Enhancing Knowledge Management and Adaptation Capacity for Integrated Management of Water Resources in the Indus River Basin

Authors: Karki, Madhav Bahadur, Shrestha, Arun Bhakta, and Winiger, Matthias

Source: Mountain Research and Development, 31(3) : 242-251

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-11-00017.1

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

Enhancing Knowledge Management and Adaptation Capacity for Integrated Management of Water Resources in the Indus River Basin

Madhav Bahadur Karki[1], Arun Bhakta Shrestha[1], and Matthias Winiger[2]*
* Corresponding author: mkarki@icimod.org
[1] International Centre for Integrated Mountain Development (ICIMOD), GPO Box 3226, Khumaltar, Lalitpur, Kathmandu, Nepal
[2] University of Bonn, Department of Geography, Meckenheimer Allee 166, D-53115 Bonn, Germany

The Indus River Basin is characterized by downstream areas with the world's largest irrigation system, providing food and energy security to more than 215 million people. The arid to semiarid basin is classified as a net water deficit area, but it also suffers from devastating floods. Among the four basin countries, Pakistan is most dependent on water originating in high mountain catchments and is therefore most vulnerable to climatic, socioeconomic, and other global changes that are impacting both supply and demand. Given the consensus that there is a lack of systematic and consistent hydrological, meteorological, biophysical, and socioeconomic data to promote integrated water resources management (IWRM) at the basin scale, an international consultation of scientists, water managers, and development partners was organized in 2010. These experts suggested developing a long-term Indus Basin Research Program aiming to build a robust, consolidated, and shared scientific knowledge base and thus improve understanding of the coupled human and ecological processes and their interrelationships in the basin. This paper summarizes the rationale for initiating such a coordinated multidisciplinary research, knowledge management, and capacity development process aiming to support water management policies and programs from design stage to implementation, using the framework of integrated river basin management (IRBM). The paper further stresses the need to implement IRBM using IWRM tools, recognizing that multiple factors and actors play critical roles in improving management of water and other natural resources to enhance overall water productivity. The steps needed to initiate and consolidate national and international institutional coordination, capacity development, and policy support to operationalize an IRBM process are spelled out. A long-term research and capacity-building program for international organizations and scientists is recommended to foster transboundary cooperation and scientific collaboration.

Keywords: *Indus River Basin; scientific knowledge base; multidisciplinary research; integrated water resources management (IWRM); integrated river basin management (IRBM); capacity building; water management policies.*

Reviewed by the Editors: *April 2011*

Accepted: *July 2011*

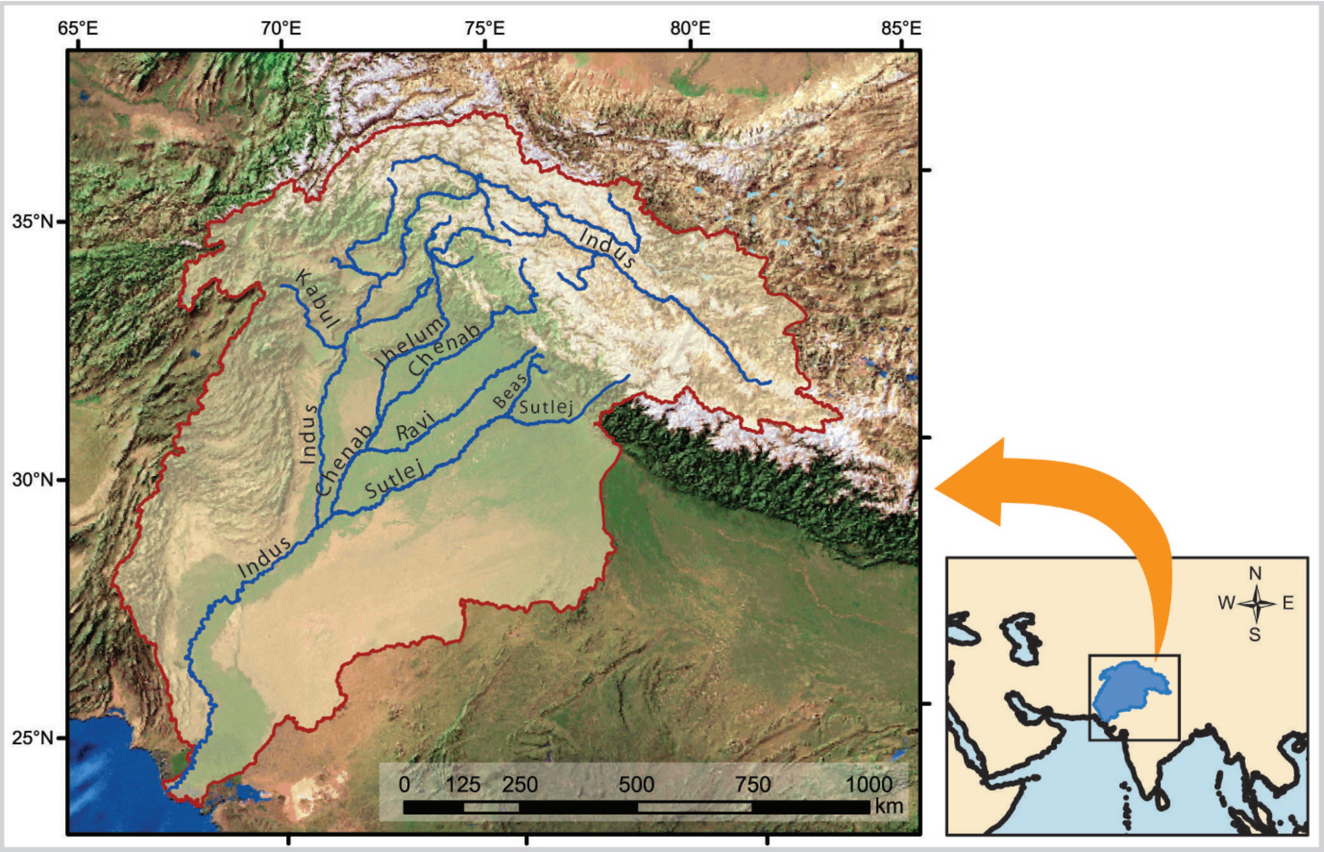
Introduction

The Indus Basin covers an area of about 1.10 million km^2 distributed among Pakistan (63%), India (29%), and the People's Republic of China and Afghanistan (8%) (Jain et al 2009). The main river originates at Lake Ngangla Rinco on the Tibetan Plateau in the People's Republic of China and includes the flow of such tributaries as Ravi, Beas, and Sutlej in India; Swat, Chitral, Gilgit, Shigar, Shyok, Indus, Shingo, Astor, Jhelum, and Chenab in Pakistan; and Kabul River draining parts of catchments in Afghanistan (Figure 1).

The Indus Basin ranks among the largest basins of the world in terms of human dependence on irrigation water sourced from the river water. The river supports a population of about 215 million people (UNEP 2008), whose livelihoods rely directly or indirectly on agriculture and other vocations dependent on the river basin resources. Current average basin water availability is estimated to be 978 m^3/person/y (Eriksson et al 2009), although the available countrywide data on per capita water availability ranged between 980–1300 (average 1100) m^3/y.

High population growth in the downstream region and growing impacts of climatic variability upstream have produced increasing stress on the water supply from the Indus River Basin system. The lower part of the basin is now one of the most water-stressed areas in the world and is likely to become a water-scarce area (Briscoe and Qamar 2005). Further anomalous weather episodes such as the exceptional floods experienced in 2010 may increase the risk of flooding, droughts, or both in the area. In addition, climate change impacts are likely to be severe in the cryosphere and on the dependent water supply (Rees and Collins 2006; Immerzeel et al 2010). In the Indus Basin, runoff is generated to a large extent by melting of snow and ice; nevertheless, the input due to rainfall varies depending on the season (Rees and Collins 2006; Immerzeel et al 2010).

FIGURE 1 Map of the Indus River Basin. (Map by ICIMOD)



Disruption in the hydrological regime can have serious impacts on people's lives in the basin, and better planning and implementation of adaptation measures thus require better information and knowledge. Policy- and decision-makers are increasingly stressing the need to improve the monitoring schemes of snow, ice, and water resources in the Hindu Kush–Himalaya region. Although several initiatives are being implemented in the basin by national and international agencies, as well as academia, optimal coordination among researchers and adequate sharing of information are lacking. This paper summarizes the state-of-the-art with regard to knowledge of water resources and their dynamics in the basin and describes the process and agenda by which we hope this gap can be filled and we can move toward efficient integrated river basin management (IRBM).

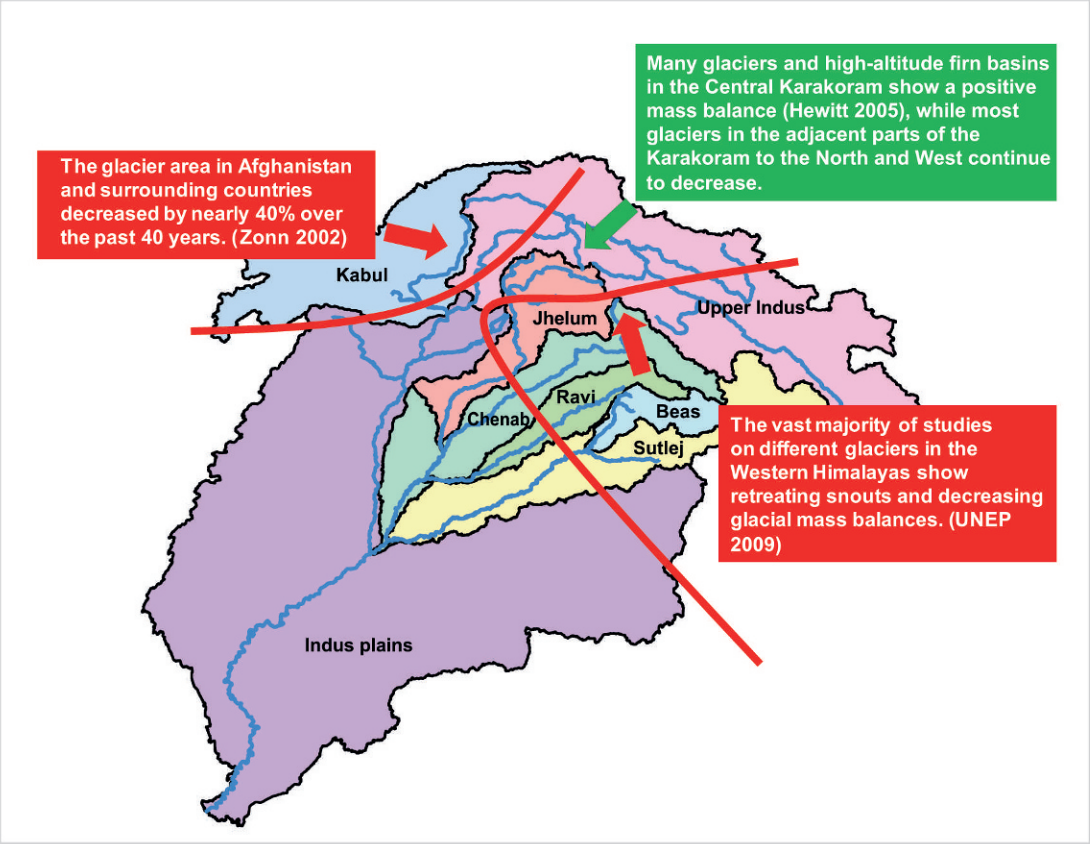
Environmental changes observed at the basin scale

Studies have provided different findings on temperature trends in the region and the basin (Bhutiyani et al 2009). Although Fowler and Archer (2006) have shown that mean and minimum summer temperatures provide a consistent trend of cooling beginning in 1961, Chaudhry and Rasul (2007) have pointed out a nonsignificant increasing trend for annual mean temperature in the mountainous areas of the Upper Indus Basin in Pakistan. In contrast, in the Baluchistan, Punjab, and Sindh provinces, a significant trend of increasing annual temperature was observed for the period from 1960 to 2007, amounting to a total of +1.15°C in Baluchistan, +0.56°C in Punjab, and +0.44°C in Sindh for this 47-year period. However, a seasonal trend in the Upper Indus Basin is visible in the form of rising summer and falling winter temperatures. On the basis of long-term data sets collected since the late 19th century, analyses of the temperature data show significant trends in increasing annual temperature in all three studied stations in the northwestern Himalayan region (Bhutiyani et al 2009). Similar results were reported by Klein Tank et al (2006).

Concerning river flow, Fowler and Archer (2006) observed a cooling regional temperature trend that produced a predicted reduction of 20% in runoff over the record period from 1961 to 2000. This predicted fall was exceeded by actual runoff decreases on the river Hunza. Fowler and Archer further observed summer temperature reductions and a positive trend in winter precipitation, implying reduced ablation and increased accumulation

http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00017.1

FIGURE 2 Glacier behavior in the Upper Indus Basin. (Map by ICIMOD)



of Karakoram glaciers. These observations are consistent with the observed thickening and expansion of glaciers in the Upper Indus Basin also discussed by Hewitt (2005). However, in the main Indus River, Ali et al (2009) did not identify a significant change in flow, neither on the basis of the inflow into Tarbela (1961–2004) and at Kalabagh (1922–2002) nor in the Jhelum River measured at Mangla (1922–2004). An increasing trend was observed in the flow of Chenab measured at Marala (1922–2004), and a significant decreasing trend was observed in the flow of Kabul River at Nowshera (1961–2004).

Concerning glacial behavior in the basin, scientists disagree about whether all glaciers of the Himalaya–Karakoram–Hindu Kush region are retreating. Mayewski and Jeschke (1979) used termini movements as the sole indication of advance or retreat of glaciers in the greater Himalayan region. They showed that most glaciers in the Himalaya have been in a general state of retreat since 1850, while trans-Himalayan glaciers showed cycles of advance and retreat. Goudie et al (1984) found historical records of glacier fluctuations in the Himalaya and the Karakoram, indicating that in the late 19th and early 20th centuries, the glaciers were generally advancing, followed by predominant retreat from 1910–1960. Hewitt (2005) concluded that most glaciers of the Karakoram–Himalaya were also observed to diminish from the 1920s to the early 1990s, in line with the glaciers from most parts of the world, with the exception of some short-term advances and surges in the 1970s. However, in the late 1990s, many glaciers located in the highest watersheds of the Central Karakoram began expanding (Figure 2). Probable reasons for this contrasting behavior are attributed to possibly changing atmospheric circulation patterns; increased precipitation; a local trend of decreasing temperatures, particularly in summer (Fowler and Archer 2006); or the influence of thick debris coverage, which protects the ice against melting (Hewitt 2005; Hewitt 2011, in this issue).

The glaciers in the Indian part of the Himalaya have been retreating since the earliest recording began around the middle of the 19th century (Raina 2009). Glacier cover has also decreased in the adjacent areas on the Tibetan plateau and the mountain regions of the People's Republic of China, as compiled by Li et al (2008). According to these authors, the Himalayan glaciers and the glaciers in the Qilian and Tianshan mountains have shrunk significantly, about 5 to 10% in the last 30 years. Moreover,

http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00017.1

scientists have noticed that Himalayan glaciers are impacted by anthropogenic factors such as aerosols with black carbon and dust, deforestation, forest fires, human-induced pollution, and emission of greenhouse gases (UNEP 2009).

Uncertainties in scientific understanding of environmental dynamics

The current state of knowledge on environmental change in the Indus Basin—particularly the divergent findings on changes briefly presented earlier—clearly reveal uncertainties and inconsistencies in methodologies and subsequent results. The existing monitoring network, including all stations of national and international organizations, does not adequately represent the heterogeneous mountain terrain. The climate varies between valleys and mountaintops, between aspects and orientations, and among different locations. Moreover, a transboundary assessment of the trends is missing, because all analyses focus on areas within a single country. In this respect, here are some of the main issues that need to be dealt with.

Glaciers in the uplands of the Indus, including the eastern and western rivers, are the lifeline of Pakistan's economy. The hydrological significance of glaciers in the basin is very high (UNEP 2007). About 40% of the meltwater originates from glaciers in the Indus Basin (Immerzeel et al 2010). The glacier environment of the greater Himalayan region is still a large "black box," as shown by the great variance in reported results on glacier numbers, area, and ice volume. In addition, glaciers in the Himalayan region behave in part differently from those in the Karakoram (Hewitt 2005; Hewitt 2011, in this issue). However, whether these changes are due to internal changes of geometry of the ice or actual increases in glacial mass balance is still subject to research and clarification. The influence of debris cover is variable and differs from glacier to glacier. To improve understanding of the glacier–hydrology relationship and dynamics under climate change, hydrological modeling at different scales is crucial. Moreover, monitoring of the evolution of the glaciers in the greater Himalayan region is essential, as their melting may (1) negatively affect regional water supply in the next decades (Barnett et al 2005), (2) significantly contribute to ongoing sea level rise (Kaser et al 2006), and (3) increase natural hazards linked to glaciers (especially glacial lake outburst floods) (Mool et al 2001).

Understanding of the vertical and horizontal distribution of precipitation, key factors in the hydrological system, is poor (Winiger et al 2005; Hewitt 2011, in this issue). Furthermore, future precipitation projections are associated with a large uncertainty, as has been shown with the comparison of different general circulation models, as well as the validation of the Providing Regional Climates for Impacts Studies model runs with Climatic Research Unit data (Saeed et al 2009). In addition, downscaling work to date has been based on coarse resolution, resulting in a crude overview of future scenarios. It does not allow determination of the impact of climate change at a subbasin level, which is crucial for planning of water resources development. The capacity for downscaling and developing regional scenarios with low uncertainties needs to be enhanced, high-quality research needs to be improved, and new initiatives need to be supported.

The case of Pakistan

The Indus Basin has a complex geopolitical situation. The headwaters are located mainly in two countries, the People's Republic of China and India, and only a small portion of the basin is in Afghanistan, whereas a major portion of the basin is located in Pakistan. There is no transboundary institutional arrangement for Indus Basin water management except the 40-year-old Indus Basin treaty between India and Pakistan (Briscoe 2010). The treaty has served as a model of relationship between India and Pakistan and has been an efficient mechanism for sharing water from the major rivers and tributaries. However, due to the changing climate and uncertainty of water availability, the effectiveness of the treaty has been greatly reduced (Briscoe 2010). This mainly has to do with increasing demand for water, likely changes in supply of water, and reduced dependability of supply due to expected variability in the volume of supply, its seasonality, and rainfall regimes (Archer et al 2010). Climate change may play a minor role, but changes in the cryospherical reservoir are expected; moreover, the role of extreme events such as floods and the impact of socioeconomic factors are unknown (Archer et al 2010). As evoked earlier, Pakistan's vulnerability to water stress is particularly high.

Indeed, the level of 1037 m^3/capita annual water withdrawal in Pakistan is already about three quarters of the available annual renewable water resources of 1304 m^3 (FAO 2011). The annual water availability per person in Pakistan is already below the critical stress level of 1700 m^3/person/y (Vaidya 2009; Hussain and Mann 2010; Qureshi 2011, in this issue). Pakistan is facing major threats to its future water, food, and energy security due to several drivers, of which climate change is a recent one. Socioeconomic, demographic, institutional, governance, and management-related drivers have been playing more significant roles for many years. It is feared that if sound adaptive and risk management measures are not taken urgently, Pakistan will be heading toward being a water-scarce country (Archer

http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00017.1

et al 2010). This calls for a fresh look into water resources management in the Indus Basin.

Pakistan is also using a very high portion of its renewable annual water yield. Only a small portion of the available water is left to be harnessed to fill the supply gap in the nonagriculture sector—close to 97% of water (both surface and ground) is allotted to irrigation (Hussain and Mann 2010). There are serious issues related to water governance, equity (interprovince and intercommunity allocation), and water use efficiency in Pakistan (World Bank 2006). Embarking on integrated water resources management (IWRM) approaches has been advocated (World Bank 2006), but this demands a sound knowledge base supported by robust information and data supply. Without long-term development of a quality database to scientifically assess the impacts of climate change on water resources, adaptation measures such as augmentation of supply sources through increased natural and artificial storage of water, as well as improvement of water management, cannot be effectively designed, let alone implemented. To design a more integrated and transboundary approach to water management in the Indus Basin, an international expert consultation was organized in July 2010, bringing national, regional, and international scientists, water managers, policy-makers, and donors together.

Results of the consultation of Indus Basin experts

The scientists and water managers critically reviewed ongoing research and development work and identified major research, knowledge, and capacity gaps in the context of rapid changes in climatic and socioeconomic scenarios. Interdisciplinary research and knowledge development and sharing efforts were initiated at a globally coordinated level with a view to enabling policy- and decision-makers to enhance their understanding of environmental risks and challenges faced by the basin and eventually come up with a long-term action plan for launching a holistic and adaptive program to improve the management of scarce water resources.

The experts identified common issues including the scattered nature of research, uncoordinated research efforts, and lack of sharing of results with the planners and managers in the country. Currently, a large number of national and international agencies are involved in setting up hydrometeorological stations to carry out glacial monitoring and even developing models to project future scenarios in some cases. Some of these research projects have provided an excellent understanding of the changes in climate and environment parameters of the basin. There is also a growing interest within the countries in the basin to develop glaciological and hydroglaciological research programs. However the lack of both national and regional coordination among various institutions in planning the installation of observation networks and sharing the data generated is one of the biggest constraints in this regard. Many international institutions follow their own research protocols and knowledge-sharing practices. In general, the researchers were found to have rather short-term interests and a narrow focus. They are generally working in isolation without proper coordination with relevant national institutions, and often the data collected remain confined to the researchers themselves and are not made available to the policy community to promote application of data and information to solve water management problems.

Participants therefore called for launching a multidisciplinary and multicountry research campaign to actively support a longer-term vision of integrated and holistic management of water and other natural resources of the Indus. Such a program should aim to work in the entire Indus Basin, eventually covering all four countries sharing the basin: Afghanistan, the People's Republic of China, India, and Pakistan.

However, it was agreed that given the widespread concerns about the changing and stressful water supply scenario in lower basin, the first priority should be given to Pakistan in any future initiative regarding the Indus Basin. It was agreed that although socioeconomic drivers play important role in the lower part of the basin, large climatic variability seems to dominate the situation in the upper catchments. The goal is to understand the entire change processes and their dynamics so that the impact of climate change on water availability, variability, and impact in future water supply and other ecosystem services can be separately monitored. As a first step in this direction, regular monitoring of the cryosphere and generation of data could help in understanding changes in ice and snow dynamics. However, it was stressed that the upstream changes have to be studied in tandem with downstream water needs and the likely impacts they may cause in agriculture, which are of greater importance from the users' point of view and needs (Qureshi 2011, in this issue). The experts pointed out the need to pay equal attention to the downstream part of the basin in any long-term adaptation research program. The need for a robust hydrological modeling exercise was also identified as an important activity to regularly assess changes and their impacts in water resources management.

Specifically, the participants identified the following key priority areas for scientific studies:

1. Improved understanding of the changes and variability in the climate of the Indus Basin;

http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00017.1

BOX 1: Why IWRM and IRBM in the Indus Basin?

Among the most cited water management frameworks in managing transboundary rivers, IRBM practiced in different parts of the world provides useful lessons to promote the integrated management of Indus water (Gupta 2011; Lindemann 2005; Hooper 2008; Kennedy et al 2009; UNESCO-IHP 2009).

IWRM is defined by the Global Water Partnership as "a process that promotes the coordinated development and the management of water, land and related resources, to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (cited in UNESCO-IHP 2009: 3). "The river basin approach seeks to focus on implementing IWRM principles on the basis of better coordination amongst operating and water management entities within a river basin, with a focus on allocating and delivering reliable water-dependent services in an equitable manner. It is an holistic approach that seeks to integrate the management of the physical environment within that of the broader socioeconomic and political framework" (cited in UNESCO-IHP 2009: 3). IRBM operates based on the principle that naturally functioning river basin ecosystems, including accompanying wetland and groundwater systems, are the source of freshwater (GWP 2000).

In the context of the Indus Basin, there is a strong recognition of the existence of multiple risk and uncertainty factors affecting the sustained supply of water from the limited upstream sources to meet the unlimited downstream needs. There is also a risk of annual and seasonal variability in water supply, due mainly to changing cryospherical, hydrological, ecological, and atmospheric factors. Therefore, the future management strategy of the Indus River Basin must be based on maintaining a sound balance among land, water, vegetation, and socioeconomic factors. The IRBM framework can also contribute to sustainable development goals, because it can contribute to both climate change adaptation and disaster reduction, which are becoming increasingly crucial in the Indus due to the combined impacts of climate and socioeconomic changes.

2. Intensification in the use of remote sensing tools for collecting data;
3. Reducing the scale issue in building climate scenarios using downscaling techniques;
4. Understanding glacier behavior using a combination of in situ and remote sensing observations, paleoclimatic analysis, and modeling (Hewitt 2011, in this issue);
5. Understanding other factors influencing hydrology, including the role of avalanches, debris cover, and dirt cover, including black carbon deposit (Hewitt 2011, in this issue);
6. Understanding water balance using state-of-the-art tools, including improved hydrometeorological observation networks;
7. Understanding the roles of socioeconomic, institutional, and policy-related factors; and
8. Involving stakeholders to develop adaptive water management.

Toward an integrated framework

It is clear that there is an urgent need to implement a vision of an integrated and sustainable management of land, water, plants, knowledge, and human resources in the Indus Basin. This can be done first by developing trust and confidence among all stakeholders utilizing these resources in the basin. It is necessary to develop a common understanding and vision of future water challenges facing all the countries, leading to the realization that solutions could be found through a joint and collaborative approach (Hooper 2008). In many international river basins, the implementation of IRBM policies and programs has yielded better solutions (Burns et al 2001). The proposed approach for the Indus Basin can draw upon a number of good practices already used in Australia, the United States, and South Africa (Hooper 2008).

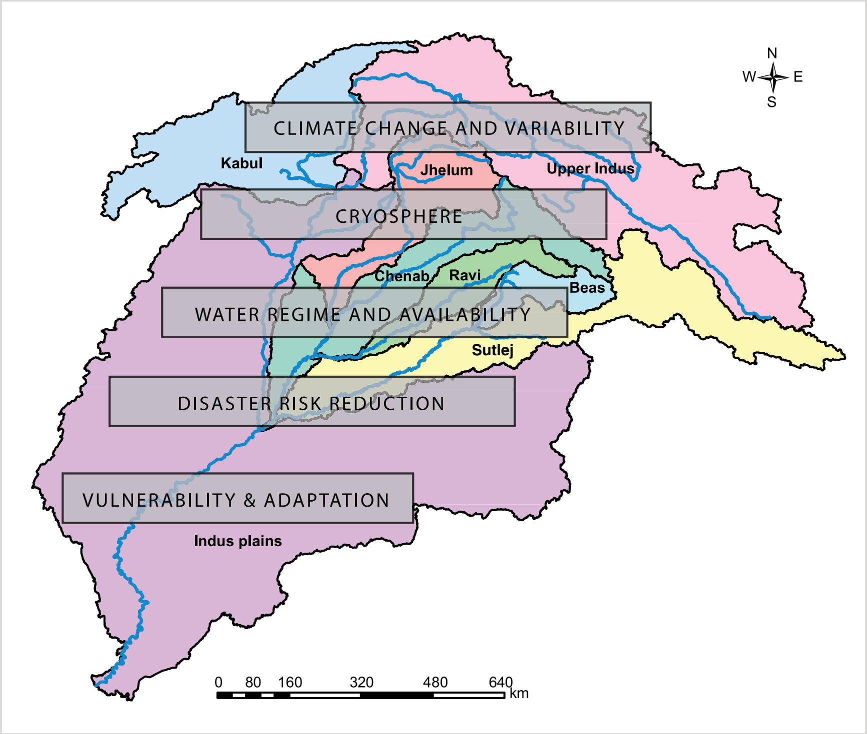
As argued previously, the future strategy for managing water in the Indus Basin must be integrated (multisector), comprehensive (upstream–downstream), sustainable (intracommunity and intergeneration), and environmentally sound, yielding efficient, equitable, and effective results. This is possible by adopting IWRM principles and approaches at subbasin and basin levels (see Box 1). Also, because the Indus River has a number of subbasins and transboundary catchments, a basinwide framework within which the IWRM approach can be applied at different levels, especially within national boundaries, will be necessary and productive. This can be achieved through an internationally accepted framework of IRBM (see Box 1). The acceptance of an IRBM framework will require a comprehensive basinwide data and information collection that can be used to prepare basinwide and subbasinwide water resources management and sustainable development plans. The IWRM tools (UNESCO-IHP 2009) can be derived from the overall plan using an integrated approach to resources management and planning that promotes collaboration and consensus-building process among different stakeholders in the basin. Based on the outcome of the international consultation, as well as a review of experiences worldwide, a stagewise approach is suggested to achieve the vision of the IRBM, with the following steps:

1. Stakeholder consultation;
2. Systematic data gathering through coordinated research;
3. Development of transboundary cooperation frameworks; and
4. Information and knowledge sharing to support IRBM and IWRM policies and programs.

The purpose of the entire research and knowledge development campaign would thus be to support the vision of IRBM

http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00017.1

FIGURE 3 Schematic representation of thematic areas at different geographical layers. (Map by ICIMOD)



using IWRM tools and practices (UNESCO-IHP 2009). To achieve this, engagement and full participation of major national research agencies as the key stakeholders would be necessary. Emphasis will have to be given to generating and sharing transboundary knowledge, information, and data—as well as to networking, which will help develop a regional cooperation framework by first building trust among the partners. To institute coordination and collaborative arrangement in the program, the experts advised that regional and international advisory bodies be constituted.

The Indus Basin program: toward implementation

Stakeholder consultation

A first consultation took place at the initiative of the International Centre for Integrated Mountain Development (ICIMOD) but needs to be repeated to achieve incremental learning and actions. Among the future actions, national, regional, and global teams will have to be created, with scientists, researchers, managers, and policy-makers as stakeholders who will design and implement the action research on long-term impact and vulnerability analysis and the adaption actions needed by generating and sharing data and information on different aspects and features of climate and environmental changes in the Indus Basin, especially in areas such as impact on river runoff, river hydrology, and water cycle.

The program should follow both multidisciplinary and multisectoral action research approaches with a longer-term and basinwide scope involving relevant and interested national and international institutions and experts. The approach should be nested, with research at different scales with different thematic focuses—horizontally and vertically (Figure 3). The research should be conducted by national agencies with the support of regional and international knowledge centers. ICIMOD aims to be the nodal regional organization to plan, design, and coordinate a long-term Indus Basin program for which a road map has been developed and agreed upon by the experts.

Systematic data gathering through coordinated research

Clearly, there is a need to have systematically generated and updated spatial and nonspatial data and information, and these data need to be shared among researchers, scientists, and water managers. Moreover, as Viviroli et al (2011) underline, "research on mountain water resources must become more integrative by linking relevant disciplines," and the information needs to specifically support integrated and transboundary approaches to better handle risk and uncertainty by enabling resource managers to manage both the "too much" and "too little" water scenarios (Figure 3). In addition, the scientific knowledge base needs to be robust and help understand the intricate relationship among the natural, socioeconomic, and environmental factors influencing basin ecosystems and water resources in Indus. It is also necessary to obtain an active and mutually beneficial participation of all relevant stakeholders, especially local community and water managers, to make the program successful.

Development of transboundary cooperation frameworks

As mentioned previously, the first step toward implementing IRBM framework using IWRM principles is to build trust and partnership among different national and regional partners and stakeholders. Generation and sharing of data, information, and knowledge were agreed by the international experts to be the most suitable means to promote cooperation in the prevailing geopolitical environment

http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00017.1

to eventually achieve transboundary cooperation within the IRBM framework. Lessons learned from global experience in river basin management (WWF 2001; Hooper 2008) indicate that having a long-term vision for the whole river basin to which major stakeholders subscribe needs to be followed by a proper strategy of water management at the river basin scale. The IWRM approaches and actions at subbasin or country levels provide such a strategy. The Indus consultation brought all stakeholders together in building common vision and strategy along this line.

Information and knowledge sharing to support IRBM and IWRM policies and programs

Long-term monitoring and database development and sharing program should be established, concentrating on the upper basin to provide trends and scenarios at the basin and subbasin scales that can be useful to water managers and policy-makers. It is expected that this activity will not only build national and regional research capacity but also eventually develop an integrated river basinwide database and information system (IRBIS). The purpose of such a database will be to help address a number of key issues that are already identified (Wescoat 1991; WWF 2001; Archer et al 2010; Immerzeel et al 2010). IRBIS will be the single source of data on which IRBM and IWRM can be based in the Indus Basin. Data should be made readily available and accessible to water resource planners and managers to enable them to more judiciously plan and design water infrastructures and execute development programs and projects to meet the future supply needs. The key factors that need to be considered in operationalizing the IWRM approach within the IRBM framework can be summarized as follows:

1. Inadequate storage capacity in the basin (both artificial and natural) to manage floods and droughts in an integrated manner;
2. Uncertainties brought about by climate change in influencing river hydrology;
3. Increasing water shortages and the need to avert food production decrease due to heavy dependence on irrigation water;
4. Poor capacity to interpret and implement IWRM at both federal and provincial levels (World Bank 2006).

The specific challenges in Pakistan

In the specific case of Pakistan, additional challenges need to be met: water allocation and entitlements in the complex canal irrigation network of Pakistan have been an issue for years, because the water rights of main canals have not been established on an equitable, historically and socioeconomically acceptable basis. We believe that progress in this area is possible if the IWRM principles are applied and implemented. River basin management within Pakistan will also face additional challenges due to increasing water demand in the complex social and ecological downstream regions, which suffer floods during the summer and droughts in the winter and spring seasons at an average interval of about 5 years (Briscoe 2010; Chaudhry 2010). This will require higher efficiency, lower wastage, and equitable management of limited water resources that can help increase water productivity. Integrated planning and management of the basin water are therefore necessary conditions for Pakistan to successfully meet these multiple challenges. For this, a comprehensive future water management strategy needs to be evolved that factors in the most likely future trends in climate variability, and significant investments in research, capacity building, and water resources development have to be generated to undertake long-term adaptive and holistic water resources management.

Indus Basin experts (Wescoat et al 2000; Archer 2003; Briscoe and Qamar, 2005; World Bank 2006; Briscoe 2009; Archer et al 2010; Viviroli et al 2011) agree that Pakistan needs to adapt to climate and socioeconomic changes, including population growth, in managing water resources by identifying and implementing no- or low-regret adaptive strategies that are not limited to infrastructure development alone. The Upper Indus, especially the catchments of Mangla and Tarbela dams, have fairly well-developed watershed management practices and infrastructure whose improvements and expansions will require improved understanding of the hydrological cycles and maintaining the balance between demand in the lower catchments and supply systems upstream.

The vast irrigation systems of the Lower Indus also have to adapt to the future changes. For example, the currently incurred heavy loss of canal water both during conveyance and application can be significantly reduced through better lining of the canals and improved on-farm management of irrigation (Chaudhry 2010). Although the current estimate is that in the immediate future the river water supply is expected to increase, because variability in volume and seasons of water availability are expected to change (Archer et al 2010), there is a need for establishing better projections of future scenarios. However, because the current availability of water in Pakistan is only around 1100 m^3/capita, there is already an acknowledged scenario of water deficit that needs to be considered in any long-term adaptation plans.

Pakistan also needs to build additional water storage facilities, combining both artificial and natural storage facilities, because currently it can only store 30 days of average flow

http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00017.1

in the Indus, compared to the 1000 days in developed countries such as the United States and Australia (Briscoe 2011). Therefore, the bulk of the additional water will have to come mainly from increased storage facilities created in the upper catchments, combined with improved efficiency of the canal delivery system downstream, focusing on supplying water when needed, specifying better water entitlements rather than generalized water rights, and gearing water toward regions and crops that have the highest productivity per unit of water (Shah 2010). At the same time, the concept of building a series of large dams within the Upper Indus Basin should be planned only after serious consideration of possible environmental and socioeconomic impacts. Devising better technologies for increasing water efficiency and conjunctive use of surface and groundwater (Shah 2010) are other steps that are needed. The expertise available with specialized agencies such as the International Institute of Water Management (IWMI) and ICIMOD, and interest to develop policies that are regionally differentiated, can help ensure resource sustainability and high productivity (Sharma et al 2010), which we believe can be an appropriate way forward for the Indus program.

Conclusion and recommendations

The Indus River is a dynamic, complex, and large basin that covers four countries and has a complex mosaic of ecological, political, and socioeconomic systems. The state of scientific research—although extensive—remains poorly coordinated, and data and information are largely unshared. The national scientific capacity in the main downstream country, Pakistan, should be improved and should include scientific interests and capacities from outside Pakistan, which are rather high and available for collaboration. As an intergovernmental organization with membership of all four Indus Basin countries, ICIMOD not only is mandated to build on the scientific information and knowledge base but also has the capacity and strategy to develop a long-term research program and capacity-building activities engaging different national, regional, and international stakeholders—especially national partners such as the Water and Power Development Authority, the Pakistan Meteorological Department, and IWMI—to work simultaneously on science, practice, management, and policy. Creating a solid foundation based on scientific research, combined with documentation of good local practices, can promote both IRBM and IWRM in better planning and managing water resources of the Indus.

Given the geopolitical reality of the basin, a bottom-up, short- and long-term, and national and regional collaboration framework is recommended, first focusing on generation of necessary long-term and scientific data and information and then embarking on the development of a pilot national level collaboration framework for Pakistan. However, the overall strategy remains to strengthen links between upstream changes in the water scenario with downstream imperatives driven by socioeconomic factors. Such a basinwide strategy is expected to require policy reforms that first could be implemented within the national boundaries and eventually could be used to influence and contribute on a regional scale.

ACKNOWLEDGMENTS

The authors acknowledge the valuable support received from ICIMOD's management, as well as from the professional staff of the Integrated Water and Hazards Management program for putting together this paper. The authors also acknowledge the role of the work by all scientists, researchers, and water resource managers whose past work on Indus water has been quoted in this paper. Any omission or inadequate acknowledgment of their work is ours only. The views expressed in this paper are those of the authors, and they do not necessarily represent the views of the organizations with which the authors are associated.

REFERENCES

Ali G, Hasson S, Khan A. 2009. *Climate Change: Implications and Adaption of Water Resources in Pakistan.* Research Report RR 13. Islamabad, Pakistan: Global Change Impact Studies Centre.

Archer DR. 2003. Contrasting hydrological regimes in the Upper Indus Basin. *Journal of Hydrology* 274: 98–210.

Archer DR, Forsythe N, Fowler HJ, Shah SM. 2010. Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions. *Hydrology and Earth System Sciences* 14:1669–1680. http://dx.doi.org/10.5194/hess-14-1669-2010.

Barnett TP, Adam JC, Lettenmaier DP. 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature* 438: 303–309. http://dx.doi.org/10.1038/nature04141.

Bhutiyani MR, Kale VS, Pawarc NJ. 2009. Climate change and the precipitation variations in the northwestern Himalaya: 1866–2006. *International Journal of Climatology* 30(4):535–548.

Briscoe J. 2009. Water, agriculture, and development: The quality of advice? *In:* Einhorn JP, Peterson ER, editors. *Water and Agriculture: Implications for Development and Growth. Essays from the CSIS and SAIS Year of Water Conference 2009.* Washington, DC: Center for Strategic and International Studies, pp 1–24.

Briscoe J. 2010. Perspectives: Troubled waters—Can a bridge be built over the Indus? *Economic & Political Weekly* 45(50):28–32.

Briscoe J. 2011. Invited opinion interview: Two decades at the center of world water policy. Interview with John Briscoe by the Water Policy Editor-in-Chief Jerome Delli Priscoli. *Water Policy* 13:147–160. http://dx.doi.org/10.2166/wp.2010.000.

Briscoe J, Qamar U. 2005. *Pakistan's Water Economy Running Dry.* Washington, DC: World Bank.

Burns B, Bandaragoda DJ, Samad M, editors. 2001. *Integrated Water-Resources Management in a River-Basin Context: Institutional Strategies for Improving the Productivity of Agricultural Water Management.* Proceedings of the Regional Workshop, Malang, Indonesia, 15–19 January 2001. Battaramulla, Sri Lanka: International of Water Management Institute.

Chaudhry QZ, Rasul G. 2007. Development of a meso-scale convective system over the foothills of Himalaya into a severe storm. *Developments in Earth Surface Processes* 10:301–311. http://dx.doi.org/10.1016/S0928-2025(06)10033-4.

Chaudhry SA. 2010. Pakistan: Indus Basin water strategy—Past, present and future. *Lahore Journal of Economics* 15:187–211.

Eriksson M, Jianchu X, Shrestha AB, Vaidya RA, Nepal S, Sandström K. 2009. *The Changing Himalayas: Impact of Climate Change on Water Resources and Livelihoods in the Greater Himalayas.* Kathmandu, Nepal: International Centre for Integrated Mountain Development; Rome, Italy: Food and Agriculture Organization. http://www.fao.org/nr/aquastat; accessed on 5 June 2011.

FAO [Food and Agriculture Organization]. 2011. *Aquastat.* Rome, Italy: FAO. http://www.fao.org/nr/aquastat; accessed on 5 June 2011.

Fowler HJ, Archer DR. 2006. Conflicting signals of climatic change in the Upper Indus Basin. *Journal of Climate* 19:4276–4293.
Goudie AS, Brunsden D, Collins DN, Derbyshire E, Ferguson RI, Hashmet Z, Jones DKC, Perrot FA, Said M, Waters RS, Whalley WB. 1984. The geomorphology of the Hunza valley, Karakoram Mountains, Pakistan. *In:* Miller KJ, editor. *The International Karakoram Project*. Cambridge, United Kingdom: Cambridge University Press, pp 268–354.
Gupta AD. 2011. Challenges and opportunities for integrated water resources management in Mekong River Basin. *In: Role of Water Sciences in Transboundary River Basin Management, Thailand, 2005*. Thailand: School of Civil Engineering, Asian Institute of Technology, pp 221–230. http://www.ihwb.tu-darmstadt.de/media/fachgebiet_ihwb/lehre/iwrdm/literature/challengesand opportunitiesforiwrminthemekongriverbasin dasgupta.pdf; accessed on 19 July 2011.
GWP [Global Water Partnership]. 2000. *Integrated Water Resources Management*. Technical Advisory Committee (TAC) Background Paper No. 4. Stockholm, Sweden: GWP, TAC.
Hewitt K. 2005. The Karakoram anomaly? Glacier expansion and the elevation effect. *Mountain Research and Development* 25(4):332–334.
Hewitt K. 2011. Glacier change, concentration, and elevation effects in the Karakoram Himalaya, Upper Indus Basin. *Mountain Research and Development* 31(3):188–200.
Hooper BP. 2008. Covenant action to facilitate integrated river basin management. *Water SA* 34(4):456–460.
Hussain Z, Mann MI. 2010. *Indus River Basin of Pakistan*. Islamabad, Pakistan: Ministry of Food and Agriculture, government of Pakistan.
Immerzeel W, von Beek L, Bierkens M. 2010. Climate change will affect the Asian water towers. *Science* 328:1382–1385. http://dx.doi.org/10.1126/science.1183188.
Jain S, Goswami A, Saraf A. 2009. Assessment of snowmelt runoff using remote sensing and effect of climate change on runoff. *Water Resources Management* 24:1763–1777.
Kaser G, Cogley JG, Dyurgerov MB, Meier M, Ohmura A. 2006. Mass balance of glaciers and ice caps: Consensus estimates for 1961–2004. *Geophysical Research Letters* 33(19):1–5. http://dx.doi.org/10.1029/2006GL027511.
Kennedy K, Simonovic S, Tejada-Guibert A, de França Doria M, Martin JL. 2009. *IWRM Implementation in Basins, Sub-basins and Aquifers: State of the Art Review.* The United Nations World Water Development Report 3. Paris, France: United Nations Educational, Scientific and Cultural Organization.
Klein Tank AMG, Peterson TC, Quadir DA, Dorji S, Zou X, Tang H, Santhosh K, Joshi UR, Jaswal AK, Kolli RK, Sikder AB, Deshpande NR, Revadekar JV, Yeleuova K, Vandasheva S, et al. 2006. Changes in daily temperature and precipitation extremes in central and south Asia. *Journal of Geophysical Research* 111(D16105). http://dx.doi.org/10.1029/2005JD006316.
Li X, Cheng G, Jin H, Kang E, Che T, Jin R, Wu L, Nan Z, Wang J, Shen Y. 2008. Cryospheric change in China. *Global and Planetary Change* 62(3–4): 210–218. http://dx.doi.org/10.1016/j.gloplacha.
Lindemann S. 2005. Erfolgsbedingungen von internationalem Flussmanagement: Der Fall des Südlichen Afrikas. *In:* Kipping M, Lindemann S, editors. *Konflikte und Kooperationum Wasser—Wasserpolitik am Senegalfluss und Internationales Flussmanagementim Südlichen Afrika*. Munster, Germany: Lit-Verlag, pp 108–234.
Mayewski PA, Jeschke PA. 1979. Himalayan and trans-Himalayan glacier fluctuations since AD 1812. *Arctic and Alpine Research* 11(3):267–287.
Mool PK, Bajracharya SR, Joshi SP. 2001. *Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods: Monitoring and Early Warning Systems in the Hindu Kush–Himalayan Region*. Kathmandu, Nepal: International Centre for Integrated Mountain Development.
Qureshi AS. 2011. Water management in the Indus Basin in Pakistan: Challenges and opportunities. *Mountain Research and Development* 31(3):252–260.
Raina VK. 2009. *Himalayan Glaciers: A State-of-Art Review of Glacial Studies, Glacial Retreat and Climate Change*. MoF Discussion Paper. New Delhi, India: Ministry of Environment and Forest.
Rees HG, Collins DN. 2006. Regional differences in response of flow in glacier-fed Himalayan rivers to climatic warming. *Hydrological Processes* 20: 2157–2169.
Saeed F, Anis MR, Aslam R, Khan AM. 2009. *Development of Climate Change Scenarios for Specific Sites Corresponding to Selected GCM Outputs, Using Statistical Downscaling Techniques*. Research Report RR 09. Islamabad, Pakistan: Global Change Impact Studies Centre.
Shah ESRA. 2010. *Overview of Challenges and Strategies of Water Resources Management in Pakistan*. Lahore, Pakistan: Centre of Excellence in Water Resources Engineering, University of Engineering and Technology.
Sharma B, Amarsinghe U, Xueliang C, de Condappa D, Shah T, Mukherji A, Bharati L, Ambili G, Qureshi A, Pant D, Xenarios S, Singh R, Smakhtin V. 2010. The Indus and the Ganges: River basins under extreme pressure. *Water International* 35(5):493–521. http://dx.doi.org/10.1080/02508060.2010.512996.
UNEP [United Nations Environment Programme]. 2007. *Global Outlook for Ice and Snow*. Oslo, Norway: UNEP, Grid-Arendal.
UNEP [United Nations Environment Programme]. 2008. *UNEP Sourcebook Integrating Adaptation to Climate Change into UNEP Programming*. Nairobi, Kenya: UNEP.
UNEP [United Nations Environment Programme]. 2009. *Recent Trends in Melting Glaciers, Tropospheric Temperatures over the Himalayas and Summer Monsoon Rainfall over India*. Nairobi, Kenya: UNEP, Division of Early Warning and Assessment.
UNESCO-IHP [International Hydrological Programme of the United Nations Educational, Scientific and Cultural Organization and the Network of Asian River Basin Organizations]. 2009. *Introduction to the IWRM Guidelines at River Basin Level*. Paris, France: UNESCO. http://unesdoc.unesco.org/images/0018/001850/185074e.pdf; accessed on 5 June 2011.
Vaidya R. 2009. The role of water storage in adaptation to climate change in the HKH region. *ICIMOD Newsletter* 56:10–13.
Viviroli D, Archer DR, Buytaert W, Fowler HJ, Greenwood GB, Hamlet AF, Huang Y, Koboltschnig G, Litaor MI, López-Moreno JI, Lorentz S, Schädler B, Schreier H, Schwaiger K, Vuille M, Woods R. 2011. Climate change and mountain water resources: Overview and recommendations for research, management and policy. *Hydrology and Earth System Sciences* 15:471–504. http://dx.doi.org/10.5194/hess-15-471-2011.
Wescoat Jr JL. 1991. Managing the Indus River basin in light of climate change: Four conceptual approaches. *Global Environmental Change* 1(5): 381–395. http://dx.doi.org/10.1016/0959-3780(91)90004-D.
Wescoat Jr JL, Halvorson S, Mustafa D. 2000. Water management in the Indus Basin of Pakistan: A half century perspective. *International Journal of Water Resources Development* 16:391–406.
Winiger M, Gumpert M, Yamout H. 2005. Karakorum–Hindukush–Western Himalaya: Assessing high-altitude water resources. *Hydrological Processes* 19:2329–2338.
World Bank. 2006. *Better Management of Indus Basin Waters; Strategic Issues and Challenges*. Washington, DC: World Bank.
WWF [World Wide Fund for Nature]. 2001. *Elements of Good Practice in Integrated River Basin Management: A Practical Resource for Implementing the EU Water Framework Directive*. Brussels, Belgium: WWF.
Zonn IS. 2002. *Water Resources of Northern Afghanistan and Their Future Use.* Report prepared for Soyuzvodproject. Moscow, Russia: Soyuzvodproject. http://www.cawater-info.net/afghanistan/pdf/zonn.pdf; accessed on 5 June 2011.