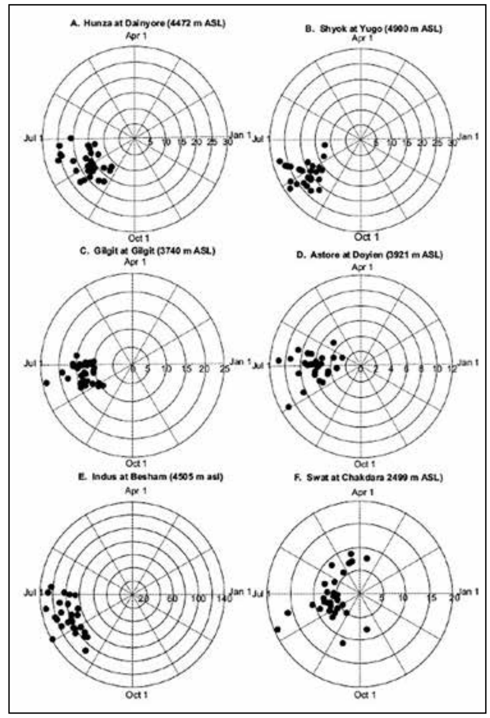


Figure 2. Polar plots showing the magnitude (m3 s−1 ×100) and timing of annual peak daily flows at six representative stations within the Upper Indus basin. Mean catchment elevation is shown.
Source: Sharif et al. (2013)

As different catchments within the Indus Basin are feed to varying degrees by water flow from these three regimes, the timing of their annual maximum mean daily flow also varies as shown in Figure 2 (Sharif et al., 2013). As illustrated, annual peak flow in the high altitude catchments of the Hunza and Shyok rivers (Graphs A and B respectively) occurs in late July and August, reflecting the large contribution of glacial melt to their runoff volume. In catchments located at middle altitudes, such as those of the Astore and Gilgit rivers, annual peak flow occurs earlier in the year—in June and July (Graphs C and D respectively). In these catchments water flow is predominantly governed by the nival regime. Annual peaks on the main stem of the Indus River, as represented by measurements at the Besham gauging station located immediately upstream of the Tarbela Reservoir (Graph E), reflect a combined contribution from both the glacial and nival regimes. Here the annual peaks range from the end of June to mid-August. Peak flow dates along the Swat River (represented in Graph F) are characterised by a broader range that extends from April (generated by spring rainfall and early snowmelt) to July and August (due to monsoon-related peaks).

While the above descriptions provide a general picture of the factors influencing hydrologic patterns in the Indus Basin, it is important to keep in mind that a limited number of studies of the hydrology of the Upper Indus basin have been completed. While the hydrology of the southern portion of the Indus River is well studied, hydrologic patterns in the Upper Indus Basin have been described as a "black box" (Yu et al., 2013). Current understanding of climate patterns, local hydrology and glacier behaviour in the Upper Indus Basin is based on limited analysis using a limited data base (Yu et al., 2013).

4.0 Historical Climate and Hydrology Trends

The climate of the Indus Basin varies significantly both spatially and temporally, with the lower portion of the basin being sub-tropical arid and semi-arid to temperate sub-humid while the mountainous Upper Indus Basin has an alpine climate (FAO, 2011). The basin's climate is shaped by four seasons: a cool dry winter from December to February; a hot pre-monsoon season from March through May; a rainy monsoon season from June through September; and a post-monsoon period from October to November (Blood, 1996). The length of these seasons varies depending on location in the basin.

Significant temperature differences are found within the basin, with average maximum summer temperatures in the southern plains reaching more than 35oC while the temperature only rise to an average of 10oC to 15oC in its upper reaches. In contrast, minimum winter temperatures currently vary from an average of 10oC to 15oC in the south to an average of less than -20oC in the high alpine areas (see Figure 3) (Shrestha et al., 2015).

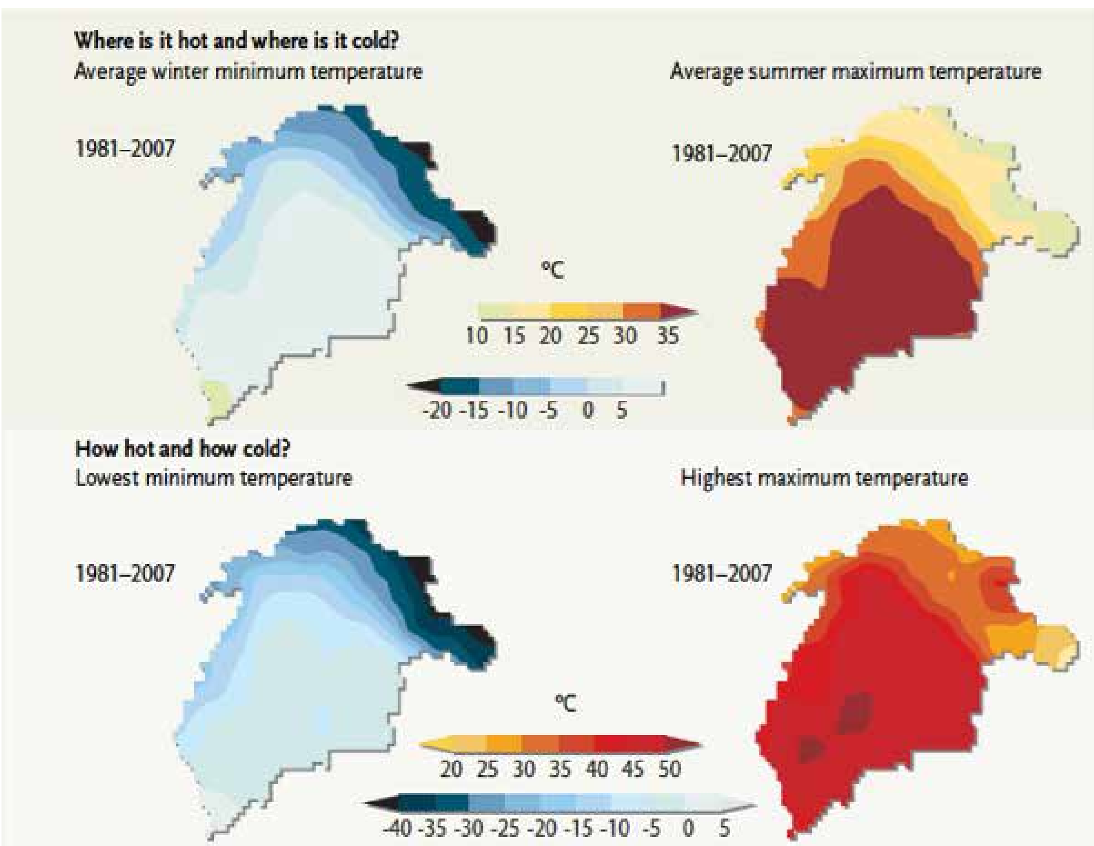


Figure 3. The spatial and temporal distribution of temperatures across the Indus Basin.

Source: Shrestha et al. (2015)

Similar diversity is found within the region's precipitation regime (see Figure 4). While annual precipitation in the lowlands of the basin ranges between 100 and 500 millimeters per year, it rises to about 600 millimetres at 4,400 metres above sea level and can reach 1,500 to 2,000 millimetres per year on mountain slopes located 5,500 metres above sea level. However, along northern valley floors, precipitation can be as little as 100 to 200 millimetres per year (FAO, 2011; Fowler & Archer 2005; Laghari et al. 2012; Mukhopadhyay & Khan 2014; Wake 1989). As it receives significantly more precipitation than the lower basin, the Upper Indus Basin plays a critical role in water availability in the whole basin throughout the year (Archer & Fowler, 2004; Shrestha et al., 2015; Laghari et al., 2012).

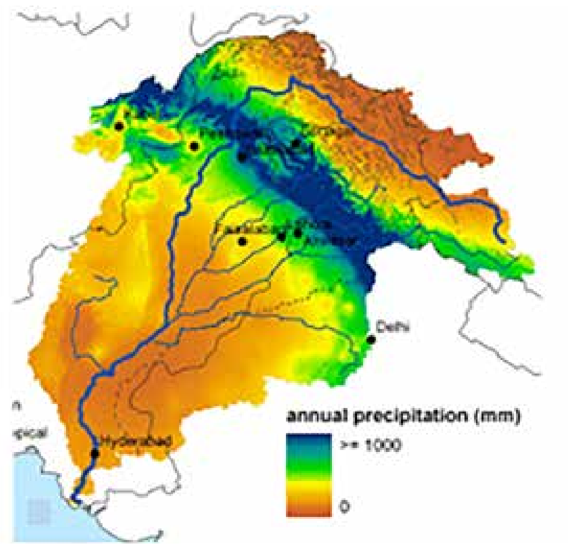


Figure 4. Precipitation gradients in the Indus Basin.

Source: Laghari et al. (2012)

In terms of precipitation dynamics, the HKH region typically has been characterized by two main sub-regions (Archer & Fowler 2004; Palazzi et al., 2014; Syed et al. 2006; Yadav et al. 2012):

- The western Hindu-Hush Karakoram, including the Indus Basin, in which precipitation (largely in the form of snow) is generally carried by the westerly winds during the winter and spring. This winter precipitation falling from October to March, largely in high-altitude and mid-altitude catchments, is the main source of snowfall accumulation that feeds glaciers and, upon melting, runoff into the Indus River (Archer, 2006; Bocchiola et al., 2011; Miller et al., 2012).
- The eastern Himalaya in which precipitation is controlled by the summer monsoon.

In the Indus Basin, falling to the west of the Himalaya divide, the summer monsoon and local circulations only account for one-third of annual precipitation (Ali et al. 2015; Young & Hewitt 1990). While the foothills of the HKH in Pakistan derive some precipitation in the monsoon season (Miller et al., 2012), the high mountains of the Upper Indus Basin limit the intrusion of the monsoon, whose influence weakens northwestward (FAO, 2011).

How key climate parameters, namely temperature and precipitation, have already begun to change and may be expected to change in the future will directly influence future hydrological conditions in the Indus Basin given their direct influence on the glacial, nival and rainfall regimes. The remainder of this section summarizes available research on recent temperature and precipitation trends and highlights some observed changes in hydrological patterns associated with these changes.

4.1 Temperature: Historical trends

Many studies have been conducted that analyse historical climate trends in Pakistan and the Indus Basin (e.g. Fowler & Archer, 2006; Farooqi et al., 2005; Singh et al., 2008; Sheikh et al. 2009; Zahid & Rasul, 2009; Yu et al., 2013; Shrestha et al., 2015). Among those looking specifically at changes in temperature within the political boundaries of Pakistan, Sheikh et al. (2009) undertook trend analysis using Climatic Research Unit gridded data. Their study found an overall increase in temperature by +0.6°C over the 1900s with a statistical significance level of 99 percent. They also report that these trends do not follow a consistent regional pattern. The country's north, including the Upper Indus Basin, has experienced a warming trend over the past 50 years while some parts of the lower Indus Basin have cooled. This conclusion is in agreement with a trend analysis conducted by the Pakistan Meteorological Department (Afzaal et al., 2008) that found an overall warming of 0.64°C in Pakistan between 1900 and 2007, and a 95 percent confidence level that cycles of increasing and decreasing temperatures occurred during this period.

In a study focused on the Upper Indus Basin, Fowler and Archer (2006) concluded that there is a strong contrast between winter and summer temperature trends and between maximum and minimum temperatures. Using data obtained from seven instrumental records of stations located between 1,370 and 2,390 metres above sea level, seasonal and annual trends over the period 1961 to 2000 were examined. Their analysis reveals that average and maximum winter temperatures exhibited statistically significant increases (0.1 - 0.55°C per decade), while average and minimum summer temperatures showed consistent cooling. Their results also show that summer cooling is dependant on elevation, with greater cooling taking place at higher elevations, while winter warming has been confined to lower altitudes (Fowler & Archer, 2006).

Fowler and Archer's findings are in agreement with a study by Sheikh et al. (2009) in which they concluded that mean maximum temperatures in the pre-monsoon season have experienced statistically significant warming trends in most parts of Upper Indus Basin between 1951 and 2000. As illustrated in Figure 5, looking specifically at the Greater Himalayan region of Pakistan, mean maximum temperatures (Figure 5a) have increased in all season except the monsoon season. In contrast, mean minimum temperatures (Figure 5b) have decline in all seasons, with larger cooling trends occurring in the monsoon season and the post-monsoon period. When mean temperatures are examined (Figure 5c) it appears that there has been a significant increase in temperatures in the pre-monsoon season and a large decline in temperatures in the monsoon season, leading an overall modest increase for the year as a whole. This change reflects an enhanced range of diurnal temperature, which means that days have become warmer and nights colder (Sheikh et al., 2009). Explanations to this phenomenon are not yet clear, but Fowler and Archer (2006) anticipated that it may be associated with a coupling of regional feedbacks, such as aerosol cooling, to large-scale climatic processes. More recently, it is report that Fowler et al. have suggested that this observed decline in summer temperatures may be due to monsoon rains moving further northward as the climate warms, pushing dry, westerly winds northward and increasing cloud cover (Qiu, 2016).

A study by Khattak et al. (2011) also reported that maximum winter temperature between 1976 and 2005 demonstrate an increasing trend of 0.45°C, 0.42°C and 0.23°C per decade for the upper, middle and lower parts of the Indus Basin respectively.

In summary, analysis of historical temperature datasets shows a statistically significant warming trend over all of Pakistan in the pre-monsoon season, and cooling trends for the monsoon season in most parts of the country. However, for the Upper Indus Basin region in particular, temperature exhibits a strong increase in the winter and pre-monsoon seasons, but it also shows a cooling trend during the monsoon period.

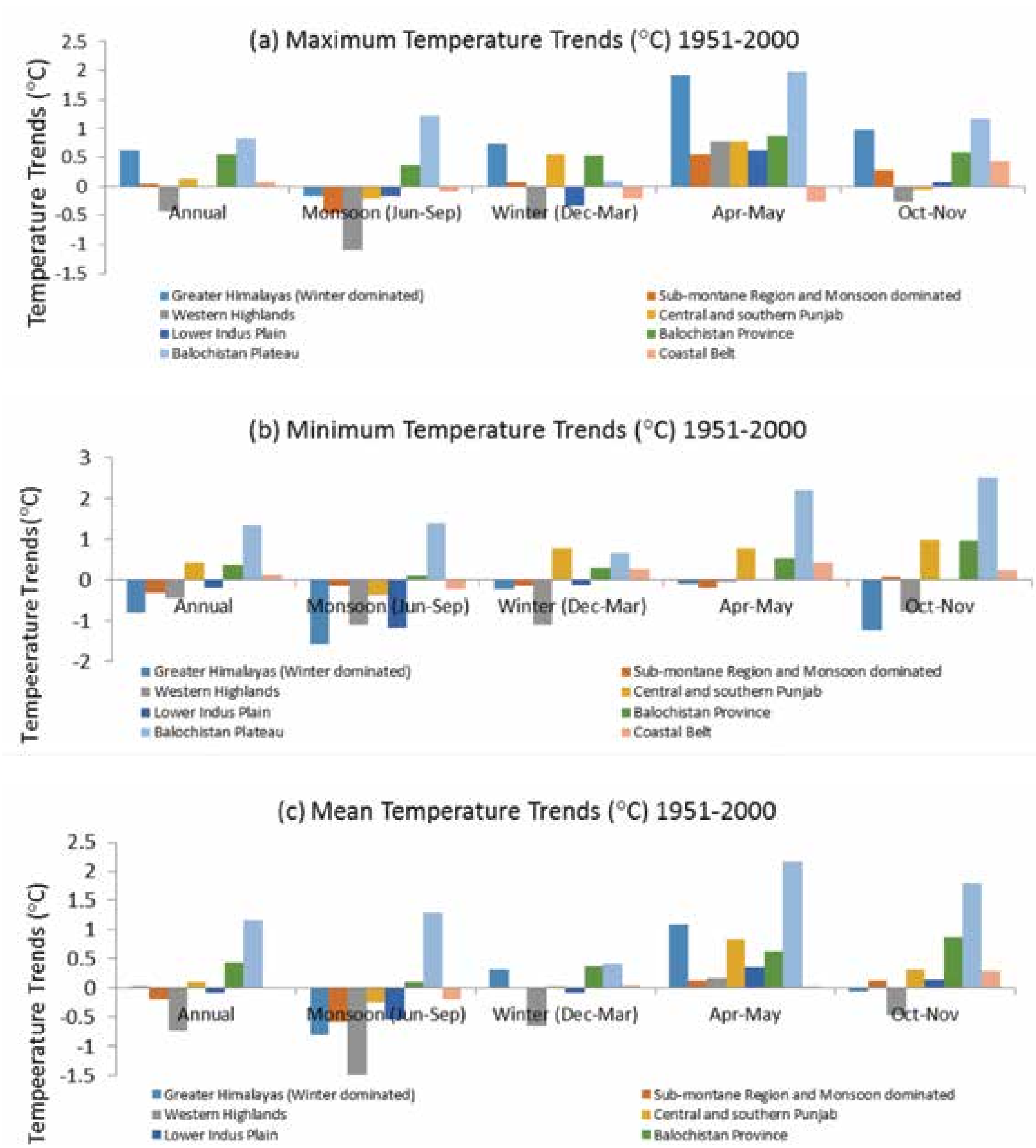


Figure 5. Seasonal historical trends for maximum, minimum and mean temperature levels in the Indus Basin.

Source: Shiekh et al. (2009)

4.2 Precipitation: Historical trends

Existing annual and decadal variability in precipitation levels within Pakistan due to factors such as changes in monsoon patterns makes it more challenging to detect emerging precipitation trends spurred by global climate change. Available studies for Pakistan as a whole have generally reported a lack of any notable trends in past precipitation records, although they do suggest that there may have been an increase in annual and seasonal precipitation in recent decades.

In their examination of changing climatic trends throughout Pakistan, Yu et al. (2013) reported a trend of increasing annual precipitation in the 1900s at a statistically significant level of 1 percent. As illustrated in Figure 6, though, their report also notes that the extent and direction of change in mean annual and seasonal precipitation levels between 1951 and 2000 has varied substantially between different regions of the country. There has been a strong trend toward increasing precipitation levels in the Upper Indus, Punjab and northern Balochistan plateau, whilst the western Balochistan plateau and particularly the coastal belt has experienced declining precipitation levels (Yu et al., 2013). On a seasonal basis, a number of studies indicate that summer (monsoon) rainfall has been on a statistically significant increasing trend since 1961, and that this positive trend is spread over almost all parts of Pakistan (Fowler & Archer, 2006; Sheik et al., 2009; Archer et al., 2010; Yu et al., 2013).

In terms of changes specifically within the Indus Basin, Shresta et al. (2015), as illustrated in Figure 7, and Singh et al. (2011) suggest that the period of the 1950s to the early-1980s was much drier compared to the period of the 1980s to the 2010s. Both studies reported a trend toward increased rainfall over the past 30 years, as well as a notable increase in the frequency of heavy rainfall events. However, Singh et al. (2011) report that while the southern part of the Indus Basin has experienced a slight increase in precipitation, most of the stations in the northern half of the basin report a significant decline in both total annual precipitation and summer precipitation.

In their review of the potential impacts of climate change on the Indus Basin, Nepal and Shresthra (2015) present results of a statistical analysis (linear regression) of historical precipitation records from 1985 to 2005. Their analysis did not identify any significant long-term trends, either increasing or decreasing, in any of the seasonal or annual series investigated. However, the analysis also compared recent precipitation levels to more historic levels and found a statistically significant increase in annual precipitation since 1961, with an upward trend in winter precipitation at all stations north and south of the Himalayan divide. For summer rainfall since 1961, however, there has been a statistically significant increase only at stations north of the Himalayan divide (and therefore outside of the Indus Basin). There was no clear evidence regarding whether this difference is the result of more frequent monsoon storms or a stronger influence by the westerly winds (as cited in Archer & Fowler, [2004]).

Khattak et al. (2011) also investigated historical trends (1967-2005) in the Upper Indus Basin. They applied a non-parametric statistical test (Mann-Kendall) on data sets for several meteorological variables from 20 meteorological stations. Their results show a statistically significant increase in precipitation in the summer season (June to August) with a rate of increase of 23.9 millimetres over the 39 years examined. A statistically non-significant increase in precipitation was also observed for the winter and spring seasons.

Finally, Fowler and Archer (2005) in their analysis of the historical climate record (1961-1999) concluded that winter, summer and annual precipitation across the Upper Indus Basin region shows evidence of a positive trend. Winter precipitation showed statistically significant trends at the sub-catchments level, with increases ranging between 16 and 18 percent.

Taken as a whole, these studies suggest that the Upper Indus Basin has experienced an increase in precipitation levels in the past three decades, particularly in the winter. They also suggest that there has been an increase in the intensity of rainfall, with more rain falling in fewer rainy days. However, there is uncertainty remaining regarding historical trends given the limited number of studies and meteorological data available.

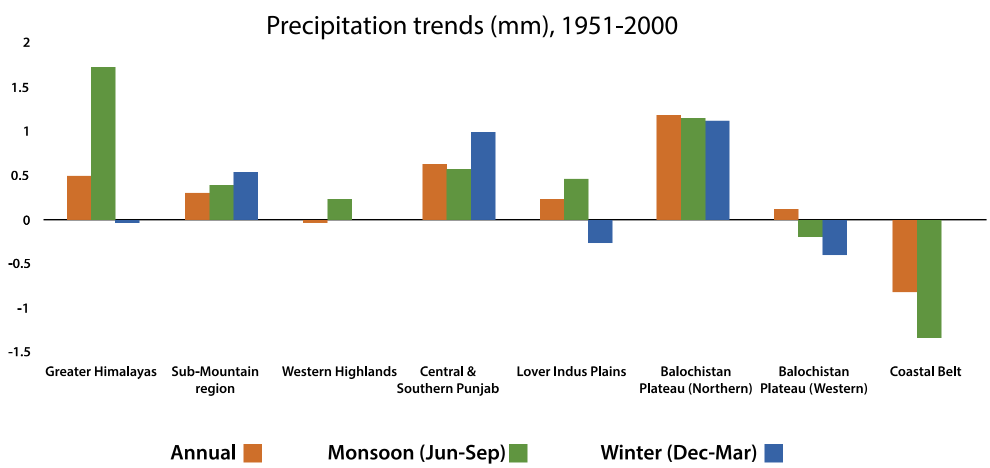


Figure 6. Precipitation trends over the different regions in Pakistan.

Source: Adapted from Yu et al. (2013)

4.3 Hydrology: Historical trends

Little research has been published to date on how hydrological patterns have or have not changed in recent decades due to the observed increases in winter temperatures and declining summer temperatures in the Upper Indus Basin and the variable trends in precipitation levels. However, it is reported that gauge data from hydrological stations along the Indus River and three of its tributaries document a seasonal decline in river flow (Qiu, 2016). Based on data collected at the Tarbela dam, the Pakistan Water and Power Development Authority suggests that, between 1962 and 2012, flows declined during the kharif season (April to August) while increasing slightly during the rabi season (October to December) (Khan, 2016). Overall their results suggest that there has been a decline in river flow between 1962 and 2014 (Qiu, 2016).

This reported trend is consistent with the observed decline in spring and summer temperatures, which would reduce the rate of ice and snow melt in the Upper Indus Basin that is critical to downstream water flow. The observed reduction of temperatures in these

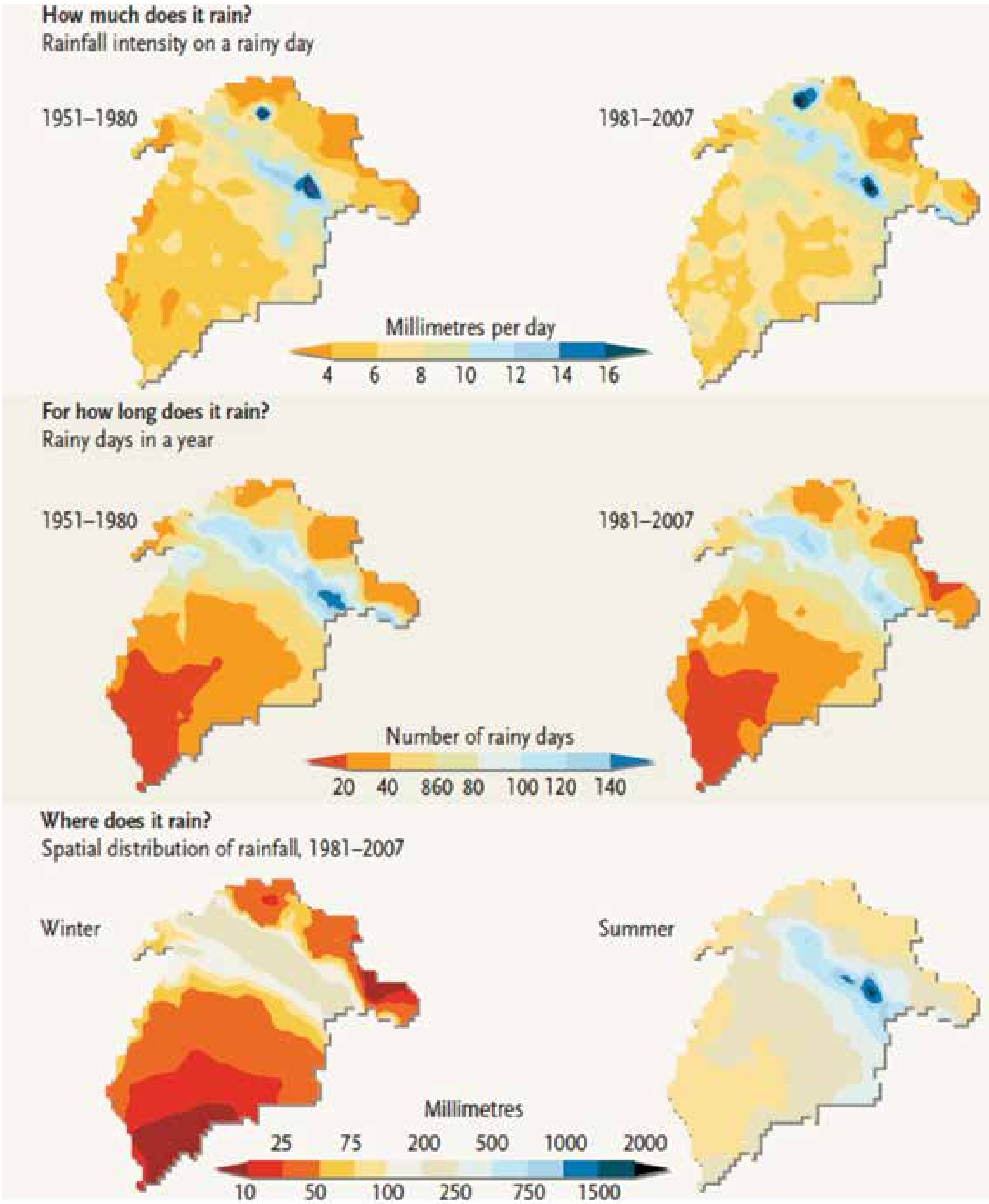


Figure 7. Indicators of changes in precipitation in the Indus Basin between the period 1951 to 1980 and between 1981 and 2007.

Source: Shrestha et al. (2015)

seasons also may help explain the "Karakoram anomaly," a unique phenomenon in which some glaciers in the Karakoram region are reported to have either slightly gained mass or stayed neutral (Qiu, 2016). Further research is required, though, to better assess historical trends in available hydrological data.

5.0 Projected Changes in the Climate and Hydrological Regime of the Indus Basin

The Indus Basin is already experiencing changes in its climatological regime, as witnessed by the recorded changes in its temperatures and precipitation patterns. Given the intimate role that climate plays in the Indus Basin's hydrological regime, ongoing shifts from historical norms may be expected to alter water flow patterns in the region. Any changes in climatological parameters will have an impact on the distribution and timing of precipitation (snowfall and rainfall) and on the melting of snow and ice, and therefore on the hydrological regime of the Indus Basin. Drawing upon the content of the literature identified through the systematic review, this section begins by synthesizing available information regarding projected changes in the region's temperature and precipitation patterns. It then looks at projected changes in the basin's different hydrological regimes—the glacial, nival and rainfall regimes—before presenting a summary of current analysis regarding potential overall changes in its hydrologic patterns.

5.1 Temperature: Projected changes

Although a number of regional climate models provide guidance regarding how South Asia's climate might change in the coming decades, only a few multi-model climate projections have been developed for Pakistan. Climate projections at the sub-national scale remain to be completed.

One of these analyses is a study conducted by Gebre and Ludwig (2014) that assessed the spatial and temporal impacts of climate change on the Indus Basin's climatological and hydrological regimes. Their study used 0.5 by 0.5 degree resolution data for five different (bias corrected) CMIP5 climate models and used the Representative Concentration Pathways (RCPs) 4.5 and 8.5 emission scenarios. The analysis used ordinary kriging geospatial interpolation techniques to spatially analyse precipitation and temperature (maximum and minimum) projections for the period of 2035 to 2064 and from 2071 to 2100 against a baseline period of 1971 to 2005.

The projections developed by Gebre and Ludwig (2014) suggest that mean monthly maximum temperature projections will continue to increase under all scenarios and for all future time periods. Maximum summer temperatures (June to August) could increase by 1°C to 4°C by the period of 2071 to 2100 under RCP 4.5 scenario, compared to a baseline period of 1971 to 2005. As shown in Figure 8b, the temperature change in the Himalayas and other high elevation regions is projected to be higher than in the southern parts of the basin (Gebre and Ludwig, 2014). This latter trend has also been reported by the Intergovernmental Panel on Climate Change, which reported in its Fourth Assessment Report that warming of the Himalayas is occurring at a rate three times that of the global average (Parry et al., 2007).

Similar to Gebre and Ludwig (2014), Shrestha et al. (2015) in their Himalayan Climate and Water Atlas demonstrate that major parts of the Indus Basin are projected to warm in the summer by 2°C to 5°C under RCP 4.5 between 2021 and 2050, against a baseline period of 1961 to 1990. Even greater warming is projected under RCP 8.5, particularly in the Upper Indus Basin region. They also report that winter temperatures could increase by 2°C to 4°C across the basin in both scenarios, with only a few areas experiencing temperature changes that exceed 4°C or are lower than 2°C (see Figure 9).

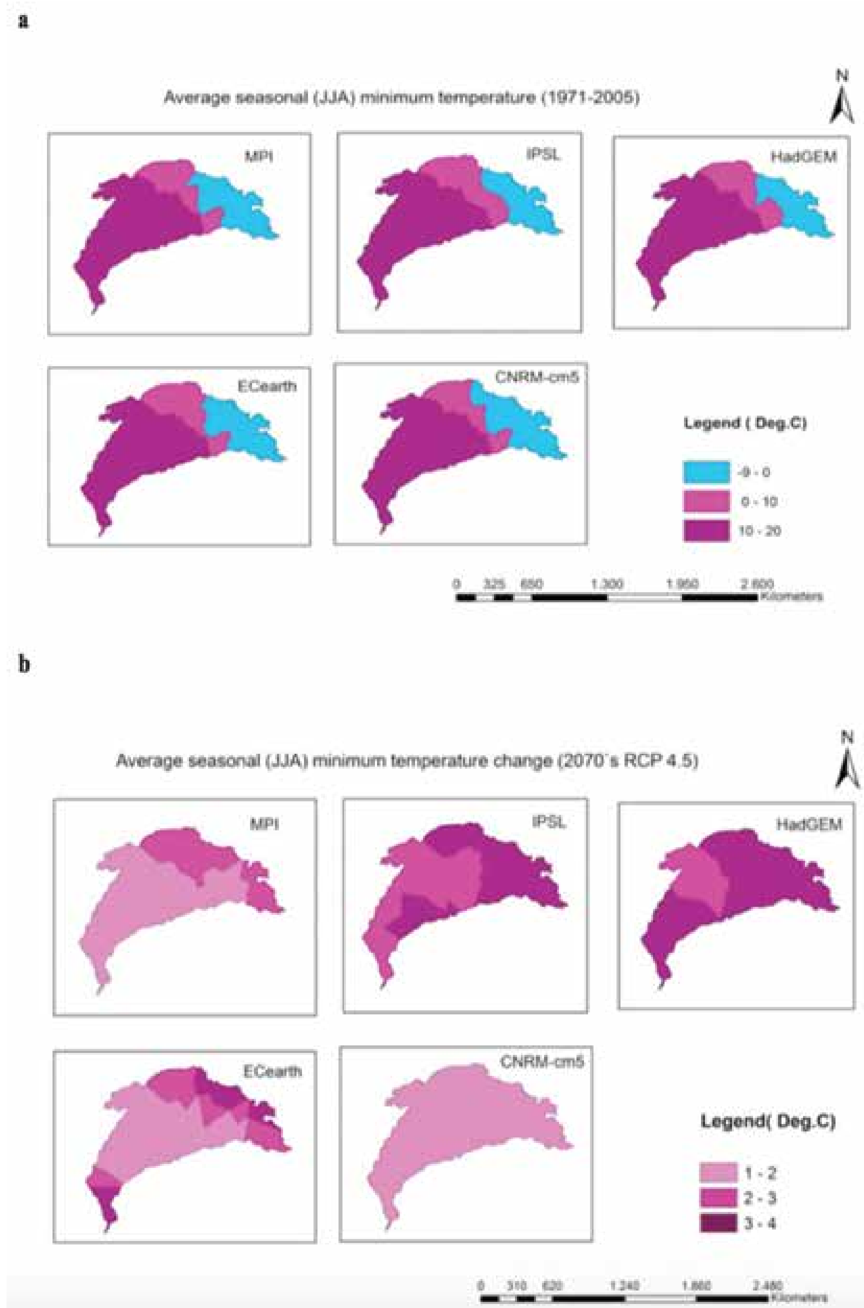


Figure 8. Multimodal base line average seasonal minimum temperature (1971- 2005) (a) compared to five General Circulation Models spatial distribution of base line average seasonal minimum temperature (b).

Source: Gebre and Ludwig (2014).

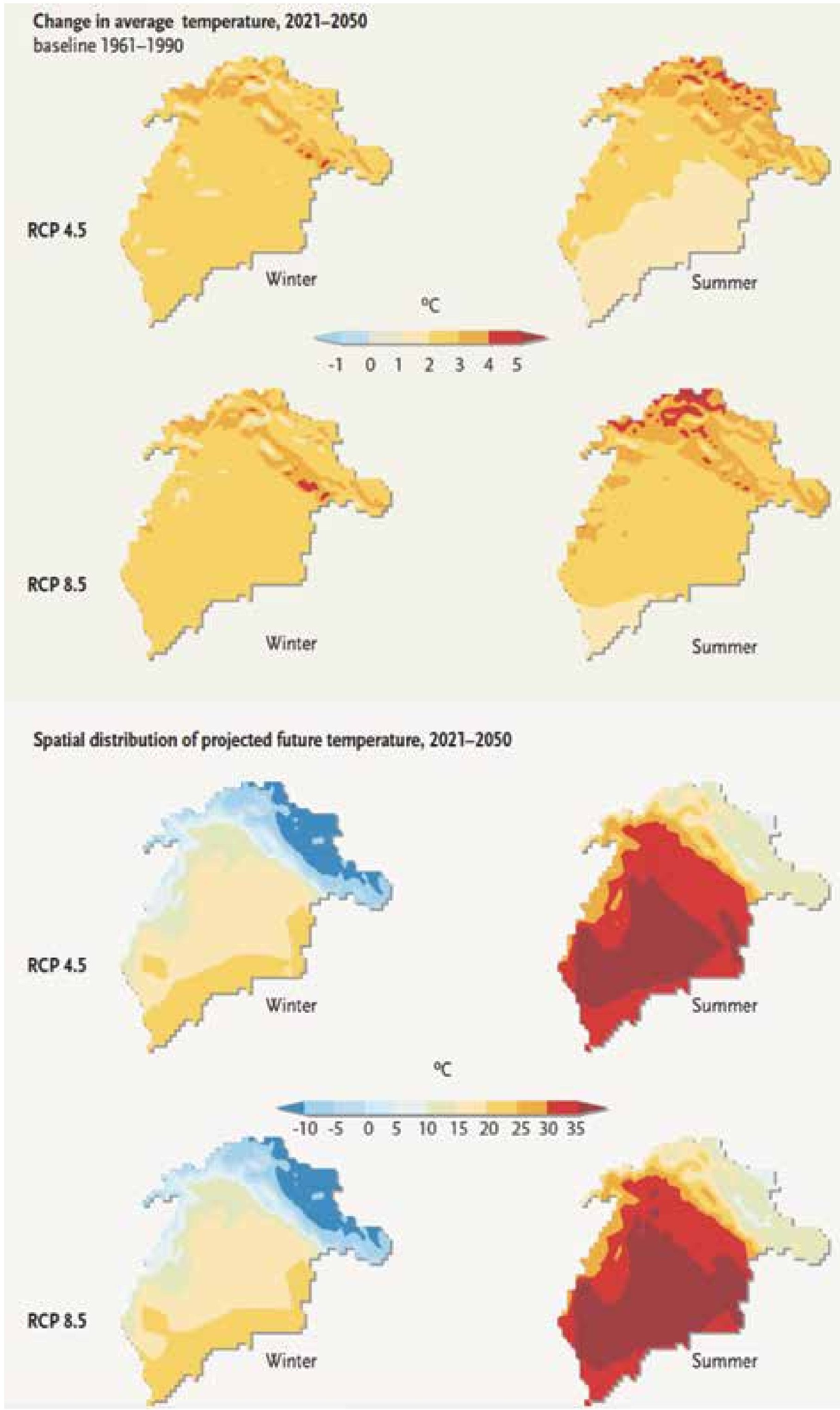


Figure 9. Change in average seasonal temperature in the Indus Basin over the period 1961-1990 and future projection for the period 2021-2050 under both RCP scenarios 4.5 and 8.5.

Source: Shrestha et al. (2015)

5.2 Precipitation: Projected changes

Studies examining potential future precipitation patterns in the Indus Basin have generally found that precipitation levels may increase during this century, but that considerable uncertainty remains.

In their recent study, Shrestha et al. (2015) concluded that precipitation levels in the Indus Basin will increase during the summer period (June to August) over its upper, central-eastern and southern regions. As shown in Figure 10, portions of these regions could see an increase in precipitation of 10 to 25 percent between 2021 and 2050 under both RCP 4.5 and 8.5 scenarios compared to a baseline period of 1961 to 1990. During the same season and timeframe, precipitation is projected to decrease in the central-western portion of the basin, potentially by as much as 25 percent under RCP 8.5 scenario. In the winter, similar patterns are projected. The central-western portion of the basin is projected to experience declines in precipitation, with larger decreases projected under the RCP 4.5 scenario compared to the RCP 8.5 scenario, while increases are projected to be experienced in other portions of the basin (Shrestha et al., 2015).

Analysis by Rajbhandari et al. (2014) using the Regional Climates for Impacts Studies (PRECIS) model project an overall increase in the number of the rainy days in the upper part of the basin and decreases over the southern part. Their projections also show that the middle part of the basin will have fewer rainy days but that this change will be accompanied by an increase in rainfall intensity. On a seasonal basis, Rajbhandari et al. (2014) observed that projected changes in summer monsoon precipitation was non-uniform across the basin, and that different simulations produced significantly different spatial patterns. Therefore, they concluded that uncertainty remains regarding future changes in this season. Winter simulations were more consistent, showing an increase in precipitation over that Upper Indus Basin and a decrease over the lower part of the basin (Rajbhandari et al., 2014).

The findings of Rajbhandari et al. (2014) are consistent with the conclusions of Gebre and Ludwig (2014), who report General Circulation Models projections that show an increase in precipitation in the Upper Indus Basin at the end of the century and a decrease in the lower part of the basin. Through a comparison of outputs from five General Circulation Models using the RCP 4.5 and 8.5 scenarios, Gebre and Ludwig (2014) projected that average monthly precipitation levels will increase during the summer season (June to August) and decrease in the winter season, with changes being more pronounced in the period of 2071 to 2100 compared to the period of 2035 to 2064.

As illustrated in Figure 11, the average seasonal (June to August) spatial precipitation distribution changes for 2071 to 2100 of RCP 4.5 shows an overall positive indication of increasing precipitation in the future, particularly in the northern part of the basin, based on results from five different Global Circulation Models. However, there is considerable variation between the model results with one suggesting a decline in precipitation over most of the basin while others suggest large increases in precipitation (up to 40 to 60 percent).

As it can be noted from this review, great uncertainty remains regarding how precipitation patterns in the Indus Basin will change in the future, particularly with respect to winter precipitation—with some studies indicating that it will increase and others indicating the opposite for different regions of the basin. The number of variances between studies regarding the extent and distribution of future precipitation changes can most likely be attributed to differences in methods, data periods, and sources of climate projection data. This uncertainty has a critical influence on efforts to anticipate future runoff in the Indus River given the importance of winter precipitation to the system's current hydrological patterns.

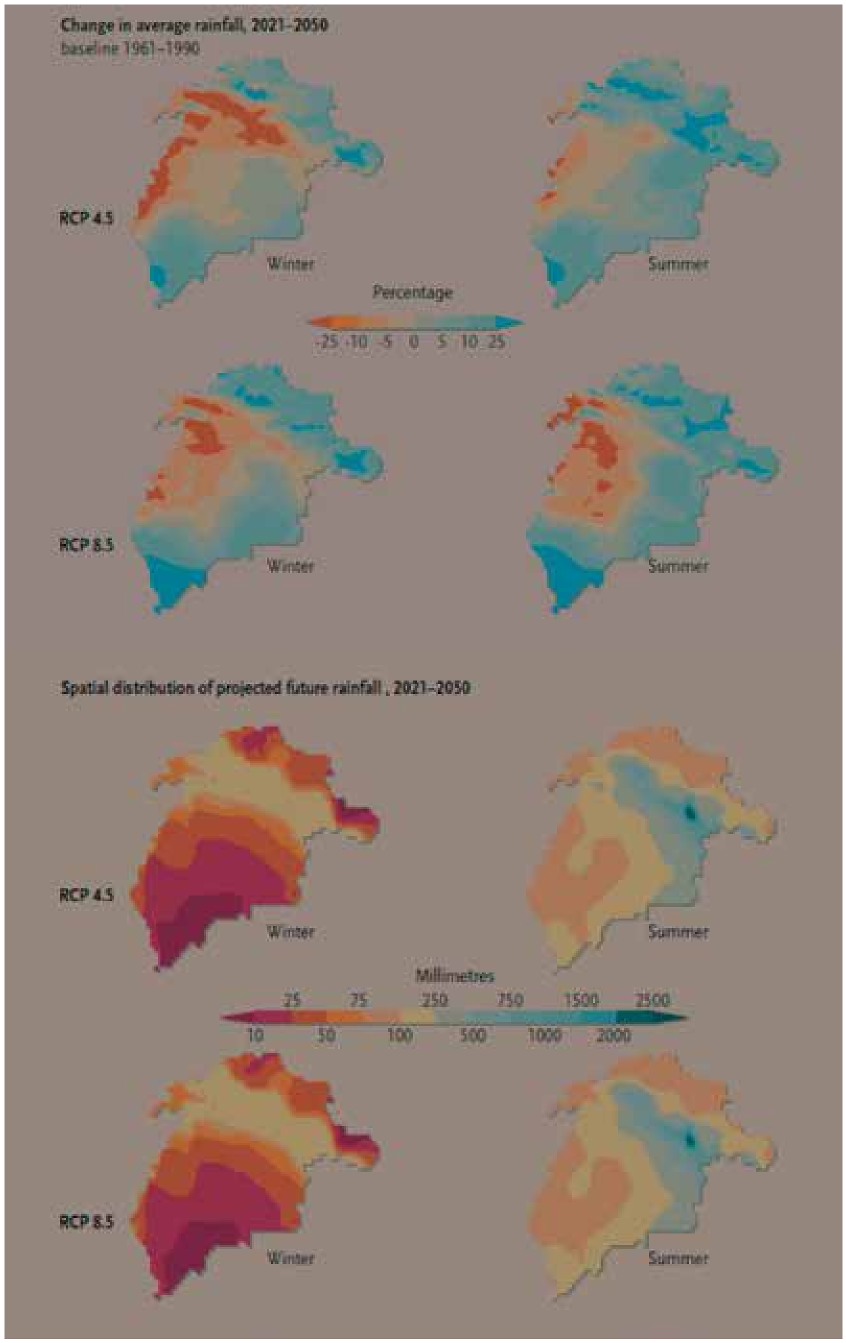


Figure 10. Change in average precipitation for the period 2021-2050 compared to a baseline period of 1961-1990.

Source: Shrestha et al. (2015)

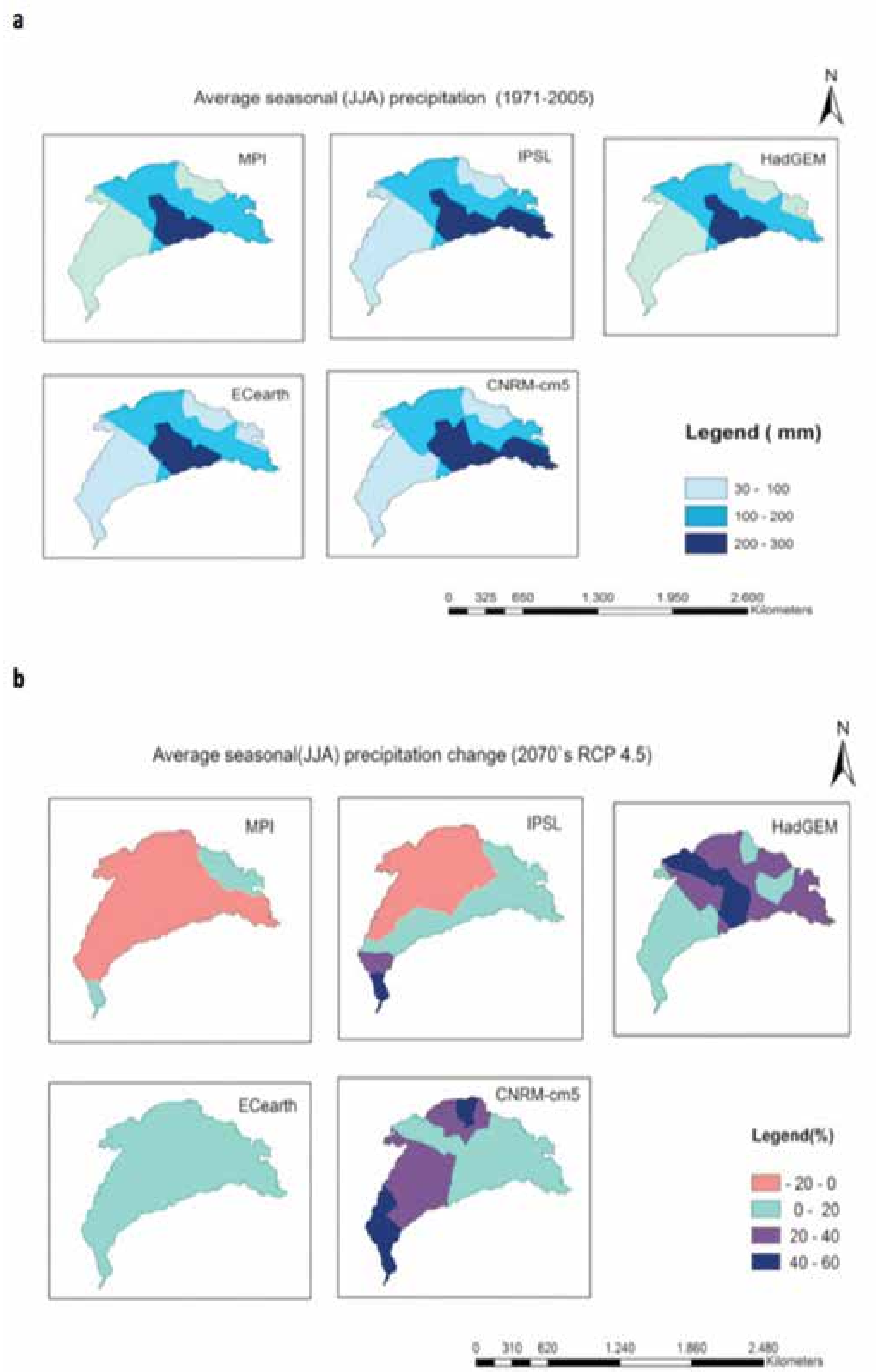


Figure 11. Multimodal baseline average seasonal precipitation (1971-2005) (a) compared to five General Circulation Models spatial distribution of baseline average seasonal precipitation (2071 to 2100) (b).

Source: Gebre & Ludwig (2014).

5.3 Projected changes in the glacial, nival and rainfall regimes

Available projections suggest that temperatures in the Indus Basin will continue to rise in the coming decades—in both the summer and winter—and that, while there is less certainty, there could be an increase in mean annual precipitation in the Upper Indus Basin and a decline in the lower portion of the basin. However, available projections are inconsistent with respect to changes on a seasonal and spatial basis. How each of the glacial, nival and rainfall regimes respond to the climatic changes that occur will determine the future hydrology of the Indus Basin. Significant uncertainty remains regarding not only how each of these regimes will be affected by climate change but the interplay between them and therefore the collective outcome of these changes.

Significant attention has been given in recent years to how climate change is already changing the rate of glacial melt in the HKH region, what further changes might be expected in the future, and the socio-economic implications of these changes. Glaciers are known to be very sensitive indicators of climate change because they respond quickly to changes in their surrounding climate by gaining or losing mass in the form of snow and ice (Archer et al., 2010; Sharief et al.,2013; Shrestha et al., 2015). As previously noted, many studies have reported that the glaciers of the HKH region are losing mass and strongly retreating (National Research Council, 2007; Gautam et al., 2013; Shrestha et al., 2015). However, a number of studies in recent years have also reported the "Karakoram anomaly" of expanding or neutral glaciers in the Karakoram region. This unique phenomenon is now a subject of a great interest and extensive scientific research (Hewitt, 2005; Gardelle et al., 2012; Minora et al., 2013). This contrast in trends within the same glacial region supports the hypothesis that changes in glacial regions such as the HKH are more likely to be controlled by local dynamics than by regional or global trends (Singh et al., 2011).

Runoff in the glacial regime is positively correlated to summer temperatures, with high summer temperatures leading the higher rates of runoff (Yu et al., 2013; Singh & Bengtsson, 2005; Archer & Fowler, 2008). The results of analysis by Singh and Bengtsson (2005) reflect this existing relationship. As illustrated in Figure 12, results from their modeling show that a rise in temperature by 1°C to 3°C will increase flow from glacial melt by 16 to 50 percent. However, they note that it is very difficult to predict the impact of climate change on the glacial regime in the absence of a comprehensive inventory of glaciers that covers the entire Upper Indus Basin region. Most of the current studies available, including that of Singh and Bengtsson (2005), focus on changes in small areas that are then extrapolated to present a regional overview.

Nival regime changes are of particular interest when trying to assess the potential consequences of climate change for future hydrological patterns in the Indus Basin as it comprises the greater portion of consistent downstream water flow (Archer et al., 2010; Laghari et al., 2012). Higher winter precipitation provides the potential for higher levels of summer runoff (Archer & Fowler, 2008; Laghari et al., 2012; Yu et al., 2013). While historical trends have shown an increase in winter precipitation levels, projections from different models contradict one another and are associated with great uncertainty.

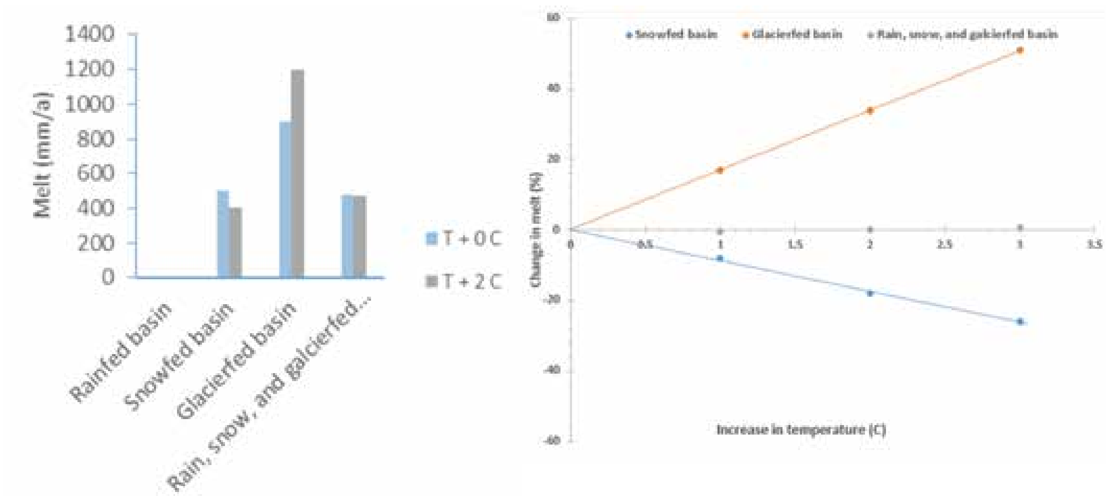


Figure 12. Impact of temperature change on annual melt for different types of basins in the Himalayan region.
Source: Reproduced from Singh & Bengtsson (2005).

The negative correlation between temperature and runoff in the nival regime also makes projections of future change more challenging. Singh and Bengtsson (2005) also modeled potential changes in annual snowmelt at different temperature levels for different catchments. As seen in Figure 12, their results show a reduction in runoff from snow-fed catchments as higher rates of evaporation lead to greater loss of water to the atmosphere. Their results project a decline in runoff of about 18 percent for a 2°C rise in mean temperatures and a 25 percent reduction for a 3°C rise in mean temperatures. This situation in which there is potential for climate change to drive both increases and decreases in runoff from the nival regime makes it problematic to assess future changes in runoff from snowmelt.

With respect to changes in the rainfall regime, most climate models predict that monsoon rainfall will increase under both RCP 4.5 and 8.5 scenarios in most parts of Pakistan. Available studies looking at South Asia as a whole also suggest that there will be greater inter-annual and intra-seasonal variability in monsoonal precipitation. Should mean annual global temperatures reach 4°C, it has been projected that annual mean monsoon intensity could increase by 10 percent and year-to-year variability could increase by 15 percent compared to average levels during the first half of the 1900s. "Taken together, these changes imply that an extreme wet monsoon that currently has a chance of occurring only once in every 100 years is projected to occur every 10 years by the end of this century" should mean annual global temperatures reach 4°C (World Bank, 2013: p.107-108). Such increases in future monsoon precipitation of the Indian sub-continent will increase the risk of more frequent flooding. However, as previously noted, future precipitation projections for the Indus Basin still remain very uncertain due to the complexity of the region's topography and marine influences.

5.4 Projected changes in Indus Basin discharge

A limited number of studies have been conducted that assess future changes in water flow in the Indus Basin as a whole, both in the near and longer term. These include Shrestha et al. (2015), Yu et al. (2013) and Laghari et al. (2012), which have provided projections for near-term changes in the basin's hydrology. All three of these studies conclude that the volume of water flow in the Indus Basin will not change significantly prior to 2050. These studies draw this conclusion based on the projections which forecast that decreases in glacial melt runoff (prior to 2050) will be compensated by runoff that is generated from the increasing monsoonal rainfall. While no significant change in total flow volume is projected, modelling results by Yu et al. (2013) show that the main impact of climate change in the short term could be slight shifts in the timing of peak flow to earlier in the year.

Two studies looking at the potential changes in the basin's hydrological regime in the longer term (e.g. by 2100) also were examined as part of this review. In their research, Immerzeel et al. (2009) used hydrological models that incorporated snowmelt runoff to examine the potential impacts of climate change on water discharge in the basin. Using the output of Regional Climates for Impacts Studies (PRECIS) regional simulation for the period 2071 to 2099 under the A2 SERS scenario, they examined potential flows should the glacier area of the Indus Basin decrease by 0 percent, 50 percent and 100 percent. The model used the period 2001 to 2005 as a base line and was calibrated by using daily flow from Besham Qila, a gauging station just upstream Tarbela reservoir. As illustrated in Figure 13, under the hypothesis of a 50 percent decrease in glacial cover due to rising temperatures, glacier runoff was decreased by only 22 percent. However, total runoff in the basin increased by 7 percent as the loss in glacier runoff was offset by a significant increase (53 percent) in (monsoon) rainfall concentrated in the period between June to August. In contrast, under the hypothesis that there would be a 100 percent decrease in glacial runoff, the projected discharge drops significantly. It should be noted that under existing models it is projected that the earliest at which there will be a 50 percent loss of glacier cover is the mid-2070s and complete loss of glacier cover in the HKH region in the mid-2100s based on an assumed, conservatively estimated, annual melting rate of 1 percent of the glacial cover per year (Immerzeel et al., 2009).

Like Yu et al. (2013), Immerzeel et al. (2009) also projects that there will be a shift in the timing of peak flows in the Indus Basin. Under the three scenarios examined in their study, modeling results suggest that there will be a significant increase in discharge rates between weeks 14 and 25 of the calendar year (approximately April to mid-June) compared to a baseline of recorded flows between 2001 and 2005. Overall, peak flow is projected to move three to four weeks earlier in the year compared to its current peak period of weeks 26 and 27 of the calendar year (June/July) (Immerzeel et al., 2009).

An earlier study by Akhtar et al. (2008) generated similar results as Immerzeel et al. (2009). Their detailed modeling of climate change impacts in the Upper Indus Basin using the SRES A2 scenario for 2071 to 2100 found that discharge increased as long as glacier coverage remained at 50 to 100 percent. However, discharge reduced substantially under conditions in which there was 0 percent glacier coverage.

Overall these near- and long-term modelling results for the impact of climate change on hydrological patterns in the Indus River Basin suggest that significant differences in water flow will not be experienced until after 2100. In the near-term the most likely change to occur is a shift in the timing of peak of flow to earlier in the year, a shift that can be expected to have implications for agricultural production in Pakistan. An increase in flows into the Tarbela reservoir earlier in the year may, for example, increase the volume of water available to support irrigated agriculture throughout the basin.

However, as observed by Yu et al. (2013: p.58), there is "no compelling evidence either for or against the impact of a changing climate on the hydrometeorology and glaciers of the UIB." This lack of compelling evidence stems from the continued absence of sufficient data upon which to track past trends and develop projections; the challenge of creating scenarios with the extreme climate of the Upper Indus Basin; and the lack of knowledge regarding changes in the glaciers of the Karakoram range.

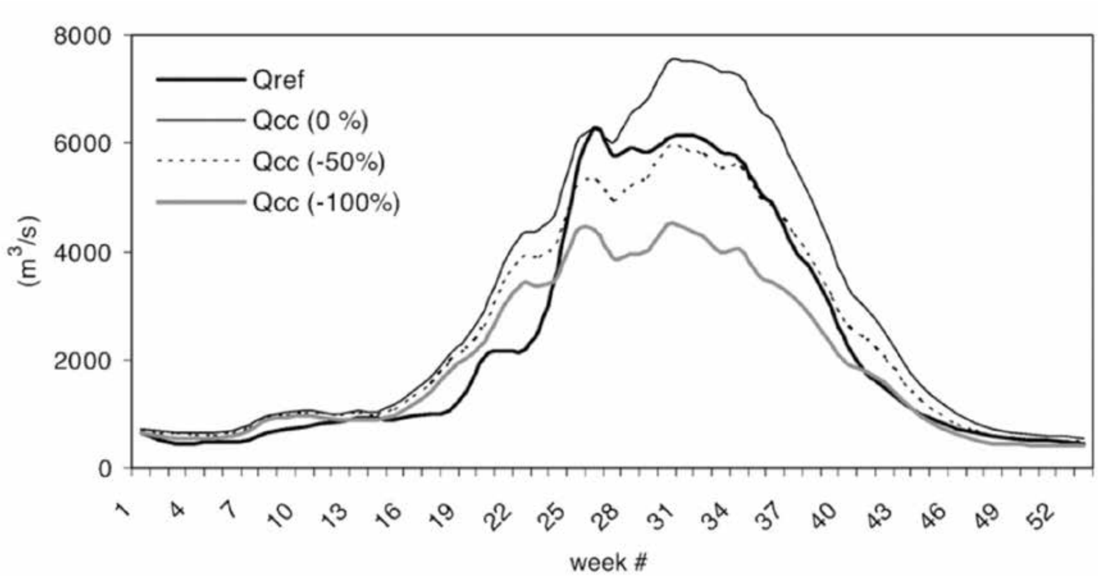


Figure 13. Modelled weekly stream flow at Besham Qila, a gauging station just upstream Tarbela reservoir (2001-2005), and for three climate change scenarios with different glacier extents (0, 50 and 100%).

Source: Immerzeel et al. (2009).

6.0 Discussion

The glacier and snow-pack dependent rivers basins of South Asia have been identified as climate change "hot-spots" due to their sensitivity to changing climatic conditions and the dependence of more than a billion people on the water resources they provide (De Souza et al., 2015). Varying levels of glacial retreat has been observed throughout much of the HKH region, with potentially negative implications for downstream livelihoods and economies in the near- and long-term. However, despite ongoing intensive research, the impact of changes in temperature and precipitation on the HKH region are not yet clear or fully understood (Archer et al., 2010; Yu et al., 2013; Shrestha et al., 2015).

This situation is perhaps particularly acute in the Indus Basin. While the Himalayas comprise the most studied area within the HKH region, only a limited number of studies have looked at climate change implications for the whole region of the Upper Indus Basin. Most available studies focus at the sub-basin level, and the limited number of studies completed make it challenging to look at the whole region as one connected system. Further reflecting the limited research that has been undertaken in this basin's vast and complex upper reaches, there is uncertainty regarding the contribution of glacier melt to annual stream flow volume and the extent to which flow results from other sources such as snowmelt and monsoon rainfall. The complex topography of the HKH region also limits the credibility of available climate projections for the region and therefore projected changes in downstream hydrology patterns.

The evidence that is available suggests that climate change will have a relatively low impact on overall annual discharge in the near-term (i.e. prior to 2050). However, there may be a shift in peak flows to earlier in the year. This shift, along with any changes in future monsoon rainfall patterns, may be expected to impacts crops growth and yield (Imran et al., 2014). More studies are needed, though, to understand potential intra-annual changes and how extreme events may be impacted (Nepal & Shresthra, 2015).

Through this review of available literature, it has also become evident that the following gaps exist that limit understanding of climate change's impact on future water flows in the Indus Basin:

- **Hydro-meteorological monitoring network and data availability:** In general, the mountainous regions need to be equipped with more weather stations than the flat regions to gain a good representation of the mountain climate heterogeneity (Fowler & Archer, 2005). The existing network of weather stations in the Upper Indus Basin mountain region almost falls short by one order of magnitude of the minimum number recommended by World Meteorological Organization (1994). It recommends having one precipitation gauge per 250 square kilometres; in the Upper Indus Basin the actual density is less than one gauge per 5,000 square kilometres (Archer et al., 2010). The Asian Development Bank (2010) has recommended that least 75 automatic weather stations and 35 hydrological monitoring stations be installed in the high elevation areas of the

Upper Indus Basin to meet optimum observational demands. The Pakistan Meteorological Department (PMD) has stated that at least 50 more meteorological stations are needed in the Upper Indus Basin, adding to the 18 currently operated by the Water and Power Development Authority and 11 operated by PMD.

A further challenge is the predominance of monitoring stations in valley floors, which creates a bias in the whole monitoring network of the Upper Indus Basin. To obtain an assessment that is regionally representative, it is essential to establish a dense monitoring network that is able to capture seasonal variations across the region. This would allow more effective modelling of the hydrodynamic characteristics of the entire Upper Indus Basin. In addition, a joint program is needed to maintain and operate Pakistan's existing hydro-meteorological monitoring network to enable better management of data and the network itself.

Briscoe and Qamar (2007) and Archer et al. (2010) also concluded that a significant measurement limitation lies in the lack of monitoring stations along the main, branch and distribution channels of the Indus Basin Irrigation System. This lack of flow measurements in the Indus Basin Irrigation System drives the use of simple time-based water allocation practices, and consequently restricts the ability of the government to sustainably regulate water flow in the system.

- **Large uncertainties in precipitation projections and hydrological models:** Large uncertainties remain regarding precipitation projections for the Indus Basin derived from different General Circulation Models (Lutz et al., 2014; ADB, 2010). While winter precipitation is a key driver of the whole basin's hydrologic regime, its future projections are the most uncertain compared to other climate indicators. Moreover, most of the current downscaling work is produced from high coarse resolution models, which produces a crude overview of the future scenarios. More refined models are needed in particular to capture the complexity of mountainous areas. In the absence of better modelling capacity, it is very difficult to determine the impact of climate change at sub-basin level, which is very important for water resources development planning. In addition, current understanding and representation of the different hydrological regimes of the Indus Basin is not yet well understood and associated with large uncertainties. Better quantification of the hydrological processes within the basin's three regimes at different scales and obtaining better and higher resolution winter precipitation projections would be essential steps toward obtaining a more detailed and comprehensive picture of future water availability in the Indus Basin.

- **Lack of comprehensive glacial data and understanding of its physical processes:** Many studies report that the glaciers of the HKH are not very well understood and remain a "black box." Most scientific research on Himalayan glaciers has focused on isolated data or individual perception that does not provide an objective or systematic assessment of the evidence base or true understanding of ongoing physical changes. Moreover, current scientific knowledge is still unable to explain the reason for the Karakoram anomaly. As the glacial and nival regimes contribute about 60 percent of the discharge in the Indus Basin, monitoring the evolution of glacial cover in the Karakoram range and the

HKH mountains more generally is required to better inform estimates of future water availability and provide early flood warning of risks such as glacial lake outburst floods. While early warning systems have been established in three valleys of the Upper Indus Basin, appropriate systems are needed in all vulnerable valleys.

- **Strengthen research capacity within Pakistan.** Through the systematic review process, it was observed that only about 15 percent of the publications identified for inclusion in the analysis was based on research conducted by Pakistani researchers. Most of the relevant publications were produced by PMD, whose studies were focused mostly on historical trend analysis. Future climate projections using multiple models and the current RCP scenarios remain to be completed. Greater capacity needs to built within Pakistan's government and academic research institutes to be able to undertake these and other studies, and to publish their results.

7.0 Conclusions

The objective of this study was to assess the current state of knowledge regarding how climate change will alter hydrologic flows in the Indus Basin due to factors such as glacial retreat, changes in winter precipitation patterns, and changes in monsoon patterns. The analysis was based on a systematic review of literature that included both peer-reviewed publications and grey literature.

Analysis of historical temperature datasets shows a statistically significant warming trend over Pakistan with mean annual temperature having increased by about 0.6°C over the last century. However, different trends have been observed in different regions of the country and between seasons. In the Upper Indus Basin, temperatures in the winter season show a strong increasing trends, while in the summer they show a cooling trend. When future projections are examined, though, most models are in agreement that there will be an increase in mean temperatures on an annual basis and within both the winter and summer season. Available projections under RCP 4.5 scenario suggest that temperatures will increase by a range of +1°C to +4°C across the Indus Basin by the end of the century.

Most of the reviewed studies report a lack of any strong historical trends in precipitation levels. However, they suggest that there has been an increase in annual and seasonal precipitation in the past three decades. Analysis for winter precipitation, which is positively correlated to basin discharge, was typically found to have an upward trend. It has also been suggested that the Upper Indus Basin is experiencing more intense rainfall, with more rain falling in fewer rainy days. In the remainder of the basin it is suggested that rainfall intensity has decreased and the number of the rainy days has remained almost the same. Future precipitation projections based on different model runs indicate that mean annual precipitation may increase by the end of the present century. However, the uncertainty margin for precipitation projections remains very large, with different models giving significantly different results. In particular, there is significant uncertainty regarding future changes in winter precipitation levels.

Indus Basin discharge is driven by three different regimes: the glacial regime, the nival (snowmelt) regime, and the rainfall regime. It has been repeatedly reported that about 60 percent of the basin's discharge comes from the glacial and nival regimes as ice and snow melt. The glacial regime is driven by temperature and solar radiation conditions of the current summer, and also is characterized by large variations in responses due to the inherently diverse topography and climate of the Upper Indus Basin. Winter precipitation drives nourishment of the glacial areas and the accumulation of snow cover. Understanding the physical processes and dynamics of these regimes is a key element of efforts to quantifying the potential impact of climate change on downstream flow levels and therefore future water availability in the basin.

Future projections show that water availability in the short and mid-term (i.e. until about 2050) will not change significantly, but indicate a possible shift in the timing of peak flow to slightly earlier in the year. Results of longer term projections are less conclusive, but some modelling efforts conclude that even with a 50 percent reduction in glacial cover there will not be a signification change in discharge as loss of glacial melt will be counterbalanced by an increase in runoff from higher rainfall amounts during the monsoon season.

In conclusion, the available literature suggests that significant changes in water flow in the Indus Basin are not expected to occur in the near future and that significant gaps in data and analysis remain which makes long-term projections highly uncertain. Stronger understanding of likely future water flows in the Indus Basin will require improvements in hydro-meteorological monitoring networks in the Upper Indus Basin and greater access to available data. It will also require improvements in hydrological and climate modeling to better represent the complexity of the Indus Basin. There is also a need to shed light on the so-called "black box" of current understanding of the extent and physical processes of the glaciers in the catchments that feed the Indus Basin. Finally, greater effort is needed to strengthen the capacity of researchers and institutions in Pakistan to undertake the data collection and analysis needed to inform domestic decision-making as the country prepares for the consequences of a changing climate.

References

Afzaal, M., Haroon, M. A., & Zaman, Q. (2009). Interdecadal oscillations and the warming trend in the area-weighted annual mean temperature of Pakistan. Pakistan Journal of Meteorology, 6(11), 13-19.

Akhtar, M., Ahmad, N., & Booij, M. J. (2008). The impact of climate change on the water resources of Hindukush–Karakorum–Himalaya region under different glacier coverage scenarios. Journal of hydrology, 355(1), 148-163.

Amin, M. (2004). Pakistan's groundwater reservoir and its sustainability. Proceedings 2nd ICID Asian Regional.

Archer, D. R., & Fowler, H. J. (2004). Spatial and temporal variations in precipitation in the Upper Indus Basin, global teleconnections and hydrological implications. Hydrology and Earth System Sciences Discussions, 8(1), 47-61.

Asian Development Bank (ADB). (2010). Islamic Republic of Pakistan: Glacial Melt and Downstream Impacts on Indus Dependent Water Resources and Energy.

Babel, M. S. and Wahid, S. M.: Freshwater under threat: South Asia, Asian Institute of Technology (AIT), United Nations Environment. Programme (UNEP), 2008.

Bajracharya, S. R., Maharjan, S. B., Shrestha, F., Guo, W., Liu, S., Immerzeel, W., & Shrestha, B. (2015). The glaciers of the Hindu Kush Himalayas: current status and observed changes from the 1980s to 2010. International Journal of Water Resources Development, 31(2), 161-173.

Berrang-Ford, L., Pearce, T. and Ford, J. (2015). Systematic review approaches for climate change adaptation research. Regional Environmental Change. 15: 755-769. Retrieved from http://link.springer.com/article/10.1007%2Fs10113-014-0708-7#page-1

Blood, P. R. (Ed.). (1996). Pakistan: A country study. DIANE Publishing.

Briscoe, J. and Qamar, U. (2007). Pakistan's Water Economy Running Dry. Karachi: Oxford University Press. Commissioned by the World Bank.

De Souza, K., Kituyi, E., Harvey, B., Leone, M., Murali, K. and Ford, J. (2015). Vulnerability to climate change in three hot spots in Africa and Asia: key issues for policy-relevant adaptation and resilience building research. Regional Environmental Change, 15:747–753.

Farooqi, A. B., Khan, A. H., & Mir, H. (2005). Climate change perspective in Pakistan. Pakistan Journal of Meteorology, 2(3).

Fischer, G., Shah, M., Tubiello, F. N., & Van Velhuizen, H. (2005). Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 360(1463), 2067-2083.

Food and Agriculture Organization (FAO). (2011). Indus basin. Retrieved from http://www.fao.org/nr/water/aquastat/basins/indus/index.stm

Fowler, H. J., & Archer, D. R. (2005). Hydro-climatological variability in the Upper Indus Basin and implications for water resources. Regional Hydrological Impacts of Climatic Change—Impact Assessment and Decision Making, 295, 131-138.

Fowler, H. J., & Archer, D. R. (2006). Conflicting signals of climatic change in the Upper Indus Basin. Journal of Climate, 19(17), 4276-4293.

Frenken, K., Spottorno, C. (2012). Irrigation in Southern and Eastern Asia in figures. FAO the United Nation.

Gardelle, J., Berthier, E., & Arnaud, Y. (2012). Slight mass gain of Karakoram glaciers in the early twenty-first century. Nature geoscience, 5(5), 322-325.

Harrington, L., Cook, S. E., Lemoalle, J., Kirby, M., Taylor, C., and Woolley, J.: Cross-basin comparisons of water use, water scarcity and their impact on livelihoods: present and future, Water Int., 34, 144–154, doi:10.1080/02508060802661584, 2009.

Hewitt, K. (2005). The Karakoram anomaly? Glacier expansion and the 'elevation effect,' Karakoram Himalaya. Mountain Research and Development, 25(4), 332-340.

Indus Water Treaty (IWT). (1960). "The Indus Waters Treaty." Signed at Karachi on September 19.1960: 300-65.

Immerzeel, W.W., Droogers, P., de Jong, S.M., and Bierkens, M.F.P. (2009). Large-scale monitoring of snow cover and runoff simulations in Himalayan river basins using remote sensing. Remote Sensing of Environment. 113 (2009): 40-49.

Immerzeel, W. W., Van Beek, L. P., & Bierkens, M. F. (2010). Climate change will affect the Asian water towers. Science, 328(5984), 1382-1385.

Imran, A., Zaman, Q., Rasul, G., & Mahmood, A. (2014). An analytical study of variations in the monsoon patterns over Pakistan. Pakistan Journal of Meteorology Vol, 10(20).

International Monetary Fund. (2015). Issues in managing water challenges and policy instruments: Regional perspectives and case studies. Retrieved from http://www.imf.org/external/pubs/ft/sdn/2015/sdn1511tn.pdf

Kahlown, M. A., & Majeed, A. (2003). Water-resources situation in Pakistan: challenges and future strategies. Water Resources in the South: Present Scenario and Future Prospects, 20.

Khan, A. (2016). Glacier Monitoring: WAPDA's initiative in the Upper Indus Basin. Presented at the International Conference on Climate and Environmental Change Impacts on the Indus Basin Waters, Kathmandu, Nepal, 17-18 February 2016.

Khan, M. and Pervaiz, A. (2012). National Sustainable Development Strategy: Pakistan's pathway to a sustainable and resilient future. Islamabad: Government of Pakistan and UNDP.

Khattak, M. S., Babel, M. S., & Sharif, M. (2011). Hydro-meteorological trends in the upper Indus River basin in Pakistan. Climate research, 46(2), 103-119.

Kulkarni, A., Patwardhan, S., Kumar, K. K., Ashok, K., & Krishnan, R. (2013). Projected climate change in the Hindu Kush-Himalayan region by using the high-resolution regional climate model PRECIS. Mountain Research and Development, 33(2), 142-151.

Laghari, A. N., Vanham, D., & Rauch, W. (2012). The Indus basin in the framework of current and future water resources management. Hydrology and Earth System Sciences, 16(4), 1063-1083.

Lau, W. K., & Kim, K. M. (2012). The 2010 Pakistan flood and Russian heat wave: Teleconnection of hydrometeorological extremes. Journal of Hydrometeorology, 13(1), 392-403.

Lutz, A. F., Immerzeel, W. W., Shrestha, A. B., & Bierkens, M. F. P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. Nature Climate Change, 4(7), 587-592.

Maddocks, A., Young, R., and Reig, P., Ranking the World's Most Water-Stressed Countries in 2040

Miller, J. D., Immerzeel, W. W., & Rees, G. (2012). Climate change impacts on glacier hydrology and river discharge in the Hindu Kush-Himalayas: a synthesis of the scientific basis. Mountain Research and Development, 32(4), 461-467.

Minora, U., Bocchiola, D., D'Agata, C., Maragno, D., Mayer, C., Lambrecht, A., ... & Smiraglia, C. (2013). 2001–2010 glacier changes in the Central Karakoram National Park: a contribution to evaluate the magnitude and rate of the" Karakoram anomaly". The Cryosphere Discussions, 7(3), 2891-2941.

Mukhopadhyay, B., & Dutta, A. (2010). A stream water availability model of Upper Indus Basin based on a topologic model and global climatic datasets.Water resources management, 24(15), 4403-4443.

National Research Council. (2007.) Himalayan Glaciers: Climate Change, Water Resources, and Water Security. Washington, DC:

Nepal, S. & Shrestha, A. B. (2015). Impact of climate change on the hydrological regime of the Indus, Ganges and Brahmaputra river basins: a review of the literature. International Journal of Water Resources Development, 31(2), 201-218.

Panday, P., K. Frey, B. Ghimire (2011). 'Detection of the timing and duration of snowmelt in the Hindu Kush-Himalaya using QuikSCAT, 2000–2008', Environmental research letters, vol. 8 (no.1): 014020-014033.

Parry, M. L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (Ed.). (2007). Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge and New York: Cambridge University Press.

Qiu, J. (2016). Stressed Indus River threatens Pakistan's water supplies. Nature News and Comment. Retrieved from http://www.nature.com/news/stressed-indus-river-threatens-pakistan-s-water-supplies-1.20180

Reggiani, P., & Rientjes, T. H. M. (2015). A reflection on the long-term water balance of the Upper Indus Basin. Hydrology Research, 46(3), 446-462.

Savoskul, O. S. & Smakhtin, V. (2013). Glacier systems and seasonal snow cover in six major Asian river basins: Hydrological role under changing climate (Vol. 150). International Water Management Institute.

Sharif, M., Archer, D. R., Fowler, H. J., & Forsythe, N. (2013). Trends in timing and magnitude of flow in the Upper Indus Basin. Hydrology and Earth System Sciences, 17(4), 1503-1516.

Sheikh, M. M., Manzoor, N., Adnan, M., Ashraf, J., & Khan, A. M. (2009). Climate profile and past climate changes in Pakistan. GCISE report No. RR-01, Islamabad.

Shrestha, A., Agrawal, N., Alfthan, B., Bajracharya, S., Maréchal, J., van Oort, B. (Eds.). (2015). The Himalayan Climate and Water Atlas: Impact of Climate Change on Water Resources in Five of Asia's Major River Basins. ICIMOD, GRID-Arendal and CICERO, Kathmandu, Nepal.

Singh, P. & Bengtsson, L. (2005). Impact of warmer climate on melt and evaporation for the rainfed, snowfed and glacierfed basins in the Himalayan region. Journal of Hydrology, 300(1), 140-154.

Singh, S. P., Bassignana-Khadka, I., Karky, B. S., & Sharma, E. (2011). Climate change in the Hindu Kush-Himalayas: the state of current knowledge. International Centre for Integrated Mountain Development (ICIMOD).

Syed, F. S., Giorgi, F., Pal, J. S., & King, M. P. (2006). Effect of remote forcings on the winter precipitation of central southwest Asia part 1: observations. Theoretical and Applied Climatology, 86(1-4), 147-160.

United Nations Framework Convention on Climate Change (UNFCCC). (2008). Impacts, vulnerabilities and adaptation in developing countries. United Nations Framework Convention on Climate Change.

Wake, C. P. (1989). Glaciochemical investigations as a tool for determining the spatial and seasonal variation of snow accumulation in the central Karakoram, northern Pakistan. Ann. Glaciol, 13, 279-284.

World Bank. (2005). Country Assistance Strategy. Pakistan's economy running dry. World Bank, Pakistan Resident Mission, Islamabad.

World Bank. (2013). Turn Down the Heat: Climate extremes, regional impacts and the case for resilience. A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. Washington: World Bank. Retrieved from http://documents.worldbank.org/curated/en/2013/06/17862361/turn-down-heat-climate-extremes-regional-impacts-case-resilience-full-report

World Meteorological Organisation (1994). Guide to Hydrological Practices. WMO-164, 5th edition. Geneva: World Meteorological Organization.

Yadav, R. K., Kumar, K. R., & Rajeevan, M. (2012). Characteristic features of winter precipitation and its variability over northwest India. Journal of earth system science, 121(3), 611-623.

Young, G. J., & Hewitt, K. (1990). Hydrology research in the upper Indus basin, Karakoram Himalaya, Pakistan. Hydrology of Mountainous Areas. IAHS Publ, 190, 139-152.

Yu, W., Yang, Y. C., Savitsky, A., Alford, D., Brown, C., Wescoat, J., & Debowicz, D. (2013). The Indus basin of Pakistan: The impacts of climate risks on water and agriculture. World Bank Publications.

Annex 1: List of peer-reviewed and grey literature used in the systematic review

Archer, D. R., & Fowler, H. J. (2008). Using meteorological data to forecast seasonal runoff on the River Jhelum, Pakistan. Journal of Hydrology, 361(1), 10–23.

Archer, D. R., Forsythe, N., Fowler, H. J., & Shah, S. M. (2010). Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions. Hydrology and Earth System Sciences, 14(8), 1669–1680. Retrieved from http://doi.org/10.5194/hess-14-1669-2010

Bajracharya, S. R., Maharjan, S. B., Shrestha, F., Guo, W., Liu, S., Immerzeel, W., & Shrestha, B. (2015). The glaciers of the Hindu Kush Himalayas: current status and observed changes from the 1980s to 2010. International Journal of Water Resources Development, (ahead-of-print), 1–13.

Bocchiola, D., & Diolaiuti, G. (2013). Recent (1980–2009) evidence of climate change in the upper Karakoram, Pakistan. Theoretical and Applied Climatology, 113(3-4), 611–641.

Farhan, S. B., Zhang, Y., Ma, Y., Guo, Y., & Ma, N. (2014). Hydrological regimes under the conjunction of westerly and monsoon climates: a case investigation in the Astore Basin, Northwestern Himalaya. Climate Dynamics, 44(11-12), 3015–3032.

Forsythe, N., Fowler, H. J., Kilsby, C. G., & Archer, D. R. (2012). Opportunities from Remote Sensing for Supporting Water Resources Management in Village/Valley Scale Catchments in the Upper Indus Basin. Water Resources Management, 26(4), 845–871. http://doi.org/10.1007/s11269-011-9933-8

Forsythe, N., Kilsby, C. G., Fowler, H. J., & Archer, D. R. (2012). Assessment of runoff sensitivity in the Upper Indus Basin to interannual climate variability and potential change using MODIS satellite data products. Mountain Research and Development, 32(1), 16–29.

Fowler, H. J., & Archer, D. R. (2006). Conflicting signals of climatic change in the Upper Indus Basin. Journal of Climate, 19(17), 4276–4293.

Gautam, M., Timilsina, G., & Acharya, K. (2013). Climate Change in the Himalayas: Current State of Knowledge (Policy Research Working Paper No. 6516). The World Bank.

Hassan, M., Shamim, M. A., Hashmi, H. N., Ashiq, S. Z., Ahmed, I., Pasha, G. A., … Han, D. (2015). Predicting streamflows to a multipurpose reservoir using artificial neural networks and regression techniques. Earth Science Informatics, 8(2), 337–352.

Hasson, S., Böhner, J., & Lucarini, V. (2015). Interactive comment on "Prevailing climatic trends and runoff response from Hindukush–Karakoram–Himalaya, Upper Indus basin" by S. Hasson et al. Earth System Dynamics Discussion. 6, C437-C449.

Hewitt, K. (2005). The Karakoram anomaly? Glacier expansion and the 'elevation effect,' Karakoram Himalaya. Mountain Research and Development, 25(4), 332–340. ICIMOD. (n.d.). The Himalayan Climate and Water Atlas.

Intergovernmental Panel on Climate Change (IPCC). (2007). Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.). Cambridge and New York: Cambridge University Press.

Kilroy, G. (2015). A review of the biophysical impacts of climate change in three hotspot regions in Africa and Asia. Regional Environmental Change, 15(5), 771–782.

Kulkarni, A., Patwardhan, S., Kumar, K. K., Ashok, K., & Krishnan, R. (2013). Projected climate change in the Hindu Kush-Himalayan region by using the high-resolution regional climate model PRECIS. Mountain Research and Development, 33(2), 142–151.

Miller, J. D., Immerzeel, W. W., & Rees, G. (2012). Climate Change Impacts on Glacier Hydrology and River Discharge in the Hindu Kush-Himalayas A Synthesis of the Scientific Basis. Mountain Research and Development, 32(4), 461–467. http://doi.org/10.1659/MRD-JOURNAL-D-12-00027.1

Minora, U., Bocchiola, D., D'Agata, C., Maragno, D., Mayer, C., Lambrecht, A., … Compostella, C. (2013). 2001–2010 glacier changes in the Central Karakoram National Park: a contribution to evaluate the magnitude and rate of the "Karakoram anomaly." The Cryosphere Discussions, 7(3), 2891–2941.

Mukhopadhyay, B., & Dutta, A. (2010). A Stream Water Availability Model of Upper Indus Basin Based on a Topologic Model and Global Climatic Datasets. Water Resources Management, 24(15), 4403–4443. http://doi.org/10.1007/s11269.010.9666.0

Mukhopadhyay, B., & Khan, A. (2015). A re-evaluation of the snowmelt and glacial melt in river flows within Upper Indus Basin and its significance in a changing climate. Journal of Hydrology, 527, 119 – 132. http://doi.org/http://dx.doi.org/10.1016/j.jhydrol.2015.04.045

National Academy of Sciences. (2012). Himalayan Glaciers: Climate Change, Water Resources, and Water Security. Washington, D.C., USA: The National Academies Press.

Nepal, S., & Shrestha, A. B. (2015). Impact of climate change on the hydrological regime of the Indus, Ganges and Brahmaputra river basins: a review of the literature. International Journal of Water Resources Development, (ahead-of-print), 1–18.

Palazzi, E., von Hardenberg, J., Terzago, S., & Provenzale, A. (2015). Precipitation in the Karakoram-Himalaya: a CMIP5 view. Climate Dynamics, 45(1-2), 21–45. http://doi.org/10.1007/s00382-014-2341-z

Rasul, G., Afzal, M., Zahid, M., & Bukhari, S. (2012). Climate Change in Pakistan: Focused on Sindh Province (Technical No. PMD-25/2012). Islamabad, Pakistan: Pakistan Meteorological Department.

Sharif, M., Archer, D. R., Fowler, H. J., & Forsythe, N. (2013). Trends in timing and magnitude of flow in the Upper Indus Basin. Hydrology and Earth System Sciences, 17(4), 1503–1516. http://doi.org/10.5194/hess-17-1503-2013

Singh, S. P., Bassignana-Khadka, I., Karky, B. S., & Sharma, E. (2011). Climate change in the Hindu Kush-Himalayas: the state of current knowledge. International Centre for Integrated Mountain Development (ICIMOD).

Soncini, A., Bocchiola, D., Confortola, G., Bianchi, A., Rosso, R., Mayer, C., … Diolaiuti, G. (2015). Future Hydrological Regimes in the Upper Indus Basin: A Case Study from a High-Altitude Glacierized Catchment. Journal of Hydrometeorology, 16(1), 306–326. http://doi.org/10.1175/JHM-D-14-0043.1

Soncini, A., Bocchiola, D., Confortola, G., Nana, E., Bianchi, A., Rosso, R., … Vuillermoz, E. (2015). Hydrology of the Upper Indus Basin Under Potential Climate Change Scenarios. (G. Lollino, A. Manconi, J. Clague, W. Shan, & M. Chiarle, Eds.).

Yu, W., Yang, Y.-C., Savitsky, A., Alford, D., Brown, C., Wescoat, J., & Debowicz, D. (2013). The Indus basin of Pakistan: The impacts of climate risks on water and agriculture. World Bank Publications.

Zhang, G., Yao, T., Xie, H., Wang, W., & Yang, W. (2015). An inventory of glacial lakes in the Third Pole region and their changes in response to global warming. Global and Planetary Change, 131, 148–157. http://doi.org/10.1016/j.gloplacha.2015.05.013

Appendix 3: Water Demand Study

Future Water Demand in Pakistan: Potential changes under different scenarios

The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action

Prepared by: Hisham Osman, International Institute for Sustainable Development

1. Introduction

It is widely recognised that Pakistan is headed toward a serious water crisis. Climate change, population growth, inefficient use of water for irrigation, and groundwater overexploitation limit the country's water security. Several studies have concluded that Pakistan is going to face physical water scarcity by 2025 (International Monetary Fund, 2015; Mustafa et al, 2013; World Wildlife Fund, 2003). The agricultural sector, the mainstay of the country's economy, uses more than 80% of the total available water. As a consequence, the gap between water availability and water demand particularly widens during the summer growing season when crop water requirements are at their highest levels. Despite these existing stressors and expectations of greater water scarcity in the future, issues related to water demand have not yet been adequately addressed in Pakistan. This situation limits the country's preparedness to sustainably manage its water resources.

This report provides a macro-level analysis of projected changes in water demand in Pakistan. It synthesizes of existing research regarding potential water demand in Pakistan in 2050 under five different scenarios that each take into consideration factors such as population growth, rates of urbanization, economic development and potential changes in agricultural practices. Outcomes of this analysis are compared to current knowledge regarding likely changes in future water flows in the Indus Basin in light of climate change. This assessment is intended to inform policy measures that could be taken by the Government of Pakistan as it seeks to enhance its future water, energy and food security.

This briefing note was produced as part of project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action" (June 2015 to July 2016) led by the Pakistan Ministry of Climate Change and implemented in partnership with the United Nations Development Programme, the Centre for Climate Research and Development at COMSATS Institute of Information Technology, Islamabad, and the International Institute for Sustainable Development. Funding for this project was provided by the Overseas Technical Unit of the Italian Embassy in Pakistan.

2. Methodology

This study is based on a review of secondary sources identified through a general web search using Google, Google Scholar and Web of Knowledge. The main criteria for the selection and inclusion of literature used in the analysis reflect the primary focus of the study, namely studies focused on Pakistan and at least discussing current and/or future (2050) water demand for one of the following three sectors—agriculture, industry and municipal use. A list of secondary literature sources relevant to water demand in Pakistan identified and reviewed as part of this study is provided in Annex A.

After identifying relevant available literature, these sources were reviewed and analyzed to provide an understanding of historical water demand trends by sector and, to the extent possible, the factors likely to drive future water demand. This information was used to establish a baseline for water demand to be compared with future scenarios. Water demand was then identified and calculated for five scenarios: a business-as-usual scenario; a moderate water demand management scenario; a strong water demand management scenario; an above business-as-usual scenario with exceeded extrapolation of current water demands; and a climate change scenario. Outcomes of these demand scenarios were then compared to projected levels of water availability in the Indus Basin, which covers about 65 percent of Pakistan's total territory and is its primary source of water (Food and Agriculture Organization [FAO], 2011). The final step of the analysis was to identify gaps and limitations that emerged from the assessment and draw out relevant recommendations for government.

3. Current State of Water Demand in Pakistan

Historical water demands:

Pakistan is very arid country, with a long-term mean precipitation rate of 365 mm per year, most of which is delivered during the monsoon season (June to August). Significant variation occurs between different regions of the country, with the southern regions (including the Baluchistan Plateau) being drier than the northern regions (Panday et al., 2011; Shrestha et al., 2015). The main source of renewable water in Pakistan is the Indus River and its tributaries. The Indus Basin provides approximately 80% of the water used in irrigated agriculture, which produces about 90% of agricultural output (Yu et al., 2013). A significant portion of the country's electricity also is generated from the rivers (Laghari et al., 2012). According to global water information system database, AQUASTAT, produced by the Food and Agriculture Organization (FAO, n.d.), the long-term basin-wide surface water availability is approximately 246.8 km3, of which about 55 km3 is internal renewable water.

In general, water demand is usually categorized into three main sectors: agricultural, municipal and industrial. In the Pakistani context, with the Indus Basin Irrigation System (IBIS) having been in operation since the British colonial period, the agricultural sector has always been the major component (almost 90%) of the country's total water demand. The IBIS is one of the largest canal irrigation systems in the world, spread over the flat plains of the Indus Valley, irrigating an area of 14.87 million ha (FAO, 2011). Figure 1 represents water availability and demand in Pakistan in 2008 (FAO, n.d.), recording water demand for the agricultural sector at 172.4 km3, for municipalities at 9.7 km3, and for industrial sectors at 1.4 km3.

Figure 2 and Table 1 show the historical trend of total water withdrawals as well as water withdrawals for each of the three key sectors. It can be observed that total demand has increased significantly during the last two decades compared the 1990s and the 1980s, by a rate ranging between 7% to 11%. The rate of increase in water demand for agriculture varied between 6% and 8%, while municipal water withdrawals grew by more than 150% between 1990 and 2000, and by 50% between 2000 and 2008. Interestingly, industrial water demand dropped during the last decade from 3.47 km3 to 1.4 km3 according to the FAO (n.d.) and the World Bank (2016). This negative trend in industrial water withdrawals might be attributed to the considerable economic variability that the country experienced in the mid-2000s (GOP & UNEP, 2013); several studies have reported that there is a linear relationship between Gross Domestic Product (GDP) and industrial water demand (Wada et al., 2011; Shen et al., 2008; Oki & Kanae, 2006).

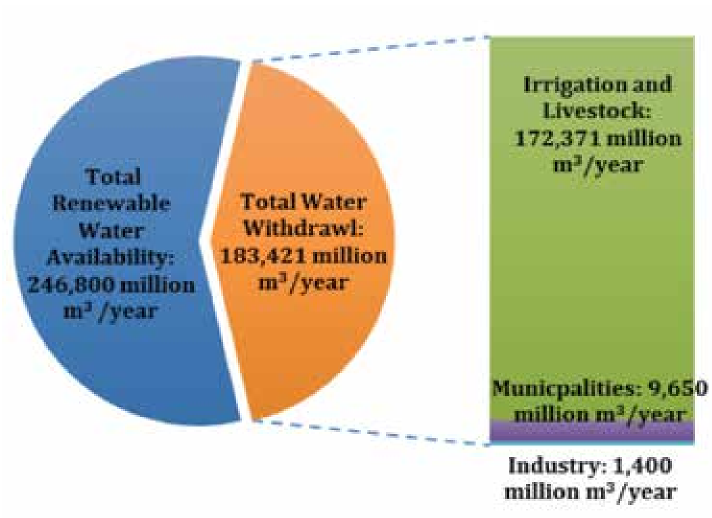


Figure 1. Water availability and demand in Pakistan in 2008.

Source: FAO (n.d.)

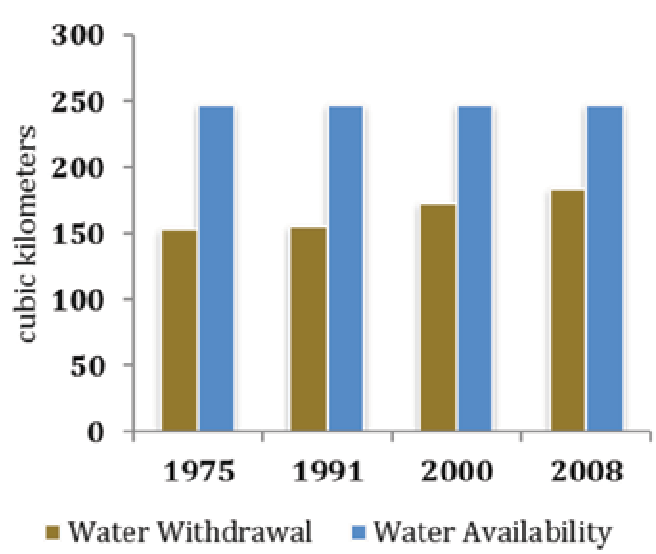


Figure 2. Historical water withdrawal and availability in Pakistan.

Source: FAO (n.d.)

Table 1. Historical water demand by sector in Pakistan.

Year	Agriculture (km3/year)	Industry (km3/year)	Municipal water (km3/year)	Total water withdrawal (km3/year)
1975	150.3	1.534	1.534	153.4
1991	150.6	2.5	2.5	155.6
2000	162.7	3.47	6.39	172.6
2008	172.4	1.4	9.65	183.5

Source: FAO (n.d.).

In any water demand study, population growth rate is one of the main parameters used when projecting future demand levels. Other parameters include water prices (prices elasticity), climate, regulations and economic development. In the Pakistani context, the most likely increase in future water demand will come from the expansion of cities and urban development (Mustafa et al., 2013).

Since Pakistan's independence in 1947, five national censuses were conducted in the years 1951, 1961, 1971, 1981 and 1998 (Amir & Habib, 2015). These censuses found high population growth rates in the country, ranging between 2.4% and 3.77% (see Table 2). The United Nation's Department of Economics (2015) estimated that Pakistan's population would grow to about 189 million people by 2015, and projected that the country's population would reach 245 million people in 2030 and 309 million people in 2050 (see Figure 3).

Table 2. Historical population distribution in Pakistan (in 1000s)

Year	Growth rate (in %)	Total Population	Population by province					
			Punjab	Sindh	KPK	Baluch-istan	FATA	Islam-abad
1951	-	33,740	20,541	6,048	4,557	1,167	1,332	96
1961	2.43	42,880	25,464	8,367	5,731	1,353	1,847	118
1972	3.77	65,309	37,607	14,156	8,389	2,429	2,491	238
1982	2.9	84,254	47,292	19,029	11,061	4,332	2,199	340
1998	2.7	132,352	73,621	30,440	17,744	6,566	3,176	805
2015	2.7-1.59	188,438	104,819	43,339	25,263	9,348	4,522	1,146

Source: Amir & Habib (2015)

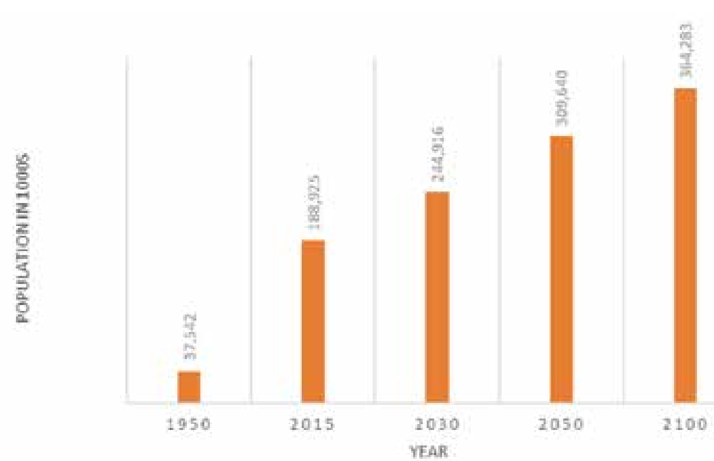


Figure 3. Projected population of Pakistan in thousands.

Source: UN (2015)

One of the most common approaches used to describe the degree to which a population is experiencing water scarcity is the ratio between the available renewable water resources and human population, which is referred to as annual per capita water. The Falkenmark water scarcity indicator is perhaps the most used measure on a country scale. Based on per capita usage, the water condition in a country is defined as presented in Table 3.

Table 3. Water scarcity indicator	
Index (m3 per capita)	Condition
>1,700	No Stress
1,000-1,700	Stress
500-1,000	Scarcity
<500	Absolute Scarcity
Source: Falkenmark (1989)	

Figure 4 shows the relationship between water availability, usage and population in Pakistan between 1967 and 2011. As it is evident from the figure, water availability per capita is declining dramatically in the country, having decreased from 5,260 m3 in 1951 to roughly 1,040 m3 in 2010 (Mustafa et al., 2013; Amir & Habib, 2015). Therefore, based on the United Nation's estimation for population in 2015, Pakistan is currently a water scarce country with less than 1,000 m3 of water available per capita.

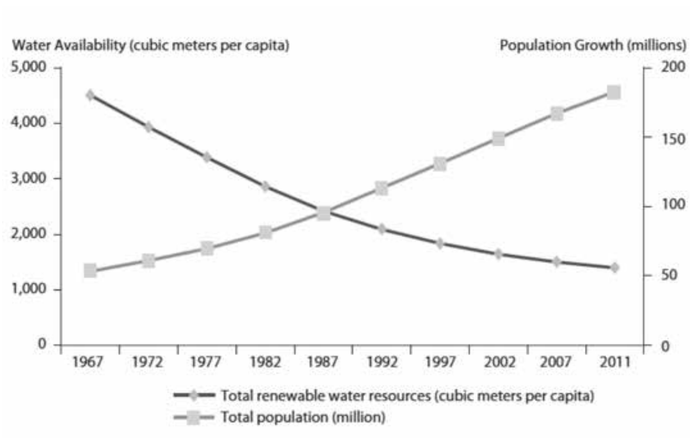


Figure 4. Population growth and water availability per capita.

Source: Mustafa et al (2013)

4. Future Water Demand Scenarios

The level of water demand in Pakistan will be determined by a range of interacting factors such as population growth, urbanization rates, economic development, agricultural production and climatic conditions. To inform estimates of future water demand in the country, four main drivers are considered: population dynamics, rates of municipal water withdrawals, estimated rates of industrial withdrawal and projected changes in agricultural water withdrawals. Expected trends within these key drivers have then been used to inform the development of five scenarios for future water demand out to 2050: a business-as-usual scenario; a moderate water demand management scenario; a strong water demand management scenario; an above business-as-usual scenario with exceeded extrapolation of current water demands; and a climate change scenario.

4.1 Assumed changes in key drivers of demand

Population dynamics:

As discussed in Section 3, the average annual population growth rate in Pakistan was 2.61% for the period 1961 to 2011. At the same time, the average growth rate of 1.81% for the last decade (2001 to 2011) suggests that population growth is declining (Mustafa et al., 2013). Nonetheless, population projections assume that there will be 309 million people in Pakistan by 2050 (UN, 2015), with the rate of urbanization rapidly increasing. Studies indicate that the proportion of Pakistanis living in urban areas was 38.8% in 2015 and will reach 46.6% in 2030 and 57.5% in 2050 (United Nations, 2014)

Municipal water withdrawals:

In this study, the forecast for the municipal water demand is based on the commitments of the National Drinking Water Policy (Government of Pakistan, 2009), which defines water access as the availability of 45 litres per capita per day (l/c/d) in rural areas and 120 l/c/d in urban areas (Amir & Habib, 2015). By using the anticipated changes in Pakistan's population structure (UN, 2014) and rates of water use per capita per day in urban and rural area, the projections presented in Table 4 were calculated for municipal water demand.

Table 4. Projection of municipal water withdrawals

Year	Urban		Rural		Total	
	Population (in millions)	Water Demand (billion m3)	Population (in millions)	Water Demand (billion m3)	Population (in millions)	Water Demand (billion m3)
2015	73.303	3.21	115.622	1.90	188.925	5.11
2030	114.131	5.00	130.785	2.15	244.916	7.15
2050	178.043	7.80	131.597	2.16	309,640	9.96

Industrial water withdrawals:

Water is used by the industrial sector in Pakistan for different industries such as textiles, food, chemicals and thermal generation (cooling systems) (Suttinon et al., 2009). In their study, Amir and Habib (2015) reported that there is minimal direct information available on water demand for the country's industrial sector. They therefore based their calculations on standard data and references from other countries (mostly India) and estimated industrial water withdrawals in 2005 at 2.5 billion m3.

Suttinon et al. (2009) calculated future water withdrawals for industrial purposes (for different groups of industries) in Pakistan as a function of the industrial GDP growth rate. They based their analysis of industrial water demand on two main variables: the economic value and the consumption of water unit (used in processes) per value of production. The economic value was calculated as industrial cost of production in monetary value by using the Supply and Use (Input-Output) tables produced by the National Accounts of Pakistan (1999-2000). Water consumption was then forecasted as the amount of water needed to produce a product in monetary term (e.g. m3 per day to produce 1US$ million) for each major industrial group.

Suttinon et al. (2009) used the year 2002 as the baseline for their calculations, and adopted the details of water use pattern in each industry from a case study from Thailand. They projected the water withdrawals for years 2020 and 2030 under three economic development scenarios: low (industrial GDP growth rate 2.7%), medium (6.9%) and high (9.7%). In this study, we adopted the approach used by Suttinon et al. (2009) to forecast industrial water use up to 2050 (see Figure 5).

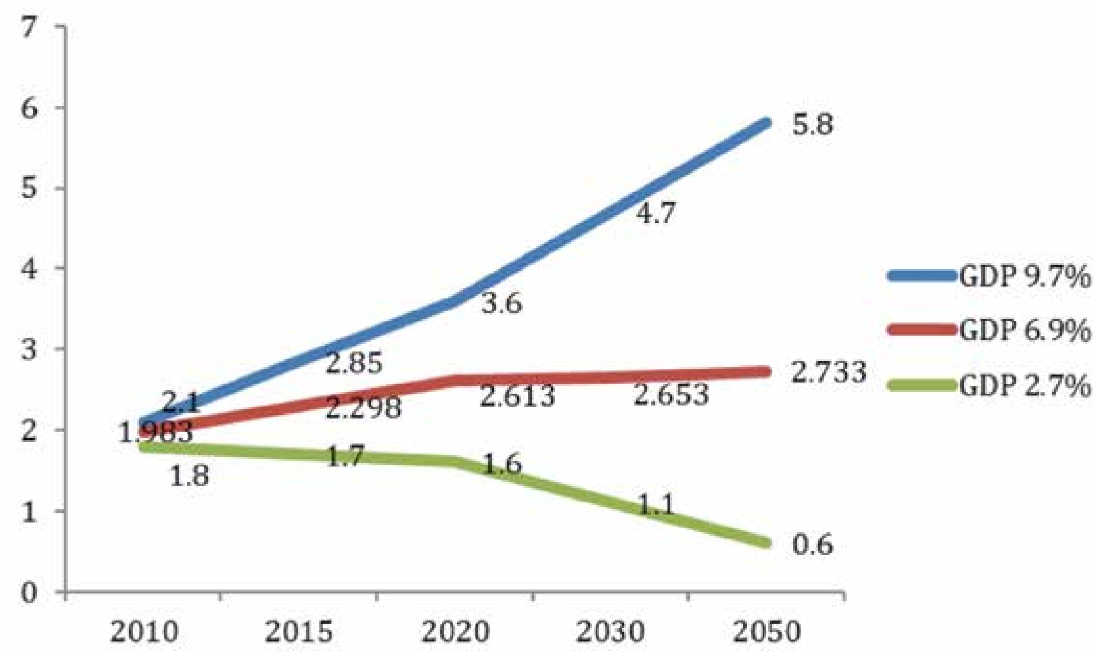


Figure 5. Projection on industrial water demands under three GDP growth rates.

Source: Adopted from Suttinon (2009)

Agricultural water withdrawals:

In Pakistan, the agricultural sector is characterized by increased demand for higher agricultural productivity, and the considerable low efficiency of the IBIS system (about 30% delivery ratio) due to age and poor maintenance (Qureshi, 2011; Bhatti et al., 2009). Pakistan's net sown area is repeatedly reported as having become almost stagnant at around 16 million hectares, while the cropped area still has a slightly positive trend (see Figure 6) (Amir & Habib, 2015).

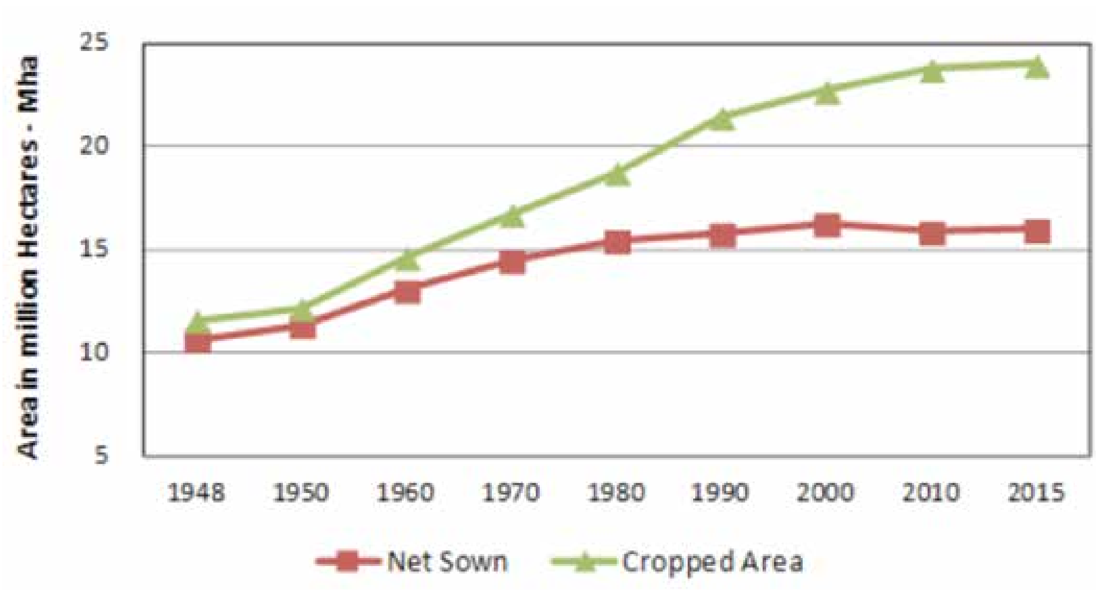


Figure 6. Total cropped and sown area of Pakistan.
Source: Amir & Habib (2015)

4.2 Future water demand scenarios

Business-as-usual scenario:

The business-as-usual scenario is based on the assumption that all of the parameters driving water demand in the municipal, industrial and agricultural sectors remain the same without considering the effects of climate change. Moreover, this scenario assumes that the irrigated area and level of irrigation system efficiency will follow the same trend as in the previous decade. The projection results from this scenario (Figure 7) show that there will be an increase in water demand of 15 km3 in 2050 compared to 2015. As a result of the projected significant increase in population and urbanization in 2050—309 million people, of which 57% is urban—domestic water demand will be almost double compared to 2015. However, water withdrawals from the industrial sector will only slightly increase (from 2.3 to 2.72 km3) based on an assumed industrial GDP growth rate of 6.9%.

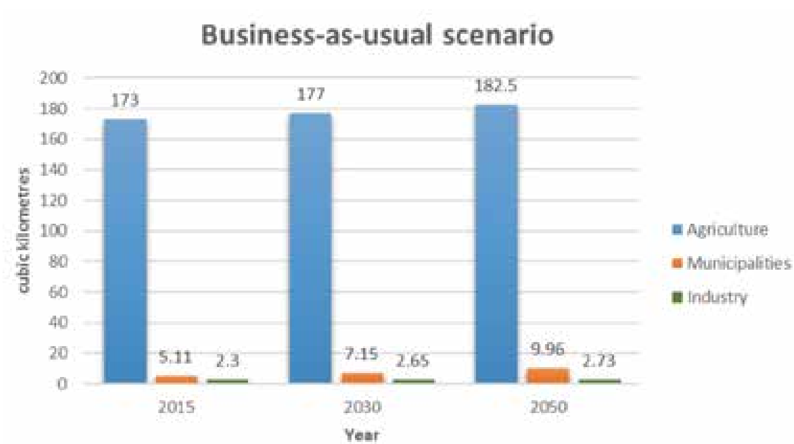


Figure 7. Business as usual scenario projections

Moderate water demand management scenario:

The scenario examines the effects of a moderate water demand management policy with technical interventions to increase the average delivery ratio from 30% to about 37%. This improved efficiency could be achieved through more sustainable irrigation methods such as sprinkler or drip irrigation. This scenario assumes that all other factors remain with the same as in the business-as-usual scenario. The results (Figure 8) show that although the growth rate of agriculture has been kept the same, water withdrawals for 2030 and 2050 have significantly decreased. The amount of water that will be conserved under this scenario compared to the business-as-usual scenario is about 11 km^3 in 2030 and 12.5 km^3 in 2050.

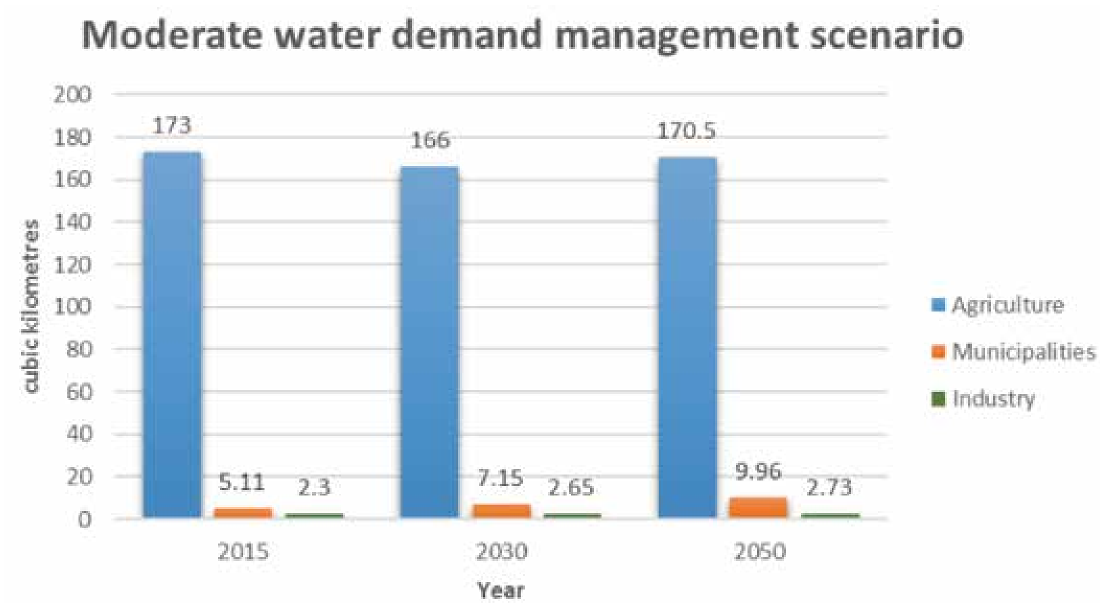


Figure 8. Moderate water demand management scenario projection.

Strong water demand management scenario:

In this scenario a greater number of measures are assumed to be taken to better manage water demand in the agricultural sector. The scenario does not take into consideration the potential impacts of climate change and assumes that all other factors remain the same as in the business-as-usual scenario. Assuming that the overall efficiency of Pakistan's irrigation system increases to 45%, the scenario projects that agricultural water demand will decline by 10 km3 in 2030 and 7 km3 in 2050 from the current water demands.

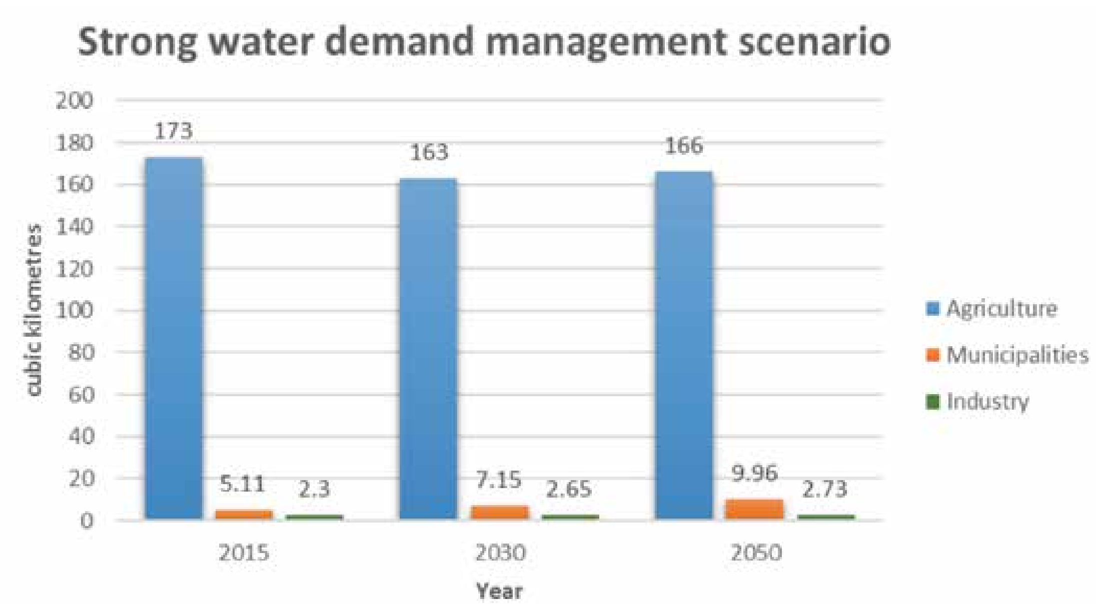


Figure 9. Strong water demand management scenario projection

Above business-as-usual scenario with exceeded extrapolation of current water demands:

This scenario projects water demand (Figure 10) for a scenario in which demand exceeds the extrapolation of current water demand levels (i.e. greater than the business-as-usual scenario) due to greater economic development and a larger rate of population growth (a 15% increase compared to that estimated by the UN), which would affect the growth in municipal water demand. To reflect the impact of a higher rate of economic development, the industrial GDP growth rate was increased from the medium projection used by Suttinon et al. (2009) of 6.9% to the high industrial GDP growth rate of 9.7%. To account for the higher rate of growth in municipalities water demand, the figures in Table 4 were re-calculated using a new rate of population growth of 15%. As a result, total water demand for this scenario increased by about 3 km3 in 2030 and 5 km3 in 2050 compared to the same years in the business-as-usual scenario.

Climate change scenario:

The climate change scenario takes into consideration the impact of rising temperatures on water demand while assuming no change in demand management efforts, and keeps all other factors the same. Based on available temperature and precipitation projections for Pakistan, a 3°C rise in temperature was adopted to represent the impact of climate change. Amir and Habib (2015) in their study reported that a temperature increase of 3°C by 2050 could result in an increase in agricultural water requirements of 6% by 2025 and 12 to 15% by 2050. The results of the projections in this scenario show a dramatic increase in water demand to 206.2 km3 in 2050 compared to 182.5 km3 for the same year in the business-as-usual scenario.

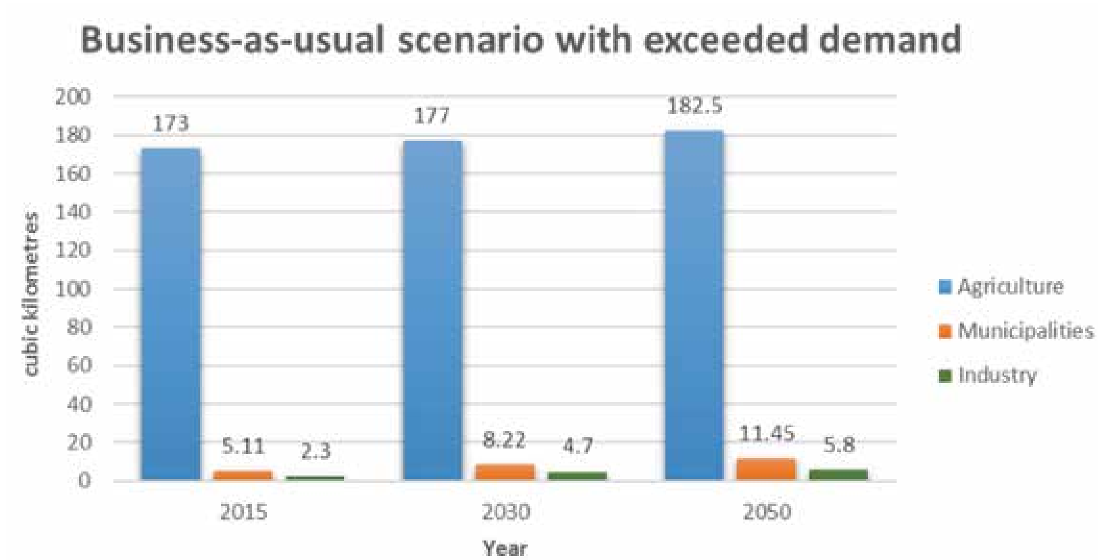


Figure 10. Business as usual scenario with exceeded demand

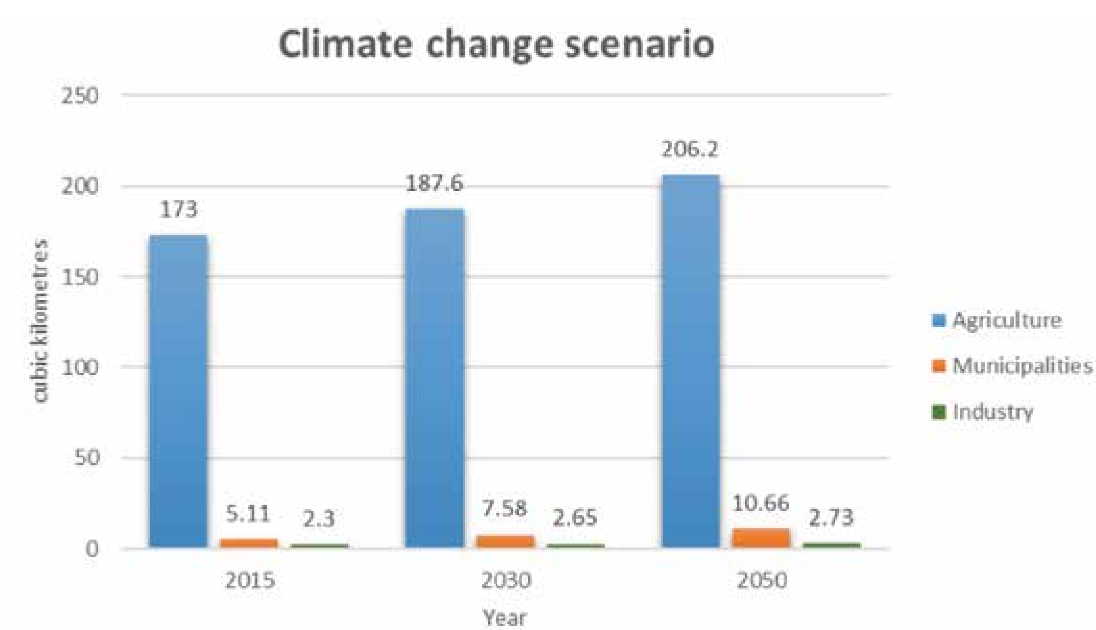


Figure 11. Climate change scenario projections

5. Discussion

After conducting this review, a number of general observations can be made regarding the nature and availability of literature related to current and future water demand in Pakistan:

- Only a limited number of studies are available that address various types of water demand in Pakistan, an observation also made by Amir and Habib (2015) in their comprehensive study;

- Most available studies are high level and use data that is "aggregated" to the national level. Thus, they lack details on the potential implications of increasing water demand in different regions of the country. Moreover, the literature lacks information about industrial water demands and the trade-off between irrigation needs and hydropower generation;
- Most of the future projections on water demand are based on simple linear regression models, which is mainly attributed to the limited availability of time series data.

Based on this study, it is clear that in the absence of moderate to strong water conservation measures there will be a significant increase in the level of water demand, and the gap between water demand and water availability will become wider, particularly when the impacts of climate change are taken into consideration. Temperature increases by 2050 as a result of global warming will have the greatest impact on the water demand levels. To date, however, Pakistan has not undertaken significant scientific research to better understand the impact of climate change on future water demand, particularly within the agriculture sector.

6. Conclusions

This paper sought to develop a macro-level understanding of projected changes in water demand in Pakistan. Using secondary sources, it assessed potential demand for water in Pakistan in 2050 under five different scenarios. Based on the completed analysis, the following key messages emerge:

- The current classification of Pakistan on most international water stress indices is as a water stressed country, with water availability per capita just above 1000 m3 and decreasing exponentially as the population continues to grow.
- Total water demand under a business-as-usual scenario is projected to be almost 200 km3 by 2050, of which agricultural demand would be 182 km3.
- The water demand management scenarios show that just increasing irrigation efficiency by ratios as small as 7% and 10% can conserve a considerable amount of water—approximately 10 km3 to 15 km3 respectively.
- Climate change will have a significant impact on future water demand, with a temperature increase of 3°C potentially increasing water demand in 2050 by almost 24 km3 compared to the business-as-usual scenario.

References

Amir, P. and Habib, Z., (2015). Estimating the impacts of climate change on sectoral water demand in Pakistan. Action on Climate Today.

Bhatti, A. M., Suttinon, P., & Nasu, S. (2009). Agriculture water demand management in Pakistan: a review and perspective. Society for Social Management Systems, 9(172), 1-7.

Falkenmark, M. (1989). The massive water scarcity now threatening Africa: why isn't it being addressed? Ambio, 112-118.

Food and Agriculture Organization (FAO). (no date). AQUASTAT Home [web site]. Retrieved from http://www.fao.org/nr/water/aquastat/main/index.stm

Food and Agriculture Organization (FAO). (2011). Indus basin. Retrieved from http://www.fao.org/nr/water/aquastat/basins/indus/index.stm

Government of Pakistan (2009). National Drinking Water Policy. Ministry of the Environment. Retrieved from: http://environment.gov.pk/NEP/DWPolicyOct2009.pdf

Government of Pakistan (GOP) and the United Nations Environment Programme (UNEP). (2013). The Environment and Climate Change Outlook for Pakistan. Retrieved from http://www.mocc.gov.pk/gop/index.php?q=aHR0cDovLzE5Mi4xNjguNzAuMTM2L21vY2xjL2ZybURldGFpbHMuYXNweD9pZD00JmFtcDtvcHQ9cHVibGljYXRpb25z

International Monetary Fund. (2015). Issues in managing water challenges and policy instruments: Regional perspectives and case studies. Retrieved from http://www.imf.org/external/pubs/ft/sdn/2015/sdn1511tn.pdf

Laghari, A. N., Vanham, D., & Rauch, W. (2012). The Indus basin in the framework of current and future water resources management. Hydrology and Earth System Sciences, 16(4), 1063-1083.

Mustafa, D., Akhter, M., & Nasrallah, N. (2013). Understanding Pakistan's water-security nexus. United States Institute of Peace, 2301.

Oki, T. & Kanae, S. (2006). Global hydrological cycles and world water resources. Science, 313(5790), 1068-1072.

Organization for Economic Cooperation and Development (2005). Glossary of Statistical Terms: Physical supply and use tables. [web page] Retrieved from https://stats.oecd.org/glossary/detail.asp?ID=6541

Panday, P., K. Frey, B. Ghimire (2011). 'Detection of the timing and duration of snowmelt in the Hindu Kush-Himalaya using QuikSCAT, 2000–2008', Environmental research letters, 8 (1): 014020-014033.

Qureshi, A. S. (2011). Water management in the Indus basin in Pakistan: challenges and opportunities. Mountain Research and Development, 31(3), 252-260.

Shen, Y., Oki, T., Utsumi, N., Kanae, S., & Hanasaki, N. (2008). Projection of future world water resources under SRES scenarios: water withdrawal. Hydrological Sciences Journal,53(1), 11-33.

Shrestha, A., Agrawal, N., Alfthan, B., Bajracharya, S., Maréchal, J., van Oort, B. (Eds.), 2015. The Himalayan Climate and Water Atlas: Impact of Climate change on water resources in five of Asia's major river basins. ICIMOD, GRID-Arendal and CICERO, Kathmandu, Nepal.

Suttinon, P., Bhatti, A. M., & Nasu, S. (2009). Industrial and household water demand management: a case study of Pakistan.

United Nations. Department of Economic. (2014). World Urbanization Prospects 2014: Highlights. United Nations Publications.

United Nations. Department of Economic. (2015). World Population Prospects: The 2015 Revision. United Nations Publications.

Wada, Y., Van Beek, L. P. H., & Bierkens, M. F. (2011). Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability. Hydrology and Earth System Sciences,15(12), 3785-3808.

World Bank (2016). Data: Pakistan. Retrieved from http://data.worldbank.org/country/pakistan

World Wildlife Fund (WWF). (2003). Agricultural water use and river basin conservation. Gland. Switzerland.

Yu, W., Yang, Y. C., Savitsky, A., Alford, D., Brown, C., Wescoat, J., & Debowicz, D. (2013). The Indus basin of Pakistan: The impacts of climate risks on water and agriculture. World Bank Publications.

Annex A: Identified Sources

The following sources have been identified as being relevant for informing the content of the water demand report:

Archer, D. R., Forsythe, N., Fowler, H. J., & Shah, S. M. (2010). Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions. Hydrology and Earth System Sciences, 14(8), 1669-1680.

Amir, P. & Habib, Z. (2015). Estimating the impacts of climate change on sectoral water demand in Pakistan. Action on Climate Today.

Bhatti, A. M., Suttinon, P., & Nasu, S. (2009). Agriculture water demand management in Pakistan: a review and perspective. Society for Social Management Systems, 9(172), 1-7.

Falkenmark, M. (1989). The massive water scarcity now threatening Africa: why isn't it being addressed? Ambio, 112-118.

Kahlown, M. A., & Majeed, A. (2003). Water-resources situation in Pakistan: challenges and future strategies. Water Resources in the South: Present Scenario and Future Prospects, 20.

Laghari, A. N., Vanham, D., & Rauch, W. (2012). The Indus basin in the framework of current and future water resources management. Hydrology and Earth System Sciences, 16(4), 1063-1083.

Majeed, Z., & Piracha, A. (2011). Water Conservation of Pakistan's Agricultural, Municipal and Industrial Water. International Journal of Water Resources and Arid Environment, 1(3), 232-8.

Mustafa, D., Akhter, M., & Nasrallah, N. (2013). Understanding Pakistan's water-security nexus. United States Institute of Peace, 2301.

Naheed, G., & Rasul, G. (2010). Projections of crop water requirement in Pakistan under global warming. Pakistan Journal of Meteorology, 7(13), 45-51.

Oki, T. & Kanae, S. (2006). Global hydrological cycles and world water resources. Science, 313(5790), 1068-1072.

Panday, P., K. Frey, B. Ghimire (2011). Detection of the timing and duration of snowmelt in the Hindu Kush-Himalaya using QuikSCAT, 2000–2008, Environmental research letters, 8 (1): 014020-014033.

Piracha, A., & Majeed, Z. (2011). Water use in Pakistan's agricultural sector: water conservation under the changed climatic conditions. Water Resour. Arid Environ, 1(3), 170-179.

Qureshi, A. S. (2011). Water management in the Indus basin in Pakistan: challenges and opportunities. Mountain Research and Development, 31(3), 252-260.

Seckler, D. W. (1998). World water demand and supply, 1990 to 2025: Scenarios and issues (Vol. 19). International Water Management Institute.

Shen, Y., Oki, T., Utsumi, N., Kanae, S., & Hanasaki, N. (2008). Projection of future world water resources under SRES scenarios: water withdrawal/Projection des ressources en eau mondiales futures selon les scénarios du RSSE: prélèvement d'eau. Hydrological Sciences Journal,53(1), 11-33.

Shrestha, A., Agrawal, N., Alfthan, B., Bajracharya, S., Maréchal, J., van Oort, B. (Eds.) (2015). The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins. ICIMOD, GRID-Arendal and CICERO, Kathmandu, Nepal.

Suttinon, P., Bhatti, A. M., & Nasu, S. (2009). Industrial and household water demand management: a case study of pakistan.

United Nations. Department of Economic. (2014). World Urbanization Prospects 2014: Highlights. United Nations Publications.

United Nations. Department of Economic. (2015). World Population Prospects: The 2015 Revision. United Nations Publications.

Wada, Y., Van Beek, L. P. H., Viviroli, D., Dürr, H. H., Weingartner, R., & Bierkens, M. F. (2011). Global monthly water stress: 2. Water demand and severity of water stress. Water Resources Research, 47(7).

Wada, Y., Van Beek, L. P. H., & Bierkens, M. F. (2011). Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability. Hydrology and Earth System Sciences,15(12), 3785-3808.

Wada, Y., Wisser, D., Eisner, S., Flörke, M., Gerten, D., Haddeland, I., ... & Tessler, Z. (2013). Multimodel projections and uncertainties of irrigation water demand under climate change. Geophysical research letters, 40(17), 4626-4632.

World Wildlife Fund (WWF). (2003). Agricultural water use and river basin conservation. Gland. Switzerland.

Appendix 4: Energy Policy Brief

Climate Change Implications for Future Energy Development in Pakistan

A briefing paper prepared as part of the project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action" - May 2016

Prepared by: Anika Terton, International Institute for Sustainable Development

1. Introduction

This briefing paper outlines the current state of Pakistan's energy supply sector, with a specific focus on thermal power and hydroelectric power production, and how its future development plans could be affected by climate change. It has been completed as part of "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action" project led by the Ministry of Climate Change and implemented in partnership with the United Nations Development Programme—Pakistan, the Centre for Climate Research and Development at COMSATS Institute of Information Technology Islamabad, Pakistan, and the International Institute for Sustainable Development (IISD), Canada. The analysis of future trends in energy production draws on research completed as part of the IISD-led Low Carbon Scenario Analysis project.

2. Pakistan's energy sector

Pakistan's energy sector faces a continuous series of crises, characterized by power outages, cuts and rotational load shedding. The country also experiences concurrent water shortages and has been identified as one of the most water stressed countries in the world (ADB, 2013). With a surging population estimated at 185 million (World Bank, 2016) and projected to grow, increasing urbanization and an expanding industrial base, the demand for energy and water is reaching new heights in Pakistan.

Pakistan relies mainly on hydro and oil for its generation of power from modern sources, as well as natural gas, resulting in a total electricity generation capacity of 23,412 megawatts (MW) (in 2011). Based on 2010-11 figures, Pakistan's total mix of modern energy sources was comprised of 65 percent thermal generation, 28 percent hydropower, 3 percent nuclear power generation, and 1 percent comes from other sources, including coal, wind and solar (UNIDO, 2013).

Electricity generation is mainly carried out by the public sector and independent power producers. The three public corporate entities responsible for electricity generation are the Pakistan Atomic Energy Commissions (PAEC), which is responsible for energy produced from nuclear resource; the Water and Power Development Authority (WAPDA), which is responsible for water and hydropower development; and the Pakistan Electric Power Company (Pepco), which handles the management of WAPDA's 14 public limited companies in thermal power generation, transmission, distribution and billing. All three entities report to the Ministry of Water and Power. Two other public entities also report to the Ministry of Water and Power: the Private Power and infrastructure Board (PPIB) and the Alternate Energy Development Board (AEDB) (International Business Publications, 2015).

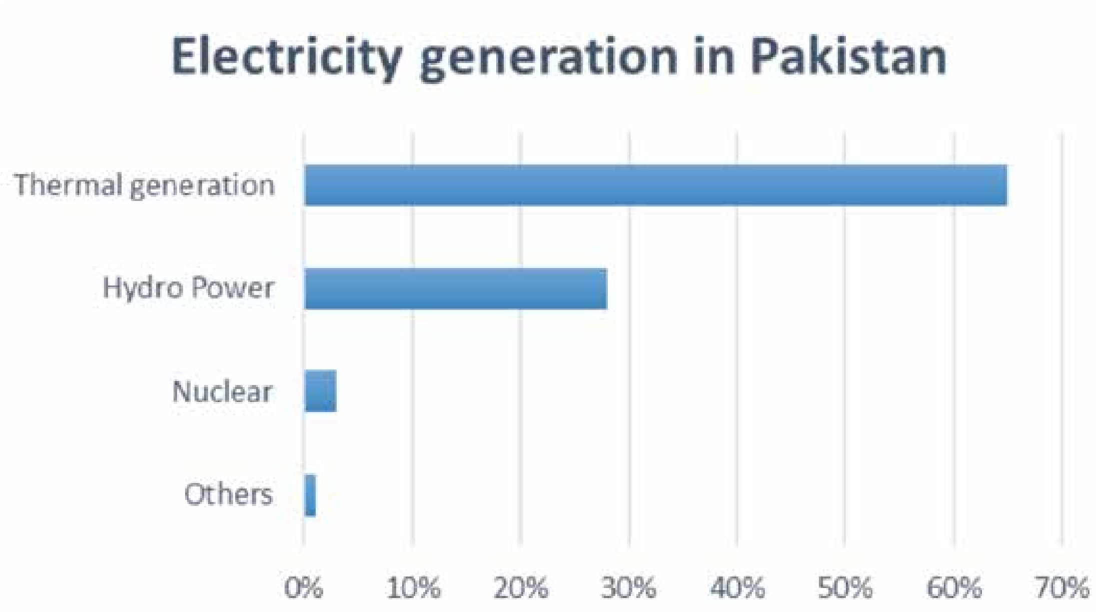


Figure 1. Electricity generation in Pakistan

Source: Adapted from UNIDO, 2013

The severe electricity crisis currently facing Pakistan reflects a growing gap between demand and supply over the past several years (Qureshi & Akintug, 2014). According to the National Transmission and Despatch Company (NTDC), electricity consumption is set to continue to increase at a rate of about 8 percent each year (NTDC, 2011). Successive governments have set tariffs on electric utilities below the cost recovery level and funded the difference in the form of subsidies. The gap between the high cost for power generation and regulated electricity prices resulted in utilities being unable to cover the cost of production and investments. Attempts to restructure and liberalize the electricity market in Pakistan have been difficult, resulting in sub-marginal electricity tariffs, unpaid bills, and power shortages. For instance, Pakistan experienced a shortfall of almost 6,000 MW in the year 2011-12, as the demand was at 18,876 MW and supply remained at 12,775 MW, leading to brownouts and blackouts across the country and power rationing (Qureshi & Akintug, 2014; PPIB, 2013). Additionally, the country is dealing with an inefficient power transmission and distribution system that currently records losses of 23-25 percent due to poor infrastructure, mismanagement and theft. In response, the Government of Pakistan has developed a power policy to support the current and future energy needs of the country that sets key targets in terms of the demand-supply gap, affordability, efficiency, financial viability and governance of the systems (PPIP, 2013).

3. Thermal power generation in Pakistan

Thermal power generation in Pakistan is derived from oil and coal. Oil is mostly imported by Pakistan, arriving in the form of crude oil and finished gasoline products. Petroleum imported in 2014-15 was worth $11.7 billion, a major portion of the country's trade bill (Muzamil, 2015).

A key petroleum product produced is furnace oil, the use of which increased substantially due to the build-up of thermal power plants. Installing furnace oil based power plants is considered a cheap and quick method to produce electricity in large quantities. Furnace oil also often sells at a lower price compared to diesel or gasoline. Between 2002 and 2008, furnace oil had become very expensive, but is now more affordable again due to low crude oil prices (Muzamil, 2015; ICCI, n.d.).

Currently, thermal power generation stands at about 13,670 MW and generates 65 percent of Pakistan's electricity. At present, Pakistan has 44 existing thermal power stations in service, including those operated by independent power producers and state-owned generation companies (Q. Sabir, p. comm., May 13, 2016). Thermal power generation faces a number of issues due to a highly politicized government-controlled power sector, with the government unable to improve poor performance. The state-owned plants have low conversion efficiencies, are costly to maintain and operate, and face limitations of the transmissions and distribution system. Privately owned power-sector thermal power plants are more efficient but suffer from fuel availability and circular debt problems resulting in their under-utilization (International Business Publications, 2015).

The majority of existing plants can be found in Punjab and Sindh, Pakistan's most populous, urbanized and industrialized provinces, which demand large amounts of water and energy. The Indus River provides key water resources for both provinces, in particular the breadbasket of Punjab province, which accounts for most of the nation's agricultural production.

Future development plans

While Pakistan's energy portfolio is complemented by an increasing share of natural gas and renewable energy sources, one of the largest coal deposits in the world was discovered in the country in 1991, the Thar coalfield (Muzamil, 2015). This has raised questions regarding the potential to convert existing fuel oil fired power plants to coal, using local resource deposits. At present, Pakistan operates only one coal-fired power plant but is currently constructing and proposing 11 projects, including a proposal by China (Gadani Energy Park) to install 10 coal power plants of 660 MW each at a cost of $1.4 billion (The Express Tribune, 2014). However, large uncertainties remain around the actual implementation of the project due to a lack of investor commitment and economic viability (Ghumman, 2015). As per data provided by the Planning Commission of Pakistan, 24 more new independent power producer plants will be added by 2025 (Q. Sabir, p. comm., May 13, 2016), which could substantially add to the country's power generation capacity. Future development plans could also be influenced by the government's decision to further privatize public sector thermal power plants, which would create incentives for power generation companies to strengthen their technical capabilities, make plants fully operational, and also improve their efficiency.

Implications of climate change

Thermal power production is sensitive to climatic changes given its high dependence on the use of water resources as well as its sensitivity to temperature changes. Thermal power plants generate electricity by converting heat into power. Most heat water to transform it into steam, which spins the turbines that produce electricity (UOCS, n.d.). After passing through the turbine, the steam is cooled down and condensed to start the cycle again. All power plants need to cool down the steam and most of them use water to do so, which requires them to be near a water source, such as a river, lake or ocean. The process of power generation from thermal power plants therefore consumes large amounts of water and cooling steam, with usually about 90 percent of the total water amount being used for cooling purposes. The efficiencies of a thermal power plant can be affected by the cooling methods deployed, not so much by the type of fuel that is used. For example, dry cooling requires less water than cooling towers (GWF, 2015).

A systematic review of recent projections of water supply in the Indus River Basin indicates that availability will not change significantly in the short and mid-term (i.e. prior to 2050) but could result in a shift in the timing of the peak flow (Immerzeel et al., 2009). While the results of future projections and modelling for longer terms appear to be inconclusive, some modelling efforts conclude that even a 50 percent reduction in glacial cover will not change discharges to the Indus River significantly as loss of glacial meltwater will be counterbalanced by runoff from increased rainfall.

However, projected increases in air temperatures may affect thermal power plants by decreasing the efficiency of the thermal conversion process. Within this process, thermal energy is converted into mechanical energy and then into electrical energy using steam turbines that depend on thermodynamics of the heat cycle (heat and temperature and their relation to energy and work). The efficiency of this process is "determined by the temperature of the heat source and the heat sink (air or water)." An increase in air temperature would lead to reduced efficiency of the process resulting in a loss of production or electrical output (Makky & Kalash, 2013). For gas turbines, a small number of studies estimated that a rise of 5.5°C in ambient air temperature may reduce output by approximately 3 to 4 percent (ADB, 2012).

While the projections foresee limited changes in water supply in the near- and medium-term, climate change is likely to lead to an increase in water demand by the thermal sector. However, it appears national planning for power generation does not fully account for the issue of long-term water demand in the country. In order to make informed decisions and avoid irreversible consequences, it will be crucial to understand water and energy interdependencies, along with a full understanding of what the water requirements of thermal power stations in Pakistan are now and in the future. No figures or information were available about the water use intensity of thermal power plants according to fuel type and cooling system. This kind of information and data could inform decisions such as retrofitting cooling systems or switching to more efficient cooling methods that would allow a reduction in water demand, especially in areas where priority is given to other water uses, such as irrigation.

4. Hydroelectric power production in Pakistan

Pakistan is a country with abundant hydropower resources that is keen to facilitate private investors to promote hydropower generation as it presents a stimulator for the socio-economic uplift of the country. Moreover, as a country with limited fossil fuel reserves, hydropower systems present strong economic incentives (Siddiqi et al., 2012) and simultaneously can be a catalyst for climate change mitigation (MOCC, 2015).

The hydropower sector is managed by the Water and Power Development Authority, which is also the largest electric power producer in Pakistan. It is estimated that Pakistan has hydropower potential of about 60,000 MW, almost all of which lie in the provinces of Khyber Pakhtunkhwa, Gilgit-Baltistan, Punjab and Azad Jammu and Kashmir (PPIB, 2011). The total installed capacity of hydropower capacity was 6,720 MW as of 2010, which represents only 11 percent of the country's total proved hydropower potential. Figure 2 presents an overview of the total hydropower potential by province, followed by Figure 3 that categorizes hydropower potential in terms of available basin, river, and small hydel potential sites available in the country. Out of the 60,000 MW, 75 percent of all hydropower potential in Pakistan is contained in the Indus River Basin (Qureshi & Akintug, 2014).

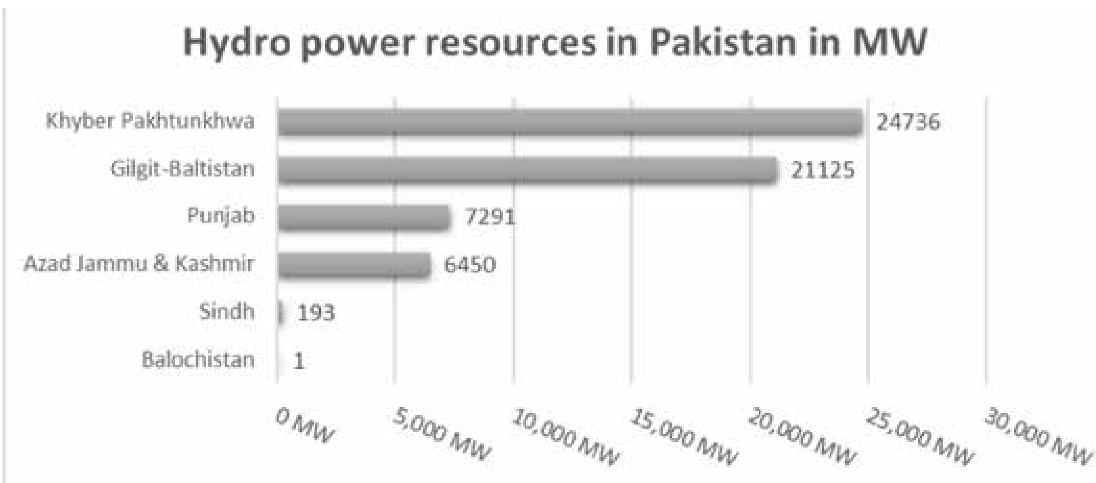


Figure 2. Hydropower resources in Pakistan in MW

Source: Private Power and Infrastructure Board, 2011

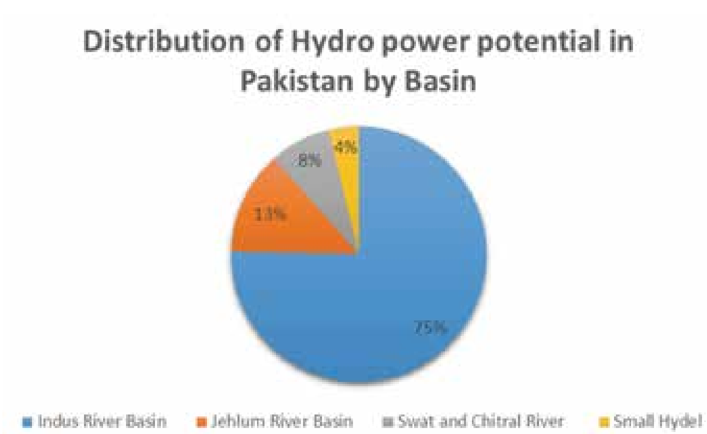


Figure 3: Distribution of hydro power potential in Pakistan by Basin

Source: Qureshi and Akintug, 2014

Figure 4 provides an overview of how the total installed capacity of hydropower projects is distributed among the provinces. Up to 2010, the country produced 6,720 MW, out of which 3,849 MB was in Khyber Pakhtunkhwa, 1,699 MW in Punjab, and 1,039 MW in Azad Jammu and Kashmir. This distribution reflects the greater potential for hydropower generation in Pakistan's northern mountainous areas. Hydropower resources located in the southern part are scarce and mainly comprised of small to medium schemes on barrages and canal falls (PPIB, 2011).

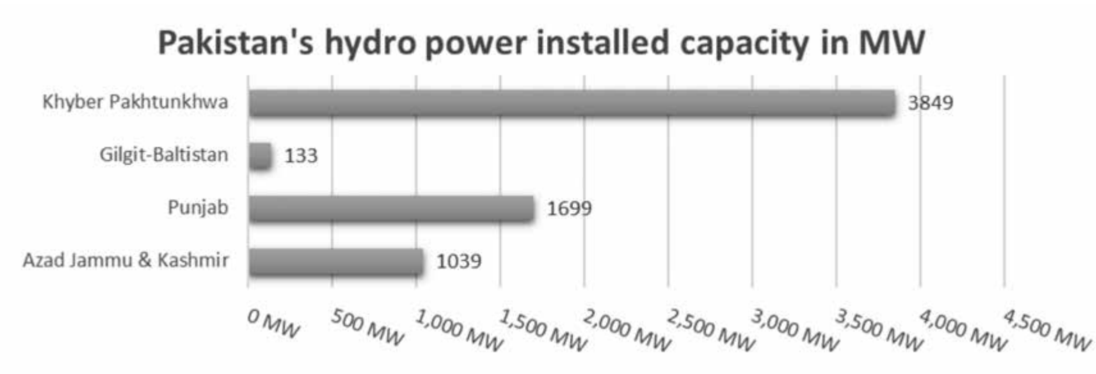


Figure 4: Pakistan's hydropower installed capacity

Source: Private Power and Infrastructure Board, 2011

Future development plans

Given the deepening energy and water crises in Pakistan and the large potential and characteristics of hydropower in promoting the country's energy security and flexibility in system operation, the government has tried to accelerate hydropower development through a number of policy initiatives. Through its Integrated Energy Plan 2009-2022, the Government of Pakistan developed a long-term plan to ensure energy security with major emphasis on indigenous energy resources. The plan lays out how all energy resources are utilized to meet the growing energy demand of the country. For the production of hydropower, the plan mandates to increase capacity to 17,392 MW by the fiscal year 2022-23 "at any cost," emphasizing the secondary goal of hydropower projects ability to store water to meet water requirements. According to the plan, this would require simultaneously constructing 3 to 4 large dams (MOF, 2009).

The country's National Power Policy sets out a vision for Pakistan to develop the most efficient and consumer centric power generation system that meets the needs of its population and boosts its economy in a sustainable and affordable manner. It therefore emphasizes the government's intention to significantly push towards building medium and long-term hydel capacity in the country, including large scale hydro projects such as Bunji (7,100 MW potential) and Diamer-Bhasha (4,500 MW potential) that could move Pakistan closer to energy independence and security (PPIB, 2013). At the same time, it would also reduce its dependency on any single source, particularly imported fossil fuels.

WAPDA has been working on an ambitious plan called the National Water Resources and Hydropower Development Programme Vision 2025 with the goal to develop 16,000 MW of hydropower capacity. Further objectives include to compensate and adjust for predicted climatic changes, protect the agricultural sector from droughts, increase reservoir capacities and prevent water shortages in the future (MWP, 2003).

Over time, a lot of feasibility studies and engineering design work has been carried out to determine the country's hydropower potential. Table 1 presents large-scale hydropower projects that are currently under consideration until 2030. If developed, the projected hydropower generation of these projects alone would be 25,530 MW by 2030 (IISD, forthcoming). Based on the projects that are under implementation (mostly small hydel projects) along with the ones under consideration, the total hydel capacity can be expected to potentially grow to 42,765 MW by the year 2030 (IISD, forthcoming). Given that the current installed hydropower capacity in Pakistan is 6,720 MW (PPIB, 2011), this represents approximately a six-fold future increase.

Table 1: Large-scale Hydropower projects currently under consideration until 2030

Name of Project	Potential Capacity (in MW)
Bunji	7100
Dasu	4320
Diamer Basha Dam	4500
Kohala	1100
Munda (Mohamand)	800
Patan	2300
Tarbela 4th extension	1410
Thakot	4000
TOTAL	25530

Source: IISD, Low-Carbon Scenarios Analysis for Pakistan (forthcoming)

While there is a reliable level of certainty for smaller future hydropower projects to be built in Pakistan, large projects encounter a number of barriers. Large hydropower projects have a number of social, political and technical issues associated with them. Various factors have contributed to the slow pace of hydropower development in Pakistan such as the lack of adequately investigated projects, environmental concerns, resettlement and rehabilitation issues, land acquisition problems, regulatory issues, long clearance and approval procedures, power evacuation problems and, in some cases, inter-provincial issues and law and order problems. Over the past three decades, construction of new dams on the Indus River system have been a major source of conflict between the upper and lower riparian provinces. The Province of Sindh has been strongly opposing new dams on the Indus River due to concerns about the socio-economic impacts of large dams, particularly on the province's flood plains and delta (Bhutto et al., 2012). Finding appropriate financing models adds another barrier. Lengthy lead times for planning, permitting and construction along with high-up front cost create a challenging environment for private investment (Siddiqi et al., 2012).

In comparison, small hydropower projects (up to 25 MW) have emerged as an alternative and preferred option, especially in mountainous terrain. Small hydro systems are beneficial from a variety of perspectives, including low upfront cost, suitability for private sector development, and minimal or no requirement for power transmission infrastructure (which makes them ideal for deployment in rural areas), along with reduced impacts on the environment. The development of these projects has been actively encouraged and projects have been given exemptions from initial environmental examination requirements (Siddiqi et al., 2012; Bhutto et al., 2012). While small and micro hydropower projects are a beneficial tool for local sustainable energy development, in particular in mountainous off-grid areas, the scale of power they generate will not meet the growing energy demand Pakistan is experiencing in highly populated and industrialized regions. Nonetheless, they provide a suitable option for mountain and isolated rural communities.

Despite the potential of hydropower to contribute to Pakistan's future energy demands, mitigate hazardous greenhouse gas emissions and other vital services, such as water storage capacity, a substantial increase in hydropower development remains uncertain. In response to the pressures of large-scale hydropower projects and historical experience, it is likely that the list of projects currently designated as "under implementation" may in realty either take years for commissioning or will never be built. Based on the former, Figure 5 compares two future scenarios, one that considers full implementation of all hydropower projects currently "under implementation" and "under consideration," while the second excludes the projects listed in Table 1 due to the likelihood that they will not be implemented fully considering their size and the socio-political barriers that they would have to overcome.

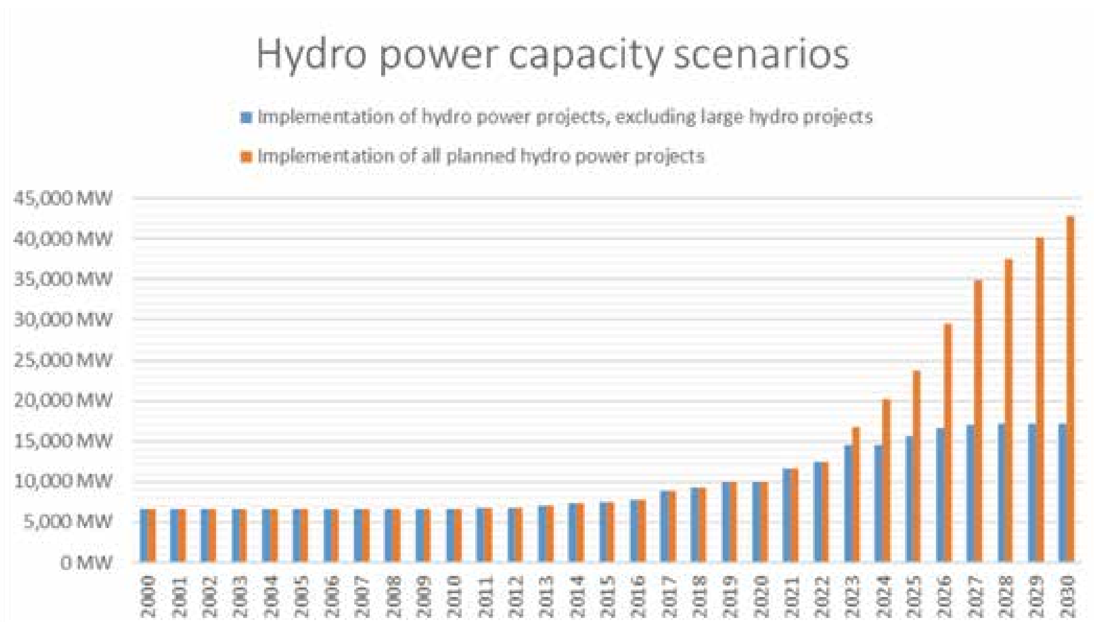


Figure 5: Hydropower capacity scenarios in Pakistan

Source: IISD, Low-Carbon Scenarios Analysis for Pakistan (forthcoming)

Implications of climate change

In spite of the challenges large-scale hydro power projects face, both future scenarios presented in Figure 5 foresee a growth in installed hydropower capacity in Pakistan. Climate change will present an additional stressor as potential changes in patterns of monsoon rains, winter precipitation, and snow and ice melt could alter the spatial and temporal distribution of water. Significant uncertainties remain regarding not only how each of these regimes will be affected by climate change but the interplay between them and therefore the collective outcome of these changes. It is therefore important to provide a better understanding of how the possibility for changing flows and hydrology of the Indus River may lead to an increase or decrease in hydropower potential. Subsequently, this could inform decision-makers if large-scale hydro projects are the most optimal and feasible option compared to alternatives, such as a combination of small, medium and large hydropower projects or alternative energy sources to achieve the country's objectives laid out in the National Power Policy.

Depending on the expected lifespan of newly installed hydro dams, the progressive loss of glaciers beyond the middle of this century and its potential impacts on water flows in the Indus River in the 2100s could potentially affect hydroelectric generation capacities and water supplies. In the near-term, however, reduced availability of water supply in the Indus River basin does not appear to be a significant threat.

Perhaps of greater concern is the potential for a shift in the timing of the peak run-off. Analysis completed by Immerzeel et al. (2009) suggests that under different scenarios of glacial retreat, discharge could significantly increase between week 14 and 25 of the calendar year, which currently coincides with the onset of the growing season and therefore a critical period in which irrigation waters are needed. Energy demand is currently high in the summer season, but with a rise in temperatures, peak demand could begin earlier in the year, potentially leading to conflicting water demands, particularly given Pakistan's current inadequate storage facilities. Shifting peak flows could undermine the current balance between agricultural production and energy generation. Thus, greater analysis is needed to better understand the potential for growing trade-offs between irrigation and energy generation and careful assessment of the need for changes in water allocation rules.

Lastly, run-of-the-river hydroelectric projects that generate electricity by using part of natural stream flows and natural elevation differences may be more sensitive to changing flow patterns. As flowing water causes the turbines to spin, flow patterns directly influence the amount of energy generated. The impact of a changing climate on monsoon patterns and glacial and snow melt will influence the timing and variation of daily flow patterns, creating uncertainties regarding electricity generation. Better quantification of the current hydrological regime will be beneficial in providing a more detailed assessment of anticipated changes in flow patterns.

5. Conclusions

This briefing paper outlined the current state of Pakistan's energy supply sector, with a specific focus on thermal power and hydroelectric power production. It aimed to shed light on how future energy development plans could be affected by climate change.

Future projections regarding water supply analysis in Pakistan have concluded that water availability in the basin prior to 2050 will not change significantly but could result in a shift in the timing of peak flow. Thermal power production is sensitive to temperature changes and is highly dependent on available water resources. Projected temperature increases for Pakistan will likely affect thermal power plants by decreasing the efficiency of the thermal conversion process resulting in a loss of electrical output. While total water availability may be relatively steady at least until the mid-century, industrial and population growth will become greater stressors on water demand. To the author's knowledge, it appears that national planning for power generation does not fully account for the issue of long-term water demand in the country. No figures or information were available about the water use intensity of thermal power plants. This kind of information and data could inform decision-making with regards to retrofitting cooling systems or switching to more efficient cooling methods that would allow a reduction in water demand, especially in areas where priority is given to other water uses, such as irrigation.

Despite the potential of hydropower to contribute to Pakistan's future energy demands and the government's initiatives to accelerate hydropower, a substantial increase in hydropower development in Pakistan remains uncertain due to the social, political and technical issues associated with them. In spite of these challenges hydro-power electricity generation is forecasted to grow. While changes in water flow patterns in the Indus River Basin will not necessarily result in any implications for large hydro projects, a projected change in peak run-off and increasing temperatures could lead to conflicting water demands between different users. It is therefore important that the resulting growing trade-offs between other water users and energy generation are considered and changes in water allocation rules are carefully assessed.

Demands for greater amounts of energy and water may be expected to occur with population growth, urbanization and industrialization—leading to greater likelihood of competing demands between different users. Future energy development processes will have to take into account the water and energy inter-linkages and employ management practices and conservation initiatives to address trade-offs and promote synergies where possible among competing water users.

References

Asian Development Bank (ADB). (2013). Asian Development Outlook 2013: Asia's Energy Challenge. Retrieved from http://adb.org/sites/default/files/pub/2013/ado2013.pdf

Asian Development Bank (ADB). (2012). Climate Risk and Adaptation in the Electric Power Sector. Retrieved from http://www19.iadb.org/intal/intalcdi/PE/2012/12152.pdf

Bhutto, AW., AA. Bazmi, G. Zahedi. (2012). Greener energy: Issues and challenges for Pakistan-hydel power prospective. Renewable and Sustainable Energy Reviews 16.

Clarke, M. (2015). Climate change mitigation and adaptation considerations for hydropower projects in the Indus Basin. 35th Annual Conference of the International Association for Impact Assessment. Retrieved from http://conferences.iaia.org/2015/Final-Papers/Clarke,%20Michael%20%20Climate%20Change%20Mitigation%20and%20Adaptation%20Considerations%20for%20Hydropower%20Projects%20in%20the%20Indus%20Basin.pdf

Global Water Forum (GWF). (2015). Water for thermal power plants: Understanding a piece of the water energy nexus. Retrieved from http://www.globalwaterforum.org/2015/06/22/water-for-thermal-power-plants-understanding-a-piece-of-the-water-energy-nexus/

Ghumman, K. (2015). Gadani energy park won't be completed during PML-N govt term, NA told. Dawn. Retrieved from http://www.dawn.com/news/1172113/gadani-energy-park-wont-be-completed-during-pml-n-govt-term-na-told?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+dawn-news+(Dawn+News)

Immerzeel, W.W., Droogers, P., de Jong, S.M., and Bierkens, M.F.P. (2009). Large-scale monitoring of snow cover and runoff simulations in Himalayan river basins using remote sensing. Remote Sensing of Environment. 113 (2009): 40-49.

International Business Publications. (2015). Pakistan Energy Policy, Laws and Regulations Handbook (Volume 1). Strategic Information and Basic Laws. Retrieved from https://books.google.ca/books?id=nWbxCQAAQBAJ&pg=PA50&lpg=PA50&dq=Pakistan+Electric+ Power+Company&source=bl&ots=2jqA2cJIMr&sig=R0ukUXjMaUwf7SdVVUJVwFDxB-4&hl=en&sa=X&ved=0ahUKEwi9zfvI34HLAhXEsIMKHYdZADg4ChDoAQg9MAU#v=onepage&q=Pakistan%20Electric%20Power%20Company&f=false

International Institute for Sustainable Development (IISD). (forthcoming). Low-Carbon Scenarios Analysis for Pakistan.

Islamabad Chamber of Commerce & Industry. (n.d.). An Overview of Electricity Sector in Pakistan. Report. Retrieved from http://icci.com.pk/data/downloads/63/1293619048_1.pdf

Makky, M. and Kalash, H. (2013). Potential Risks of Climate Change on Thermal Power Plants. Retrieved from https://www.researchgate.net/publication/236174007_Potential_Risks_of_Climate_Change_on_Thermal_Power_Plants

Ministry of Climate Change (MOCC). (2015). Pakistan Intended Nationally Determined Contributions (INDCs) (zero draft). Government of Pakistan. Retrieved from http://www.mocc.gov.pk/gop/index.php?q=aHR0cDovLzE5Mi4xNjguNzAuMTM2L21vY2xjL3VzZ

XJmaWxlczEvZmlsZS9JTkRDJTIwUEFLSVNVNUQU4lMjAtemVybyUyMGRyYWZ0LS5wZGY%3D

Ministry of Finance (MOF). (2009). Integrated Energy Plan 2009-2022. Report to Expert Energy Group. Government of Pakistan. Retrieved from http://www.pc.gov.pk/hot%20links/integrated_energy_plan2009-22.pdf

Ministry for Water and Power (MWP). (2003). Pakistan's Vision of Water Management. Paper presented at Pakistan Development Forum. Retrieved from http://siteresources.worldbank.org/PAKISTANEXTN/Resources/Pakistan-Development-Forum/water-Mgmt.pdf

Muzamil, H. (2015). Pakistan's energy mix: power and politics. Dawn. Retrieved from http://www.dawn.com/news/1210831

National Transmission and Despatch Company (NTDC). (2011). Electricity Demand Forecast based on Multiple Regression Analysis. Period 2011 to 2035. Retrieved from http://www.ntdc.com.pk/EDF20112035.pdf

Private Power and Infrastructure Board (PPIB). (2011). Hydropower Resources in Pakistan. Government of Pakistan. Retrieved from http://www.ppib.gov.pk/HYDRO.pdf

Private Power and Infrastructure Board (PPIB). (2013). National Power Policy 2013. Government of Pakistan. Retrieved from http://www.ppib.gov.pk/National%20Power%20Policy%202013.pdf

Qureshi, F.U. and Akıntuğ, B. (2014). Hydropower Potential in Pakistan. Retrieved from https://www.researchgate.net/publication/268224059_Hydropower_Potential_in_Pakistan

Siddiqi, A., J. Wescoat Jr., S. Humair, K. Afridi. (2012). An empirical analysis of the hydropower portfolio in Pakistan. Energy Policy 50 (November).

Sustainable Development Policy Institute (SDPI). (2012). Pakistan Power Sector Outlook: Appraisal of the Karachi Electricity Supply Company (KESC) in Post Privatization Period. Retrieved from http://sdpi.org/policy_outreach/news_details771.html

The Express Tribune Pakistan. (2014). Helping hand: China signs agreements worth $30b. Retrieved from http://tribune.com.pk/story/676128/helping-hand-china-signs-agreements-worth-30b/

The World Bank. (2016). Pakistan. Retrieved from http://data.worldbank.org/country/pakistan

United Nations Industrial Development Organization (UNIDO) and International Center on Small Hydro Power (ICSHP). (2013). World Small Hydropower Development Report 2013. Pakistan. Retrieved from http://www.smallhydroworld.org/fileadmin/user_upload/pdf/Asia_Southern/WSHPDR_2013_Pakistan.pdf

Union of Concerned Scientist. (n.d.). How it Works: Water for Power Plant Cooling. Retrieved from: http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/water-energy-electricity-cooling-power-plant.html#.VxlF3tUrLIU

Appendix 5: Agriculture Policy Brief

Climate Change Implications for Pakistan's Agriculture Sector

A briefing paper prepared as part of the project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action"

June 2016

Prepared by: Dr. Saeed A. Asad and Jo-Ellen Parry

Summary

Pakistan's agriculture, and thus its food and water security, is largely dependent on the Indus River and its tributaries, from which it draws around 90% of its water for agricultural purposes. As observed by the Intergovernmental Panel on Climate Change in its Fourth Assessment Report, (IPCC, 2007), South Asian countries are expected to be significantly affected by the world's changing climate and worst case scenarios could be observed in the region's water and agriculture sectors. Influenced by climate change the likely consequences for these sectors could be:

- Less water availability, resulting in shifts in cropping patterns and crop rotations.
- Significant reduction in the production of Pakistan's main cash crops such as wheat, rice, sugarcane, cotton and maize.
- Reduced cereal production by up to 20% in southern Pakistan compared with minor improvements in yield in the country's northern belt.
- Livestock production is anticipated to decline by 30% as rangelands become increasingly stressed by longer droughts and by human and animal migration around riverine areas.

Although it is not clear how precipitation patterns and run-off from snow and glacier melt could change in the future, it is generally anticipated that climate change will lead to changes in seasonal water flow patterns in the Indus River system, with a potential for higher run-off and river flows in the coming decades, followed by an overall decrease in flows beginning sometime in the 2100s. As influenced by changes in temperature and precipitation, a decrease of 8-10% in wheat yields may occur whereas rice productivity may decrease by up to 20% compared to current figures. Maize yield likely will be substantially decreased with increasing temperatures up to 1.8oC in central Punjab and if the current scenario of further increases in temperature continues, yields from this commodity may decrease by 20% by 2050. Cotton crops would be equally affected by temperature increases whereby studies have projected that a 1°C rise in temperature during the vegetative and flowering stages of growth could reduce yields by 24.14% and 8% respectively. These negative impacts of temperature on cotton production are most striking for Sindh. Responding to the current and projected scenarios of water availability several measures should be initiated to ensure

water and food security in a changing climate such as: enhancing water storage capacity, launching low cost water saving technologies (high efficiency irrigation systems), increasing rain and flood water harvesting, regulating ground water resources, and breeding/ cultivating less water intensive crops. The development of livestock breeds that have higher productivity potential for milk and meat, and are less prone to heat and drought stress, also should be strengthened.

1. Pakistan: An Agrarian Economy

Pakistan by birth is an agricultural country; 45% of the total labor force—30% of which are women—is engaged in agricultural production (Ministry of Finance, 2013; Salik et al., 2015). Moreover, around 67% of the population living in rural areas are dependent on agriculture in one way or the other (Maqbool and Bashir, 2009). Today, approximately 22% of national Gross Domestic Product (GDP) and 70% of Pakistan's export earnings are derived from the agricultural sector (FAO, 2015b). However, the sector's contribution to national GDP varies from year to year, reflecting in part its vulnerability to climate risks (Yu et al., 2013).

Food self-sufficiency is a growing concern in Pakistan. Food supply varies from year to year and falls below the global average of 2,797 kilocalories (kcal) per capita per day. Despite increased food production, there has been little change over the past two decades in the estimated proportion of the population that is undernourished, which has declined from 24% in 1999-01 to 20% in 2010-12 (FAO, 2016).

2. The Water and Agriculture Nexus

Agricultural production in Pakistan is intimately linked to the availability of water resources, particularly the amount of water flowing through the approximately 576,000 square kilometers of the Indus River basin (GOP and UNEP, 2013). This dependency stems from the fact that out of Pakistan's 26 million hectares (Mha) of agricultural lands, about 90% of total agricultural production is derived from the 18 Mha of irrigated lands (Yu et al., 2013). As of the 1990s, Pakistan's irrigation system consisting of the Indus River and its tributaries was recognized as the world's largest contiguous irrigation system. Its total length is 58,000 kilometers, which expands to over 1.6 million kilometers when farm water channels and field ditches are included.

Fed by snow melt in the Karakoram and Himalayan mountain ranges along with monsoon rains, the Indus River and its tributaries bring approximately 191 million acre-feet (MAF) of water annually to Pakistan, most of which is diverted for irrigation. Despite this level of flow and the presence of one of the most extensive irrigation and canal networks in the world, Pakistan is classified as a water stressed. Water availability is just over 1,000 cubic meters per capita today, against 5,600 cubic meter per capita availability at the time of independence, and current scenarios suggest that the country will become water scarce by 2035 (LEAD Pakistan, 2014). In part, this is because demand for water by the agriculture sector, particularly for irrigation, is expected to increase at a higher rate than all other sectors to meet the rising food production requirements of an increasing population.

While the Indus River basin is richly endowed with land and water resources vital for the country's agricultural economy, it faces high levels of variability and uncertainty due to factors related to climate, hydrology, agricultural sustainability, food consumption, and natural hazards. Water availability for agriculture is also influenced by a number of infrastructure related concerns. For example, due to the non-availability of enough storage facilities and sedimentation of existing reservoirs, approximately 25 to 30 MAF of water flows in to the sea annually (Ministry of Water and Power, 2005). As well the Indus River Irrigation System is characterized by large inefficiencies at the canal, watercourse and field levels. In large part this is due to the lack of adequate recurrent expenditures and in part due to system efficiencies that result in farmers at the tail end of the canal system rarely getting water. Furthermore, water charges are low, recovery rates are limited, and collected water revenues go to the general revenue budget rather than to provincial irrigation departments. In Punjab province, for example, water is charged at a flat rate of Rs. 85 per cropped acre during the summer (kharif season) and Rs. 50 per acre during the winter (Rabi season), which generates revenues equivalent to only 68% of operation and maintenance expenditures (GOP, 2013). Similarly, the gap between operation and maintenance expenditures and revenue collection is 80 and 77% in Sindh and Khyber Pakhtunkhwa, respectively (GOP, 2013).

The need for major reforms in the water sector are well recognized and a number of initiatives related to changing the institutional setup, raising and rationalizing water charges, and improving water use efficiencies are required. A renewed political commitment by the federal and provincial governments will help implement the changes needed to ensure a viable, more efficient and sustainable irrigation system for Pakistan.

3. Climate Change and Water Availability

Along with the challenges of inadequate and ageing water infrastructure, increasing water demand, and poor management of the Indus River Irrigation System, climate change is projected to be an additional stressor on Pakistan's water resources. Changes in Pakistan's climate have already been observed, with mean annual temperatures reported as having risen by 0.6°C over the course of the 20th century. Several reports also state that there has been an observed overall trend of rising precipitation levels, particularly during the monsoon season, but patterns vary by region and season. Thus, while precipitation levels in the Upper Indus Basin have been increasing, they have been declining areas such as the western Baluchistan plateau and coastal areas. Changes in precipitation trends are more visible in the southern portion of Pakistan (Yu et al., 2013).

Global and regional climate models consistently indicate that Pakistan's climate will see a continued increase in mean annual temperatures in the coming decades. Multi-modal projections such as those developed by Shrestha et al. (2015) suggest that major parts of the Indus Basin could warm in the summer by 2°C to 5°C under a low emission scenario by 2050, and even more under a high emission scenario, particularly in the Upper Indus Basin region. Winter temperatures are also projected to increase by 2°C to 4°C across the basin in both low and high emission scenarios by 2050, with only a few areas experiencing temperature changes that exceed 4°C or are lower than 2°C.

Future precipitation projections suggest that mean annual precipitation will increase across the Indus Basin by 2100, with increases particularly occurring between June and August. However, projections for future winter precipitation patterns in the Upper Indus Basin are not in agreement and lack consistency. This uncertainty is problematic given that winter precipitation in Upper Indus Basin is a key driver of the whole hydrologic system of the Indus Basin.

Driven by these changes in climatic conditions, the spatial and temporal distribution of water resources are expected to change on an annual and inter-annual basis (GOP, 2012). These changes will be driven by altered glacial melt patterns in the Hindu Kush-Karakoram-Himalaya ranges and potential changes in monsoon patterns. It is estimated that between 50% and 70% of the water flow in the Indus River basin comes from snow and ice melt. Considerable uncertainty prevails regarding how each of these factors will be affected by climate change and therefore how associated run-off is likely to change in future (Yu et al., 2013). The literature also indicates that glacial lake outbursts in the Himalayas in the coming two to three decades are anticipated to increase the risk of downstream flooding (Bajracharya et al., 2015), which could have implications for Pakistan's agricultural production.

Uncertainty remains regarding how monsoon patterns might change in the future, with some studies suggesting that there could be increases in mean precipitation levels and rainfall extremes (Christensen et al., 2013), as well as greater inter-annual and intra-seasonal variability in monsoon rainfall (World Bank, 2013). Other studies, though, suggest that monsoon rains could decline by 20% by the end of next century, which would have serious repercussions on rainfed agriculture. Under this scenario, the anticipated deficit in water needed for agriculture by 2030 is evaluated to be between 25% to 30% (Rasul and Ahmed, 2012).

Overall, in the near-term (i.e. before 2050), total water flows in the Indus Basin are anticipated to remain relatively stable, although there could be an increase in flows due to higher run-off as temperatures warm (particularly if there is a reversal of the current summer cooling trend) and a shift in the timing of peak water flow to earlier in the year. Looking beyond the end of this century, continued increases in temperature could lead to the complete loss of glaciers in the Upper Indus Basin, which would result in a significant decrease in overall flows. Such a change naturally would have critical, long-term implications for Pakistan's agriculture sector.

4. Agriculture and Climate Change Vulnerability

Agriculture is perhaps the sector most vulnerable to potential climate risks triggered by climate change such as uncertain monsoon patterns, rising mean annual temperatures, higher levels of spring run-off, and possibly reduced flows in the dry season. Changes in water availability may alter sowing and harvesting patterns in the coming two to three decades. Significant reductions in crop yields could also result from elevated temperatures speeding up crop growth, resulting in a shortening of the growth period and potentially leading to reduced productivity of crops and fodder (GOP, 2012).

Similar to crops, the livestock production is also very vulnerable to the impacts of climate change. Together with poultry, the livestock production contributes half of the value provided by the agriculture sector to the national GDP (GOP, 2009). The direct effects of climate change on livestock may result in lower production of milk and meat and reduced reproductive capacity as temperatures rise. Risks such as climate-related disease epidemics may also increase. Additionally, the indirect impacts of a changing climate could include, among others: negative impacts on fodder crop productivity; decreased nutritional quality and palatability of forage plants due to increasing concentration of carbon dioxide (resulting in a carbon:nitrogen imbalance); competition for land between fodder and staple crops;

increased water requirements (by both fodder crops and animals); and host-pathogen interactions. The vulnerability of the livestock sector to climate change is particularly high because it depends largely on grazing on rangelands whose capacity for adaptation is very low (GOP, 2013).

Studies have identified risks for specific crops. As suggested below, water-intensive crops such as sugarcane and rice potentially could be the most affected by climate change:

- **Wheat:** A decrease of 8-10% in wheat yields may occur. The population will need to reduce its dependence on wheat and shift to use of coarse grains such as barley, sorghum, millets, oats and coarse rice (Janjua et al., 2010).
- **Rice:** Production may be reduced by up to 20% compared with current figures (Tariq et al., 2014).
- **Maize:** A recent study by the University of Agriculture Faisalabad revealed that maize yield will be substantially decreased as temperatures increase up to 1.8oC in central areas of Punjab. If the current scenario of a consistent increase in temperatures continues, the commodity yield may decrease by 20% beyond 2050 (Khaliq, 2008).
- **Cotton and Sugarcane:** According to some recent research, cotton (Raza, 2015) and sugarcane (Zhao, 2015) production would be severely impacted by changing rainfall patterns, rising temperatures and declining supplies of surface water. The negative impacts of temperature on cotton production are more striking for Sindh. It has been projected that a 1°C rise in temperature during the vegetative and flowering stages of growth would reduce yield by 24.14% and 8% respectively (Raza, 2015).

Regional differences are also expected:

- In **Punjab and Sindh**, water shortage could take a toll on about 20% to 25% of cultivable land, rendering it unfit for agriculture (Malik, 2012). As well, it has been projected that a 4oC increase in temperatures and 3% rise in precipitation by 2080 could result in a loss in agricultural productivity of up to 13% in Punjab and Sindh (Dehlavi, Groom and Gorst, 2014). Similar results have been generated by Yu et al. (2013), with more adverse change potentially being experienced in Sindh.
- In **Northern areas** of the country, wheat, maize and rice yields could increase due to longer and hotter summer seasons (Rasul and Ahmed, 2012).

In response to an increasingly water stressed situation, farmers may shift from the production of staples to alternate, less water intensive crops such as pulses and oil seed crops. Overall, in monetary values, these changes in production could result in up to a 5% decline in agricultural GDP from its base value by the end of 21st century (Husain, 2015).**5. Key findings**

Pakistan's agriculture sector will be particularly affected by the following climatic changes:

- Rising mean annual temperatures
- Changes in precipitation patterns, including uncertain monsoon patterns, that will likely vary depending on season and location
- Variable river flows, with the potential in the near-term for higher run-off in the spring and reduced flows in dry season.

Factors that make Pakistan's water sector vulnerable to the impacts of climate change include:

- Increasing demand of water due to an ever increasing population
- Water logging, salinity, and poor maintenance of the Indus River canal system
- Water pricing that is inadequate to cover existing operation and maintenance costs
- Lack of capacity building among the farming community for water conservation
- A water table rapidly lowering by more than 20 feet annually due to over-exploitation of ground water in parts of Sindh, Baluchistan and populated cities such as Lahore, Quetta and Karachi.

Overall, the issues arising from climate change for Pakistan's agriculture sector are:

- Less water availability resulting in shifting of cropping patterns and crop rotations
- Significant reduction in the production of cash crops such as wheat, rice, sugarcane, cotton and maize.
- Reduced cereal production by up to 20% in the southern part of the country compared with minor improvement in yield in northern belt.
- Livestock production is predicted to decline by 30% in part because rangelands will become increasingly stressed by longer droughts, which to led to people and animals migrating to riverine areas and greater competition over available resources.

6. Recommended adaptation actions

Following actions could be taken to adapt to the changing circumstances to ensure the national food and water security:

- Breed/cultivate less water intensive crops.
- Encouraging rain and flood water harvesting.
- Regulate ground water usage to stop over exploitation.
- Initiate water conservation technologies such as drip or sprinkler irrigation methods in selected areas, raised bed technology that save up to 50% of irrigation water, and increased crop productivity.
- Enhance water storage capacity.
- Implement waste water recycling in urban settings.
- Up-scaling of land leveling, which enables 30% water saving with corresponding increases in productivity.
- Develop and introduce better varieties of livestock which have higher productivity of milk and meat, are less prone to heat stress, and are more drought tolerant.

References

Asian Development Bank (ADB). (2013). Asian Development Outlook 2013: Asia's Energy Challenge. Retrieved from http://adb.org/sites/default/files/pub/2013/ado2013.pdf

Asian Development Bank (ADB). (2012). Climate Risk and Adaptation in the Electric Power Sector. Retrieved from http://www19.iadb.org/intal/intalcdi/PE/2012/12152.pdf

Bhutto, AW., AA. Bazmi, G. Zahedi. (2012). Greener energy: Issues and challenges for Pakistan-hydel power prospective. Renewable and Sustainable Energy Reviews 16.

Clarke, M. (2015). Climate change mitigation and adaptation considerations for hydropower projects in the Indus Basin. 35th Annual Conference of the International Association for Impact Assessment. Retrieved from http://conferences.iaia.org/2015/Final-Papers/Clarke,%20Michael%20%20Climate%20Change%20Mitigation%20and%20Adaptation%20Considerations%20for%20Hydropower%20Projects%20in%20the%20Indus%20Basin.pdf

Global Water Forum (GWF). (2015). Water for thermal power plants: Understanding a piece of the water energy nexus. Retrieved from http://www.globalwaterforum.org/2015/06/22/water-for-thermal-power-plants-understanding-a-piece-of-the-water-energy-nexus/

Ghumman, K. (2015). Gadani energy park won't be completed during PML-N govt term, NA told. Dawn. Retrieved from http://www.dawn.com/news/1172113/gadani-energy-park-wont-be-completed-during-pml-n-govt-term-na-told?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+dawn-news+(Dawn+News)

Immerzeel, W.W., Droogers, P., de Jong, S.M., and Bierkens, M.F.P. (2009). Large-scale monitoring of snow cover and runoff simulations in Himalayan river basins using remote sensing. Remote Sensing of Environment. 113 (2009): 40-49.

International Business Publications. (2015). Pakistan Energy Policy, Laws and Regulations Handbook (Volume 1). Strategic Information and Basic Laws. Retrieved from https://books.google.ca/books?id=nWbxCQAAQBAJ&pg=PA50&lpg=PA50&dq=Pakistan+Electric+ Power+Company&source=bl&ots=2jqA2cJIMr&sig=R0ukUXjMaUwf7SdVVUJVwFDxB-4&hl=en&sa=X&ved=0ahUKEwi9zfvl34HLAhXEsIMKHYdZADg4ChDoAQg9MAU#v=onepage&q=Pakistan%20Electric%20Power%20Company&f=false

International Institute for Sustainable Development (IISD). (forthcoming). Low-Carbon Scenarios Analysis for Pakistan.

Islamabad Chamber of Commerce & Industry. (n.d.). An Overview of Electricity Sector in Pakistan. Report. Retrieved from http://icci.com.pk/data/downloads/63/1293619048_1.pdf

Makky, M. and Kalash, H. (2013). Potential Risks of Climate Change on Thermal Power Plants. Retrieved from https://www.researchgate.net/publication/236174007_Potential_Risks_of_Climate_Change_on_Thermal_Power_Plants

Ministry of Climate Change (MOCC). (2015). Pakistan Intended Nationally Determined Contributions (INDCs) (zero draft). Government of Pakistan. Retrieved from http://www.mocc.gov.pk/gop/index.php?q=aHR0cDovLzE5Mi4xNjguNzAuMTM2L21vY2xjL3VzZ

Appendix 6: Water Quality and Health Policy Brief

Climate Change Implications for Water Quality and Human Health in Pakistan

A briefing paper prepared as part of the project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action"

June 2016

Prepared by: Dr. Toqeer Ahmed, Centre for Climate Research and Development, COMSATS Institute of Information Technology, Islamabad

Summary

Health-related vulnerabilities due to changes in water quality and the distribution of water- and vector-borne diseases are increasing due to changing climatic conditions. Pollution from urban runoff already is deteriorating the quality of water used for drinking and other purposes. As well, floods pollute both surface and groundwater resources and have a direct impact on water quality as flood waters carry contaminants into drinking water sources. With climate change, higher temperatures and greater risk of the occurrence of floods, droughts and heavy rainfall events could more heavily impact water quality in the future. Microbial water quality will vary with changing temperatures as the growth of microbes is directly correlated with temperature; some bacteria grow at a higher temperature while others are more likely to grow at moderate temperatures. Water quality indicators also respond immediately to changes in flow rate, which is climate-dependent; a low discharge rate along with increasing temperatures will surge microbial growth. Glacier melting can affect water chemistry and river runoff, and may increase in the future as the climate changes. Water-borne and water-related diseases, such as cholera, can increase due to more polluted surface water in flood affected areas. Vector-borne diseases, such as malaria, are also influenced by water availability and temperature. International studies have documented the potential for water quality to be negatively affected and for both water-borne and water-related diseases to increase due to climate change. However, few studies have been conducted to assess the water quality, including the bacteriological water quality, of the Indus River and other surface and ground water sources under changing climate scenarios in Pakistan. Information on the impacts of climate change on water quality and health is insufficient and it is therefore highly recommended to explore how water quality might be altered under different climate scenarios. The potential impacts of climate change on water quality also should be integrated into relevant national policies. It should be monitored regularly, especially post severe weather events and natural disasters. There is also a need to protect water sources and improve water quality to address severe health impacts stemming from water-borne and related diseases now and in the future.

Climatic conditions and water quality

The quality of water in Pakistan is increasingly vulnerable to factors such as the growth in population, anthropogenic activities and urbanization along with industrialization. These are severely impacting surface water pollution due to heavy metals, sediments, nutrients, pesticides, and organic pollutants among others. Increase in microbial contents in natural water resources impact the whole ecosystem and human health. At the same time, there is growing concern about the potential impact of changes in climatic conditions like temperature, precipitation, floods, water scarcity or droughts on current and future water quality and water-borne diseases. Water quality parameters like pH, dissolved oxygen, micronutrients, organic pollutants and pathogens are directly affected by different climatic conditions, like drought, temperature and rainfall that affect water availability and seasonal fluctuations. According to the Intergovernmental Panel on Climate Change, high temperature and variation in extremes events like floods and drought are projected to effect water quality and will increase water pollution intensity (Bates et al., 2008).

Changes in rainfall patterns are impacting both the availability and quality of water. Climate change will influence glacier melting which can affect water chemistry and river runoff. As reported in the past studies, water availability is decreasing from 5,600 to 1,017 cubic metres per capita and going to decrease further in the future because of rising temperatures, excessive use of water, poor water conservation strategies and ground water over-extraction. Additionally, certain regions of the country (Sindh and Baluchistan) face drought conditions while other parts (Punjab and Khyber Pakhtunkhwa) will experience the opposite. These climatic conditions affect both chemical and biological water quality. Decreases in water availability will negatively impact water quality indicators such as faecal coliform and E. coli, while increases in water availability can have the opposite affect (Liu and Chan, 2015).

Floods pollute surface and ground water resources, deteriorating water quality. Floods increase urban runoff that brings pollutants into these water resources. Large amounts of contaminants are transported from industrial and agricultural areas to rivers. Areas affected by flooding often experience an increase in the demand for clean drinking water. Difficulties providing sufficient drinking water results in increases of waterborne and other water-related diseases due to polluted surface and ground water people consume instead in flood affected areas.

Drought affects water quality because less water is available to dilute contaminated water. Drought conditions force inhabitants to use contaminated sources of water for drinking and for other uses. In some parts of the country, wastewater (highly contaminated water) is used for irrigation because treated water is unavailable. Consequently, vegetables and crops are polluted with pesticides, heavy metals and other pollutants. The practice of dual clean water use is taking place in the country and people are using the clean water both for irrigation and drinking purposes.

Similarly, temperature and rainfall conditions affect water quality. During monsoon season, the rainfall leads to water quality deterioration because of transport of pathogens, dissolved organic pollutants and mixing of pollutants with drinking water supplies, including both surface and ground water supply. Fecal indicator bacterial growth increases during monsoon. Heavy runoff transports the contaminants from one area to another but when the opposite conditions occur, water quality will be of more inferior quality. In contrast, when low rainfall takes place less water is available to dilute pollutants within surface and ground water resources (Mirza et al., 2007). Shift in density of water in the reservoir may change the bacterial population in environment (Guillaume and Rita, 2009).

Increases in temperature are expected to decrease water quality of water resources because of temperature stability, low discharge, increase in phosphorus and other nutrients from sediments and transformed mixing behaviors. Low discharge rates with increasing temperature increase microbial growth. Increasing temperatures are expected to increase microbial growth. Biochemical processes occurring in the water bodies depend on a number of external conditions. Higher temperature will definitely increase the reaction rate. Global warming can affect the oxygen concentration in water bodies. Physicochemical parameters will be negatively affected by increase in temperature. Zhang et al. (2015) found potential positive effects of temperature increase on water quality parameters (nitrate, nitrogen and total phosphorous) with changes in seasonal conditions. Another study also supports the idea of decrease in water quality with increased temperatures (Zwolsman and van Bokhoven, 2007). The impacts of climate change on water resources and related health risks are discussed in Figure 1.

Human influences on both surface and ground water, heavy metal, pesticides pollution and deteriorated water quality of the Indus River and other Pakistan water resources has already been reported (Ata et al., 2013; Jabeen et al., 2015). Zhang et al. (2015) reported that water quality of the Indus River and other water resources in the Himalayan region are under the influence of climate change due to glacier melting which affects the river runoff and water chemistry. Saeed and Attaullah (2010) studied the impact of floods on ground water quality in Khyber Pakhtunkhwa (Charsadda and Nowshera) by collecting post-flood samples which were found to be contaminated. They concluded that floods have a direct impact on water quality and water quality becomes no more reliable after an area is hit by flooding. Oxfam has reported that the ground water quality situation of coastal areas has deteriorated (Abbass, 2009).

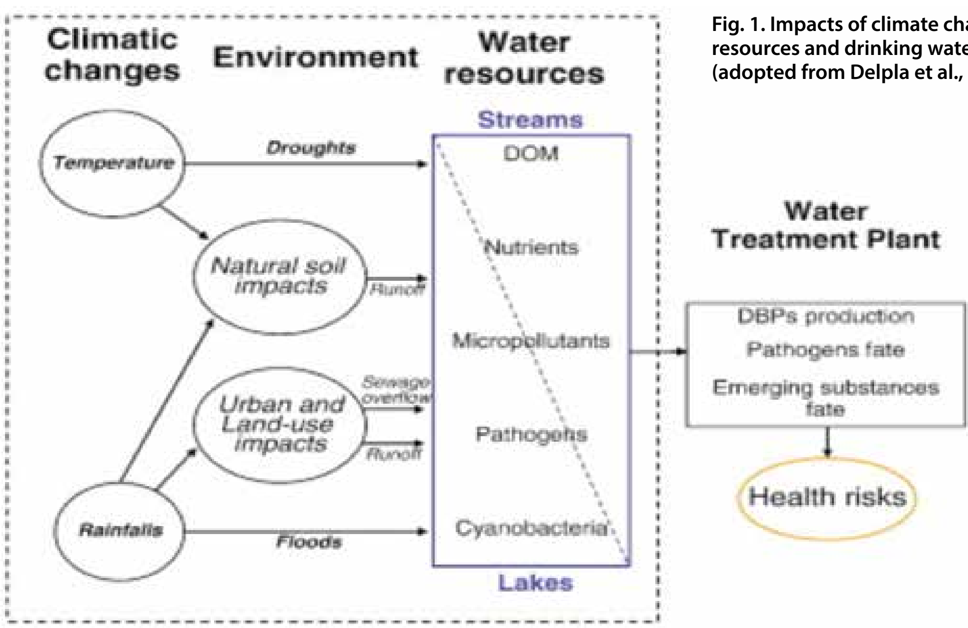


Fig. 1. Impacts of climate change on water resources and drinking water quality (adopted from Delpla et al., 2009).

Water quality and its impacts on human health:

Access to clean water is important for healthy living. Poor water quality has severe effects on human health, and are more common in developing countries, where their impacts are increasing day by day. Anthropogenic activities and a lack of education and awareness are exaggerating these conditions. Empirical studies conducted in the past by government, private organizations, universities and NGOs reported that management and monitoring of water quality is poor (Azizullah et al., 2011; Murtaza et al., 2008; Ahmed et al., 2015; Watto et al., 2006). Some are relating it to low water availability or water scarcity. Microbial water quality has the worst effects on human health.

Similarly, pesticides and other chemical pollutants generated by industries are contaminating our water resources affecting water quality. Farmers are at high risks of pesticides due to their direct exposure which are also found in both surface and ground water resources and have both acute and chronic effects on human health (Tariq et al., 2007; Azizullah et al., 2011). Even essential nutrients like calcium, magnesium, sodium, potassium and others can cause serious problem like hypercalcemia and other related issues when they exceed the permissible limit. Nitrates in excess can cause blood disorders, cancer and geno-toxic effects (Azizullah et al., 2011).

Climate change, water-borne diseases and water-related diseases:

Climate change is impacting both water- and vector-borne diseases throughout the world and is expected to become one of the most significant public health complications. Changing climatic conditions are expected to lead to shifts in the prevalence of water- and vector-related diseases like malaria, dengue fever and cholera. Climatic factors like temperature, humidity, change in rainfall pattern, and floods, along with environmental factors linked to urbanization and other anthropogenic activities, control the distribution, life cycle and efficiency of transmission of these diseases. Increases in vector-related diseases like malaria, dengue fever, dengue hemorrhagic fever, chikungounia, yellow fever, filariasis etc. due to polluted surface water have been reported. Similarly, water-borne diseases like cholera, typhoid, dysentery and others prevail due to unhygienic and polluted drinking water conditions.

Water abundance, scarcity and pollution also affects various water-borne diseases (e.g., Cholera, Typhoid, Amoebiasis, Giardiasis, etc.), water-washed diseases (e.g., skin and Trachoma diseases, dysentery, Amoebiasis, Enteroviral diarrhea etc.), water-based diseases (e.g., Schistosomiasis), and water-related diseases (e.g., malaria, dengue, yellow fever, filariasis etc.) (World Health Organization [WHO], 1996). Typhoid alone effects 17 million people per year, and 6 million people become blind annually due to Trachoma. According to a report by the Pacific Research Institute, 76 million people will die by 2020 due to preventable water-borne and water-related diseases (Gleick, 2002).

As Pakistan's climate varies greatly between regions and across its four seasons (as seen in Figure 2), the occurrence of water-borne and water-related diseases varies within the country. For example, malaria and other water-related, vector-borne diseases flourish in Pakistan after the monsoon season, especially during the period of August to November.

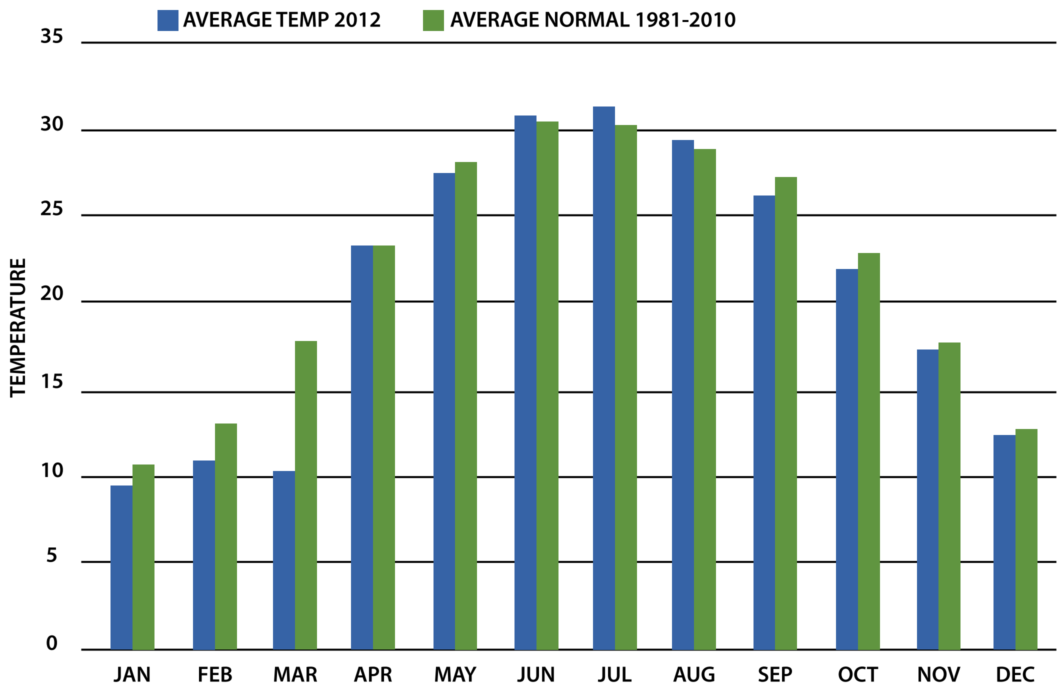


Fig.2. Comparison of average temperature of 2012 with normal in the past (1981-2010) (adopted from PMD, 2012)

Malaria

According to the World Health Organization (WHO, 2016), 3.2 billion people (half of the world population) are at risk of getting malaria, more than 200 million people globally were infested by malaria in 2015, and of these about 438,000 died. The disease particularly affects poor people. Before 1970, it was epidemic in only nine countries but in recent decades it has spread throughout the world. Malaria is now found in more than 100 Asian, African and other developing countries worldwide. According to American Mosquito Control Association, 40% of the world's population is susceptible to malaria and one child is killed by malaria every 40 seconds. The disease is of particular concern in Pakistan as, according to Country Coordination Mechanism-Pakistan, it is second most prevalent, serious, and sometime fatal ailment amongst the top 10 priority sicknesses in the country (CCM-Pak, 2016).

Malaria is caused by biting female mosquitoes of the Anopheles species, of which Anopheles gambiae is the most active one. They transmit one of four different types of parasites of the genus Plasmodium into the blood of humans: Plasmodium falciparum, P. vivax, P. ovale, or P. malariae (CDC, 2016). Mosquitoes lay eggs in stagnant surface water, pools etc., and complete their four-stage life cycle in 7 to 20 days. The Anopheles species is mostly active at night. Transmission and severity of disease depends on location and the age of the person. High temperatures negatively affect the virulence capacity of Anopheles. Malaria is not a contagious disease but it can spread from mother to unborn child or through blood transfusion. Major symptoms include high fever with shivering, headache, nausea, body pain and weakness.

In Pakistan, malaria is caused by transmission of the parasites Plasmodium malariae, P. falciparum (12% of cases), and P. vivax (80% of cases) (WHO, 2015c). Transmission occurs in the post-monsoon season (September to November) every year. The major mosquito species that transmit these parasites are Anopheles culcifacies and A. stephensi (WHO, 2015c). The mosquito species A. fulviatilis and A. annularis were recently identified in Baluchistan and the Federally Administered Tribal Areas (Mukhtar, 2009). The proportion of cases spread through P. falciparum in 2013 differed between the regions of Pakistan as depicted in Figure 3. Between 2010 and 2014, as illustrated in Figure 4, the majority of malaria cases in Pakistan were due to P. vivax and there was an increase in the incidence of confirmed cases during this time period (WHO, 2015c). Pakistan's Directorate of Malaria Control has a goal of reducing by 75% the malarial disease burden in high, moderate and low endemic districts of Pakistan by 2020.

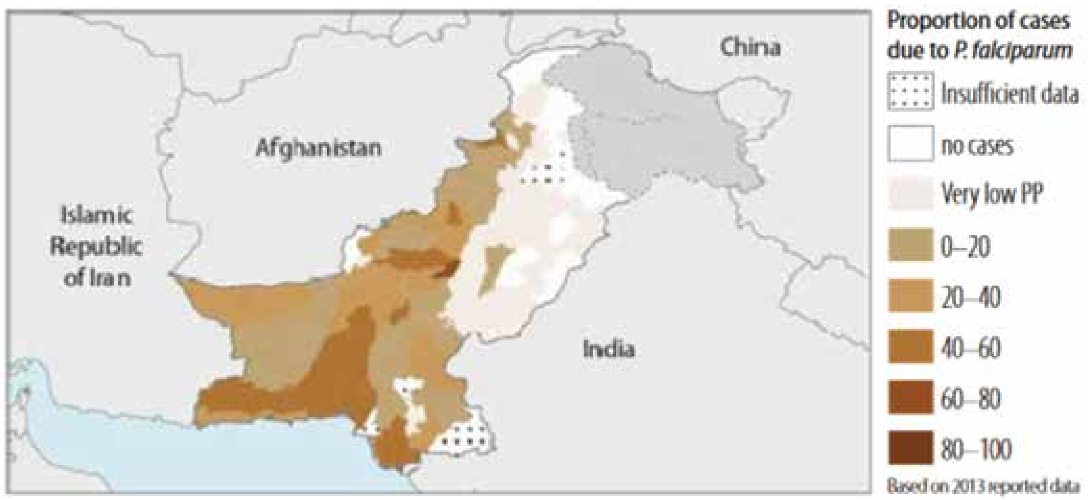


Fig.3. Proportion of number of cases spread through P. falciparum in Pakistan in 2013 (adopted from WHO, 2015c).

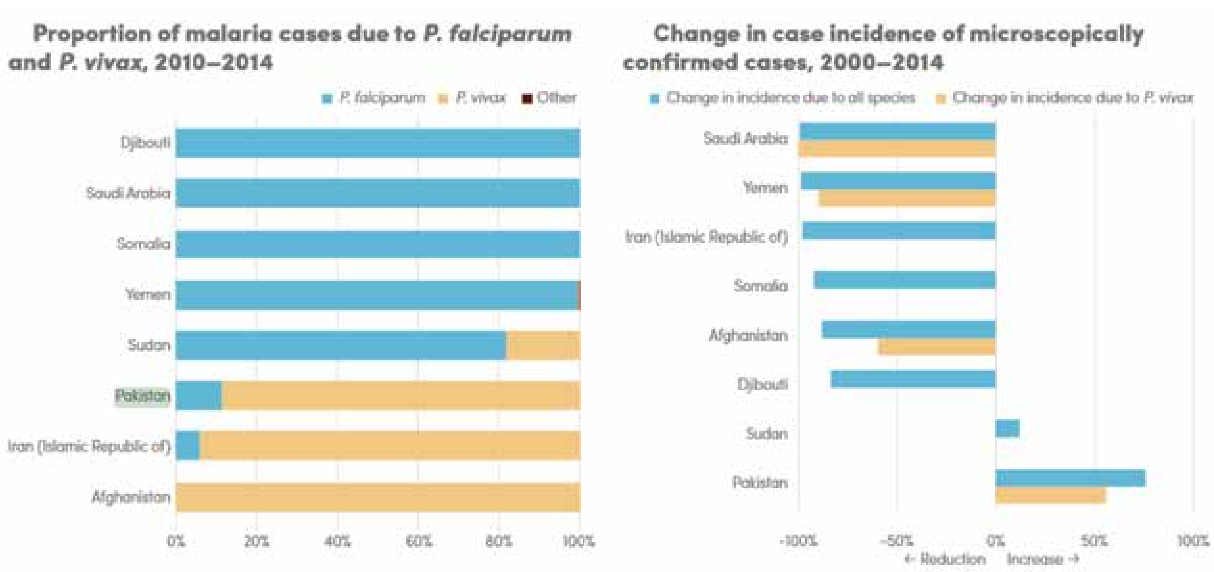


Fig. 4. Proportion of malaria cases due to P. falciparum, P. vivax and others between 2010-2014 and change in incidence of confirmed cases between 2000-2014 (adopted from WHO, 2016).

Temporal variation of malaria is strongly associated with climatological variables like temperature and average rainfall in the area (Ahmad et al., 2015). Surface water, vegetation, and mid-season temperature provides habitat for breeding and supports the growth of the mosquitoes that carry the disease-causing parasites. With changing rainfall patterns and increases in temperature due to climate change, the population density and geographic distribution of malaria carrying mosquito species will also be changed. Yi et al. (2014) have reported on global warming's effect on mosquitoes, the diseases they transmit, and their control strategies. They report that higher rainfall can increase vector populations and transmission of diseases by providing more habitats and breeding places. However, this increase does not occur under all conditions; floods can have a negative effect on the density of mosquito populations because floods may wash or destroy their eggs and larvae.

Malaria can be controlled by different methods like chemical, biological, physical, personal protection measures and environmental management. Environmental management, health education programs, spraying and protection by different ways can be helpful. Mukhtar (2010) discussed the method for prevention and control of vectors and related diseases in detail. Integrated vector management strategies are being applied that are cost effective and environment friendly. Ahmad et al. (2015) studied the water-based malarial diseases using modelling techniques and suggest paying more attention to water supply, solid waste and sewage collection systems, and to include GIS-based surveillance.

Given the changing climate it will be important to monitor the annual parasite incidence in Pakistan. This need already has been included in government policy. Additionally, it would be fruitful if climate change impacts on water- and vector-borne parasites could be studied, along with their control under changing climatic conditions. Such action could reduce the future of diseases such as malaria and dengue fever.

Cholera

Cholera is a water-borne diarrheal disease caused by the bacteria Vibrio cholera, which is naturally present in water environments. Vibrio cholera enter into the body through fecal oral route and is spread through contaminated water and food. It can cause severe problems if left untreated. According to the World Health Organization, an estimated 1.4 to 4.3 million cases of cholera, and 28,000 to 142,000 deaths, occur annually due to this disease (WHO, 2015a). Two serotypes (O139 and O1) can cause outbreaks. As reported, V. cholera (O139) was the major cause of illness, particularly among elderly persons and children. About 80% have minor or mild symptoms but the remaining 20% can have severe diarrhea along with dehydration (WHO, 2015a). Symptoms include abdominal cramps, diarrhea, gastrointestinal illnesses but in severe cases causes watery diarrhea along with other complications. Untreated cases may lead to severe dehydration and death.

According to Naseer and Jamali (2014), not a single case of cholera in Pakistan was reported to WHO between 1992 and 2005. In 2010, about 99 cases of V. cholera (O1) have been reported to WHO by the Ministry of Health, with incidence occurring in flood affected provinces like Punjab, Khyber Pakhtunkhwa and Sindh. According to WHO (2015b), 1,218 cholera cases were reported by Pakistan in 2014 and it remains a public health problem related to water contamination in the country.

In developing countries like Pakistan, problems such as urbanization, population growth, declining water availability and quality, and poor infrastructure are factors that make them more vulnerable to the occurrence of cholera. This disease is linked with deprived environmental management and people that have inadequate sanitation facilities, such as Internally Displaced Persons, travelers (especially children) and pregnant women, are more vulnerable to this disease. Deterioration of water quality after floods—the occurrence of which may increase in Pakistan with climate change—and the unavailability of clean drinking water can increase the risk of cholera and other water-related diseases.

Cholera can be prevented and controlled by adopting better sanitation and clean drinking facilities, and by establishing better infrastructure and health care facilities in flood affected areas. Vaccination against cholera can provide short-term relief along with other control measures. In the long-term, though, there is need for the provision of clean drinking water, better sanitation and improved environmental management. Cholera can easily be treated by providing basic health care facilities in affected areas as 80% of cases can be cured by providing oral rehydration and clean drinking water. Health campaigns and raising awareness by using modern techniques among the affected people in the local languages can be the best strategies to control cholera.

Research gaps and recommendations:

Climate change impacts on human health, either through its implications for water quality or for vector- or water-borne diseases have not yet been well recognized in Pakistan and few studies focused on its implications for the country have been undertaken. Yet it can be predicted that with changing climatic conditions, future water quality might be effected negatively, and that both water-borne and water-related diseases might increase.

Given this observation, the following research gaps have been identified and recommendations are suggested accordingly:

- Given the large research gap regarding the relationship between climate change impacts and changes in water quality and water-borne diseases, it is highly recommended to explore the water quality scenario under changing climatic conditions. Poor water quality has serious health impacts and it must be explored under current and future climatic conditions.
- Empirical studies have been conducted in the past related to the issue of climate change on water quality in Vietnam and the knowledge gaps suggest that adaptive measure should be undertaken to avoid mishaps related to climate change in the future (Whitehead et al., 2009; Hien et al., 2016). Similar studies are suggested on the Indus River and other water resources in Pakistan. There is need to study the challenges to cope with the risk of water scarcity, quality with special reference to climate change.
- Globally, less attention has been paid to study the impact of climate change on bacteriological water quality and few studies have been conducted to assess the water quality of rivers. Similar studies should be conducted in the future in Pakistan.
- Water quality should be monitored at regular time intervals, especially pre- and post-extreme weather events and natural disasters and it is recommended that water quality

under changing climate change should be included in existing national climate change and water policy documents.

- Given the important influence of water quality on human health, now and under changing climatic conditions, greater investment is needed in actions that protect water quality and water resources, so as to decrease the future of water-borne and related diseases.
- More research is needed on the potential impact of climate change on the abundance and distribution of water- and vector-borne parasites, such as malaria, dengue fever and cholera, as well as strategies for their control under changing climatic conditions. Such action could reduce the future incidence of these diseases.
- Investment is needed in the health care system, particularly in flood affected areas, to increase its capacity to manage the expected increase in the occurrence of water- and vector-borne diseases associated with changing climatic conditions.
- Health campaigns and other awareness raising efforts that use modern techniques and local languages are needed to inform those most at risk of the best strategies to control malaria and cholera.

References

Abbass, Z. (2009). Climate Change, Poverty and Environmental Crisis in the Disaster Prone Areas of Pakistan. Oxfam Great Britain.

Ahmad, S.S., Aziz, N., Butt, A., Shabbir, R., Erum, S. (2015). Spatio-temporal surveillance of water based infectious disease (malaria) in Rawalpindi, Pakistan using geostatistical modeling techniques. Environmental Monitoring and Assessment. 187:555. DOI: 10.1007/s10661-015-4779-9.

Ahmed, T., Pervez, A., Mehtab, M., & Sherwani, S. K. (2015). Assessment of drinking water quality and its potential health impacts in academic institutions of Abbottabad (Pakistan). Desalination and Water Treatment, 54(7), 1819-1828.

Azizullah, A., Khattak, M. N. K., Richter, P., & Häder, D. P. (2011). Water pollution in Pakistan and its impact on public health—a review. Environment International, 37(2), 479-497.

Bates B. C., Kundzewicz Z. W., Wu S. and Palutikof J. P. (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

Centre for Disease Control and Prevention. (2016). Infectious Diseases Related to Travel. Retrieved from http://wwwnc.cdc.gov/travel/yellowbook/2016/infectious-diseases-related-to-travel/yellow-fever-malaria-information-by-country/india#seldyfm707. Last accessed on June, 2016.

Country Coordination Mechanism-Pakistan (CCM-Pak). (2016). Disease Prevalence Scenario. Retrieved from http://www.ccmpakistan.org.pk/disease_malaria.ph. Last accessed on June, 2016.

Delpla, I., Jung, A. V., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. Environment International, 35(8), 1225-1233.

Global Health and Education Foundation. (2016). Safe drinking water is essential. Retrieved from https://www.koshland-science-museum.org/water/html/en/Treatment/Diseases-Caused-by-Defective-Sanitation.html. Last accessed April 2016.

Guillaume, C. and Rita, R.C. (2009). Cholera and Climate: A Demonstrated Relationship. Trans. Am. Clin. Climatol. Assoc. 120: 119–128.

Hien, H. N., Hoang, B. H., Huong, T. T., Than, T. T., Ha, P. T. T., Toan, T. D., & Son, N. M. (2015). Study of the Climate Change Impacts on Water Quality in the Upstream Portion of the Cau River Basin, Vietnam. Environmental Modeling and Assessment, 1-17.

Hunter, P.R. (2003). Climate change and waterborne and vector-borne disease. Journal of Applied Microbiology. 94. 37S-46S. Retrieved from http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2672.94.s1.5.x/pdf

Jabeen, F., Chaudhry, A. S., Manzoor, S., & Shaheen, T. (2015). Examining pyrethroids, carbamates and neonicotenoids in fish, water and sediments from the Indus River for potential health risks. Environmental Monitoring and Assessment, 187(2), 1-11.

Liu, W. C., & Chan, W. T. (2015). Assessment of the climate change impacts on fecal coliform contamination in a tidal estuarine system. Environmental Monitoring and Assessment, 187(12), 1-15.

Mirza, M. A., Khuhawar, M. Y., & Arain, R. (2007). Quality of Spring Water in the Catchment Areas of the Indus River. Asian Journal of Chemistry, 19(7), 5279.

Mukhtar, M. (2009). Guideline for anti-vector interventions for Monsoon season. Directorate of Malaria control program. Pakistan Ministry of Health.

Mukhtar, M. (2010). Guideline for the control of vectors of public health importance after monsoon rain in Pakistan. Directorate of Malaria control program. Pakistan Ministry of Health.

Murtaza, G., Ghafoor, A., & Qadir, M. (2008). Accumulation and implications of cadmium, cobalt and manganese in soils and vegetables irrigated with city effluent. Journal of the Science of Food and Agriculture, 88(1), 100-107.

Naseer, M. and Jamali, T. (2014). Epidemiology, determinants and dynamics of cholera in Pakistan: gaps and prospects for future research. J. Coll. Phy. Surg. Pak. 24(11):855-60.

Pakistan Meteorological Department (PMD). (2012). Climate of Pakistan. NDMC, H-8, Islamabad.

Sadia, A., Feroza, H. W., Imran, Q., Muhammad Hamid, S. W., Tirmizi, S. A., & Muhammad, A. Q. (2013). Monitoring of anthropogenic influences on underground and surface water quality of Indus River at district Mianwali-Pakistan. Turk. J. Biochem, 38(1), 25-30.

Saeed, T.U. and Attaullah, H. 2014. Impact of Extreme Floods on Groundwater Quality (in Pakistan). British Journal of Environment and Climate Change. 4(1): 133-151.

Tariq, M. I., Afzal, S., Hussain, I., & Sultana, N. (2007). Pesticides exposure in Pakistan: A review. Environment International, 33(8), 1107-1122.

Wattoo, M. H. S., Wattoo, F. H., Tirmizi, S. A., Kazi, T. G., Bhanger, M. I., & Qbal, J. I. (2006). Pollution of Phulali canal water in the city premises of Hyderabad: Metal monitoring. Journal of the Chemical Society of Pakistan, 28(2), 136-143.

Whitehead, P. G., Wilby, R. L., Battarbee, R. W., Kernan, M., & Wade, A. J. (2009). A review of the potential impacts of climate change on surface water quality. Hydrological Sciences Journal, 54(1), 101-123.

World Health Organization (WHO). (1996). World Health Organization Guidelines for Drinking-water Quality, Volume II, 2nd Edition. Geneva: World Health Organization.

World Health Organization (WHO). (2015a). Cholera report. Retrieved from http://www.who.int/mediacentre/factsheets/fs107/en/. Last accessed on June, 2016.

World Health Organization (WHO). (2015b). Weekly epidemiological record: Cholera 2014. 90: 517-544

World Health Organization (WHO). (2015c). World Malaria Report 2015. Retrieved from http://www.who.int/malaria/publications/country-profiles/profile_pak_en.pdf. Last accessed on June, 2016.

World Health Organization (WHO). (2016). Malaria report. Retrieved from http://www.who.int/mediacentre/factsheets/fs094/en/. Last accessed on June, 2016.

Zhang, C., Lai, S., Gao, X., & Xu, L. (2015). Potential impacts of climate change on water quality in a shallow reservoir in China. Environmental Science and Pollution Research, 22(19), 14971-14982.

Zhang, Y., Sillanpaa, M., Li, C., Guo, J., Qu, B., & Kang, S. (2015). River water quality across the Himalayan regions: elemental concentrations in headwaters of Yarlung Tsangbo, Indus and Ganges River. Environmental Earth Sciences, 73(8), 4151-4163.

Yi, H., Devokota, B.R., Yu, J., Oh, K., and Kim, H. (2014). Effects of global warming on mosquitoes & mosquito-borne diseases and the new strategies for mosquito control. Ent. Res. 44(6): 215-235.

Appendix 7:

Road maps of potential options for addressing gaps

A briefing paper prepared as part of the project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action"

Prepared by: Jo-Ellen Parry, International Institute for Sustainable Development

This appendix provides detailed descriptions of the priority options identified through this study for strengthening Pakistan's capacity to undertake the research and action required to reduce the risks arising from the impacts of climate change on water resources in the Indus River Basin. Action plans or road maps are presented for the following options:

- Accelerate uptake of sustainable irrigation practices by smallholder farmers
- Strengthening post-secondary education in the area of climate change
- Establishing a central repository of water data and analysis
- Modernizing Pakistan's streamflow monitoring network

7.1 Road map: Accelerating sustainable irrigation practices by smallholder farmers

Summary

This action will support smallholder farmers in the adoption of more efficient irrigation technologies and better land management practices in order to improve the efficiency of water use within the agriculture sector and increase the climate resiliency of the Indus Basin Irrigation System.

Main elements

This action seeks to increase the ability of small landholder farmers in Pakistan to access and use water-efficient irrigation technologies and sustainable land management practices through an integrated and holistic approach that will overcome existing barriers. The action will promote development of an irrigation system that is:

- Economically sustainable by establishing a well-designed incentive structure that ensures that appropriate technologies are available to smallholders at an affordable price—while also encouraging access to private sector finance and the development of local manufacturing and distribution systems.

- Socially sustainable by ensuring that the approach increases crop productivity, improves farmer incomes and livelihood sustainability, and provides more opportunity for smallholders to be directly engaged in managing the irrigation system.
- Environmentally sustainable by ensuring that the system provides the targeted capacity building and incentives needed to reverse current trends of groundwater depletion, soil erosion, waterlogging, and soil subsidence and salinization.

Achievement of these objectives will increase the climate resilience of smallholder farmers by enhancing their ability to adapt to a more uncertain climatic future and by improving the resiliency of the irrigation system as a whole.

The main tasks associated with designing an integrated initiative that will achieve these objectives are:

1. *Landscape analysis.* A range of actors are currently working to improve the functionality and productivity of irrigated agriculture systems in Pakistan, prominent among which are provincial irrigation departments, research institutes (e.g. the Pakistan Agricultural Research Council), multilateral organizations (e.g. the World Bank), and non-governmental organization (e.g. World Wildlife Fund). A mapping of these actors, their current and planned activities focused on supporting smallholder farmers, and the location of these initiatives will be undertaken as a first step. Information will be gathered through key informant interviews, complemented by desk-based review of relevant project documents. This information will provide a baseline against which to develop a new initiative that complements ongoing and planned initiatives, and avoids duplication.

2. *Best practices review.* In conjunction with the landscape analysis, a review will be undertaken of lessons learned regarding the most effective strategies for enabling smallholder farmers to adopt sustainable irrigation and land management practices. Through interviews and a review of secondary sources, this assessment will take into account experiences not only within Pakistan but also in other South Asian countries facing similar challenges. Particular attention would be given to successful strategies related to topics such as: smallholder farmers' capacity to access finance to purchase appropriate technologies and transition to new agricultural practices, such as through micro-finance schemes or tailored incentives (subsidies) that are economically, socially and environmentally sustainable; developing integrated value chains that promote local manufacturing, marketing and maintenance of appropriate high efficiency irrigation technologies; building the capacity of agricultural extension workers and farmers; and community-based management of irrigation systems.

3. *Identification of priority needs.* Based on a review of federal and provincial government policies and plans, as well as expert analysis and farmers' knowledge regarding the barriers to the uptake of sustainable irrigation systems and practices, priority locations and interventions for improving smallholder irrigation systems will be identified. This prioritization process will take into consideration outcomes of the landscape assessment and best practices review. Economic, social and environmental criteria will be used

to determine priority needs, so as to target smallholder farmers that are particularly economically less privileged and are not currently being supported through other initiatives. The outcomes of this process would be validated through provincial and local stakeholder consultation processes.

4. *Detailed design of targeted program.* A full proposal for a multi-year program of action that responds to the identified priority needs in a selected location will be developed and reviewed in a participatory manner. Elements of program are expected to include:
    - Strengthening the private sector's capacity to develop and finance low-cost, high efficiency irrigation systems, such as drip, bubbler and sprinkler irrigation systems, so as to foster creation of a permanent local market for these technologies.
    - Developing sustainable strategies for providing farmers with access to the financing needed to purchase appropriate irrigation technologies, such as through microfinance schemes, targeted incentives and the reform of existing subsidies.
    - Delivering farmer field schools to promote among other topics: improved land management practices such as land leveling and the use of raised bed technology; soil conservation strategies; planting less water intensive crop varieties; crop water requirements; and the management and distribution of irrigation water.
    - Strengthening the capacity of provincial government officials, including extension officers, to communicate and work with smallholder farmers to select, use and maintain sustainable irrigation and land use management practices; and to effectively and efficiently manage irrigation systems.
    - Forming of farmer' councils to increase community-level management of irrigation systems.
    - Strengthening the capacity of research institutes and academia to undertake applied research that meets the needs of smallholder farmers, and develop stronger coordination between academia, research and extension departments.
    - Communication and outreach at the local level regarding the need to conserve water and increasing efficiency of its use, particularly as a strategy for increasing resilience to climate change.

Rationale for selection of this action

Pakistan is rapidly moving from becoming a water stressed to a water scarce country, driven primarily by factors such as population growth, industrialization, urbanization and the loss of existing sweet water sources to pollution. Even in the absence of climate change, these factors will continue to drive increasing water demand and growing competition for a finite resource. The vast majority of water demand at present comes from the agricultural sector, largely to support the approximately 14.3 million hectares of land (or about 85 percent of Pakistan's cropped area) irrigated through the Indus Basin Irrigation System (USAID, 2009). The agricultural sector will continue to be the dominant user of water in Pakistan in the future.

At the same time, Pakistan's irrigation system is highly inefficient at the canal, watercourse and field levels, with only about 30 percent of water flowing through the Indus Basin

"Without a better understanding of the timing and sources of runoff from the catchment basins of the upper Indus, the nature and severity of any climate change impacts cannot be assessed with confidence" (Alford et al., 2016: p.61).

Irrigation System being delivered to farms and farmers at the tail end of the system rarely getting water (GOP, 2013a). This situation is known to arise from a combination of factors including aging infrastructure and poor maintenance (Qureshi, 2011; Bhatti et al., 2009), which in turns stems in large part from weak management, an absence of regulatory enforcement, and poorly designed financial incentive and recovery systems. Water usage rates do not reflect the real cost of operating and maintaining the system and recovery rates of limited, leading to a lack of appropriate, sustained investment in the country's irrigation system (GOP, 2013a). Poor design of the system also incents farmers to overwater their crops, which has led to waterlogging and salinization. Climate change will place additional pressure on this faltering system. Even in the absence of potential changes in peak flow patterns and run-off volumes, climate change will expose the system to higher rates of evapotranspiration and greater damage from extreme weather events.

The need to upgrade, extend and improve the efficiency of Pakistan's irrigation system, to both increase resilience in the face of climate change and enhance food security, is widely acknowledged. Pakistan's Vision 2025 commits to establishing irrigation policies that "ensure efficient use of water" (GOP, 2014: p.82) and calls for more effective methods for water distribution, minimization of wastage, rationalization of pricing, and more efficient use so as to enable sustainable social and economic development (GOP, 2014). Pakistan's National Climate Change Policy and its associated framework for implementation both call for the rehabilitation and upgrading of the country's irrigation infrastructure, reducing losses from the irrigation system, adoption of more efficient irrigation techniques, development of (financial) incentives for the adoption of efficient irrigation techniques, and using improved irrigation and land management techniques to enhance crop productivity per unit of water (GOP, 2012; 2013b). Similar statements and recommendations are contained in the Task Force on Food Security (2009), National Economic and Environmental Development Study (2011), and the draft Agriculture and Food Security Policy (2013), amongst many others.

While significant investments are needed to upgrade and expand the existing irrigation system, there is a complementary need to improve the capacity of smallholder farmers to adopt water-efficient irrigation technologies and water-conserving agricultural practices that increase productivity per drop of water used. There is also a need for rationale pricing policies that avoid the creation of market distortions through poorly designed subsidies and incentives. Investment in such initiatives will enable creation of the sustainable and climate resilient irrigation system Pakistan needs to ensure its future water, energy and food security.

Current status

A number of large projects focused on improving Pakistan's irrigation system are currently being implemented with funding from organizations such as the World Bank, the Asian Development Bank, and the United States Agency for International Development (USAID).

Among these initiatives are:

- The Punjab Irrigated Agricultural Productivity Program (US$ 423.50 million) supported by the World Bank, which is providing farmers with more efficient irrigation systems and better technologies to improve the efficiency of water use in crop production (World Bank, 2014).
- The Sindh Irrigated Agricultural Productivity Enhancement Project, for which the World Bank has approved US$187 million to support more efficient water usage, including through the introduction of high efficiency irrigation systems (World Bank, 2015).
- The Punjab Irrigated Agriculture Investment Program financed by the Asian Development Bank, through which upgrades are being undertaken of existing barrages and some support provided to enhance the capacity of farmer groups to engage in management of the irrigation system.
- The Gomal Zam Irrigation Project in Khyber Pakhtunkhwa funded by USAID (US$ 76.5 million), which is financing the construction of an irrigation and drainage system downstream of this dam.

Many of these large projects have a significant infrastructure development and/or rehabilitation component, with less funding being allocated to working directly with smallholder farmers. In parallel, efforts to engage farmers in the uptake of high-efficiency irrigation systems and better land management practices are the primary focus of a number of smaller initiatives, such as those being implemented by:

- The Climate Change, Alternate Energy and Water Resources Institute of the National Agricultural Research Centre within the Pakistan Agricultural Research Council, which is developing and testing different water conservation systems and strategies such as drip and sprinkler irrigation systems, centre pivot sprinkler irrigation systems, furrow-bed systems, and integrated water resource management (CAEWRI, n.d).
- The Pakistan Council of Research in Water Resources, which is working to provide farmers with appropriate technologies and support, such as by: working with more than 100,000 farmers to install drip irrigation systems in Punjab; providing advice on when and how much water is required by different crops given anticipated weather conditions; and introducing flow monitors on some irrigation channels (M. Ashraf, personal communication, June 7, 2016).
- Oxfam Novib's Inclusive Water Governance Programme, which strives in part to promote more effective use and better delivery of water resources by encouraging smallholder farmers to adopt better water use techniques and engage in the operation and maintenance of water resources (Oxfam, n.d.).
- The Indus Consortium, which is working with smallholder farmers and those at the tail end of irrigation canals in Punjab and Sindh to improve the governance of local irrigation systems (H. Jarwar, personal communication, June 2, 2016).

A scaling up of these efforts that directly engage farmers in the adoption of more sustainable irrigation practices is needed for Pakistan to address its growing competition for a finite supply of available water resources and vulnerability to climate change.

Expected impacts/ resultS of action

Outcomes from implementation of this action are expected to include:

- Uplifting of the socio-economic conditions of smallholder farmers.
- Improved productivity of staple crops, such as rice, with less water, thereby increasing food security and strengthening the national economy.
- Reduced vulnerability of small landholder farmers to greater climate variability, including climate change-driven increases in the risk of droughts, heavy rainfall events, and floods, and the associated impact of these changes on the timing and volume of water available for irrigation.
- Protection of fertile land against erosion, waterlogging and salinization due to a decline in the use of conventional irrigation methods.

Outputs are expected to include:

- Increased uptake by smallholder farmers of water-efficient irrigation technologies due to improved access to micro-credit, the availability of locally-manufactured appropriate technologies, and greater knowledge regarding the benefits and effective use of sustainable irrigation systems.
- Improved land management practices by smallholder farmers.
- Active and well-trained farmers' councils engaged in the operation and maintenance of local irrigation systems.
- Improved coordination amongst different provincial and federal government departments with respect to the adoption, use, monitoring and financing of irrigation systems tailored to the needs of smallholder farmers.
- Greater awareness within Pakistani research organizations regarding the needs of smallholder farmers and increased collaboration with provincial government departments.

Key concerns, barriers or challenges

Potential challenges to successful implementation of this action include:

- Successfully designing a program tailored to the specific circumstances of the targeted region that will achieve the goal of enabling smallholder farmers to overcome existing economic and social barriers to adopting new agricultural practices and irrigation technologies.
- Ensuring complementarity, and avoid duplication, of actions being implemented as part of current and planned initiatives led by international, federal, provincial and local organizations.
- Vested interests who have a desire to maintain existing political and social-economic relationships.

Potential implementation partners

The lead partners to be engaged within this initiative would be provincial departments responsible for irrigation, agriculture (particularly agricultural extension workers), and finance as well as local Irrigation and Drainage Authorities. Additional support would be provided by:

- Federal government entities with responsibilities related to country's irrigation systems such as the Indus River System Authority.
- Research organizations such as the Pakistan Agricultural Research Council and the Pakistan Council of Research in Water Resources, who would support the development and dissemination of appropriate technologies and land use management practices.
- Local private sector technology suppliers able to manufacture and sell appropriate high efficiency irrigation systems at affordable prices.
- Local large landowners, whose support often will be required for effective change to take place.
- Non-governmental organizations able to support outreach and capacity building with farmers.

Timeframe

This action will be implemented through three phases:

- Design phase: a one year to 18-month design phase in which the landscape analysis, best practices review, priority needs assessment and detailed project design would be completed;
- Pilot phase: a 4 to 5-year pilot phase in which the initiative would be launched in each Union Council within the selected project location, outreach undertaken with a cross-section of target villages, farmers' councils formed, engagement activities undertaken with the private sector, and capacity building activities undertaken with provincial government officials and farmers.
- Upscaling phase: a 4 to 5-year phase in which activities will be extended to all villages in the Union Council, incorporating lessons learned through the pilot phase, and joint councils are formed that involve very small land holders (those having less than three acres of land).

Estimated cost of the action

The estimated cost for undertaking this work would be: US$300,000 to US$350,000 for the design phase; between US$2.0 to $4.0 million for the pilot phase, depending on the scope of planned activities; and US$4.0 to $8.0 million for the up-scaling phase. This estimate takes into consideration the previously identified ongoing initiatives in Pakistan as well as the following additional examples of similar initiatives:

- The Strengthening Irrigation Management System including Agriculture Extension through Farmers' Participation in the Punjab Province implemented between 2009 and 2013 with financial support from the Japan International Cooperation Agency (approximately 200 million Yen or about US$ 1.9 million) that aimed to improve the management and maintenance of irrigations systems in three irrigation zones in Punjab, and increase water use efficiency and on-farm productivity (Japan International Cooperation Agency, n.d).

- Horti-Sempre, an income generation project in Mozambique financed by the Swiss Development Cooperation (€ 4.25 million) that included a component in which farmers evaluated new micro-irrigation technologies and then support was provided to encourage the local private sector to make these technologies available (GFA Consulting Group, n.d).
- The Participatory Irrigation Development Programme in Tanzania implemented by the International Fund for Agricultural Development (IFAD). This six year, US$25.3 million project sought to strengthen irrigation and low-cost water control systems, improve agricultural productivity, strengthen farmers' organizations, and improve the capacity of local institutions to advance smallholder irrigation development (IFAD, n.d.).
- The Irrigation Technology Pilot Project to Face Climate Change project in Jordan (US$4.5 million over four years) which will promote sustainable, reliable and economically competitive irrigation technologies (IFAD, 2015).

Immediate next steps

- Stakeholder consultations with irrigation departments, extension workers, technology suppliers, and non-governmental organizations regarding engagement in the initiative and priority areas for intervention.
- Consultations with bilateral donors regarding their current and planned initiatives.
- Consultations with a cross-section of chairmen of Union Councils and farmer's representatives to assess their interests with respect to improved irrigation systems and observed barriers to their use.

References

Bhatti, A. M., Suttinon, P., & Nasu, S. (2009). Agriculture water demand management in Pakistan: a review and perspective. Society for Social Management Systems, 9(172), 1-7.

Climate Change, Alternate Energy and Water Resources Institute (CAEWRI) (no date). Agricultural Water Management Program. Retrieved from http://www.parc.gov.pk/index.php/en/caewri-rshprog/caewri-awmp

GFA Consulting Group (no date). Horti-Sempre – income generation through microirrigation, Mozambique. Retrieved from http://www.gfa-group.de/Horti-Sempre_income_generation_through_microirrigation_3679686.html

Government of Pakistan (GOP). (2012). National Climate Change Policy. Islamabad: Ministry of Climate Change.

Government of Pakistan (GOP). (2013a). Agriculture and Food Security Policy (Draft). Islamabad: Ministry of National Food Security and Research.

Government of Pakistan (GOP). (2013b). Framework for Implementation of Climate Change Policy (2014-2030). Islamabad: Climate Change Division.

Government of Pakistan (GOP). (2014). Vision 2025: One Nation – One Vision. Islamabad: Ministry of Planning, Development & Reform. Retrieved from http://pakistan2025.org/wp-content/uploads/2014/08/Pakistan-Vision-2025.pdf

International Fund for Agricultural Development (IFAD). (no date). United Republic of Tanzania: Participatory Irrigation Development Programme (PIDP). Retrieved from https://www.ifad.org/evaluation/reports/ppa/tags/tanzania/1086/1860133

International Fund for Agricultural Development (IFAD). (2015). Jordan: Irrigation Technology Pilot Project to Face Climate Change. Retrieved from https://www.ifad.org/documents/10180/cd529f1a-f708-42da-a190-379faf30b521

Japan International Cooperation Agency (no date). Strengthening Irrigation Management System Including Agriculture Extension through Farmers' Participation in the Punjab Province. [web page] Retrieved from http://www.jica.go.jp/pakistan/english/activities/activity02_23.html

Oxfam (n.d.). Indus Inclusive Water Governance. Retrieved from http://www.oxfamnovib.nl/Redactie/Pdf/IndusBrochureOnline.pdf

Qureshi, A. S. (2011). Water management in the Indus basin in Pakistan: challenges and opportunities. Mountain Research and Development, 31(3), 252-260.

United States Agency for International Development (USAID). (2009). Pakistan's Food and Agricultural Systems. Retrieved from: http://pdf.usaid.gov/pdf_docs/PNADO507.pdf

World Bank. (2014). Improving Punjab Irrigation: More crops from every drop. Retrieved from: http://www.worldbank.org/en/news/feature/2014/04/18/improving-punjab-irrigation-more-crops-from-every-drop

World Bank. (2015). World Bank Approves US $187 million to Enhance Agriculture Productivity in Sindh. Retrieved from http://www.worldbank.org/en/news/press-release/2015/03/20/world-bank-187-million-enhance-agriculture-productivity-sindh

Annex: Sample of recent and ongoing irrigation projects in Pakistan

Project Name	Objective	Funder	Timeframe
Sindh Irrigated Agriculture Productivity Enhancement Project	To improve irrigation water management at tertiary and field level in Sindh.	World Bank (Total: US$ 242 million)	2015-2021
Additional Financing for Sindh Water Sector Improvement Phase 1	The objective of the additional financing for the First Phase of Sindh Water Sector Improvement Project for Pakistan is to improve the efficiency and effectiveness of irrigation water distribution in Ghotki Area Water Board (AWB), Nara AWB, and Left Bank AWB, all in the Province of Sindh, particularly with respect to measures of reliability, equity and user satisfaction.	World Bank (US$ 138 million)	2015-2019
Punjab Irrigated Agriculture Productivity Improvement Program Phase-I	The projects main objective is to improve productivity of water use in irrigated agriculture. This will be achieved through improved physical delivery efficiency and irrigation practices, crop diversification and effective application of inputs that will translate into greater agricultural output per unit of water used. The projects objectives would contribute to increased agricultural production, employment and incomes, higher living standards and positive environmental outcomes.	World Bank (US$ 423.5 million)	2012-2018
Punjab Irrigated Agriculture Investment Program - Project 1	The project seeks to promote economic growth, increase farm incomes and improve resource sustainability through enhanced productivity of irrigated agriculture and improved management of Punjab's water resources.	Asian Development Bank (US$ 281 million)	2007-2016
Punjab Irrigated Agriculture Investment Program - Project 2	A new Khanki Barrage will be constructed on River Chenab at 275m downstream of the existing khanki headworks. It will replace a 120 years old existing structure.	Asian Development Bank (US$ 309 million)	2012-2016
Punjab Irrigated Agriculture Investment Program Tranche 3	Pakpattan Canal and Suleimanki Barrage Improvement Project is located in Punjab Province of Pakistan. Improvement of Suleimanki Barrage will ensure reliable water supply to 1.01 million ha through its three canals including Pakpattan, Fordwah and Eastern canals and will benefit more than 360,000 farming families.	Asian Development Bank (US$ 85.4 million)	2013-2017
Punjab Irrigated Agriculture Investment Program – Tranche 4	Undertaking infrastructure upgrades, complemented by efforts to form farmer groups, to increase agricultural production and farm income in the Lower Bari Doab Canal command area.	Asian Development Bank (US$ 26.57 million)	2015 – 2017

Project Name	Objective	Funder	Timeframe
Jalalpur Irrigation Project	An International organization/NGO will mobilize farmers, establish water users' groups and manage their training through participatory consultation and on-site demonstrations. It will explain the project objectives, major outputs and outcome to the farmers. The consultation will help in implementation on-farm and institutional components of the project.	Asian Development Bank (US$ 900,000)	2013-2015
Gomal Zam Irrigation Project	The project seeks to provide flood control and roundtheyear supply of irrigation water in the Tank and Dera Ismail Khan (D.I.Khan) districts of Khyber Pakhtunkhwa. Through this project, USAID funds construction of an irrigation and drainage system downstream from the Gomal Zam Dam situated in South Waziristan. When completed, the irrigation system will provide nearly 325,000 acrefeet of water annually to irrigate 191,000 acres of farm land in KP.	USAID (US$ 76.5 million)	2007-2015
Satpara Development Project	The Satpara Development Project is constructing onfarm irrigation systems on 15,500 acres downstream from the Satpara Dam in GilgitBaltistan. The project is improving the supply of irrigation water by lining the primary, secondary and tertiary level water courses and ensuring efficient water use through the introduction of drip and sprinkle irrigation systems. These improvements increase the productivity and availability of the region's highvalue fruit, vegetable and fodder crops.	USAID (US$ 20 million)	2012-2017

7.2 Roadmap: Strengthen post-secondary education in the area of climate change

Summary

This action will strengthen climate change education at the post-secondary level in Pakistan, increasing the number of individuals entering into the work force that have a committed interest in this issue and the training needed to engage in impact, vulnerability and adaptation-related research and actions.

Main Elements

The objective of this option is to strengthen the capacity of Pakistan's post-secondary education system (universities and technical institutes) to provide training related to climate change and water studies, as well as sustainable development in a changing climate more generally. Achieving this objective will require a systematic and long-term approach that builds the capacity of learning institutions as well as develops the skills of individuals. Actions will be needed to:

- Develop tailored curriculum in priority scientific and social disciplines
- Strengthen teaching capacity through the development of teaching and practice modules as well as through the creation of professional development opportunities
- Create learning opportunities for students
- Increase opportunities to share climate change-related research and foster development of a national community of practice in the field of climate change adaptation

The main tasks associated with the design and implementation of this option are described below:

1. *Stakeholder analysis and engagement.* Building on initial work completed as part of this project, an analysis will be undertaken to identify stakeholders within government and academia who are or could be involved in strengthening post-secondary education in the field of climate change, with a particular focus on water-related issues. This will include national and provincial ministries directly engaged in shaping learning systems as well as relevant sectoral ministries (water and power, agriculture, infrastructure, health, etc.).

   A stocktaking of existing priorities and initiatives will also be undertaken as part of this step that takes into consideration:

   - Existing climate change-related training, programs and initiatives being implemented at the post-secondary level by universities and technical institutes—to understand what training is already available, who is delivering this training, its quality and lessons that have been learned through these ongoing efforts.
   - Existing efforts to strengthen post-secondary education and training institutions more generally, as reflected in national and provincial policies and existing capacity development initiatives, to better enable alignment with ongoing initiatives.

This process could be facilitated through a national planning workshop in combination with expert interviews and a policy review. An outcome of this process will be an assessment of the potential interest of different educational institutions in strengthening their capacity to deliver quality climate change-related training, which will be a step toward identification of key implementation partners.

2. *Assessment of learning needs.* A needs assessment will be undertaken to gain a deeper understanding of the climate change-related knowledge and technical skills required by key sectors and assess their current and future level of demand for these skills. This information will be used to ensure the development of curricula and climate change education programs that produce graduates with capacities desired in the work place.

   Implemented through focus group discussions, workshops and expert interviews, the assessment will reach out to federal and provincial government ministries (such as those responsible for water, health, hydrometeorology and agriculture) as well as the private sector, research institutions and NGOs that currently are or could be engaged in climate change and water related research and actions. Key questions that could be asked as part of this assessment include (Haipaap, Horstbrink & Mackay, 2013):

   - What types of functions and tasks related to climate change adaptation need to be undertaken by individuals within these surveyed organizations and institutions – now and likely in the near future?
   - What skills, knowledge and competencies are needed to undertake these functions and tasks?
   - How sufficient are existing human resource capacities and skills to perform these functions and tasks?

Priority areas in which to provide learning and skills development will be identified out of this process. This analysis would complement past efforts to identify priority knowledge gaps, which suggest that there is a need to build human resource capacities in areas such as: regional climate modelling, weather forecasting services, numerical weather predictions (spatial and temporal), Geographical Information Systems (GIS), remote sensing, hydrology, flood forecasting, hydrometeorology, integrated flood management, glacial monitoring, climate change monitoring, communications (such as of forecasts and warnings), and institutional coordination and collaboration (GOP, 2012; WMO, 2010).

3. *Assessment of delivery capacities*. As effective delivery of education in the field of climate change depends on the expertise and teaching capacity of knowledge delivery agents (professors and lecturers), an assessment of the capacities of learning institutions will be undertaken to determine required learning and skills development needs. The assessment could be conducted using methods such as document review, focus groups and expert interviews. Based on similar assessments conducted as part of the UN CC:LEARN program, guiding questions that could be used in this assessment include (Haipaap, Horstbrink & Mackay, 2013: p.27):

   - "Does the institution offer learning activities or courses on, or related to, climate change? Which programmes? Which specific topics are covered?

- "What expertise do professors/teachers working for the institution have concerning specific topics of climate change?
- "Is there a specific topic related to climate change that the institution would like to provide within a programme but currently lacks the human or financial resources to do so?
- "Has the institution developed any learning materials, training modules, e-learning courses, etc. relevant for climate change?"

Information gathered through this process would be used to develop a profile of the existing training being provided in the area of climate change. Through a comparison of outcomes of the needs assessment completed in step 2 and the assessment of existing capacities to deliver climate change and water learning opportunities, priority gaps will be identified.

4. *Development of an action plan*. Taking into account the identified priority gaps in existing learning opportunities, an action plan will be developed to support individual learning and strengthen the capacity of learning institutions through professional and curriculum development. The action plan should be developed though a multi-stakeholder process to ensure its continued relevance to both post-secondary education institutions and potential employers in government, the private sector, etc. The resulting action plan could be presented in terms of short term (1 to 3 years), medium term (4 to 10 years) and long-term (more than 10 years) objectives.

   Expected elements of the resulting action plan include:

   - Preparation of curricula and courses to support professional learning and skills development for course instructors, professors and researchers.
   - Professional development opportunities to increase the capacity of education planners, curriculum developers and teaching staff to effectively deliver climate change-related courses and engage in relevant research. This could be achieved through international exchanges, study tours, and participation in programs such as the Asia-Pacific Network for Global Change Research's CAPaBLE program.
   - Establishment of climate change-focused curricula and Masters-level associated degree programs tailored to the needs of different sciences and social sciences disciplines.
   - Development of a competitive grants program to promote research in the area of climate change and water that is designed to address identified priority knowledge gaps, such as the links between climate change and water quality and health, the effectiveness of different adaptation options, or ways to promote water conservation through water pricing or efficient irrigation technologies.
   - Provide young researchers with targeted scholarship opportunities to undertake climate change focused research and training at reputable international higher education institutions.
   - Improve Pakistani teaching staff, researchers and students' linkages with experts based at international research institutions through guest lectures and teaching exchange

programs.

- Create greater opportunities for the dissemination of research within Pakistan, such as through regularly scheduled climate change research symposiums and establishment of relevant journals (either print or online).

The action plan will be supported by an implementation framework that clearly defines responsibilities with respect to:

- Coordination of the activities to be implemented under the action plan
- Implementation of each of the planned activities
- Establishment and implementation of a monitoring and evaluation system, including identification of a baseline and measurable indicators
- Identification of fund raising strategies

Rationale

For Pakistan to effectively respond to the impacts of climate change on its hydrological regime, significant in-country expertise and capacity will be required to monitor and forecast changes in biophysical parameters, assess the potential ramifications of these changes for different economic sectors, regions and peoples, and develop and implement strategies for minimizing expected adverse impacts. At present, however, this in-country expertise is largely absent—significantly impeding the capacity of Pakistan to understand, plan for and respond to the threat posed by the impacts of climate change now and in the decades to come. As stated in the National Climate Change Policy, Pakistan "does not have enough climate change scientists, modelers, technologists and experts who can handle international negotiations" and "there is a lack of credible institutions in Pakistan to deal with comprehensive climate change science, modeling, management, adaptation, mitigation, and policy issues" (GOP, 2012: 30).

Findings from this study confirm this statement. Only a limited number of Pakistani researchers were found to have published research conducted in the field of climate change impacts and adaptation both in peer-reviewed publications and grey literature. The bulk of available climate change research and analysis pertinent to Pakistan has been conducted and published by international academic researchers, multilateral organizations, and NGOs. As well, it was observed that while a number of different organizations in Pakistan reported that they are engaged in climate change research, their involvement seemed to be more opportunistic (i.e. driven by available project funding) as opposed to being a principal focus of their work (exceptions being organizations such as the Global Change Impact Studies Centre). There is a clear need to increase the number of researchers within Pakistan who are deeply engaged and interested in pursuing research in this area on its own merit and have the capacity and opportunity to pursue work in their field of interest.

A central factor impeding the emergence of a robust climate change research community in Pakistan is the limited attention given to climate change and its implications in the existing education curriculum. While climate change education needs to be delivered at all levels, a priority concern is the limited availability of robust climate change education within higher education institutions (universities and technical institutes). This impediment has been understood for a number of years. The NCCP, for example, cites "limited investment in climate change education" as a constraint on Pakistan's capacity to meet the climate change challenge (GOP, 2012: 30) and calls for the "introduction of the climate change issue in higher education curricula" (GOP, 2012: x). Strengthening research capacity is also identified as priority action in the Ministry of Climate Change's Work Programme for Climate Change Adaptation and Mitigation. Despite these acknowledgements, efforts to overcome this recognized capacity gap have so far been limited and a significant ramping up of effort is required.

Current Status

At present, Pakistanis with expertise in the area of climate change generally have degrees granted by international universities. In part this situation stems from the fact that no post-secondary education institution in Pakistan currently offers a Masters or PhD degree program specifically specialized in the field of climate change, either in the sciences or social sciences. As well, at present climate change is not offered as an associate degree by any academic institution in Pakistan.

Climate change is beginning to be taught as part of individual courses, though, in accordance with the Higher Education Commission's environmental sciences curriculum revised in 2013. At the undergraduate level, the curriculum includes a required fourth year course, "Climate Change," that provides a general introduction to climate change mitigation and adaptation, and the possible implications of climate change for society. The course outline draws particular attention to links between climate change and water resources management. At the Master degree level, "Climate Change Adaptation and Mitigation" is one of four recommended core courses. It is intended to provide graduates with a Master of Science in Environmental Science with an understanding of the drivers of climate change and its impacts on different economic sectors and society.

While climate change has been integrated into the Environmental Sciences curriculum, it remains to be integrated into the curriculum of other disciplines such as agriculture, engineering and disaster mitigation. Moreover, surveyed experts expressed concern regarding the degree of expertise of the faculty teaching climate change science within Pakistan, and the need for better basic education regarding climate system dynamics.

Specific projects underway to strengthen the capacity of Pakistan's post-secondary sector to deliver quality education related to climate change are limited. Among being implemented in this area is the five-year, US$127 million USAID-funded U.S.-Pakistan Centers for Advanced Studies project officially launched in early 2015 in collaboration with the Higher Education Commission of Pakistan (Siddiqui, 2015). The objective of the project is to further build a culture of applied research in Pakistan through actions such as modernization of curricula, undertaking joint research by US and Pakistani universities, and fostering exchanges between students and faculty. The partner universities and their focus areas are as follows (USAID, 2016):

- Water, involving Mehran University of Engineering and Technology, Jamshoro, and the University of Utah.

- Agriculture / food security, involving the University of Agriculture, Faisalabad, and University of California Davis.
- Energy, involving the National University of Science and Technology, Islamabad, the University of Engineering and Technology, Peshawar, and Arizona State University.

As part of this initiative, the Center for Advanced Studies in Agriculture at the University of Agriculture, Faisalabad, has established five chairs, including a Climate Change Chair that will undertake analysis related to climate change risks and impact. It will also identify strategies for achieving climate smart development and maximizing food security. Among the intended deliverables of the Climate Change Chair are the establishment of an accessible Climate Data Bank, development of climate scenarios using General Circulation Models, and developing adaptation and resilience strategies for Pakistan's agricultural sector (University of Agriculture, Faisalabad, n.d.). Plans are underway to start a graduate program in 2016 focused on climate change and agriculture intended to attract candidates with background in areas such as agronomy, agricultural engineering, veterinary sciences, forestry, soil sciences, plant genetics and agricultural economics.

Activities within the Center for Advanced Studies in Water at Mehran University are focused on waste water and solid waste treatment, and at present there appear to be no plans to strengthen teaching related to climate change as part of this initiative. Thus while the U.S.-Pakistan Centers for Advanced Studies project is expected to make a positive contribution to improve post-education within Pakistan, additional action is needed to enhance education within the water and climate change nexus across a broader range of institutes.

The Swiss Agency for Development and Cooperation is also providing funding to support the development of a climate change centre at the University of Agriculture, Peshawar. Established in 2014, the centre has been established to help farmers and other interested parties access the information needed to mainstream climate change adaptation into their activities, with a focus on needs in Khyber-Pakhtunkhwa. Its objectives also include sensitizing relevant University departments and helping them enrich their teaching and research related to climate change adaptation, and providing research and learning opportunities for University staff, faculty members and students (University of Agriculture Peshawar, n.d.). To date the Centre has conducted research related to, for example, the impacts of climate change on specific crops as well as supported PhD studies (Business Recorder, 2016).

Expected impacts / results of action

Outcomes arising from implementation of this action are expected to include:

- Improved capacity to meet the needs of the Pakistani work force with respect to undertaking the activities and analysis required to advance adaptation planning and mainstreaming efforts.
- Increased knowledge regarding climate change-related risks and vulnerabilities, and strategies for ameliorating these risks.

Outputs would include:

- Greater awareness within higher learning institutions of the relevance of climate change research to existing disciplines and fields of study
- Further development of relevant curricula and learning materials
- Improved capacity of teachers to teach climate change related issues.

Key concerns, barriers or challenges

Engaging senior officials within government and institutes of higher learning on the need to strengthen the educational opportunities related to climate change could be challenging as it is anticipated that many will have limited or no understanding of climate change issues and concerns.

Potential implementation partners

Key partners are expected to include:

- Ministry of Climate Change, which would play a coordination and facilitation role.
- Higher Education Commission of Pakistan, to support curriculum improvements or development, enhance teaching capacities, provide technical expertise on development of education strategies, and support implementation.
- Sectoral ministries and government research institutions at the national and provincial levels, who would provide input regarding learning needs in their sector.
- Universities and technical training institutes, who will be engaged in implementation.
- NGOs who have experience with climate change training programs and awareness of needs.

Timeframe

The first phase of activity (needs assessments and development of action plan) will be implemented over a period of 18 to 24 months. The action plan could be implemented over a period of five years, followed by review and potential revisions and renewal.

Estimated cost of the action

The estimated cost for this initiative is US $1.0 – $2.0 million, depending on the scope of work undertaken. This estimate based on the funding provided in support of the ongoing U.S.-Pakistan Centers for Advanced Studies program as well as other comparable initiatives in other countries:

- The USAID/Uganda Education and Research to Improve Climate Change Adaptation project, a US$4 million initiative over four years working to build "a hub of academic, professional development, and research excellence in climate science, climate adaptation, and related disciplines," with a priority focus on agriculture (USAID, n.d). Activities underway within this project include improving undergraduate, graduate and post-graduate education in relevant disciplines and supporting research in the agricultural sector related to climate change impacts and adaptation.

- The Climate Change Adaptation Research and Capacity Development in Ghana project, which is working to improve climate change science teaching, research and learning at the University of Ghana. The International Development Research Centre (IDRC) provided approximately US$1.0 in support of this project (IDRC, n.d.).
- The Regional Capacity Building for Sustainable Natural Resource Management and Agricultural Productivity under a Changing Climate project being undertaken in Uganda, Ethiopia and South Sudan with NOK 18 million (approximately US$2.1 million) in funding from NORAD. Focusing in the areas of agriculture and natural resource management, the project aims to strengthen the human and institutional capacities to better enable them to respond to climate. Actions include reviewing and strengthening academic programs, strengthen research and teaching capacities, improving educational and research management capacity at the doctoral and post-doctoral levels, and supporting staff exchange and joint collaborative research.

Immediate next steps

- Ministry of Climate Change to secure the support of the Higher Education Commission in further efforts to strengthen the provision of post-secondary education related to climate change.
- Engage in discussions with potential funders of this action.
- Initiate stakeholder engagement process to secure the interest of potential partners, particularly within the education system.

References:

Asia-Pacific Network for Global Change Research. (no date). CAPaBLE. Retrieved from http://www.apn-gcr.org/programmes-and-activities/capable/

Business Recorder (2016). SDC launches climate change centre at UAP. Business Recorder (June 15). Retrived from http://www.brecorder.com/general-news/172/56811/

Haipaap, A., Horstbrink, A. & Mackay, A. (2013). Guidance Note for developing a National Climate Change Learning Strategy: Strengthening human resources and skills to advance green, low emission and climate resilient development. Prepared for the One UN Climate Change Learning Partnership (UN CC:LEARN). United Nations Institute for Training and Research. Retrieved from http://www.uncclearn.org/national-projects/guidance-note-developing-national-climate-change-learning-strategy

International Development Research Centre (IDRC). (no date). Climate Change Adaptation Research and Capacity Development in Ghana. Retrieved from https://www.idrc.ca/en/project/climate-change-adaptation-research-and-capacity-development-ghana

Government of Pakistan (GOP). (2012). National Climate Change Policy. Islamabad: Ministry of Climate Change.

Siddiqui, R.H. (2015). US-Pakistan Centers for Advanced Studies Launched. Pakistan Link. Retrieved from http://pakistanlink.org/Community/2015/June15/19/01.HTM

United States Agency for International Development (USAID). (no date). USAID/Uganda Education and Research to Improve Climate Change Adaptation. Retrieved from: https://www.usaid.gov/sites/default/files/documents/1860/Education_and_Research_to_Improve_Climate_Change_Adaptation.pdf

United States Agency for International Development (USAID). (2016). Centers for Advanced Studies Program. Retrieved from https://www.usaid.gov/news-information/fact-sheets/centers-advanced-studies-program

University of Agriculture, Faisalabad (no date). Pakistan Centers for Advanced Studies in Food Security/Agriculture: Climate Change Chair. Retrieved from http://uaf.edu.pk/USPCAS-AFS/downloads/Climate_change.pdf

University of Agriculture, Peshawar (no date). Climate Change Centre (CCC): Adaption to climate change in 21st century. Retrieved from http://www.aup.edu.pk/ccc.php

World Meteorological Organization. (2010). WMO Fact-Finding and Needs-Assessment Mission to Pakistan, Islamabad, 4-8 November 2010: Mission Report. Retrieved from: http://www.wmo.int/pages/prog/dra/rap/documents/PakistanMissionReport.pdf

7.3 Roadmap: Establish a central repository of water data and analysis

Summary

This action will support climate adaptation decision-making and planning by establishing a centralized, open access data portal through which researchers, scientists, academics and decision makers can access historic and present standardized surface and ground water metadata sets, visualizations, and related analysis regarding hydrologic and meteorological conditions in a changing climate.

Main Elements

The objective of this action is to establish a central online repository for water data, research and analysis that meets the identified needs of intended users, which are expected to primarily include researchers based in different research institutes, government departments, academic institutions, and non-governmental organizations. The envisioned water portal would provide access to hydrology metadata sets (flow rates, withdrawal rates, quality parameters), visualization products (maps, graphs, tables), climate data (historic and projections), and a curated library of technical reports, research papers, and policy assessments pertaining to climate change and water issues in Pakistan. The portal will make available data for all regions of Pakistan and would be supported by a GIS interface and content management system to enable access to locally and regionally appropriate information.

The purpose, content and structure of the platform will be determined based on a clear understanding of the needs of the intended users of the site. In the absence of such an understanding, knowledge platforms can be created that provide services that do not meet the platform's intended purpose, duplicate efforts compared to what is being undertaken by others, lead to further gaps in information and knowledge provision, and generally result in a misuse of resources (Hammill, Harvey & Echeverria, 2013).

The objectives of this action will be achieved through implementation of the following work elements:

1. *Best practices review.* National governments throughout the world, as well as some international organizations, have established open data portals that provide access to streamflow and ground water data. A review of these existing portals will be undertaken to ensure that the water portal developed for Pakistan is informed by international best practice. Desk-based analysis will be complemented by interviews with data managers to better understand issues such as data collection, data access, quality control procedures, metadata management, access agreements, user protocols, content management systems, and portal management.
2. *Mapping of existing data sources and materials.* Through desk-based research and the stakeholder consultation process, existing water data sets will be identified along with past research and technical reports related to water and climate change that may be housed within the portal. Interviews with relevant experts and data managers will also

be undertaken to gain a detailed understanding of the collection, quality control and management practice associated with different data sets.

3. *Stakeholder consultations.* To ensure that the structure, orientation and content of the water portal meets the needs of intended users, extensive consultations will be held with key stakeholder groups through local and national workshops and expert interviews. The consultations will strive to gain input regarding the type of water-related data required by researchers, the desired format for providing this data, and issues related to accessing the data that should be considered. In parallel with this activity, discussions also will be initiated with data holders regarding their support for the creation of the open data portal, including the potential inclusion of their data sets.

4. *Development of protocols for data quality, access and usage.* Quality control and quality assurance protocols will be developed to ensure the reliability of the data provided through the established portal. Guidance will be sought from international organizations when devising these protocols to ensure that requirements of the International Standard Organizations for certification etc. are fulfilled. Agreements (memorandum of understandings) with data providers will be negotiated and finalized. Procedures by which users may access data provided through the site will also be determined. These procedures will maintain respect for any existing copyrights, intellectual property rights and data agreements. Drafted protocols and procedures will be reviewed through focus group discussions with experts to ensure their robustness and validity.

5. *Design, review, creation and launch of planned data portal.* The structure and content management system for the portal will be developed, drawing upon knowledge gained through the best practices review and input from the stakeholder consultations. The most appropriate institution to host the site will also be determined (potentially the Ministry of Science and Technology). Draft plans will be presented to stakeholders for feedback through a national workshop, prior to proceeding with the establishment and official launch of the portal.

6. *Capacity building.* Prior to and following launch of the web portal, capacity building opportunities will be provided to strengthen the ability of personnel to effectively engage in activities such as adherence to quality assurance and quality control standards, web portal management, curation of online literature, and user engagement and feedback processes. The latter might involve the creation of offline knowledge sharing opportunities hosted by the water portal management team. Such events can serve to raise awareness about the platform's services, build users' trust and knowledge regarding its content, and serve to share research based on data contained within the portal.

Rationale for selection of this action

Various provincial and federal departments and agencies currently collect water-related data for different purposes, be it related to streamflow levels, allocations and use for irrigation, or for water quality monitoring. Researchers monitoring glaciers, snow cover and meteorological changes in the Hindu Kush-Karakoram-Himalayan (HKH) mountains also are generating relevant databases. By and large, however, this data is not publically available and has not be archived in a format that enables it to be used by future researchers. Moreover, it has been collected, classified and stored using different approaches, which limits comparability between different sources and the data's capacity to contribute to evidence-based policy and decision making.

In light of this situation, data access has been identified as a significant barrier to conducting research related to hydrology and climate change in Pakistan. Researchers have highlighted challenges associated with locating available data regarding parameters such as glacial fluctuations, surface water runoff and ground water levels, as well as published and unpublished technical reports, research papers and policy analyses. They also have pointed to the high cost of purchasing data for research, and concerns regarding the quality of the data that is being provided. This inability to access reliable, quality controlled water metadata and/or its derived products limits the capacity of researchers to produce the analysis needed to inform planning for current and future water needs. In turn this limits Pakistan's capacity to undertake climate vulnerability assessments and develop federal and provincial adaptation plans.

Establishment of an open access data portal or repository focused on surface and ground water resources would help to overcome these challenges. The envisioned data portal would be accessible to researchers from all regions of Pakistan, and supported by a well-trained team responsible for timely and accurate updates, the production of associated knowledge products, and the maintenance of a data and information archives. The site would also provide access to climate related data, and could eventually contain data related to natural resources (e.g. forest cover)

The need for such as portal has previously been recommended, with the Task Force on Climate Change calling for the establishment of a "National Data Bank for climatological, hydrological, agro-meteorological and other climate change related data to cater for the needs of all relevant institutions" (GOP, 2010: p.75). This recommendation is reflected in the National Climate Change Policy, which notes the need to establish a "national clearing-house for regularly updated climate change related data sharing and networking" (GOP, 2012: p.32). Moreover, the Framework for implementation of the national climate change policy identifies the need to establish a "water resources database for knowledge management and dissemination of necessary information" as part of efforts to ensure that water allocations reflect changes in sectoral demand spurred by climate change (GOP, 2013: p.23).

Current status

Through national and regional initiatives, data related to topics such as hydrology, meteorology and glaciology are beginning to be made available through different online platforms. The amount of information accessible through these platforms, though, can be limited and not necessarily of specific relevance to Pakistan. The creation of a one window operation or "one-stop shop" web portal tailored to the needs of Pakistani researchers that links provincial, national and international data sources would help to overcome this challenge.

Some current efforts underway within Pakistan upon which the creation of a new water data portal could build include:

- Plans to establish an integrated water resources database, the Water Resources Management Information System, that will be warehoused within the Pakistan Council of Research in Water Resources (PCRWR) (within the Ministry of Science and Technology) with the support of the United States Geological Survey (USGS). The goal of this warehouse would be to support science-based decision making in integrated water resources management (USGS, n.d.). PCRWR has initiated establishment of this database, which is expected to bring together existing data networks into a single system that provides access to information regarding discharge rates, temperature, rainfall levels etc. The planned system would build on PCRWR's existing GIS and database laboratory (PCRWR, 2015).

- The Water and Power Development Authority (WAPDA) makes available river flow information in the current year through its web site, namely: levels, inflow and outflow for the Indus River at Tarbela dam and the Jehlum River at the Mangla dam; inflow for the Kabul River at Nowshera and the Chenab River at Marala; and total stream inflows for the current date, the previous year and the average of the last 10 years. Information is also provided regarding flows below the Kotri barrage in the current year (WAPDA, n.d.).
- The Pakistan Meteorological Department (PMD) also makes available some real-time data through its flood forecasting division. This includes daily rainfall data recorded at different stations for the current and previous month, flow data for the Tarbela and Mangla dams, and real-time data from five automatic weather stations (PMD, n.d.).

Several international sites also provide access to water resource data for Pakistan, among which are:

- The International Centre for Integrated Mountain Development (ICIMOD) has established a Regional Flood Information System for the Hindu Kush Himalayan region that provides access to eight stations located in Pakistan. Online data is provided for a limited period (e.g. three months) while access to longer data sets can be requested (ICIMOD, n.d.1).
- ICIMOD has also established a geoportal that provides baseline information on the status of glaciers in the HKH region, disaggregated by major basins and sub-basins, that is presented in interactive maps (ICIMOD, n.d.2). Access is also provided to snow cover data in the HKH region (ICIMOD, n.d.3).
- The Water Data Portal of the International Water Management Institute (IWMI) provides a range of water and agriculture related data, including hydrological and meteorological data as well as hydrological model set-ups. This includes free access to data sets related to the Indus Basin and historical flood risk maps for the Indus Basin (IWMI, n.d.).

While these sites provide access to some data, better access to longer data sets is desirable for research and modelling. As well, concern has been expressed that some sites do not screen the quality of the data collected by others or provide information regarding the story behind the data presented. Few available sites also provide complementary access to analysis that interprets the data to make it more accessible to decision-makers, or provide access to climate change-related research and analysis.

Expected impacts / results of action

Outcomes arising from implementation of this action are expected to include:

- Improved research quality and better evidence for decision-making
- Less redundancy and more efficiency in the collection, analysis and maintenance of available data.
- Stronger relationships between researchers and data collecting organizations

Outputs are expected to include:

- Water portal able to provide reliable water data presented to a consistent standard for use in research and analysis.
- Derived products (maps, briefing notes) suitable to meeting the needs of decision-makers within and outside of government.
- Greater capacity within Pakistan to manage and ensure the quality of metadata sets and online document curation.

Key concerns, barriers or challenges

Challenges to successful implementation of this action could include:

- Hydrometeorological databases currently exist in the HKH region but typical are not shared as all data related to streamflow, for instance, has been treated as confidential information. Countries in the region, including Pakistan, therefore have not produced readily available, digitized monitoring records for hydrological data in different catchment basins (Alford et al, 2016).
- Water related data is currently being collected and housed by different federal and provincial departments and agencies in an uncoordinated manner, leading to a lack of compatibility in terms of data collection, reporting and storage, along with concerns regarding data quality and reliability. As well, significant data remains to be put into a digital format. Integrating these existing data systems and architecture into a coherent whole will be challenging.
- The ability of government departments and research institutes to access and use the data portal given current technical limitations such as internet access, processing speeds, and the cost of data transmission.
- Limited technical capacity to establish and maintain an end user informed data portal that also curates relevant research and analysis.

Potential implementation partners

The lead partners engaged in formation of the online data portal would be the Ministry of Science and Technology and its associated Pakistan Council of Research in Water Resources, the Ministry of Climate Change, the Ministry of Water and Power, and the Pakistan Meteorological Department. Each of the ministries has a central role to play in terms of shaping the objectives of the portal and providing access to existing datasets and research.

The actions should also involve representatives from the following stakeholder groups to ensure that the developed portal is informed by the needs of its end users:

- Provincial government departments, particularly those responsible for water management, disaster risk management, irrigation and agriculture.
- Federal and provincial research institutes engaged in research related to climate change and water.
- Federal agencies such as the Indus River Systems Authority and the Pakistan Bureau of Statistics.
- Non-governmental organizations engaged in climate change awareness raising and research.
- International research organizations, such as ICIMOD and IWMI, to ensure complementarity with existing initiatives.

Timeframe

The best practices review and consultation process will be conducted over a period of six months to one year, following by development and launch of the portal and completion of capacity building activities over an additional 12 months.

Estimated cost of the action

The estimated cost for undertaking this work would be US$300,000 to $400,000 to establish the portal. Additional funds would subsequently be required to enable continuous site maintenance, upgrading and data access, as well as for outreach and engagement activities.

Immediate next steps

- Collaboration with the Pakistan Council of Research in Water Resources regarding its existing initiative to establish a Water Resources Management Information System.
- Ministry of Climate Change to initiate discussions with key ministries and departments, such as the Ministry of Water and Power and the Pakistan Meteorological Department.
- Mapping of stakeholders to be engaged in the consultation process and selection of international examples of water portals for examination.

References

Government of Pakistan (GOP). (2010). Task Force on Climate Change: Final Report. Islamabad: Planning Commission.

Government of Pakistan (GOP). (2012). National Climate Change Policy. Islamabad: Ministry of Climate Change.

Government of Pakistan (GOP). (2013). Framework for Implementation of Climate Change Policy (2014-2030). Islamabad: Climate Change Division.

Hammill, A., Harvey, B. & Echeverria, D. (2013). Understanding Needs, Meeting Demands: A user-oriented analysis of online knowledge broker platforms for climate change and development. Winnipeg: International Institute for Sustainable Development. Retrieved from http://www.iisd.org/library/understanding-needs-meeting-demands-user-oriented-analysis-online-knowledge-broker-platforms

International Centre for Integrated Mountain Development (ICIMOD). (no date 1). Stations – Pakistan. Retrieved from http://www.icimod.org/?q=9509

International Centre for Integrated Mountain Development (ICIMOD). (no date 2). Status of Glaciers in the HKH Region. Retrieved from http://geoportal.icimod.org/Home/ScienceAppDetail?appid=7

International Centre for Integrated Mountain Development (ICIMOD). (no date 3). The MODIS Snow Cover data of HKH Region. Retrieved from http://geoportal.icimod.org/Home/DataSetDetail?dataSetId=20

International Water Management Institute. (no date). Water Data Portal. Retrieved from http://waterdata.iwmi.org/

Pakistan Council of Research in Water Resources (PCRWR). (2015). Water Resources Management Information System (WRMIS). Proposal.

Pakistan Meteorological Department (PMD). (no date). Flood Forecasting Division. Retrieved from http://ffd.pmd.gov.pk/cp/floodpage.htm

United States Geological Survey (USGS). (no date). Activities of the USGS International Water Resources Branch. Retrieved from http://water.usgs.gov/international/

Water and Power Development Authority (WAPDA). (no date). River inflow in Pakistan. Retrieved from http://www.wapda.gov.pk/index.php/component/content/article?id=50

7.4 Roadmap: Modernize Pakistan's streamflow monitoring network

Summary

This action will strengthen streamflow monitoring in the Upper and Lower Indus Basins to ensure the accurate and timely collection of data that can be reliably used to inform decision-making in sectors such as agriculture, energy, health and disaster risk management.

Main Elements

An enhanced streamflow monitoring network within the Indus River Basin would serve to improve capacity in Pakistan to identify changes in run-off volumes, prepare near-term flow forecasts, and develop more robust projections of future hydrological conditions. The updated network should provide runoff and downstream flow information "over a sufficient range of catchments with differing input sources" so as to be able to inform "water resources design and management, hydropower development, flood risk assessment, and river ecology" (Alford et al., 2016: 69). Strategic installation of individual and networked streamflow gauging stations also could provide more information that would help to answer climate change-related questions, such as by supporting assessments of the contribution of glacial melt, seasonal snow melt and rainfall to streamflow (Alford et al., 2016).

The objective will be achieved by implementing the following steps:

1. *Needs assessment.* Implementation of this action would begin by documenting the current status of Pakistan's streamflow monitoring system and undertaking a complete assessment of its suitability in light of international standards and the need to improve understanding of climate change impacts. Questions that may be answered include the desired objectives of the strengthened system, the locations in which data gaps are most critical, and the types of technology best suited to local conditions and needs. The assessment will also identify institutional and human resource capacity gaps and needs that should be addressed. This information will be gathered in part through a stakeholder engagement process involving leading individuals from government agencies such as the Water and Power Development Authority (WAPDA), government research institutes, international researchers, and potential funding agencies.

2. *Development of a detailed strategic implementation plan.* Taking into consideration the desired scope and objectives of a strengthened system and the identified shortcomings of the current system, a detailed plan for revitalizing Pakistan's streamflow monitoring system will be developed in collaboration with agreed partners. The plan will identify a strategic, stage-by-stage process for improving the monitoring network over time. Central questions will be addressed such as: prioritization of efforts (i.e. where to first upgrade or install monitoring systems); selection of instruments and determination of their placement; development of required human resources and institutional capacities; determination of strategies for instrument maintenance; and processes for data access, synthesis, digitization, analysis, storage and sharing (Alford et al., 2016). Attention could also be given to options for improving transboundary data sharing on a real time basis.

3. *Capacity building activities.* To enable implementation of the developed strategic plan, a capacity building strategy will be elaborated in collaboration with key stakeholders. This strategy could include workshops on appropriate data collection processes, standard operating procedures for different monitoring stations, or on the use of specific technologies. The strategy also could include the development and implementation of training for local villagers in high altitude locations as research assistants and technicians. Engaging local people in routine data collection and equipment maintenance and repair would not only provide benefits in terms of timeliness of data collection and cost savings (Alford et al., 2016) but would also generate local jobs and economic opportunities that could slow out-migration from the region.

4. *Strengthening information dissemination.* A key objective of the improved streamflow monitoring system should be to make reliable data available to researchers and decision-makers. This could be enable through the development of an open data portal, as well as forecasts and projections in formats tailored to the requirements of end users. Capacity to identify information needs and prepare appropriate knowledge products should be enhanced in conjunction with the extension and upgrading of the streamflow monitoring system.

Rationale for selection of this action

A robust and reliable streamflow network is essential to the generation of data regarding water resource availability in the short-, medium- and long-term, and the monitoring of changing trends in water availability, which is required to inform sectoral planning and action. A lack of basic data can lead to erratic water planning, deficient initiatives, and unsustainable practices (Asian Development Bank, 2014). It has also been observed that greater transparency regarding water availability, distribution, accounting and measurement has the potential to build trust between different actors (World Bank, 2008).

At present, however, Pakistan's watershed monitoring system is inadequate and its need for strengthening has been previously acknowledged by the federal government. Pakistan's Framework for implementation of the national climate change policy draws attention to the need to strengthen Pakistan's existing network of river and stream gauges to improve the provision of real-time water availability readings to the Indus River System Authority. It notably sets forward a strategy for "Strengthening the present hydrological network to monitor river flows and flood warning systems" through the completion of an initial assessment, development of a response plan, and seeking opportunities for real-time transboundary hydrological data sharing (GOP, 2013: p.18).

The recently completed survey of individuals and organizations engaged in research pertaining to climate change and water resources again emphasized the need for better access to credible watershed data. The need to strengthen human and technical capacity within the country to collect, analyze and develop forecasts using globally established procedures was also noted. Studies completed by the World Bank and the World Meteorological Organization (WMO) have also drawn attention to the need for transparent, real-time water delivery measurement systems and for enhanced capacity in the Indus River Authority and WAPDA related to decision-support systems, data management, and hydrological modelling for river and flood forecasting to be enhanced (WMO, 2010; Yu et al., 2013). A general lack of procedures for data management has been cited as key reason for stream flow data in mountain basins not being readily available in Pakistan (Alford et al., 2016).

Of particular concern is the absence of an adequate streamflow network in the Upper Indus Basin. Current research indicates that the primary zones for specific runoff, total runoff volume, ice cover area and glacial ablation occurs within the altitudinal zone of 3,000 to 6,000 meters above sea level. However, the vast majority of hydrometeorological monitoring stations across the Hindu Kush-Himalaya region are located below 1,000 metres above sea level. As such it has been recommended that efforts to strengthen monitoring stations occur within this zone (Alford et al., 2016), with the Asian Development Bank (ADB) recommending 35 hydrological monitoring stations be established in high elevation areas of the Upper Indus Basin to meet optimum observational demands (ADB, 2010).

Additionally, a lack of monitoring stations in main, branch and distribution channels of the Indus Basin Irrigation System has also been cited as a data gap (Archer et al., 2010; Briscoe & Qamar, 2007). This lack of flow measurements drives the use of simple time-based water allocations practices, which limits capacity to sustainably regulate flow in the system.

Current status

Efforts are underway in Pakistan that seek to strengthen the water monitoring network and capacity within the Indus Basin, including:

- The World Bank is currently funding the second phase of the "Water Sector Capacity Building and Advisory Services Project". The first phase (US$38 million in 2008-2016) provided modern tools to federal water management institutions, improved the management skills of their staff, and undertook targeted studies to inform policy development. The second phase of activity (US$35 million in 2016-2021) will support scaling up of ongoing activities. Priority aims are to strengthen the Indus' systems institutional and regulatory framework and improve technical capacity (e.g. for physical and numerical modeling) in the Ministry of Water and Power, WAPDA, the Indus River System Authority, and the Water Section of the Planning Development and Reform Division (World Bank, 2015). The project has supported upgrading of five telemetry stations, and is expected to upgrade five more by 2021 (World Bank, 2016).
- WAPDA has established a Glacier Monitoring Research Centre as part of the Tarbela 4th Extension Hydropower project (2012-2018, US$6.0 million) financed by the World Bank (Climate Himalaya, 2011; Hashmi, 2013) that aims to monitor glaciers in the Upper Indus Basin to inform water resource management decisions in light of climate change (Alford et al., 2016). It will conduct mass balance studies for five major glaciers in the Upper Indus Basin, monitor changes in 52 large and medium glaciers, install six new High Altitude Automatic Meteorological Stations, and forecast future water availability (Hashmi, 2013). The German Development Bank (KfW) is presently funding construction of office buildings for the Centre in Lahore and Skardu (WAPDA, 2016).

It is unclear the extent to which these initiatives are or plan to invest in improved streamflow monitoring stations in the Upper (or Lower) Indus Basin.

Expected impacts / results of action

Outcomes arising from implementation of this action are expected to include:

- More informed planning and decision-making based on improved access to reliable streamflow data, forecasts and projections.
- Greater understanding of the changes in streamflow occurring in the Indus Basin, particularly the Upper Indus Basin
- Refined capacity to assess availability of future supply against estimates of future demand.
- Increase in local employment and economic opportunities, particularly in the Upper Indus Basin.

Outputs would include:

- Increased and more reliable streamflow data
- Greater human resources and institutional capacity to engage in data collection, analysis, processing, storage and sharing.

Key concerns, barriers or challenges

Establishment of a robust streamflow monitoring network in the Upper Indus Basin will be challenged by natural factors such as the region's topography and climatic conditions. Maintenance of the stations once established could also be problematic given the difficulties associated with having government officials undertake missions to remote locations for several weeks, particularly if there is no provision for extra allowances for work completed under harsh conditions (Alford et al., 2016). Security concerns will likely also be a barrier in particular areas of the basin.

Potential implementation partners

Key partners within the federal government are expected to include: the Ministry of Climate Change, the Ministry of Water and Power, the Water and Power Development Authority, the Pakistan Meteorological Department, the Indus River System Authority and National Disaster Management Authority. Additional implementation partners would include national and international researchers as well as multilateral organizations involved in research and activities in the Upper Indus Basin such as the World Bank and the International Centre for Integrated Mountain Development.

Timeframe

The initial assessment and planning phase of activity would be completed over 12 to 18 months. The timeframe for subsequent phases of work would be determined in the detailed implementation plan.

Estimated cost of the action

The assessment phase of the project could require $200,000 to $300,000 to implement. The potential cost associated with implementation of the improved system will need to be determined based on factors such as the number of gauging stations required, the technology selected, and the desired location of new installations.

Immediate next steps

- Engagement of the Ministry of Water and Power, the Ministry of Climate Change and WAPDA in leading design and implementation of the initiative.
- Initiation of a review of current status of the existing hydrological monitoring system in relation to international standards and prior recommendations.

References

Alford, D., Archer, D., Bookhagen, B., Grabs, W., Halvorson, S., Hewitt, K., Immerzeel, W., Kamp, U. & Krumwiede, B. (2016). Monitoring of Glaciers, Climate, and Runoff in the Hindu Kush-Himalaya Mountains. Washington, D.C.: World Bank Group. Report No.67668-SAS. Retrieved from http://documents.worldbank.org/curated/en/2016/03/26048237/monitoring-glaciers-climate-runoff-hindu-kush-himalaya-mountains

Archer, D. R., Forsythe, N., Fowler, H. J., & Shah, S. M. (2010). Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions. Hydrology and Earth System Sciences, 14(8), 1669–1680. http://doi.org/10.5194/hess-14-1669-2010

Asian Development Bank (ADB). (2010). Glacial Melt and Downstream Impacts on Indus Basin-Dependent Water Resources and Energy. Retrieved from http://www.adb.org/projects/documents/glacial-melt-and-downstream-impacts-indus-basin-dependent-water-resources-and-e-0

Asian Development Bank (ADB). (2014). Water Balance. Achieving Sustainable Development through a Water Assessment and Management Plan. The Case of Federally Administered Tribal Areas, Pakistan. Retrieved from: http://www.adb.org/sites/default/files/publication/42580/water-balance-pakistan_0.pdf

Briscoe, J. and Qamar, U. (2007). Pakistan's Water Economy Running Dry. Karachi: Oxford University Press. Commissioned by World Bank.

Climate Himalaya. (2011). WAPDA gets WB funding for glacier monitoring and research centre. Retrieved from http://chimalaya.org/2011/07/17/wapda-gets-wb-funding-for-glacier-monitoring-and-research-centre/

Government of Pakistan (GOP). (2013). Framework for Implementation of Climate Change Policy (2014-2030). Islamabad: Climate Change Division.

Hashmi, D. (2013). Initiatives of the WAPDA in Monitoring Upper Indus Basin. Retrieved from http://www.evk2cnr.org/cms/files/evk2cnr.org/4_%20D_%20Hashimi_WAPDA.pdf

Water and Power Development Authority (WADPDA). (2016). WAPDA seeks NCA support to develop concept design for GMRC buildings. Retrieved from http://www.wapda.gov.pk/index.php/newsmedia/news-views/87-wapda-seeks-nca-support-to-develop-concept-design-for-gmrc-buildings

World Bank. (2008). Project Information Document: Water Sector Capacity Building and Advisory Services Project (WCAP). Retrieved from: http://www.worldbank.org/projects/P110099/water-sector-capacity-buildling-advisory-services-project-wcap?lang=en

World Bank. (2015). World Bank approves Pakistan loan for energy, water, climate. Press release. Retrieved from http://www.worldbank.org/en/news/press-release/2015/12/21/world-bank-approves-pakistan-loan-for-energy-water-climate

World Bank. (2016). Water Sector Capacity Building & Advisory Services Project (WCAP) (P110099): Implementation Status & Results Report: Sequence 19. Retrieved from http://documents.worldbank.org/curated/en/2016/04/26264421/pakistan-water-sector-capacity-building-advisory-services-project-wcap-p110099-implementation-status-results-report-sequence-19

World Meteorological Organization. (2010). WMO Fact-Finding and Needs-Assessment Mission to Pakistan, Islamabad, 4-8 November 2010: Mission Report. Retrieved from: http://www.wmo.int/pages/prog/dra/rap/documents/PakistanMissionReport.pdf

Yu, W., Yang, Y., Savitsky, A., Alford, D., Brown, C., Wescoat, J., Debowicz, D., and Robinson, S. (2013). Executive Summary. In The Indus Basin of Pakistan: The Impacts of Climate Risks on Water and Agriculture. Washington, DC: World Bank.

Appendix 8: National Symposium

Overview of the National Symposium on "The Vulnerability of Pakistan Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action"

A briefing paper prepared as part of the project "The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action"

June 2016

Prepared by: Dr. Saeed A. Asad

Centre for Climate Research and Development, COMSATS Institute of Information Technology, Islamabad

Summary

To support achievement of "The Vulnerability of Pakistan Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action" project's planned objective of increasing comprehension amongst the people of Pakistan regarding how climate change could alter the future availability of water resources, a one-day symposium was organized on May 31, 2016, in Islamabad by project partners. The Symposium aimed to:

- Provide an opportunity for Pakistani researchers working in the water resources and climate change fields to share their research on projected changes in water supply and water demand, along with the potential socio-economic implications of these changes and possible solutions.
- Share the project's findings with researchers and policy makers in Pakistan, providing them with up-to-date knowledge regarding how Pakistan's water resources are expected to be affected by climate change, potential risks to key sectors, and priority information and knowledge gaps.

To address these objectives, a call for papers was extended to experts from government research institutes, academia and non-governmental organizations working in the climate change and water fields, as well as representatives from federal and provincial government ministries. As limited research is being conducted in the climate change and water nexus in Pakistan, a limited response was observed in terms of the number of papers submitted in response to this call. Moreover, many of the papers were not of a high quality. This experience reflects the limited extent to which climate change is currently being addressed at both the policy and research levels in Pakistan.

After rigorous review, nine of the 32 papers submitted in response to the call for abstracts were selected for presentation at the national symposium. The agenda for the day was organized around three themes: water supply, water demand and policy analysis. Three presentations for each of the three themes were chosen from the nine selected abstracts. Additionally, a keynote lecturer was invited to speak at the start of each of the three themes. The keynote speakers were Dr. Ghulam Rasul (Director General, Pakistan Meteorological

Department), Dr. Bashir Ahmed (National Agricultural Research Centre) and Mr. Shams ul Mulk (ex-Chairman of the Water and Power Development Authority). The final agenda for the national symposium is provided in the Appendix of this briefing paper.

Participants:

Approximately 130 delegates from throughout the country participated in the National Symposium. The Chief Guest was His Excellency Mr. Stefano Pontecorvo, Ambassador of Italy in Pakistan. The accompanying guests were: Dr. Domenico Bruzzone, Head of Italy's Development Cooperation Agency in Islamabad; and Syed Abu Ahmad Akif, Federal Secretary, Ministry of Climate Change, Islamabad. The event's other participants represented federal and provincial governments ministries/departments, national and international non-governmental organizations, academia, students and research institutions. Participating federal government ministries included the Ministry of Climate Change, Ministry of Water and Power, Ministry of National Food Security and Research (federal water management cell), National Disaster Management Authority (Islamabad), Pakistan Environmental Protection Agency, Water and Power Development Authority, Pakistan Meteorological Department, National Engineering Services Pakistan (Lahore), Pakistan Agricultural Research Council, Nuclear Institute for Food and Agriculture (Peshawar), Baluchistan Agricultural Research and Development Centre (Quetta), and the Water Management Training Institute (Lahore).

Academia and research students from the following institutions also attended the symposium: International Islamic University Islamabad, Bahria University Islamabad, National University of Science and Technology Islamabad, COMSATS University Islamabad, and the Fatima Jinnah Women University Rawalpindi. As well, representatives from the following national and international non-governmental organizations participated: the International Union for Conservation of Nature, LEAD-Pakistan (Islamabad), Ev-K2-CNR, Pakistan Poverty Alleviation Fund, Health and Rural Development Services Foundation, Oxford Policy Management (Islamabad), and Sugag Sansar Organization (Sindh). They actively participated in the symposium and greatly appreciated the organization of a learning activity addressing one of the core issues of Pakistan.

Outcomes of the symposium:

The main points arising from the questions raised by the audience following each thematic session focused on how Pakistan's vulnerability to climate change is constraining its already limited ability to conserve water. In the future, the changing climate means that business-as-usual practices will no longer guarantee the country's water and food security given that per capita water availability is already very low. Stakeholders need to consider climate change and the country's predicted vulnerability to this process to fully understand Pakistan's position when mapping plans for its current and future water resources. The conclusions of the discussions held during the symposium confirmed that climate change and its impacts on Pakistan's water availability and agricultural productivity pose a serious threat to the country's food and water security.

Presentation focussing on water demand under changing climate scenarios (such as increasing temperatures and precipitation rates) warned that under unaltered conditions

Pakistan's agriculture sector, the major consumer of water resources, will bear irreparable losses with reduced productivity of staple crops of up to 20% by 2050. Other key messages delivered by the symposium's speakers and participants were as follows:

- Climate change is a cross-cutting issue not to be ignored; it requires the immediate attention of policy makers and researchers so as to be incorporated into the planning and management activities of all sectors.
- Pakistan's present state of per capita water availability is one of the biggest threats to attaining food security.
- Water availability is an important predictor of adaptation and a key driver of agricultural productivity and sustainability.
- The actual brunt of climate change is faced at the farm level. There is a strong need to build capacity, in both human and financial terms, to increase resilience at the farm level.
- Rain water harvesting and water conservation at the household level are areas that have been neglected so far; implementing these practices may stop the country from becoming classified as "water scarce" in the immediate future.
- Building water reservoirs to store flood water and provide water during dry spells was emphasized as a priority action for making the country more water- and food-secure.
- The need to build the ability of farmers to adapt to a changing climate and enhance their capacity to adopt high efficiency irrigation system (which could save 50% of the water needed for irrigation) was highlighted.

At the end of the symposium, Ms. Tracy Vienings, Deputy Country Director, UNDP, thanked all the participants for their attendance and contributions, and appreciated the efforts of all the partners for making this event a success.

Photo credit: UNDP. Additional photos from the National Symposium may be accessed at: https://www.flickr.com/photos/undppakistan/sets/72157666633454654

Appendix A: Final Agenda for National Symposium

The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action

Date: May 31, 2016; Time: 0900 - 1600 Hours; Venue: Shamadan Hall-II, Serena Hotel, Islamabad.

S.No	Agenda Items	Time
1	Arrival of delegates and registration	09:00
2	Guests to be seated	09:25
3	Recitation of Holy Quran	09:30
4	Welcome address by H.E. Mr. Stefano Pontecorvo, Ambassador of Italy in Pakistan	09:35
5	Welcome Remarks by Dr. Domenico Bruzzone, Head - Italy's Development Cooperation Agency/ AICS - Islamabad	09:45
6	Opening Remarks by Ministry of Climate Change	09:50
7	Presentation by IISD and CCRD on water project	10:00
8	Discussion/ Q&A Session	10:30
9	Tea Break	10:50
	Theme 1: Climate change and water supply in the Indus basin **Moderator: Ahmed Kamal**	
10	Keynote Lecture by: Dr. Ghulam Rasul, Director General, Pakistan Meteorological Department	11:10
11	Climate Change Impact on Water Resources of Upper Indus Basin: Challenges & Options for Risk Management Speaker: Dr. M. Arshad Ashraf, NARC, Islamabad	11:30
12	Statistical Downscaling of GCM Output for Estimation of Discharge for Impact Studies under Climate Change Speaker: Engr. Dr. M. Mahboob Alam, Iqra National University, Peshawar	11:42
13	Assessment of Climate Change Impacts on the Groundwater of Quetta Valley Speaker: Imran Hameed Durrani, Baluchistan University of Information Technology Engineering & Management Sciences, Quetta	11:54
14	Discussion/ Q&A Session	12:06
	Theme 2: Climate change and water demand for agriculture, energy and health **Moderator: Jo-Ellen Parry**	
15	Keynote Lecture by: Dr. Bashir Ahmed, Principal Scientific Officer, Climate Change, Alternative Energy and Water Resources Institute, National Agricultural Research Council, NARC, Islamabad.	12:20
16	Climate Trends and Its Impact on Khyber Pakhtunkhwa Agriculture Speaker: Dr. Samreen Babar, Bahria University Islamabad	12:40
17	Climate Change impacts on Water Demand of Various Sectors Speaker: Dr. Zaigham Habib, Independent consultant, Islamabad	13:52
18	Water Resources of Kachho and Future Situation in the context of Climate Change Speaker: Gulsher Panwher, Sujag Sansar Organization, Karachi	13:04

19	Discussion/ Q&A Session	13:16
20	Lunch	13:30
	Theme 3: Policy analysis - Knowledge gaps and recommendations for action Moderator: Amanullah Khan	
21	Keynote Lecture by: Engr. Shamsul Mulk, Ex-Chairman, Water and Power Development Authority (WAPDA)	14:30
22	National Climate Change Policy of Pakistan and Future Water Management Speaker: Dr. Seeme Mallick, Center for Climate Research and Development CCRD, COMSATS Islamabad	14:50
23	Water Related Vulnerability of Agriculture Sector to Climate Change in Pakistan Speaker: Dr. Amir Raza, Nuclear Institute for Food and Agriculture, Peshawar	15:02
24	Studying Detriments to WASH Response in Vulnerable Women Populations during Flood Emergencies in Pakistan: A review of interventions from a climate risk lens Speaker: Mr. Ehsen Gulsher, Nur Center for Research and Policy, Fatima Memorial System, Lahore	15:14
25	Discussion/ Q&A Session	15:26
26	Any other items with permission of the Chair	15:41
27	Closing remarks by UNDP/ MoCC	15:50
28	Tea/ Departure of delegates	16:00

AGENZIA ITALIANA
PER LA COOPERAZIONE
ALLO SVILUPPO

REPVBBLICA ITALIANA

CCRD

IISD
International Institute for
Sustainable Development

U N
D P
Pakistan