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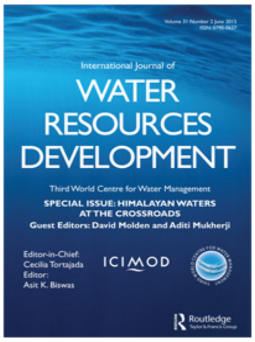

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EDITORIAL

Himalayan waters at the crossroads: issues and challenges

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The Hindu Kush Himalayas are called the water towers of Asia as they are the source of 10 major rivers and have the largest snow and ice deposits outside the two poles. Water emanating from the HKH provides food, energy and ecosystem services to up to 1.3 billion people. Climate change and socio-economic and demographic changes have put unprecedented pressure on these water resources, leading to uncertain supplies, increased demands and higher risks of extreme events like floods and droughts. The eight articles in this special issue highlight various dimensions of the Himalayan water resources by focusing on both physical and social science aspects of water management.

Keywords: Hindu Kush Himalayas; climate change; rivers; glaciers; water induced disasters; water-storage; people's perception

Introduction

This special issue of the *International Journal of Water Resources Development* presents eight articles dealing with various aspects of water in the Hindu Kush Himalayas (HKH). As the water towers of Asia, the HKH region is the source of 10 major rivers: the Indus, Ganges, Brahmaputra, Irrawaddy, Salween, Mekong, Yangtze, Yellow, Amu Darya and Tarim. These rivers directly serve 210 million people who live in the HKH and also serve 1.3 billion people who live downstream of these river basins (Eriksson et al., 2009; Figure 1). The HKH region has the highest concentration of snow and glaciers outside the two poles and is often referred to as the Third Pole. All 10 main rivers of the HKH are snow and glacier fed and hence perennial. They serve some of the most highly populated regions of the world with water for food, energy and domestic uses; they have nurtured great civilizations and sustained important ecosystems. Yet, these water systems are at a crossroads due to climate, socio-economic and demographic changes. This is exemplified by increasing water demand, and further exacerbated by uncertainties about future availability and increase in incidence of extreme events like floods and droughts.

The snow-and-glacier-melt rivers of the HKH play an important role in supporting some of the largest surface and groundwater irrigation systems of the world, such as the Indus, the Ganges and the Yellow, making the Indo-Gangetic and North China Plains among the top two irrigated areas globally. The HKH region has a feasible hydropower potential of around 500 GW, of which only a very small portion has been harnessed so far. Given the mountainous terrain, the region is also prone to natural hazards, of which floods, including glacial lake outburst floods (GLOFs), flash floods and riverine floods are

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Figure 1. The Hindu Kush Himalayas region and the 10 river basins emanating from it.

common. While understanding the science of river hydrology and glaciology is very important in the context of the HKH given the primacy of rivers, snow and glaciers, it is equally important to understand the local-level water issues facing the mountain communities. This is because decisions that affect access to water for the people of the HKH are rarely made at the river-basin scale but are forged at local levels. A balanced understanding across scales, from the river-basin scale to the micro-watershed scale, is needed if we are to arrive at a comprehensive understanding of the challenges and opportunities offered by the Himalayan waters. This cross-scale understanding must also be set in the context of the vast socio-economic and demographic changes taking place in the mountains, which face numerous drivers of change, including globalization, urbanization, out-migration and feminization of agriculture, in addition to climate change.

The purpose of this special issue is to highlight the various dimensions of Himalayan water resources and their management. The first five articles touch upon physical science aspects such as decadal changes in glaciers (Bajracharya et al.), high-altitude meteorological analysis (Shea, Wagnon, Immerzeel, Biron & Brun), climate change and its hydrological impacts (Nepal & Shrestha), and natural hazards associated with floods (Shrestha, Grabs & Khadgi) and GLOFs (Khanal et al.) and ways of mitigating them. The next three articles deal with human aspects of water management, such as water storage options in the region to meet seasonal water demands (Vaidya), people's perceptions of and water-related adaptation to climate change (Pradhan, Sijapati and Bajracharya), and the implementation challenges of integrated water resources management (IWRM; Suhardiman, Clement and Bharati) in the context of a mountainous country like Nepal. This special issue aims to be a repository of knowledge on Himalayan waters by providing a comprehensive analysis of various aspects ranging from the physical to the socio-economic and institutional-policy dimensions of water in the region.

Role of the Hindu Kush Himalayas in meeting changing water, food and energy demands

It is predicted that the countries of the HKH will increasingly face challenges in meeting water, food and energy demands due to rapid socio-economic development, population growth and urbanization. By 2025, an estimated 2.2 billion people will live in South Asia, and cereal demand will reach 471 million tonnes per year, compared to 241 million tonnes per year in 2000 (FAO, 2012; Mukherji, Facon, de Fraiture, Molden, & Chartres, 2012). Cereal demand will also increase substantially in China due to population growth and shifting of food preferences towards meat (Comprehensive Assessment, 2007). In a business-as-usual scenario, growing additional food will require more than double the water in terms of crop evapotranspiration (Comprehensive Assessment, 2007). Yet, much of South Asia and North China is already water-scarce. Similarly, South Asia faces a widespread energy crisis. Around 50% of the population lacks access to electricity, while 65% still use biomass for cooking (Rasul, 2014). The main source of energy is imported oil; South Asia's oil imports are expected to double by 2020. It is in this context of emerging water, food and energy scarcity that the role of the HKH becomes even more paramount. Understanding the Himalayan water systems is therefore crucial for ensuring long-term water, food and energy security in the HKH countries.

Irrigation is a major contributor to food security in the HKH countries. In South Asia, about 39% of cropland is irrigated, and irrigated agriculture accounts for 60–80% of food production (World Bank, 2013). In China, 41% of arable land is irrigated (53.8 million ha) and 75% of cereal production comes from irrigated agriculture (FAO, 2012). In South Asia more than 90% of withdrawn freshwater is used for irrigation, and in China this figure is close to 70% (FAO, 2012). The HKH mountain system not only provides surface water but also contributes substantially to groundwater in the region (Bookhagen, 2012). The annual contribution of groundwater flow through bedrock to the central Himalayan rivers is approximately six times that of glacial ice and snow melt (Andermann et al., 2012). Direct contribution of groundwater to irrigation has been increasing steadily and has now overtaken that of surface water in some countries. At present, groundwater contributes 79% of irrigation water in Bangladesh, 63% in India, 19% in Nepal, and 21% in Pakistan (FAO, 2012), and in general, irrigation in large parts of South Asia and the North China Plains is now almost exclusively dependent on groundwater (Shah, Singh, & Mukherji, 2006).

The hydropower potential of the HKH region is more than 500 GW (Vaidya, 2012). The contribution of hydroelectricity to total commercial energy is about 50% in Bhutan, 17% in Nepal, 13% in Pakistan, 6% in India and 4% in Afghanistan (ADB, 2011); and its contribution to the total electricity supply is about 100% in Bhutan, 92% in Nepal, 74% in Myanmar, 33% in Pakistan, 17% in India and 16% in China (Molden, Vaidya, Shrestha, Rasul, & Shrestha, 2014). Of the total hydropower potential in India, 79% (117,329 MW) is in the Himalayan region. A recent study conducted by the World Bank suggests that about 25 GW of electricity could be generated in the Ganges Basin through upstream storage of water in 23 dams, and that this could provide benefits worth USD 5 billion per year with very few negative effects (Sadoff et al., 2013). In addition to providing water, food and energy services, the HKH mountain system also regulates micro-climates and wind and monsoon circulation, and supports river and wetland ecosystems in the HKH countries. It is estimated that the Ganges River ecosystem alone supports 25,000 or more species, ranging from micro-organisms to mammals, which in turn support agriculture and provide livelihoods for millions of people.

Climate change and Himalayan glaciers

The HKH has a total of 54,252 glaciers occupying 60,054 km^2 and an estimated ice reserve of 6,127 km^3 (Bajracharya et al., this issue). There is, however, much variation between river basins, and the largest glaciated areas are found in the Indus, Brahmaputra and Ganges Basins. Over 60% of the total glacier area of the HKH is located at between 5000 and 6000 metres above seal level where meteorological observation stations are few and far between, posing unique challenges for long-term monitoring of ice and snow (Shea et al., this issue) in the HKH. The glaciers below 5700 m elevation are particularly sensitive to climate change unless they are covered by thick debris (Bajracharya et al., this issue). In addition, clean ice glaciers at low altitude and small glaciers are the most sensitive glaciers to climate change in the HKH region.

Overall, this decadal analysis shows that glaciers in almost all parts of the HKH, except in the Karakoram, have retreated over the last four decades, consistent with existing literature. Bajracharya et al. (this issue) conclude that the impacts of climate change on Himalayan glaciers are diverse and that this diversity in responses is caused by differences in climate, debris cover and the presence of glacial lakes. The need for comprehensive assessment of glacial lakes and the phenomena of GLOFs is also discussed in Khanal et al. (this issue).

Historically, knowledge of glaciers in the HKH mainly came from data on glacial snout fluctuations, but this is a poor indicator of climate change given that snout fluctuations also depend on several other variables, such as length, area and slope of the glacier, which are not related to climate *per se*. Historical records show that over the last 170 years, a majority of the Himalayan glaciers have been retreating, except for the more complicated and nuanced situation of the Karakoram glaciers (Bolch et al., 2012), where some are reported to be advancing. The climatic conditions which make the Karakoram glaciers different from other Himalayan glaciers could be attributed to extreme vertical topography (300 m/km), which is exceptional in the Himalayas (Mayewski & Jeschke, 1979) and enhances precipitation in the source area, and secondly to the thick debris cover of most of the glaciers (Hewitt, 2005; Scherler, Bookhagen, & Strecker, 2011) which reduces ablation.

In contrast to snout fluctuations, the mass balance (MB) of glaciers is directly related to climate. *In situ* surface MB measurements were started on some selected glaciers in the western Himalaya in the 1970s but discontinued after some years. Very limited *MB* studies are available for the 1990s in the central Himalaya, and with the beginning of the twenty-first century some new studies have been started in different parts of the Himalaya, including some by the International Centre for Integrated Mountain Development (ICIMOD). However, these limited measurements mostly come from small glaciers and are expected to be negatively biased; more information is needed from all sources. Recently, with the evolution of satellite imaging, several studies have been conducted to calculate the mass changes of glacierized regions worldwide. Recent studies have shown high variability in glacier mass loss on the order of 0.14–0.45 m per annum water equivalent, depending on location, suggesting that glacier melt here is not faster than the global average, and that the recession is slower than previously thought.

Overall, lack of high-altitude weather stations and long-term *in situ* MB observations limits our ability to predict the long-term impacts of climate change on glaciers, but recent advances in remote sensing have provided information that was hitherto not available. There is a need to set up more high-altitude weather stations and to triangulate results from field-based MB studies with those of remote-sensing studies in order to arrive at a comprehensive understanding of both the current and the future status of Himalayan glaciers and the impact of climate change on them.

Climate change and Himalayan rivers

As the 10 major river basins of the Himalayan region support the lives and livelihoods of nearly 1.3 billion people, it is of utmost importance to understand the impact of climate change on water availability, particularly in downstream areas. The impact of climate change on the hydrological regime of the Himalayan rivers has been widely discussed (Immerzeel, van Beek, & Bierkens, 2010), especially following the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Parry et al., 2007).

Much of the existing empirical evidence suggests that the HKH region is undergoing consistent warming (Shrestha & Aryal 2011). For example, the upper Indus Basin shows an increasing temperature trend over the past 50–100 years, although trends are not homogeneous (Bhutiyani, Kale, & Pawar, 2007; Fowler & Archer, 2006). In the Ganges Basin, there is a consistent increase in temperature with altitude (You et al., 2010). The upper Brahmaputra Basin also shows an increasing temperature trend over the last 50 years (Immerzeel, 2008). Most of the climate projections based on general circulation models and regional climate models suggest that the future will be consistently warmer.

With respect to precipitation, there are no consistent or statistically significant future projections for the region, although localized and seasonal trends have been observed (Shrestha, Wake, Dibb, & Mayewski, 2000). Precipitation is projected to increase by the end of century in the Indus (Immerzeel et al., 2010), Ganges (Kumar et al., 2011) and Brahmaputra (Immerzeel, 2008) Basins, although the magnitude of the change varies from basin to basin. In high-altitude areas, precipitation occurs as snow, which is then stored as glaciers, gradually generating melt runoff throughout the year. Melt runoff in the Himalayan river basins is highly significant. For example, glacier melt runoff provides about 40% of total streamflow in the Upper Indus and 10% in the Ganges (Immerzeel et al., 2010). However, the seasonal contribution of melt runoff is even more important than the annual contribution (Nepal, Flügel, & Shrestha, 2014; Singh & Bengtsson, 2004). In this issue, Nepal and Shrestha present a detailed literature review on the impact of climate change on hydrological regimes in the Indus, Ganges and Brahmaputra Basins, finding that overall annual volumes of flow in these rivers are not likely to change dramatically because a predicted increase in annual precipitation is likely to offset long-term decreases in contribution to flow from snow and glaciers.

According to Barnett, Adam, and Lettenmaier (2005), the warming climate will impact the global hydrological cycle. In the case of high-altitude areas dominated by glaciers, rising temperatures will cause snow lines to shift upwards and increase melt runoff per unit area. At the same time, the higher temperature will reduce the snow storage capacity of the basin as more precipitation occurs as rain rather than snow (Nepal et al., 2014). Similarly, the glacier area is likely to shrink or disappear in the lower-elevation areas due to high temperature (Lutz, Immerzeel, Shrestha, & Bierkens, 2014), affecting melt runoff. Lutz et al. (2014) projected an increase in runoff at least until 2050 caused primarily by increasing precipitation in the Ganges and Brahmaputra Basins and accelerated melt from the Indus Basin. However, changes in seasonal flow and peak distribution may be more crucial than annual changes (Singh & Bengtsson, 2004). Although total annual water availability may increase, greater hydrological extremes and shifts in seasonal peaks will counteract the benefits. For example, if most of the increased precipitation occurs during the monsoon season, it may contribute to increased floods, while lower summer river flows will have implications for the irrigation and hydropower sectors.

The impact of climate change on future hydrological regimes is subject to a wide range of uncertainty, and these results should be considered indicative rather than authoritative. This poses the question of communication of uncertainty to policy makers. Nepal and Shrestha (this issue) argue that the uncertainty of climate science and related projections must be communicated to decision makers in a language that is easily understood. It must also be borne in mind that the objective of climate projections and related impacts on water resources is to indicate the direction of these changes rather than to specify the absolute quantum of change.

Water-induced disasters in the Hindu Kush Himalayas

Two articles in this issue (Khanal et al. and Shrestha et al.) deal with water-induced disasters in the Himalayas. GLOFs are also related to climate change in that rapidly melting glaciers leave behind glacial lakes, which are then at risk of bursting due to destabilization of moraine dams. Historic records confirm incidences of GLOF events causing catastrophic flash floods from the mountains in the HKH region. The article by Khanal et al. deals with GLOF events in Nepal. Fourteen GLOF events have been identified as originating in the Nepal Himalayas in the recent past; another 10 took place in the Tibet Autonomous Region of China and impacted Nepal (ICIMOD, 2011). However, not all glacial lakes are equally likely to give rise to GLOF events, and indeed it is possible to reduce the risk of GLOF through proper mitigation measures. This requires comprehensive assessment of GLOF hazard, risk and vulnerability. The article by Khanal et al. presents a step-by-step approach for GLOF risk assessment and management in Nepal and identifies concrete mitigation strategies for reducing negative impacts of GLOF events for downstream populations.

While flash floods like those generated by GLOFs cause untold damage, it is often localized. In contrast, riverine floods, which are quite common phenomena in Himalayan rivers during the monsoon season, impact larger geographical areas and are often transboundary. In the rivers of the HKH region, in the winter, peak flow can swell to 10 or 20 times the normal flow (Molden et al., 2014), resulting in frequent flooding across national boundaries. Damage to life and property is likely to increase in the coming years, both because climate-related extreme events like floods are likely to be more frequent (Field et al., 2012) and because increases in population will result in more people settling in areas vulnerable to flooding.

About 40% of the world's poor live in the Ganges-Brahmaputra Basins (Shah, 2001), and poverty makes them disproportionately vulnerable to natural disasters like floods. Studies have shown that the incidence of heavy monsoon rains over India has doubled in the last 50 years, while the incidence of moderate and weak monsoons has decreased (Goswami, Venugopal, Sengupta, Madhusoodanan, & Xavier, 2006; Krishnamurthy, 2012), so heavy flooding is likely to be even more common in the future. At the same time, it is widely recognized that flood events in the HKH region cannot be entirely controlled by infrastructure, simply because of the huge volumes of water involved. Instead, there should be concentrated efforts to reduce flood vulnerability and mitigate flood impacts through improved flood risk management. And one such important approach to flood management is the provision of end-to-end flood forecasting and warning services. Given that most of these riverine floods are transboundary, regional cooperation is absolutely essential for a successful end-to-end flood forecasting system. Shrestha et al. describe the challenges involved in designing such a regional flood information system (RFIS) and then give a concrete example.

The Hydrological Cycle Observing System (HYCOS) is an RFIS in the Ganga-Brahmaputra-Meghna and Indus Basins. ICIMOD, in partnership with the World

Meteorological Organization (WMO) and regional member countries Bangladesh, Bhutan, China, India, Nepal and Pakistan (Molden et al., 2014), initiated this project in the mid-2000s. Based on the WMO's World Hydrological Cycle Observing System (WHYCOS), the initiative has covered all important steps of the provision of hydrological information, namely monitoring, data transmission, data analysis, data quality checking, data processing, data delivery and the development of products for users. The flood information is provided to all participating agencies and is compatible with national flood information systems. The article by Shrestha et al. charts the historical evolution of this initiative and the challenges involved in designing an RFIS.

To sum up, while water-induced hazards like GLOFs and other types of flash and riverine floods are inevitable in the HKH given its topography and climate and cannot be prevented as such, they can be managed in a way that they do not become disasters. The focus should be on proper mitigation and on ways of reducing damage to lives and property. This will involve proper planning of mitigation strategies at local, national and transboundary levels.

Climate change, water storage, IWRM and perception of water scarcity at the local level

The final three articles in this issue deal with local-level water management. The article by Vaidya underlines the importance of localized small-scale water storage to offset water scarcity caused by seasonality of rainfall. Even though the HKH is the source of 10 mighty rivers, has the largest snow and ice cover outside of the two poles, and receives high rainfall during the monsoon season, the reality remains that many people in the HKH face acute water scarcity throughout the year. The reasons are many and depend on the circumstance, but they include villages situated at higher elevations than rivers, drying-up springs, demand outstripping supply in cities, and absence of prudent water management. Such water-related distress at the local level is likely to increase further due to climate change and increase in water demand due to socio-economic changes. While there have been concerted calls for large-scale multipurpose storage dams in the HKH to cater to both irrigation and power needs, these have often been shelved on grounds of environmental costs and questions of fair compensation to local people. In contrast, local-level water storage options are attractive for a number of reasons: they have negligible environmental costs but high benefits, can be constructed and maintained relatively cheaply, and have a long tradition in the region. Vaidya presents case studies of local water storage options from different parts of the HKH and notes that the main challenges around these structures are not physical in nature but related to institutions and governance. Hence, there is a need to craft nimble and adaptable local institutions that use Ostrom's (2000) design principles for successful management of common-property resources.

Pradhan et al. look at local water issues from the perspective of people's perceptions of climate change and their resultant adaptation strategies. Their research method tries to correlate historical climate and hydrological data with people's perceptions in the Indrawati Basin in Nepal. In doing so, they find some convergence – for example, long-term temperature data show an upward trend, and local people also agree that summers are hotter and winters warmer than before. But there is also divergence, in that while there is no discernible long-term trend in either rainfall or river flows, there is almost unanimous perception among local people that water availability has declined over the last 10 years. This, the authors argue, is related to changes in water demand rather than supply. For instance, there have been changes in cropping patterns in this area, from rainfed pulses and cereals to more commercial crops like vegetables, which need assured irrigation. Also, local communities rely on springs along the hillsides for their daily water use, and anecdotal evidence suggests that these springs have been increasingly drying up in many parts of the mid-hills of Nepal. This article offers a useful tool of comparing scientific climate data with people's perceptions and then goes on to describe some of the successful adaptation strategies for coping with rising temperatures and declining water access.

The common thread connecting all the articles in this issue is that each articulates the need for better planned and integrated approaches in solving water problems. These solutions include setting up more high-altitude hydromet stations, which requires interagency cooperation in their maintenance and upkeep (Shea et al.); creation of RFISs, which entails multi-country cooperation (Shrestha et al.); proper communication of climate change and hydrological information to decision makers (Nepal and Shrestha); and coordination and multi-level governance for successful management of water storage structures (Vaidya). These integrated and multi-sectoral approaches are embodied in IWRM principles. The last article of this issue, by Suhardiman et al., is on IWRM and its implementation challenges in Nepal. The article offers four important insights on the current status of IWRM in Nepal. The first is that the mere inclusion of IWRM principles in official water policy does not ensure its acceptance among the various stakeholders, especially if it challenges existing power relations among various ministries who would need to cooperate in order to successfully implement IWRM principles. Second, and related to the first, is that stakeholders are likely to interpret the principles of IWRM in the way that works best to preserve their own sectoral mandates. Third, while IWRM works well in a local context (for example with the Village Development Committee as a unit), as exemplified by local water use master plans of NGOs like Helvetas, upscaling them to the next level (say the watershed or even district level) is challenging and has not yet succeeded in the context of Nepal. The article concludes by noting that IWRM implementation may not succeed unless there are deeper bureaucratic reforms in concerned ministries that change the 'rules of the game' and incentivize these agencies to cooperate rather than compete with each other. So, while the search for integrated and holistic solutions is universal, their real-life implementation remains as challenging as ever.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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