Thank you for agreeing to be an expert reviewer of the Hindu Kush Himalayan Monitoring and Assessment Programme (HIMAP) Comprehensive Assessment of the Hindu Kush Himalaya report chapters. The external review period is now open for the second order drafts of the chapters. This external review phase will run from 16 June to 28 July 2017, with 28 July 2017 being the cut-off date for submitting reviews. The function of expert reviewers is to comment on the accuracy and completeness of the content and the overall scientific, technical and socio-economic balance of the chapter drafts. Every reviewer will be acknowledged in the chapter they reviewed.

Comments will only be considered if they are submitted before the end of the external review phase, using the official Excel review template for the chapter that you are reviewing. Please use a separate Excel review file for each chapter you are reviewing. Your completed review needs to be uploaded to the Open Review Forum page on the HIMAP website (www.hi-map.org) before 28 July 2017. Also see this website to download the chapters and review forms and for more information.

We would like to remind you that by undertaking this review you commit to respect the terms of this external review phase – specifically not to quote, cite, copy or disseminate (including in blogs or to the media) the draft HIMAP chapters; to only provide comments using the provided templates; to comment only in English and to comment only on substance (not grammar and spelling).

The International Centre for Integrated Mountain Development (ICIMOD) is coordinating the HIMAP Comprehensive Assessment of the Hindu Kush Himalaya (see www.hi-map.org), with the engagement of over 300 researchers, practitioners, experts, and decision makers from the region and around the world. The publication of the assessment report is planned towards the end of 2017. A comprehensive assessment that goes beyond climate change, the Assessment Report, consisting of 15 chapters, contains a wide-ranging, innovative evaluation of the current state of knowledge of the region and of various drivers of change and their impacts, and a set of policy messages.

Review is an essential part of the HIMAP process to ensure the accuracy and completeness of the scientific, technical and socio-economic content and the overall balance of the HIMAP chapters. The review process of the HIMAP Assessment Chapters consists of external peer review by experts and government representatives, and open peer review, of the 2nd order drafts of the chapters. All written review comments will be provided to the chapter teams anonymously and the Review Editor of each chapter will ensure that all comments are taken into account by the author teams and adequately addressed. A record of all review comments and how they were addressed will be published online on completion of the HIMAP assessment.

Three major principles underpin the HIMAP review process. Firstly, the best possible scientific and technical advice should be included so that HIMAP Assessment Report represent the latest scientific, technical and socio-economic findings and is as comprehensive as possible. Secondly, a wide circulation process assuring representation of independent experts not involved in the preparation of the assessment report will aim to involve as many expert reviewers as possible in the HIMAP process. Thirdly, the review process will be neutral, open and transparent. Thank you for your review.
CHAPTER 8: WATER SECURITY: AVAILABILITY, USE AND GOVERNANCE

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CHAPTER OVERVIEW

KEY FINDINGS

1. The Hindu Kush Himalaya (HKH) are the source of ten major rivers that provide water security — while also supporting food and energy security and ecosystem services — for 1.3 billion people across Asia.

2. Water security is threatened by climate change and other human drivers. Equitable, productive, and sustainable water uses are limited by flood and drought cycles; by pollution from urban and industrial development; by poorly planned infrastructure; and by often-ineffective governance.

3. Good water-resource governance entails balancing evidence-based policy with political imperatives at the local, national, and HKH regional scales.

POLICY MESSAGES

1. Regional and local adaptive responses for water security will depend on increased HKH-wide cooperation, conflict management, open data sharing, and investment of funds for generating new knowledge, public awareness, and action.

2. Tradeoffs must be carefully managed — across geographical scales and among multiple sectors — in order to enhance water security, meet the Sustainable Development Goals (SDGs), and achieve Intended Nationally Determined Contributions (INDCs) for emissions mitigation as charted out in the 2015 Paris climate accord.

3. Sustaining the HKH as a global asset means increasingly engaging the people and decision makers of the region to ensure residents of HKH continue to derive commensurate benefits, while acting to enhance water security at local, national, and regional scales.

Dubbed the “water tower for Asia,” the Hindu Kush Himalaya (HKH) plays a crucial role in ensuring water, food, and energy security for much of the continent. The Hindu Kush Himalaya (HKH) is the source of ten major rivers that provide water security — while also supporting food and energy security and ecosystem services — for 1.3 billion people across Asia. This chapter takes stock of current scientific knowledge on the availability of water resources in the HKH; the varied components of its water supply; the impact of climate change on future water availability; the components of water demand; and the policy, institutions, and governance challenges for water security in the region.

Annual precipitation is the main source of water for the eastern Himalaya. Much of this precipitation comes as rain from the East Asian and Indian monsoon systems between June and September. In winter, the western Himalaya receive at least half of its precipitation from western disturbances (established but incomplete).

Our knowledge of the amount and distribution of precipitation at higher altitudes (above 5,000 meters) in the HKH is poor. Meteorological stations at these altitudes are few and far between. The lack of
reliable data has led to significant anomalies in observed rain and snow data and in observed glacier mass balances. More stations at higher altitudes are urgently needed (well established).

While glacier and snow melt are important components of overall streamflow in the region, their significance varies widely — ranging from very high in western rivers, such as the Indus, to low in eastern rivers, such as the Ganges and the Brahmaputra. In the eastern rivers, rainfall runoff contributes the largest share of streamflow. Still, this share varies substantially within each river basin:

The relative contribution of glacier and snow melt, as opposed to rainfall runoff, increases with altitude and proximity to glacier and snow reserves (well established).

Groundwater, from springs in the mid-hills of the HKH, is an important contributor to river baseflow. Yet the role and contribution of springs to overall water budgets in the region is poorly understood (well established). We urgently need better scientific knowledge of groundwater in the HKH — especially because millions of mountain people depend directly on springs. More is known about groundwater endowments in the plains: Groundwater is overexploited in the western plains, while it remains largely untapped in the eastern plains (well established).

Climate change is expected to drive consistent increases in the total runoff of the Indus, Ganges, and Brahmaputra. In the Indus, this increase will come from increased glacial melt, while in the Ganges and the Brahmaputra, it is expected to come mainly from precipitation (established but incomplete). Beyond the mid-century, the Indus Basin may experience decreases in total runoff resulting from decreasing glacial melt (inconclusive). Changes in future flow volumes will also have a seasonal dimension, with increased peak runoff and decreased low flow in some sub-basins (established but incomplete). Pre-monsoon flows are expected to decline, with implications for irrigation, hydropower, and ecosystem services.

Disaggregated water-use data are not available for the region defined as the HKH. However, across the entire territory of all eight countries with land in the HKH, about one-fifth of available renewable water resources are being used for human purposes. Countries vary widely in their water-resource endowments and withdrawals (established, but incomplete due to the unavailability of HKH-specific data).

Agriculture accounts for the largest share of water use — marking over 90% of use in Afghanistan and 65% in more industrialised China (well established). India, Bangladesh, Pakistan, and China together account for more than 50% of world’s groundwater withdrawals (well established). These withdrawals are used mostly for irrigation and in other sectors like urban water provision (well established).

The HKH includes three types of agricultural area, each with distinct implications in terms of water use: high mountains, mid-hills, and plains. Agriculture in the high mountains and the mid-hills tends to be largely rainfed, while agriculture in the plains is mostly irrigated (well established). The nature and dynamics of the region’s agriculture are shifting in response to climate and in socio-economic changes. The two most important trends in agricultural change are: first, an increasing reliance on technology in growing high-value crops; and, second, the feminisation of agriculture in response to male outmigration. This feminisation is more prevalent in the hills and mountains than in the adjoining plains (established, but incomplete).

Another use of water — hydropower — is mostly non-consumptive. Yet hydropower demands changes in the timing and location of river flow, which can harm other water users, such as irrigation and
capture fisheries (established, but incomplete). Such conflicts especially arise in the mid-hills and the
mountains — which mark the location of most current and foreseeable hydropower sites. Very often,
mountain people do not derive commensurate benefits from these projects. Appropriate benefit-
sharing norms are needed to ensure that mountain people also benefit from the region’s vast
hydropower potential (established, but incomplete).

Burgeoning cities and small towns in the HKH confront severe water stress from urbanisation, which
is often unplanned (well established). This water stress often leads to concerns over water quality, but
it can also prompt innovative solutions, such as the reuse of partially treated wastewater for agriculture
(established, but incomplete).

In response to the Millennium Development Goals, the HKH has made remarkable strides in achieving
access to safe drinking-water. The region is also committed to meeting the Sustainable Development
Goals (SDGs). Still, much work remains to be done to provide basic sanitation (well established). Rather
than managing water for health and sanitation in isolation from water for irrigation, hydropower,
municipal supply, and ecosystems, it would be more effective to integrate water management for
multiple uses.

Despite the important role of HKH rivers in providing ecosystem services and maintaining
environmental flows, these services and amenities are not well appreciated. Present law and policy
frameworks are not adequate to ensure that infrastructure development does not impinge on
ecosystem services (established, but incomplete).

Water governance in the HKH is characterised by the following:

- hybrid formal-informal regimes with a prevalence of informal institutions at the local level
  and formal state institutions at national and regional levels
- political marginality of the HKH subregions within larger nation-states
- lack of synergy and support between state and informal water-management institutions
- gender inequity in both informal and formal institutions
- urban water-supply challenges posed by formal institutional regimes often forced upon pre-
  existing informal institutions with deleterious consequences for water quality and quantity;
  and
- inadequate or non-existent transboundary institutions for water resources, heightening the
  risk of conflict while also offering opportunities for HKH-wide cooperation (well established).

To ensure water security in the HKH, adequate water availability alone is not enough — what is needed
is good water governance. Such governance must be politically and culturally tailored to the local,
national, and regional contexts. Challenges and opportunities vary at different levels: micro
(watershed and springshed); meso (river basin); and macro (regional) (established, but incomplete).

Among the leading causes of poor water governance in the HKH are unequal power dynamics,
centralised decision making, and a lack of opportunities for local communities to influence their water-
security decisions (well established). Throughout the HKH, more attention needs to be paid to the
following:

- participatory and cooperative decision making (formal, informal, and hybrid);
evidence-based policies;

- transparent program implementation;

- accountability at all levels; and

- transboundary and regional cooperation.

WATER SECURITY AND THE SUSTAINABLE DEVELOPMENT GOALS (SDGs)

Of the Sustainable Development Goals (SDGs) adopted by the global community in 2015, one — SDG 6 — is entirely focused on water. Overall, concern for water in the SDGs is more comprehensive than in the earlier Millennium Development Goals, which addressed water only in terms of sanitation and health. Although drinking-water and sanitation rightly remain central to SDG 6, other considerations have now gained importance as well: water quality; wastewater management and reuse; transboundary cooperation; ecosystem services; capacity building; and cooperation.
8.1 INTRODUCTION

Water security has emerged as a subset of human security — one that raised increasing concern throughout the first decade of the 21st century. For the purposes of the HIMAP assessment, we use a definition of water security modified from UN-Water (2013) as follows: “Water security is the capacity of HKH populations to safeguard sustainable access to adequate quantities of acceptable-quality water for sustaining livelihoods, human well-being, gender equity, socio-economic development, and cultural values, ensuring protection against water-borne pollution and water-related disasters while preserving mountain ecosystems in a regional climate of peace and political stability.”

This chapter focuses on current and future water-quantity endowments and their spatial distribution (Section 8.1), use (8.2), and governance (8.3). Although water quality is recognized as crucial to human health and ecosystem processes, due to the diversity of parameters (microbial and chemical; soluble and suspended; geogenic and anthropogenic) and to the relative lack of observed data or modeled dynamics, water quality is largely beyond the scope of the present analysis. Nonetheless, sediment in large river systems and wastewater-management challenges in HKH urban systems are discussed. Figure 8.0.1 shows the major river basins originating in the region. Throughout the chapter, we refer to nested geographical scales as: micro (local, springshed, community); meso (river basin, subnational to national); macro (HKH-regional, transboundary); and global (beyond HKH, global).

Figure 8.0.1: Major river basins originating in the Hindu Kush Himalaya

Source: Shrestha et al. (2015a)
8.2 WATER AVAILABILITY IN THE HINDU KUSH HIMALAYA

This section attempts to assess the principal sources of water in the HKH, including precipitation, glacial melt, snowmelt, runoff, river discharge, springs, and groundwater. As already noted, water quantity—not quality—is the principal focus. Temporal dynamics are specifically referred to in the section on climate-change impacts.

8.2.1 Precipitation

In general, the climate in the eastern part of the Himalaya is characterized by the East Asian and Indian monsoon systems, causing the bulk of precipitation to occur from June to September. The precipitation intensity shows a strong north-south gradient caused by orographic effects (Galewsky 2009). Precipitation patterns in the Pamir, Hindu Kush, and Karakoram ranges in the west are also characterized by westerly and southwesterly flows, causing precipitation to be more evenly distributed throughout the year, compared with the eastern parts (Bookhagen and Burbank 2010). In the Karakoram, as much as two-thirds of the annual high-altitude precipitation occurs during the winter months (Hewitt 2011). About half of this winter precipitation is brought about by western disturbances, which are eastward propagating cyclones bringing sudden winter precipitation to the northwestern parts of the Indian subcontinent (Barlow et al. 2005).

Meteorological stations are relatively sparse in the HKH, in large part due to the poor accessibility of the terrain. Precipitation is especially variable over short horizontal distances due to orographic effects; however, high-altitude precipitation-gauge networks are very rare. If there are rain gauges, they are mostly located in the river valleys where precipitation amounts are smaller than at higher altitudes. Further, most gauges have difficulty accurately capturing snowfall. Direct snow-accumulation measurements—using snow pillows, pits, and cores from accumulation zones—are also scarce and usually only account for short periods of time. Therefore, HKH precipitation predictions based on ground observations are not very accurate; in order to obtain more accurate predictions, observed data must be replaced by or supplemented with data gathered through other approaches, including remote sensing and reanalysis techniques to aid in generating gridded climate datasets. Recent research for the upper Indus basin indicates that in order to correspond with observed glacier mass balances and river discharges, the actual amount of precipitation would have to be double the amount estimated from station data (Immerzeel et al. 2015; Dahri et al. 2016). In order to obtain more accurate predictions, observed data must be replaced by or supplemented with data gathered through other approaches, including remote sensing and reanalysis techniques to aid in generating gridded climate datasets.

8.2.2 Cryospheric contributions to river flow

At the river-basin scale, except for the Indus, glaciers play a relatively small role in surface runoff. Nevertheless, recent work shows that within each basin there is significant variability (Figure 8.1.1); the closer one gets to the glaciers and snow reserves within a basin, the greater the relative importance of glacier and snowmelt runoff (Lutz et al. 2014). Several large-scale benchmark studies have focused on quantifying the importance of glacier and snow melt in the overall hydrology of large Asian river basins. Permafrost contributions are addressed in Chapter 8. Glaciers have the potential to provide seasonally delayed meltwater to rivers. Meltwater can make the greatest contribution to river flow...
during warm and dry seasons, which is particularly important to the water budget in water-scarce lowlands that are densely populated.

A global study estimating seasonally delayed glacier runoff relative to precipitation input showed that the Indus basin had the greatest human dependence on glacier water within the HKH (Kaser et al. 2010). In another benchmark study, the Normalized Melt Index (NMI) was used to quantify the importance of both glacier and snow meltwater for five major river basins in Asia (the Indus, Ganges, Brahmaputra, Yangtze, and Yellow). The NMI is defined as the volumetric glacier and snow melt in a basin divided by its downstream natural discharge. This study revealed very large differences among the basins, ranging from 46% snow and 32% glacier contributions in the Indus to 6% snow and 3% glacier contributions in the Ganges (Immerzeel et al. 2010), which is largely monsoon dominated.

**Figure 8.1.1:** Contribution to total flow by (a) glacial melt, (b) snowmelt, and (c) rainfall-runoff for major streams during the reference period of 1998–2007. Line thickness indicates the average discharge during the reference period. Source: Lutz et al. (2014) [ASK NCC FOR PERMISSION]

Another study assessed the upper limit of glacier-melt contribution to streamflow (Schaner et al. 2012) through combined use of the energy balance to estimate the amount of energy available for melt and
the Global Land Ice Measurements from Space (GLIMS) database to estimate the potential melt contribution. The results once again highlighted the Indus and small basins close to glacier outlets as the most dependent on glacial melt. Yet another study used the Variable Infiltration Capacity (VIC) model to assess the Yellow, Yangtze, Mekong, Salween, Brahmaputra, and Indus rivers. Results showed these rivers — except for the Indus — as dominated by rainfall runoff. By contrast, the total glacier and snow melt contribution to the Indus streamflow was about 80% (Zhang et al. 2013).

In the headwaters close to the glacier and snow source areas, smaller-scale studies based on either stable isotope analysis (Racoviteanu et al. 2013; ) or modeling (Immerzeel et al. 2013; Nepal et al. 2014b; Ragettli et al. 2015; Shrestha et al. 2015b; Tahir et al. 2015), showed the significant dependence of river flow on both glacier and snow melt, even if the larger basin in which the headwaters are located has minimal dependence on meltwater.

8.2.3 Rivers

As indicated in Figure 8.0.1, the HKH functions as the water tower (Immerzeel et al. 2010) for much of the southern and eastern Asian continent, serving as the source for ten major river systems. Variations are very pronounced in river discharge, the contributions of different sources, and temporal trends (both seasonal and inter-annual).

A number of studies analysing observed records have attempted to attribute observed trends in discharge to observed meteorological trends:

- A study analysing streamflow trends from nineteen stations in the upper Indus basin indicated that in highly glaciated catchments the discharge is best correlated to temperature (Archer 2003). According to the analysis, summer streamflow in middle-altitude catchments is predominantly influenced by the preceding winter’s precipitation, whereas runoff in catchments further downstream is mainly determined by rainfall in winter and during the monsoon.

- Khattak et al. (2011) found that increasing trends in streamflow could be related to increases in mean and maximum temperature, particularly in the winter and spring seasons.

- Sharif et al. (2013) concluded that highly glaciated catchments in the upper Indus basin showed decreasing trends in streamflow, whereas in less glaciated catchments, streamflow had increased. The study showed flow decreasing in early summer but increasing in winter.

- Mukhopadhyay and Khan (2014b) showed that flows in the central Karakoram increased during the melting season from 1985 to 2010. They concluded that increased runoff was possible under neutral glacier mass balance conditions as a result of increased temperature and precipitation, which allowed the rate of mass cycling of the glacier to increase as the mass balance remained neutral.

A limited number of published studies have estimated the composition of streamflow in the Indus, Ganges, and Brahmaputra within different catchments or sub-basins (Table 8.1.1). Results are difficult to compare due to the varied concepts, approaches, and application scales employed.
Table 8.1.1: Results of studies estimating streamflow composition at selected locations

<table>
<thead>
<tr>
<th>Site (river/location)</th>
<th>Reference</th>
<th>Period</th>
<th>Contribution by component (%)</th>
<th>Period</th>
<th>Contribution by component (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ragettli et al. 2015</td>
<td>2012–2013</td>
<td>40</td>
<td>2012–2013</td>
<td>34</td>
</tr>
<tr>
<td>Langtang Khola, Kyangjing</td>
<td>Immerzeel et al. 2011</td>
<td>2001–2010</td>
<td>47.0</td>
<td>2001–2010</td>
<td>38.6</td>
</tr>
<tr>
<td></td>
<td>Ragettli et al. 2015</td>
<td>2012–2013</td>
<td>26</td>
<td>2012–2013</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Ragettli et al. 2015</td>
<td>2012–2013</td>
<td>26</td>
<td>2012–2013</td>
<td>34</td>
</tr>
</tbody>
</table>

- indicates not available

The findings of each study were largely dependent on data availability and application scale (for example, the size of the catchment or basin included in the simulation). Mukhopadhyay and Khan (2014a; 2015) estimated the contributions by hydrograph-separation methods at locations with available streamflow records. Racoviteanu et al. (2013) estimated streamflow composition with a simple ice-ablation model that was independently validated with stable water-isotope sampling. Their analysis showed that groundwater is an important streamflow component close to the glacier outlets. Singh and Jain (2002) employed a basin-scale water-balance analysis with glacier melt and snowmelt.
estimated from remotely sensed snow-cover imagery, and the 59% is a glacial and snowmelt total. The estimates by Immerzeel et al. (2011; 2013) were made using a distributed model, including a simple ice flow model, whereas the estimates by Soncini et al. (2015) were made using a semi-distributed cryospheric-hydrological model fed and validated with in situ measurements. Ragettli et al. (2015) used a high-resolution, process-oriented, distributed model. Nepal et al. (2014b) used a process-based glacio-hydrological model, including an enhanced degree-day factor for water-balance assessment in the Dudh Koshi catchment (eastern Ganges tributary). Prasch et al. (2013) used a distributed process-oriented glacio-hydrological model in the Lhasa basin.

River discharge is an essential component of the regional water balance, with important contributions from glacial melt, snowmelt, and springflow within the HKH. Additionally, river flow plays a dominant role in sediment transport and groundwater recharge in the plains. Spatial and temporal trends in river flows are addressed in section 8.1.7.

8.2.4 Sediment transport

There is a strong relationship between upstream erosion and downstream sediment deposition in the HKH, where erosion is strongly determined by young and fragile geology, land-management practices, and the monsoon system (Nepal et al. 2014a). Sediment load in rivers can be used as an important proxy for evaluating ecological and environmental conditions as well as the severity of regional erosion. Erosion and sediment transport and deposition affect both the structure and function of human society — and about one third of the global sediment deposited to the oceans is estimated to be generated from the Tibetan Plateau and its neighboring regions (Milliman and Meade 1983).

The Ganges-Brahmaputra River is one of the most sediment-laden rivers in the world, with annual sediment loads of 1,235 Million tons (Mt) to 1,670 Mt (Milliman and Meade 1983; Abbas and Subramanian 1984), approximately half of which is deposited within the lower basin while the other half is delivered to the ocean (Islam et al. 1999). The annual sediment load of the Ganges River accounts for ~60% of the total sediment load in the Ganges-Brahmaputra (Abbas and Subramanian 1984). By contrast, the gross sediment-load output from the upstream Yarlung Tsangpo River in Tibet is estimated to be just a small fraction (<10%) of the total load in the Ganges-Brahmaputra River (Wasson 2003; Blöthe and Korup 2015) due to a huge volume of coarse gravel and sand deposited in the upstream river valley (Wang et al. 2015). The sediment load of the Koshi River (the eastern-most tributary of the Ganges) is reported to be about 120 Mt per year. Because of the high sediment load and the low gradient in the Indo-Gangetic Plain, the river’s channel has shifted by about 115 km over the past 220 years (Gole and Chitale 1966; Dixit 2009).

Due to its high-alpine topography, intense meltwater supply, and the summer monsoon, the Indus River transports large volumes of sediment (Nag and Phartiyal 2015), particularly from its upper reaches in northern Pakistan (Meybeck 1976; Ali and Boer 2007). The Yangtze River is ranked globally as the fifth largest river in terms of runoff and the fourth largest in terms of sediment load (Yang et al. 2011). Studies have shown that the upper river basin is the main sediment source for the Yangtze River, while significant deposition occurs in the middle and lower reaches where the slope is gentler (Chen et al. 2001; Wang et al. 2007; Yang et al. 2007). The Yellow River was once the most sediment-laden river in the world, but its sediment concentrations have decreased since the 1950s by approximately 90% under the influence of regional climate change and human activity (Xu et al. 2004; Wang et al. 2015).
8.2.5 Springs

Mountain springs play an important hydrological role in streamflow generation for non-glaciated catchments and in maintaining winter and dry-season flows across numerous HKH basins. Springs are the primary water source for rural households in the HKH; for example, 80% of rural households in Sikkim rely on springwater (Tambe et al. 2009). Springs also contribute to the baseflow of many rivers in the region. In the Indian Himalaya, 64% of the irrigated area is fed by springs (Rana and Gupta 2009).

In recent decades, due to factors related to climate change (highly variable rainfall, for example) and anthropogenic impacts (such as deforestation, grazing, and exploitative land use resulting in soil erosion), springs in the region are degraded and failing (Vashisht and Bam 2013). Due to scarce observation data, the status of most springs in this region is still unknown. According to research, nearly 50% of perennial springs in the Indian Himalaya have dried up or become seasonal (Rana and Gupta 2009). Further, the spring discharges have significantly declined (Sharma 2005). A case study in the Gaula River Basin in the central HKH, showed that by the late 1980s, springflow had decreased by at least 25% (Valdiya and Bartarya 1989). In Sikkim, in the eastern HKH, the decrease in spring discharge was found to be over 35% during the 2000s (Tambe et al. 2012). In one of the mid-hills districts of Nepal, as many as 30% of the springs have dried up within the last decade, likely the result of a combination of biophysical, technical, and socio-economic factors (Sharma et al. 2016).

To address the water crisis caused by these dried-up springs, springshed-management strategies and conservation measures should be developed by merging both scientific and community knowledge. In doing so, it is important to better establish the relationship between precipitation, recharge, and spring discharge (Negi and Joshi 2004). The few studies published on this matter are based on small, scattered areas (Negi and Joshi 2004; Vashisht and Sharma 2007; Tambe et al. 2012; Tarafdar 2013; Sharma et al. 2016) and reported results show significant variations across the HKH. While spring-discharge variation appears to be consistent with rainfall in Sikkim in the east (Tambe et al. 2012) and Uttarakhand in the central-western Himalaya (Agarwal et al. 2012), it shows an inverse pattern with monthly rainfall in the western Himalayan springs of Kashmir (Negi et al. 2012). These trends suggest that, in addition to precipitation, other causal factors and localized impacts should be investigated.

Recent studies indicate the importance of developing an improved understanding of the aquifers through which groundwater recharges springs (Jeelani 2008; Mahamuni and Kulkarni 2012). A case study in the western Himalaya shows that spring discharge during the rainy season is very high for Karst springs and much lower for alluvium (fluvio-lacustrine) and Karewa (glacio-fluvio-lacustrine) springs (Jeelani 2008).

The anthropogenic impacts on spring discharge — including those from land use changes and soil erosion — have been discussed in some studies (Singh and Pande 1989; Valdiya and Bartarya 1989; Tiwari and Joshi 2014). With glacial retreat increasing in this region, the disappearance of small glaciers may be a factor in the drying-up of springs (Fort 2015). A workable and realistic management plan for spring watersheds needs both hydrogeological and hydrological characterization of catchments as well as a reliable modeling approach (Kresic and Stevanovic 2009). Thus, additional field investigations of declining springs — along with further research, detailed geohydrology, and modeling studies of well-observed spring catchments — are needed in the HKH.
8.2.6 Groundwater in lowland areas of HKH basins

Hydrogeological characteristics of aquifers remain unknown in most parts of the HKH. Across the region, a number of groundwater studies have been conducted by characterizing aquifer systems from northwestern India (Narula and Gosain 2013; Lapworth et al. 2015) to northeastern India (Michael and Voss 2009; Mahamuni and Kulkarni 2012). In Nepal, studies conducted in Kathmandu Valley provide insight into the geological formation of aquifers (Shrestha et al. 1999), their hydrogeological characteristics (KC 2003), and their spatial distribution (Pandey and Kazama 2011). These studies constitute a valuable knowledge base for guidance in groundwater management (Pandey et al. 2010).

In South Asia, groundwater constitutes the water source for over 75% of the irrigated area (Shah 2006). Further, through the use of wells, groundwater also provides drinking-water for 85% of rural families in India (Livingston 2009). Similarly, for the HKH lowlands, groundwater is an extremely important component of water resources. Due to overexploitation and water-quality decline, significant depletion of groundwater resources has been observed throughout the Ganges-Brahmaputra plains in India and the adjacent regions (Bookhagen 2012). A satellite-based study estimates that the groundwater of northwestern Indian states was depleted by 17.7 ± 4.5 km³/yr from 2002 to 2008 (Rodell et al. 2009). Sixty percent of Indian districts are believed to be encountering groundwater depletion, contamination, or both (Kulkarni et al. 2015). Notable depletion of groundwater discharge has also been observed in Nepal (Dixit and Upadhya 2005; Pandey et al. 2010).

Groundwater from subsurface recharge and glacier and snow melt can serve as temporary storage for river discharge in the HKH. Groundwater is particularly important in supplying water resources to the middle-mountain catchments, which lack glaciers or snow as transient storage (Dongol et al. 2005). A model-based water-budget study showed that the contribution of groundwater is about six times higher than that of glacier and snow melt in the central Nepal Himalaya (Andermann et al. 2012). This study also found a significant time lag between rainfall and discharge, indicating the importance of groundwater as temporary subsurface storage for the HKH lowlands. Currently, due to data scarcity, only a limited number of model-based studies (Andermann et al. 2012; Narula and Gosain 2015; Racoviteanu et al. 2013) in the HKH adequately account for groundwater processes.

8.2.7 Implications of climate change for HKH water resources

The climate-change implications for water-resource availability — spatial distribution, temporal dynamics, and water security in general — are extremely significant. Climate-change processes and future projections for the HKH are addressed in detail in Chapter 4 and projections of glacial change are addressed in Chapter 5.

Lutz et al. (2014) showed that, as a result of climate change, a consistent increase in runoff is expected at large scales for the upstream reaches of the Indus, Ganges, and Brahmaputra rivers until at least 2050. For the upper Indus, this is mainly due to increased glacial melt, whereas for the Ganges and Brahmaputra, the projected increase in runoff is driven primarily by increased precipitation. These runoff projections have a large uncertainty, especially for the upper Indus, because projections for precipitation show contradicting patterns.

These studies also show the various responses to climate change among rivers with different streamflow patterns. For example, the Indus River flow is dominated by temperature-driven glacial melt during summer; therefore, the uncertainty in future flow is relatively minor due to the small
uncertainty in future temperature changes. On the other hand, the Kabul River has much larger
components of rainfall-runoff and snowmelt, increasing uncertainty in future flow due to the large
uncertainty in future precipitation. The absolute amounts of glacial melt and snowmelt are not
projected to change much in the Brahmaputra and the rivers in the Ganges basin, but their relative
contributions are expected to decrease due to increased rainfall runoff. As a result, projections show
increased peak discharge in the monsoon season with large uncertainty in the magnitude of flow
increases.

On a smaller scale, projections through the end of the century for the Langtang and the Baltoro
catchments (Immerzeel et al. 2013) indicate a consistent increase in total runoff for both, despite their
contrasting climates (RCP4.5 and RCP8.5) These increases range from 172 mm/yr (Langtang, 31%) to
278 mm/yr (Baltoro, 46%) in 2021–2050 for RCP 4.5 to 493 mm/yr (Langtang, 88%) to 576 mm/yr
(Baltoro, 96%) in 2071–2100 for RCP 8.5.

In the eastern Dudh Koshi catchment in Nepal, Shea et al. (2015) suggest sustained mass loss from
glaciers in the Everest region through the 21st century based on RCP 4.5 and RCP 8.5 climate
projections. Similarly, Bajracharya et al. (2014) reported a loss of glacier area of 23% in Bhutan and
25% in Nepal between 1980 and 2010. How and when the loss of glaciers will impact downstream
availability of water is an important area for further research.

Using the SWAT hydrological model, Bharati et al. 2014 assessed the likely impact of climate change
on water-resource development in the Koshi River Basin in Nepal. The study projected increased flow
volumes during the monsoon and post-monsoon and decreased flow volumes during the winter and
pre-monsoon seasons, with greater impacts likely in certain seasons and sub-basins.

Soncini et al. (2015) found similar results for the Shigar watershed (which includes the Baltoro
watershed), projecting mostly increases in flow until the end of the century and speculating on the
potential for slight decreases thereafter, once ice volumes have diminished. In this catchment, changes
in precipitation will not compensate for ice loss in the long run. Across the three different RCPs
presented in this study, the differences in streamflow change are strikingly small. The authors showed
that increases in both temperature and winter precipitation cause streamflow increases to begin
earlier, when glacier and snow begin to melt. This is most dramatic for RCP 8.5, in which two of three
General Circulation Models (GCMs) show significant flow increases beginning in April instead of June.
Other RCPs also show a shift to the earlier onset of increased flow — and this shift gets stronger toward
the end of the century. However, one of the GCMs shows a very different pattern, with flows decreasing
in spring and increasing slightly in all other months.

With projections until 2050 for the Hunza basin, Ragettli et al. (2013) showed that simulated decadal
mean runoff is relatively constant, but strongly contrasting changes occur in some of the sub-basins.
Some showed flow volume decreasing by as much as 50% due to decreases in glacial melt, while others
showed flow volume increasing due to increases in snowmelt, precipitation, and temperature. In the
basin areas with projections of decreased flow, the most pronounced reductions occur from June to
September. The annual peak runoff is projected to occur in June/July, earlier in the year than the
July/August peak of the control period.

In the Lhasa basin, Prasch et al. (2013) made hydrological projections to 2080, forcing a glacio-
hydrological model with the IPCC Special Report on Emissions Scenarios (SRES) scenarios. The authors
found that the contribution of glacial melt to total runoff will remain almost stable until 2080, although
there will be a slight increase during a short period in spring. By contrast, the contribution of snowmelt to runoff will generally decrease in the Lhasa basin, resulting in changes to water availability. Additionally, the increased evapotranspiration accompanying rising air temperatures will also reduce water availability.

Based on their review of climate-change impacts on the Indus, Ganges, and Brahmaputra River Basins, Nepal and Shrestha (2015) noted an increase in glacier and snow melt from ~2000s up to approximately mid-century, followed by a decrease. Although, increases in meltwater are likely for the next few decades, meltwater volume is likely to decrease abruptly once glacial storage is reduced. However, further studies are required to understand intra-annual changes and the impact of extreme events. Changes in extreme hydrological events in the Indus, Ganges, and Brahmaputra basins are insufficiently studied. As an increase in precipitation is generally projected, it is highly likely that precipitation extremes — and associated extreme discharges — may increase as well. Soncini et al. (2015) used downscaled GCM data to force a semi-distributed model to conduct a basic analysis of changes in extreme discharges in the Shigar catchment. Most models indicated increased discharge for the flow-return periods analysed, indicating the potential for heavier floods during the flood season from June to October.

**BOX 8.1.1 Implications of landscape-level vegetation change for evaporation**

In recent decades, vegetation changes across the Tibetan Plateau (TP) have shown significant spatial variation. Decreasing trends in Normalized Difference Vegetation Index (NDVI) during the summer growing season have been noted in the southwest, whereas obvious greening was observed in the northeast based on existing global NDVI datasets (Fig. 8.1.2). Due to warming trends and the grazing-to-grassland project implemented by the Chinese government, regional greening is confirmed by observed NDVI. Despite the warming effects of reduced albedo resulting from increased NDVI, the cooling effects of enhanced evapotranspiration (ET) dominate in the TP where ET is believed to be relatively high even at low temperatures (Shen et al. 2015). Greening with increasing NDVI as the proxy is believed to have cooling effects on surface temperatures due to enhanced ET. This is supported by the significant negative correlation between NDVI and daily max temperatures at 55 meteorological stations across the TP. An increase of NDVI by 0.1 is estimated by means of the Weather Research and Forecasting (WRF) model to result in an ET increase of ~0.5mm·d⁻¹ and a decrease in albedo of 0.01. Thus, regional vegetation greening is not only beneficial to ecosystem processes, but also to slowing warming rates.

**Source:** Shen et al. (2015).
8.3 WATER USE IN THE HINDU KUSH HIMALAYA

There are wide variations in water endowments in HKH countries in terms of per capita availability, contribution from surface and groundwater sources, and whether or not the water originated within the geographical boundaries of the country or, for that matter, within the HKH. For instance, upstream countries like Bhutan and China generate all their water within their own geographical boundaries, while the downstream country of Bangladesh gets over 90% of its water from beyond its geographical boundaries. The very nature of upstream-downstream linkages and water distribution across the countries makes it imperative that upper and lower riparian communities cooperate in sharing water equitably.

As seen in Table 8.2.1, total renewable water availability in the eight countries that constitute the HKH is 7745.5 km³ (AQUASTAT, FAO, 2016a). Of the total water resources, 1597.8 km³ (20.62%) is used annually for various purposes. Some of this usage is consumptive in nature (for agriculture, drinking, and domestic use), as opposed to the largely non-consumptive use in sectors like hydropower.

Table 8.2.2 shows the sectoral water use in various countries in the region, but for reporting reasons, these do not precisely correspond to the HKH. As with water-resource endowments, there are also wide variations in terms of total volume and per capita water withdrawal, contribution of surface and groundwater to total water withdrawals, and percentage of water withdrawals from the total renewable freshwater available. For instance, per capita water withdrawals vary from 1,096 m³/year in Pakistan to a low of 247 m³/year in Bangladesh. At the same time, Pakistan withdraws 74% of its renewable
freshwater resources, while Bhutan withdraws less than 0.5% annually. Groundwater accounts for 79.4% of water withdrawal in Bangladesh and for about 33% of water withdrawal in India and Pakistan.

### Table 8.2.1: Water-resource availability in HKH countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Long-term average annual precipitation in volume (km³/year)</th>
<th>Total internal renewable water resources (IRWR) (km³/yea r)</th>
<th>Total renewable surface water (k m³/year)</th>
<th>Total renewable ground water (k m³/year)</th>
<th>Dependancy ratio (%)</th>
<th>Total renewable water resources per capita (m³/inhab/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>327</td>
<td>213.3</td>
<td>47.15</td>
<td>65.370</td>
<td>55.68</td>
<td>10.65</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>2,320</td>
<td>334</td>
<td>105</td>
<td>1,226.6</td>
<td>1,206</td>
<td>21.12</td>
</tr>
<tr>
<td>Bhutan</td>
<td>2,200</td>
<td>84.5</td>
<td>78</td>
<td>78</td>
<td>78</td>
<td>8.1</td>
</tr>
<tr>
<td>China</td>
<td>645</td>
<td>6,189</td>
<td>2,812.4</td>
<td>2,839.7</td>
<td>2,739.0</td>
<td>828.8</td>
</tr>
<tr>
<td>India</td>
<td>1,170</td>
<td>3,846</td>
<td>1,446</td>
<td>1,911</td>
<td>1,869</td>
<td>432</td>
</tr>
<tr>
<td>Myanmar</td>
<td>2,341</td>
<td>1,415</td>
<td>1,002.8</td>
<td>1,167.8</td>
<td>1,157</td>
<td>453.7</td>
</tr>
<tr>
<td>Nepal</td>
<td>1,500</td>
<td>220.77</td>
<td>198.2</td>
<td>210.2</td>
<td>210.2</td>
<td>20.0</td>
</tr>
<tr>
<td>Pakistan</td>
<td>494</td>
<td>393.5</td>
<td>55.0</td>
<td>246.8</td>
<td>239.2</td>
<td>55</td>
</tr>
</tbody>
</table>

Source: FAO (2016a)

In spite of their varied water withdrawal, what remains constant across all of these countries is the largest the proportion of withdrawals is used for agriculture. Agriculture accounts for close to 90% of water withdrawal in all HKH countries with the exception of China, where 65% of withdrawals are applied to agriculture. However, 25% of China’s water withdrawals are used for industrial purposes, while industry accounts for less than 10% of water withdrawal in other countries, reflecting China as the most industrialized country in the HKH.
Table 8.2.2: Sector-wise water withdrawals in HKH countries

<table>
<thead>
<tr>
<th>Country; Year of data referenced</th>
<th>Total water withdrawal (km³/year)</th>
<th>Agricultural water withdrawal (km³/year)</th>
<th>Municipal water withdrawal (km³/year)</th>
<th>Industral water withdrawal (km³/year)</th>
<th>Surface water withdrawal (km³/year)</th>
<th>Groundwater withdrawal (km³/year)</th>
<th>Per capita water withdrawal per inhabitant (m³/year)</th>
<th>Freshwater withdrawal as % of total renewable water resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan; (1998)</td>
<td>20.37</td>
<td>20.00</td>
<td>0.20</td>
<td>0.17</td>
<td>17.24</td>
<td>3.042</td>
<td>937</td>
<td>31</td>
</tr>
<tr>
<td>Bangladesh; (2008)</td>
<td>55.87</td>
<td>31.5</td>
<td>3.6</td>
<td>0.77</td>
<td>7.39</td>
<td>28.48</td>
<td>247</td>
<td>2.93</td>
</tr>
<tr>
<td>Bhutan; (2008)</td>
<td>0.338</td>
<td>0.318</td>
<td>0.017</td>
<td>0.003</td>
<td>0.338</td>
<td>0</td>
<td>482</td>
<td>0.43</td>
</tr>
<tr>
<td>China; (2005)</td>
<td>554.1</td>
<td>358.02</td>
<td>67.53</td>
<td>128.55</td>
<td>452.7</td>
<td>101.4</td>
<td>414</td>
<td>19.5</td>
</tr>
<tr>
<td>India; (2010)</td>
<td>761</td>
<td>688</td>
<td>56</td>
<td>17</td>
<td>396.5</td>
<td>251</td>
<td>630</td>
<td>40</td>
</tr>
<tr>
<td>Myanmar; (2000)</td>
<td>33.23</td>
<td>29.575</td>
<td>3.323</td>
<td>0.332</td>
<td>30.240</td>
<td>2.991</td>
<td>739</td>
<td>2.8</td>
</tr>
<tr>
<td>Nepal; (2006)</td>
<td>9.497</td>
<td>9.32</td>
<td>0.147</td>
<td>0.0295</td>
<td>8.444&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.053&lt;sup&gt;a&lt;/sup&gt;</td>
<td>359</td>
<td>4.7</td>
</tr>
<tr>
<td>Pakistan; (2008)</td>
<td>183.42</td>
<td>172.371</td>
<td>9.650</td>
<td>1.4000</td>
<td>121.9</td>
<td>61.6</td>
<td>1,096</td>
<td>74</td>
</tr>
</tbody>
</table>

Source: FAO (2016b)
<sup>b</sup> derived by subtracting groundwater withdrawals from total water withdrawals

8.3.1 Agricultural water use in the mountains, hills, and plains of HKH river basins

As is the case elsewhere in the world, agriculture accounts for the highest proportion of water withdrawal in the HKH (Table 8.2.2). Agriculture in the HKH varies according to altitude. Mountains, mid-hills and plains (including foothills of the Himalaya) offer three distinct agricultural systems. In the high mountains, agriculture is dominated by livestock rearing and orchard cultivation, while in the mid-hills and the plains, cereal crops take precedence. In general, agriculture in the mountains and mid-hills tends to be rainfed, while that of the plains is mostly irrigated (Table 8.2.3).

8.3.1.1 Hill and mountain agricultural water use

Most HKH countries maintain the centuries-old tradition of farmer-managed hill and mountain agriculture. While mostly rainfed, these farms are also irrigated seasonally through local streams, springs, and glacier and snow melt. In the northern mountains of Pakistan (comprised of Gilgit,
Baltistan, Chitral, and Upper Dir), there are, broadly, two types of mountain irrigation systems — those sourced by snowmelt and those by streamflow or springwater (Ahmad 2001).

<table>
<thead>
<tr>
<th>Table 8.2.3: Rainfed and irrigated areas in the hills, mountains, and plains of the HKH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Afghanistan(^1)</td>
</tr>
<tr>
<td>Bangladesh(^3)</td>
</tr>
<tr>
<td>Bhutan(^2)</td>
</tr>
<tr>
<td>China(^\text{\textdagger})</td>
</tr>
<tr>
<td>India(^\text{\textdagger})</td>
</tr>
<tr>
<td>Myanmar(^4)</td>
</tr>
<tr>
<td>Nepal(^*)</td>
</tr>
<tr>
<td>Pakistan(^\text{\textdagger})</td>
</tr>
</tbody>
</table>
In Afghanistan, mountain area includes Badakshan, Central, Eastern, Southern, and Northern mountains; plains include Turkistan, Herat-Farah, and Helmand river valley.

In Bangladesh, districts of Bandarban, Khagrachari, and Rangamati are classified as hills; the rest of Bangladesh as plains. In table, gross cropped area has been subtracted from total irrigated area (sum total of irrigated area in different seasons) in order to derive rainfed or non-irrigated area.

Bhutan is considered as comprised of hills and mountains only.

In China, Gansu, Qinghai, Sichuan, Tibet, Yunnan, and Xinjiang provinces are considered parts of HKH.

In India, states of the Indo-Gangetic (Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal (excluding Darjeeling), and Assam (excluding Karbi Anglong and North Cachar hills) are classified as plains. The states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Meghalaya, Tripura, Manipur, Mizoram, Nagaland, Arunachal Pradesh, Darjeeling district of West Bengal, Karbi Anglong, and North Cachar hills of Assam are considered hills and mountains.

In Myanmar, Chin, Kachin, and Shan provinces are classified as hills; the rest of the provinces as plains. Data on cultivated area in Myanmar's hills and plains provinces are not available.

In Nepal, all Terai districts are classified as plains; the rest as hills and mountains.

In Pakistan, Kyber Pakhtunkhwa Province is classified as comprised of hills and mountains only; the other provinces (Punjab, Sindh, and Baluchistan) are classified as plains. NA= Not available

Snowmelt, streamflow, and/or springwater is diverted through channels along the mountain slopes to the valley bottom where fruit, vegetable, and other crops are grown. These irrigation systems are unique in that each water-source channel has its own command area and these irrigation infrastructure are maintained by active participation of water users with almost no government involvement.

While irrigation is reliable during the spring and summer seasons, it is less so in winter due to reduced snowmelt; cropping patterns are adjusted accordingly. From sowing to harvesting, women are actively involved in various aspects of the agricultural practices in these areas (Ishaq and Farooq 2016). Although water distribution may or may not be equitable, customary rules of distribution and maintenance are clearly laid out and followed by water users (Ostrom and Gardner 1993). In Afghanistan and highland Balochistan, karezes are traditional irrigation systems wherein shallow tunnels tap underground aquifers and convey water to fields downstream (See Box 8.2.1).

**BOX 8.2.1:** Glacier-fed irrigation systems in Hunza and Ladakh in Upper Indus and karezes in Afghanistan and Balochistan, Pakistan

In the Upper Hunza region of Pakistan and in the trans-Himalayan part of Ladakh in India, glacier and snow melt is the only source of irrigation. Glacio-fluvial dynamics affect these irrigation practices, and local communities adapt to these changes in different ways. In Hopar village in the Karakorum Range in Pakistan, it is not the quantity or timing of meltwater discharge that affects irrigation decisions but other factors such as water quality, reliable access, and control of turbulent flow. In Ladakh, the irrigated area is shrinking — not necessarily as a direct consequence of changing hydrology or glacial melt, but because of changing livelihood strategies involving more off-farm employment (Butz 1989; Nüsser et al. 2012).

In highland Balochistan and Afghanistan, karez irrigation has been the backbone of rural water management and agriculture for more than two millennia. A karez is an underground aqueduct that passively taps groundwater in the piedmont of the arid and semi-arid highlands. The system's key...
physical advantages are minimizing evaporative loss and delivering water from mountain aquifers to valley floor communities. Karezes require annual maintenance and karez communities have developed strong social capital to enable provision of labor and resources for their upkeep. However, karezes have increasingly come under threat across Balochistan because of uncontrolled pumping with high-power electric water pumps. In Afghanistan, more than three decades of war have taken a toll on the physical and social infrastructure of karezes. In the Mastung district in Balochistan, for example, prior to the 1980s there were 365 karezes; today there are no more than ten in operation.

The drying up of karezes has numerous damaging consequences, including the breakdown of the rural social capital anchored by the karez infrastructure. Despite a temporary increase in agricultural productivity due to availability of on-demand water, there is a long-term decline of agriculture and rural livelihoods due to groundwater depletion, as in the Quetta valley of Balochistan. This may enhance the power of the rural elites who own the electric pumps, which mine the groundwater and deprive hundreds of karez shareholders of their previously held water rights. In turn, increased rural pauperization and rural-to-urban migration results due to non-availability of water. Finally, long-term questions remain about the sustainability of human life in the arid highlands as groundwater depletes from one valley to the next due to over-pumping.

Nepal is also known for its centuries-old, farmer-managed irrigation systems. In Nepal, about 70% of irrigation systems are operated through farmer-managed irrigation systems (FMIS) (Pradhan 2000). Communities build water channels and weirs for diversion of water from spring-fed streams for growing paddy in monsoon season and, occasionally, one additional crop during the dry season. Intricate rules govern issues like water distribution, maintenance of infrastructure, and conflict resolution — and evidence shows that these systems have endured for centuries and adapted to changing circumstance (See Box 8.2.3). Similar spring- and stream-fed irrigation systems are also found in India’s western and central Himalaya (Baker 2005). In India, Mollinga (2009) reported that the irrigated land served by FMIS declined from 18.5% in 1961 to 6.8% in 1991. Other studies have reported that irrigation efficiency is higher in FMIS systems than in state-managed irrigation systems in the central Indian Himalaya (Kumar et al. 2006).

**BOX 8.2.2: Farmer-managed irrigation systems in Nepal**

Nepal has a long history of FMISs, in which farmers take sole responsibility for operating and maintaining their irrigation systems. In the absence of strong government intervention in the past, FMIS slowly developed through the collective efforts of farmers looking to irrigate their land. These FMIS provide irrigation services to about two-thirds of the country’s total irrigated area — a little more than 1.2 million hectare (Pradhan 2000). FMISs are characterized by the use of low-cost technology appropriate for heterogeneous local conditions, autonomous decision-making suited to local contexts, and collective action by farmers for the operation and maintenance of the irrigation systems (Yoder, 1986; Ostrom and Benjamin, 1993).

While many FMIS have survived decades of changes to hydro-climatic, social, institutional, and policy conditions, their performance is increasingly under stress (Janssen and Anderies 2013). Water availability for irrigation is affected by variability in the intensity and timing of precipitation. Impacts include more flooding and erosion damage to irrigation intake points and canals and,
during the dry season, less water available for irrigation and increased competition for it due to prolonged drought (Bastakoti and Shivakoti 2015). These challenges are further compounded by socioeconomic and institutional changes.

In FMIS, men have traditionally played a dominant role in the maintenance and operation of irrigation systems, but men are migrating out of the countryside and educated youth seem to have less interest in water management, leaving an increasing number of women to play a larger role in agriculture and water management, despite being unaccustomed to such tasks and often having limited experience. A recent study by Pokhrel (2014) considered why some FMIS have survived and others have declined and disappeared. The results showed the importance of adaptability in institutions concerned with the use and management of shared resources. This adaptability was characterized by a perceived fairness and bounded flexibility of the institutions — and the survival of an FMIS was dependent on this capacity to adapt to both climate change and to changes in gender relations.

In the northeastern Indian Himalaya and in the highlands of Bangladesh and Myanmar, farming systems are distinctly different from elsewhere in the HKH and shifting cultivation remains the preferred practice for the numerous ethnic groups in the region (See Box 8.2.3).

**BOX 8.2.3: Changing contours of shifting cultivation in north east India, Chittagong Hill Tracts, and Myanmar**

There are not many studies on water availability and use in Eastern Himalaya, a region known to be abundant in water resources, feeding four major river systems in the Hindu Kush Himalaya — the Brahmaputra, Ganges, Irrawaddy, and Salween. However, we do know that shifting cultivators in this region have for centuries used water resources on a sustainable basis, employing indigenous traditional knowledge and practices, such as the zabo farming system in Nagaland; the water management that sustains the rice and fish culture of Apatani tribes in Arunachal Pradesh; the bamboo drip-irrigation system of Meghalaya (Singh and Gupta 2002); or the Jhiri system in Chittagong Hill Tracts (CHT) of Bangladesh.

In terms of agriculture, many shifting cultivators in the Eastern Himalaya are converting to either settled agriculture or to growing more cash root crops on sloping lands. Cultivation on sloping lands without soil and water conservation measures has led to soil erosion and the degradation of ecosystem services. Rasul (2009) reported approximately 89–109 tons/ha/year of soil loss from the cultivation of annual crops (mainly ginger, colocasia, and turmeric) on sloping lands when conventional hoeing tillage methods were applied. With mulching, soil erosion was reduced to about 35 tons/ha/year. There are many good Sustainable Land and Water Management (SLWM) practices in the region — both traditional and new — but they have yet to be evaluated, documented, and shared.

While the exact contours of mountain and hill irrigation systems may differ in terms of water sources, distribution, and management, there are certain aspects of agricultural water management that are consistent across the entire HKH. For example, indigenous systems of water management have
developed effective methods for cooperating, sharing, and resolving disputes — and these local institutions have withstood change and adapted accordingly.

In the past two to three decades, there has been a contraction in hill and mountain agriculture due to a number of factors — both climate and non-climate induced. For instance, in the upper reaches of the Indus, canal infrastructure built for the intake of glacial melt has become dysfunctional due to glacial retreat in some regions and glacial surge in others. This necessitates the entire rebuilding of infrastructure, which is both costly and labor-intensive, beyond the reach of many communities and thus contributing to outmigration. Extreme weather events, such as flash floods, have created additional risks to irrigation infrastructure in these regions. Many FMIS in Nepal and India have also shrunk in size due to urbanization and male-specific outmigration.

However, irrigation systems are being adapted to changes in various ways. New technologies are being used (including groundwater or surface-water pumps and greenhouses for vegetable-growing); new niche and high-value crops are being introduced (including vegetables, coffee, and nuts). Due to male outmigration, women are increasingly managing these systems, but are yet to get de-jure land and water rights.

Increased outmigration also offers new opportunities. For example, in some instances, remittances are being used for improved agricultural water management — through investment in vegetable greenhouses, drips, and sprinklers. However, in other instances, entire farms are being abandoned and native vegetation is reclaiming terraces. Hill and mountain irrigation is in transition — and how this transition is handled will be crucial to future water management and to options for long-term livelihood.

8.3.1.2 Agricultural water use in the plains of HKH river basins

The extent and sources of irrigation vary; some areas like the Indo-Gangetic Plains in Pakistan, India, and Bangladesh are intensely irrigated, while those in the Nepal Terai are not. While most of these plains have canal infrastructure, groundwater has emerged as the main source of water for irrigation. The associated challenges of irrigation in the plains are of two types:

- over-extraction of groundwater and inefficient use of surface water in areas where water is already scarce (like the Indus and western Ganges)
- under-development of irrigation potential in areas of abundance like the eastern Ganges (Nepal Terai and parts of eastern India)

India is the largest user of agricultural groundwater in the world. It is estimated that there are over 20 million groundwater wells (GOI 2011), of which more than 95% are privately owned by smallholder farmers. These provide a range of livelihoods and productivity benefits to millions of smallholder farmers in India. However, within the overall groundwater story of the Gangetic plains in India, there are two distinct subplots.

The first, and rather well known, is the story of groundwater overexploitation and its consequences. This is broadly the situation in states like Punjab, Haryana, and western Uttar Pradesh. These states have a number of things in common. They receive low to medium rainfall averaging from 200 mm to 1000 mm per year. Even though they have alluvial aquifers, recharge is limited by the total amount of
effective rainfall and is, therefore, inherently low. The majority (over 70–80%) of all water extraction mechanisms (WEMs) are operated by electricity. Farmers get electricity either free of cost (Punjab) or at highly subsidized rates (Haryana; Uttar Pradesh). In all of these states, rural poverty is comparatively low and below the all-India average. Finally, groundwater and electricity are major political issues in all of these states and both remain at the center of vote bank politics. The discourse on overexploitation is fairly well known and documented (Janakarajan and Moench 2006; Moench 2007; Sarkar 2011).

But there is a second lesser-known subplot to this story — one in which groundwater development falls far short of potential recharge; where rainfall and natural recharge is very high; where most pumps run on expensive diesel or whenever farmers get electricity, for which they pay full cost (Shah 2007; Mukherji 2007). These scenarios take place where rural poverty rates are much higher than the national average and crop productivity is low — more or less all across the eastern Indo-Gangetic belt in India, namely, West Bengal, Bihar, Orissa, and Assam. Much of eastern Nepal Terai is also part of this story of underdeveloped groundwater resources.

In these areas, abundant groundwater resources coexist with high costs of groundwater extraction, restrictive access policies, low agricultural growth rates, and high rural poverty. Therefore, agricultural water management in the plains of the HKH requires different policies for regions where water resources are under stress and those where water resources are abundant. In the former, demand-management measures are required; in the later, larger investments are necessary to tap untapped water resources for future agricultural growth.

8.3.2 Water for energy

Energy production is not a consumptive use for water — unlike water used for agriculture, domestic needs, and in urban sectors. The HKH has a total of 500 gigawatts (GW) of hydropower potential, of which only a small fraction is actually developed. (Table 8.2.4)

<table>
<thead>
<tr>
<th>Country</th>
<th>Hydropower potential (Mega Watt, MW)</th>
<th>Actual hydropower developed (MW) (Year of data)</th>
<th>Actual generation in GWh (Year of data)</th>
<th>Year (Source of data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>25,000</td>
<td>1,000</td>
<td>NA</td>
<td>2006 (Government of Afghanistan, Ministry of Energy and Water, 2006)</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>1,897</td>
<td>230</td>
<td>NA</td>
<td>2014 (Bangladesh Power Development Board, 2014)</td>
</tr>
<tr>
<td>Bhutan</td>
<td>24,000</td>
<td>1,615</td>
<td>7,780</td>
<td>2015 (International Hydropower Association website, 2015)</td>
</tr>
<tr>
<td>Country</td>
<td>Capacity 2015</td>
<td>Capacity 2014</td>
<td>Capacity 2015 (IHA)</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------</td>
<td>---------------</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>570,000</td>
<td>519,370</td>
<td>1,126,000</td>
<td></td>
</tr>
<tr>
<td>India (all)</td>
<td>148,701</td>
<td>42,848.45 (2016, CEA)</td>
<td>131,000 (2014, IHA)</td>
<td></td>
</tr>
</tbody>
</table>

**Indian Himalayan States**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assam</td>
<td>680</td>
<td>429.72</td>
<td>1,010.46</td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>50,328</td>
<td>97.57</td>
<td>365.50</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>18,820</td>
<td>1,494.64</td>
<td>9,451.09</td>
</tr>
<tr>
<td>Jammu and Kashmir</td>
<td>14,146</td>
<td>2,274.35</td>
<td>4,798.65</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>2,394</td>
<td>356.58</td>
<td>256.90</td>
</tr>
<tr>
<td>Mizoram</td>
<td>2,196</td>
<td>34.31</td>
<td>NA</td>
</tr>
<tr>
<td>Manipur</td>
<td>1,784</td>
<td>80.98</td>
<td>30.23</td>
</tr>
<tr>
<td>Nagaland</td>
<td>1,574</td>
<td>53.32</td>
<td>10.44</td>
</tr>
<tr>
<td>Sikkim</td>
<td>NA</td>
<td>270.27</td>
<td>910.15</td>
</tr>
<tr>
<td>Uttarakhand</td>
<td>2,5000</td>
<td>3,756.35</td>
<td>NA</td>
</tr>
<tr>
<td>Tripura</td>
<td>NA</td>
<td>623.7</td>
<td>1,025.88</td>
</tr>
<tr>
<td>West Bengal</td>
<td>NA</td>
<td>1,328.30</td>
<td>1,198.94</td>
</tr>
<tr>
<td>Nepal</td>
<td>43,000</td>
<td>753</td>
<td>3,635</td>
</tr>
<tr>
<td>Myanmar</td>
<td>100,000</td>
<td>3,151 (2015)</td>
<td>5,520</td>
</tr>
<tr>
<td>Pakistan</td>
<td>50,000</td>
<td>6,902</td>
<td>31,084</td>
</tr>
</tbody>
</table>

**Sources:** As indicated in last column of table; Na = Not available

The hydropower sector in the HKH suffers from the twin challenges of climate change and societal pressure. For example, the sector faces major challenges due glacial melt induced by climate change. Glaciers across the region, except in the Karakoram, are retreating, leading to changes in future hydrological regimes. At the same time, risk of glacial lake outburst floods (GLOFs) and landslides are increasing, putting both existing and planned hydropower plants at risk. Nearly as important as climate risk are the societal risks of alienating local people in areas where hydropower projects are constructed.
These projects are mostly developed in mountain areas, and mountain people often understand that even as they bear the environmental and social costs of hydropower, the benefits will go to the people in the plains who get electricity. For managing this risk, hydropower companies need to provide direct and tangible benefits to the local communities.

After a hiatus of more than two decades, hydropower is back on the investment agenda of international financial institutions. New norms for environmental sustainability and benefit sharing with local communities are being developed with the hope that hydropower projects will be better built than in the past (See Box 8.2.4). For instance, Nepal has developed multiple mechanisms for sharing benefits with local communities, but these have yet to be institutionalized as norms (Shrestha et al. 2016). In India, on the other hand, mechanisms of benefit sharing are institutionalized through several policies, but lack of implementation means that local communities often protest against these projects. Overall, hydropower can be a win-win development for the region, provided that its negative externalities are managed. One particular area of concern is the irrigation-hydropower tradeoff. Not much is known about the extent to which farmer-managed irrigation systems are affected by hydropower projects, but there is some evidence that with proper planning and local participation, hydropower projects can offset some of the tradeoffs and provide additional irrigation benefits to local people.

**BOX 8.2.4: Water-related benefit sharing in hydropower projects: examples from Nepal**

Hydropower development leads to short-term and long-term changes in the hydrology of project-affected areas and often impinges on local formal and informal water rights. Hydropower projects are required to mitigate losses to local people or compensate for their losses related to the reduction of flow in project-affected areas that are either partially or completely dewatered.

In order to create benefits, hydropower developers invest in improving irrigation systems or fisheries and providing access to drinking-water. Several hydropower projects support local farmers in the construction of check dams and irrigation canals and, in some cases, also support the regular maintenance of these facilities. Among these cases, Ridi and Aadhi Khola hydropower projects have been exemplary in showing how small hydropower projects can meet the energy and food-security demands of project-affected communities. Further, the Kali Gandaki-A project recognized local fishing rights of the *Bote* indigenous fishing community, trained the community in new fishing technology, and provided access to government hatchery services. Many hydropower projects have provided drinking-water to project-affected citizens as a benefit. Water-supply lines provided by hydropower projects bring clean, reliable water closer to households, reducing the time needed to fetch it from distant sources — a change that has been especially beneficial to women.

### 8.3.3 Water for drinking and sanitation

The Millennium Development Goals (MDGs) set the target of reducing by half the proportion of people without access to safe drinking-water and basic sanitation. As seen in Table 8.2.5, most countries of the HKH have performed moderately well in terms of drinking-water access but have substantially lagged behind in achieving safe sanitation goals.
Table 8.2.5: Drinking-water and sanitation access in HKH countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Sanitation access (% of total population)</th>
<th>Drinking-water access (% of total population)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Urban</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>37</td>
<td>60</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>NA*</td>
<td>57</td>
</tr>
<tr>
<td>Bhutan</td>
<td>65</td>
<td>87</td>
</tr>
<tr>
<td>China</td>
<td>NA*</td>
<td>58</td>
</tr>
<tr>
<td>India</td>
<td>31</td>
<td>54</td>
</tr>
<tr>
<td>Myanmar</td>
<td>81</td>
<td>86</td>
</tr>
<tr>
<td>Nepal</td>
<td>62</td>
<td>NA*</td>
</tr>
<tr>
<td>Pakistan</td>
<td>91</td>
<td>NA*</td>
</tr>
</tbody>
</table>

NA* not available

Source: FAO (2011); WHO/UN-Water (2014)

NA = Not available

In 2015 the global community adopted the SDGs. Unlike the prior Millennium Development Goals (MDGs) — which addressed water only in terms of water for sanitation and health the SDG water-related goals are more comprehensive, and Goal 6 focuses on water exclusively. Drinking-water and sanitation correctly remain central, but other considerations are also considered important: water quality, wastewater management and reuse, transboundary cooperation, ecosystem services, capacity building, and cooperation.

Burgeoning urban populations in the HKH will exert further stress on already over-stretched urban services. As a result, standard solutions such as providing piped water and building more toilets will add only marginal benefits unless the realities specific to mountain water resources are taken into account. For instance, tapping mountain springs will become increasingly difficult, given the widespread anecdotal evidence of the drying up of springs. New investments will be needed for spring revival here. Most importantly, communities must be involved and have decision-making authority at all stages of water and sanitation services — from planning and construction to maintenance and management. Due to prevalent cultural norms, India’s mountain states, especially the northeastern states have driven the area to exceed national averages in terms of population access to safe drinking-water and basic sanitation.
8.3.4 Urban water

Following the global trend, all countries in the HKH are urbanizing rapidly. This means, existing urban centers will expand and new urban centers will emerge. Trends of urbanization are somewhat different in each of the HKH countries. In the Pakistan portion of the HKH, the rate of urbanization has been low due to the terrain constraints and lack of economic opportunities. The urban population in the Northern region of Pakistan is less than 20%.

In the Indian Himalaya, the rate of urbanization has been low in the higher altitudes, but it has been more rapid in the foothills (also called the Siwaliks). In western Indian Himalaya, Srinagar is the largest urban center, while in eastern Himalaya, the urban centers of Gangtok, Kalimpong, and Darjeeling, in the states of Sikkim and West Bengal respectively, have been growing at a very rapid pace. Nepal remains one of the least urbanized countries in South Asia — and also within the world. There are considerable problems in terms of definition in the study of Nepal’s urbanization because the areas designated "urban" have been defined and redefined over the years with evident lack of consistency.

In Nepal, Kathmandu is by far the largest urban agglomeration. Bangladesh occupies a very small section of the Himalaya, represented by low-elevation hills in the Sylhet district and in the Chittagong Hill Tracts (CHT). In these areas, tourism has flourished and led to the growth of a few small urban centers in CHT, namely Rangamati, Bandarban, and Khagrachari. Much of the urbanization in the region has been unplanned and haphazard leading to serious water and sanitation related problems.

The fact that mountain towns and cities are also tourist destinations amounts to additional pressure on water resources, and the water needs of the local population often are not met in pursuit of serving the water requirements of tourists. This sometimes leads to social conflicts. Table 8.2.6 shows that almost no major city in the region is self-sufficient in terms of municipal water supply.

<table>
<thead>
<tr>
<th>City, Country</th>
<th>Average elevation (m)</th>
<th>Population (year)</th>
<th>Supply (Million Liters per Day MLD)</th>
<th>Demand (MLD)</th>
<th>Demand met (percent)</th>
<th>Year of available water supply/demand data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kathmandu, Nepal</td>
<td>1,350</td>
<td>2,510,000 (2012)</td>
<td>105 Wet Season 86 Dry Season 280</td>
<td>37.5 Wet Season 30.7 Dry Season</td>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>Pokhara, Nepal</td>
<td>884</td>
<td>300,000 (2012)</td>
<td>24 Wet Season 21 Dry Season 45</td>
<td>53.3 Wet Season 46.7 Dry Season</td>
<td>2014</td>
<td></td>
</tr>
</tbody>
</table>
### Table 8.2.6: Gap between municipal water supply and demand in selected cities of the HKH countries of Nepal, India, Bhutan, and Afghanistan.

<table>
<thead>
<tr>
<th>City, Country</th>
<th>Average elevation (m)</th>
<th>Population (year)</th>
<th>Supply (Million Liters per Day MLD)</th>
<th>Demand (MLD)</th>
<th>Demand met (percent)</th>
<th>Year of available water supply/demand data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wet Season</td>
<td>Dry Season</td>
<td>Wet Season</td>
<td>Dry Season</td>
</tr>
<tr>
<td>Darjeeling, India</td>
<td>2,045</td>
<td>152,016 (2011)</td>
<td>8.3</td>
<td>2.3</td>
<td>8.6</td>
<td>96.5</td>
</tr>
<tr>
<td>Mussoorie, India</td>
<td>2,005</td>
<td>30,118 (2011)</td>
<td>7.67</td>
<td>14.4</td>
<td>NA*</td>
<td>53.3</td>
</tr>
<tr>
<td>Shimla, India</td>
<td>2,205</td>
<td>171,817 (2011)</td>
<td>54.5</td>
<td>64.7</td>
<td>84.2</td>
<td></td>
</tr>
<tr>
<td>Kabul, Afghanistan</td>
<td>1,791</td>
<td>3,476,000 (2013)</td>
<td>52.14</td>
<td>NA*</td>
<td>NA*</td>
<td></td>
</tr>
</tbody>
</table>


Almost all urban centers suffer from water shortage. Many of these urban centres are hill stations set up by the colonial British government on ridgetops, while water sources are deep down in the valleys. Compounding the problem of water shortage are issues such as outdated water-distribution systems, pipe leakages, and poor governance. Different cities have adopted different coping mechanisms — in Kathmandu and Darjeeling, private water tankers provide water to millions of residents, while in Bhutan, water supply is rationed and people are encouraged to manage their own demand accordingly. In Kathmandu, wastewater generated by city sewage is used to irrigate vegetable crops in peri-urban parts of the valley.

**BOX 8.2.5: Wastewater Use in Kathmandu Valley**

In 2011, Kathmandu had a population of 2.51 million and it has been growing at a rate of 6.6% per year — the fastest urban growth in all of Nepal. It is estimated that a total of 93 million litres per day (MLD) of wastewater is generated from the domestic sector and another 6.5 MLD from the industrial
sector. These numbers are growing by the day, but wastewater-management facilities have not expanded commensurately. Of the total wastewater generated in the valley, less than 50% is actually collected and treated; the rest is disposed of directly into the rivers.

Wastewater is used extensively for irrigation in the urban and peri-urban parts of the valley. At least one third of the cultivated area in the Valley is irrigated using wastewater — and almost two thirds of this wastewater is used directly in the fields without any kind of treatment (Bastakoti et al. 2014). A majority of the farmers reported using wastewater because there is no source of freshwater for irrigation — and also because accessing this wastewater, often used illegally, is free of cost, unlike groundwater, which requires investment in tube wells and diesel pumps. This wastewater also happens to be nutrient-rich, and therefore reduces fertilizer costs. Farmers using this water for irrigation often complain of health issues, such as skin infections, and the indirect health impacts of these pollutants on vegetables and other crops are not trivial.

However, given the lack of proper policies and infrastructure dealing with the use of wastewater in agriculture, it is unlikely that the negative health impacts of its use will be dealt with anytime soon. In this context, it is important to also understand the positive contribution of wastewater to the Valley’s agricultural economy, while framing adequate policies and institutions to manage the health risks of untreated-wastewater use.

### 8.3.5 Water quality: major biological and chemical contaminants due to urbanization

The burgeoning populations of the HKH countries have led to increased urbanization and, in turn, unplanned urban development. Water upstream is generally quite clean, given that its source is snow, glacial melt, and springs. However, as water makes its way downstream to more populated areas, it becomes increasingly contaminated with various pollutants (Shah and Shah 2015). Water-quality deterioration is increasingly becoming a recognized concern in many parts of the HKH (Merz et al. 2003). For example, the Bagmati River within the Kathmandu valley is considered one of the most heavily polluted in the world (Bhatt and Gardner 2009). The sources of pollutants in the Bagmati and other rivers are varied and include: sewage, municipal waste, open defecation, industrial wastes, and energy production (Karn and Harada 2001; Bhatt and Gardner 2009; Shah and Shah 2013).

There are no comprehensive studies addressing water quality for the HKH as a whole. However, there have been some studies comparing two or three countries, including the study by Karn and Harada (2001), which looked at surface-water pollution in Kathmandu (Nepal), Delhi (India), and Dhaka (Bangladesh). This study revealed widespread pollution of aquatic resources in all three cities through the presence of organic and pathogenic contaminants, heavy metals, and pesticides (Karn and Harada 2001). For example, in a 13 km stretch in the Bagmati River in the Kathmandu valley, biochemical oxygen demand (BOD) increased from 3.8 mg/L to 30 mg/L moving downstream during 1992–1995. Similarly, BOD in the Yamuna River in Delhi, showed an increase from 1.3 mg/L to 17 mg/L in the downstream area (Karn and Harada 2001). Similar situations were found in all of the rivers close to Dhaka (Turag, Buriganga, and Dhaleswori).

Industries contributed 14–17% of this river pollution, with pollutants coming from power plants, food-processing, breweries and distilleries, tanneries, and the industrial production of fertilizer,
insecticides, textiles, carpets, vegetable oil, dairy, pharmaceuticals, and other chemicals (Karn and Harada 2001).

Meanwhile, municipal sewage contributed nearly 85% of all river pollution. This was due to two major factors: first, the unrestricted discharge of raw or partially treated wastewater (of both domestic and industrial origin); and second, the lack of adequate regulatory pollution-control measures and their strict enforcement in real practice (Karn and Harada 2001).

The findings of another study suggested that the countries of the Ganges-Brahmaputra-Meghna River Basin are increasing their industrial activities, with approximately 70% of 300–500 million tons of heavy metals, solvents, toxic sludge, and other wastes being discharged untreated into waterways (Babel and Wahid 2009).

In terms of groundwater pollution, the urban areas of Kathmandu mostly suffer from infiltration of urban storm water, leakage of wastewaters and septic reservoirs, and improper industrial activities. These wastewaters and septic-system effluent contain high concentrations of dissolved organic carbon, ammonia, pathogens, and organic micro-pollutants, as well as heavy metals and trace elements (Pant 2011). The presence of heavy metals in groundwater in the Swat River was found to vary along different stretches and was attributed to geology, corrosion of plumbing systems, and agricultural and industrial activities (Khan et al. 2013). In this study, the concentration of heavy metals in the groundwater was higher than in surface waters (Khan et al. 2013).

Some studies have also looked at biological pollutants. In groundwater in Kathmandu, maximum coliforms were found in the samples from shallow wells (267 CFU/100 mL), while levels in tube and deep-tube wells were 129 and 149 CFU/100 mL respectively. The coliforms detected in shallow wells may be due to poor drainage, the improper construction of septic reservoirs close to groundwater sources, and the direct discharge of untreated sewage into surface waters (Pant 2011) — all of which further reflect the lack of planning and investment in the region’s water infrastructure. Similar results were reported from Rawalpindi, in Pakistan, where Sehar et al. (2011) found municipal water containing fecal coliforms due to leakage of water supply pipelines. In Srinagar, in India, significant land use changes since the early 1980s have led to pollution of the freshwater Dal Lake, due the discharge of various nutrients and pollutants (Amin et al. 2014).

In some parts of the HKH, such as Afghanistan, infrastructure has been damaged or destroyed by years of war. Only 27% of Afghanistan’s population has access to improved water sources, and only 20% have access in rural areas — marking the lowest percentage in the world. While the number of households in urban areas with access to municipal water is growing (35% in the capital city, Kabul), the system for solid-waste collection is limited, with about 70% of the city’s solid waste accumulating on roadsides and in drains, rivers, and open spaces, where it represents a significant environmental hazard. In addition, most sewage is disposed of in domestic drainage pits and shallow, open sewage channels that run along the streets, thereby threatening shallow aquifers with pollution from biological and chemical contaminants. A study on heavy metal and microbial loads in sewage-irrigated vegetables in Kabul revealed lead loads and pathogenic contamination higher than the threshold levels (Safi and Buerkert 2011). Considering the high incidences of intestinal diseases and diarrhoea, Safi and Buerkert (2011) recommended further detailed surveys and improvements to Kabul’s sewage infrastructure to eliminate potential health risks.
BOX 8.2.6: Arsenic in groundwater and its implications for agriculture

Arsenic in groundwater has emerged as a significant threat in the lower parts of the Ganges, Brahmaputra, and Mekong basins. In recent years, a growing body of literature has emerged that examines the impact of irrigation with arsenic-rich water on crop production and productivity and looks at the effectiveness of arsenic remediation in an agricultural context. A systematic review of 29 high-quality studies (Senanayake and Mukherji 2014) showed no clear relationship between arsenic content in irrigation water—or in soil with arsenic uptake by paddy grains—though, there is a near consensus that prolonged cultivation with arsenic-rich water leads to decline in paddy productivity.

A review of literature also shows that there are six broad categories of intervention that can reduce arsenic uptake by crops or prevent its entry into the human food chain. These are: deficit irrigation; soil fertilization; growing alternative field crops (other than paddy); switching to arsenic-tolerant paddy cultivars; reducing arsenic content in rice through cooking methods; and nutritional supplements. Results from these studies show that all of these interventions are successful in preventing excessive arsenic from entering the human food chain, but these practices have yet to be incorporated into mainstream extension activities.

8.3.6 Water infrastructure

Traditionally, mountain people have found ways to store water by building ponds, terracing fields, harvesting rainwater, and employing small-scale irrigation systems (Molden et al. 2014). Water is also often diverted from mountain springs, which are fed by groundwater and therefore a more reliable source during dry seasons. These methods are still practiced throughout much of the HKH middle hills. However, with increasing agricultural demand for water, the demand for better and larger infrastructure is also increasing.

This has led to construction of various irrigation structures in the region. In Pakistan, two large storage dams situated in the upper Indus basin, Tarbela dam on the Indus and Mangla dam on the Jhelum, now regulate the irrigation system relied upon by millions downstream (STIMSON 2013). In India alone, there are 4,858 completed large dams (and 313 are under construction, of which nearly 100 of these are located in the mountainous states) (CWC 2014). Most of the rivers in Nepal have almost no storage (Bandyopadhyay 2009, Wu et al. 2013). Feasibility studies for many large multi-purpose projects with storage have been proposed but development has been slow mainly due to lack of common interest and agreement between Nepal and India.

In Nepal, FMIS have, for centuries, been developed and managed by local farmers themselves. About 70% of the irrigation systems in Nepal are operated through FMIS (Pradhan 2000). Extensive embankment infrastructure has also been built on riverbanks to control floods during the rainy season.

In India, about 34,000 km of flood embankment has been constructed, largely in North and Northeast India (Mazumder 2011).

Water-related infrastructure can intensify upstream-downstream linkages, providing benefits and risks to both areas. Structures like dams and reservoirs can store water during flood periods and (a) make it available during the dry season through long-distance irrigation canals, (b) produce electricity
and (c) improve navigation. However, these structures come at a high cost to local communities displaced by them as they are forced to relocate and adjust to shifting resources and cultures.

Dams and reservoirs can also be problematic as they can block and store sediment as it descends the mountains. Fine silt and eroded materials are considered beneficial to plains farming; therefore, the blockage of natural flow can affect agriculture production. Singh (1990) has evaluated the Farakka barrage, determining that it has cost the downstream region of Bangladesh by reducing silt flow, which affects soil fertility, and by impacting the ingress of saltwater up the river, which also has negative consequences.

Further, in the Indus River Basin, downstream discharge to the sea has decreased significantly due to construction of vast networks of irrigation canals, barrages, and associated structures (Laghari et al. 2015). Laghari et al. estimated that these anthropogenic changes have resulted in five times less sediment in downstream areas before completion of infrastructure. Tahmiscioğlu and Anul (2007) highlighted that dam construction and the resulting holding of sediment can lead to changes in the natural water regime, including water-soil-nutrient composition downstream.

In Nepal, excessive river sediment has affected most of the power plants in the Himalaya through build-up in reservoirs or by erosion of turbine components, reducing the life of the plants. Al-Faraj and Scholz (2014) highlighted that human-made structures, such as dams and large-scale water systems, also decrease water availability in downstream areas of transboundary river basins.

8.3.7 Ecosystems and environmental flows

There is growing concern about the future of aquatic ecosystems in the HKH, as detailed further in Chapter 6. Increasing energy and water demands from the domestic, agricultural, industrial, and commercial sectors are leading to more plans for the development and exploitation of rivers.

There are considerable, though poorly understood, implications of climate change on increasing monsoon-season flows and decreasing dry-season flows — particularly coupled with river-flow diversions for developmental purposes. The term “environmental flow” (EF) is now commonly used to refer to a flow regime designed to maintain a river in some agreed-upon ecological condition. Each component of the natural hydrological regime has a certain ecological significance. In regulated basins, the magnitude, frequency, and duration of some or all flow components is modified. The suite of acceptable flow limits for such modifications can ensure a flow regime capable of sustaining target aquatic habitats and ecosystem processes (Poff et al. 1997). EFs can therefore be seen as a way to balance river-basin development and the maintenance of river ecology.

EF practice is not yet established in HKH countries, but it is emerging. There has been a particularly significant increase in interest in EF in India, where several EF assessments have been carried out in the last decade and the government is trying to implement an EF plan under the Ganga rejuvenation program. In Nepal, Bhutan, Pakistan, and Bangladesh, EF is beginning to enter the discussion on river development. With limited water-resource development and most infrastructure development still in the planning phase (especially in the upper mountain regions), there is still a chance to set up proactive EF measures and policies before these rivers are seriously degraded.

Despite the extensive study of environmental water allocations in some developed countries (UK, Australia, USA, and South Africa), defining precise river-flow limits to be ecologically adequate for
specific river ecosystems continues to be elusive. At present, EF are most often justified by ecological
concerns — for instance, how to preserve ecosystem health for the sake of biodiversity conservation.
This approach pays little regard to those whose livelihoods are gained directly from the rivers. For
many rural men and women in developing countries, aquatic ecosystems are essential to their
wellbeing and livelihood, providing domestic water and also sustaining fisheries, livestock, grazing,
and other important resources. Further, as a rule, current EF considerations do not consider river flows
within cultural and religious contexts, which are also very important in the HKH. Therefore, there is a
need to further develop EF-assessment methodologies for the HKH and to explore ways to incorporate
consideration of EF into river-management practices.

8.3.8 Adapting to climate change-induced water stress and vulnerability at the local level

Different countries in the HKH have different levels of water related vulnerabilities and different
capacity to cope with and adapt to those vulnerabilities. Water-related vulnerabilities in India and
Bangladesh are due to hydrological extremes. While Nepal exhibits less water related vulnerability
than its downstream neighbors, Nepal also has the least capacity to adapt to these vulnerabilities
(Babel and Wahid 2011), due to its inherent fragility as a mountain country (Jodha 2007). For instance,
the current trend of constructing deep borewells in the mid-hills in Nepal and India (Arya 2015) is
maladaptive, given that the fragile mountain aquifers cannot support intensive groundwater
extraction.

Most governmental initiatives for climate adaptation represent serendipitous adaptation and
“climate-proofing” of existing development projects (Prabhakar and Matsumoto 2010); formally
planned adaptation is still nascent. Nevertheless, communities are adapting to water-related changes
by implementing newer technologies and practices such as crop diversification, agro-forestry, organic
farming, temporary livestock sales, rotational or suspended irrigation, and delayed or suspended
cultivation. New water-sharing mechanisms are also being adopted along with other institutional
arrangements including water-demand management, social networks for irrigation maintenance,
mutual-borrowing of water and livestock, and micro-credit institutions for financial support (Liu et al.

Such autonomous adaptation based on local knowledge and prior experience is common, especially in
high mountain regions (McDowell et al. 2014), where communities can address local needs quickly and
flexibly. Consideration of local knowledge and traditional practice is essential for successful
community-initiated adaptation. As a result, adaptation planning should be dynamic and attendant to
local socio-political contexts. To improve the effectiveness of autonomous adaptation — and to avoid
potential maladaptive results — communities need improved access to climate information,
technology, financial support, leadership capacity-building, and reduced institutional barriers to
adaptation (Liu et al. 2008; Biggs et al. 2013b). Further, when guidance from government and/or NGO
programs is specific to local resources and institutional conditions, community adaptation initiatives
can be greatly strengthened, especially in mountain areas (Bandyopadhyay 2009).

8.4 WATER GOVERNANCE IN THE HINDU KUSH HIMALAYA

While the previous sections have addressed the physical availability and demand aspects of water in
the HKH and the demands for it, this section, following Biggs et al. (2013a) will argue that governance
challenges — more than water scarcity itself — form the primary obstacle to achieving water security
As suggested in earlier sections, water scarcity is institutionally mediated across geographical scales within the region. By characterizing the formal, informal, and hybrid water-governance institutions at the local/micro, subnational/national/meso, and regional/international/macro scales, the scalar governance lens then informs our discussion of the water-energy-food (WEF) nexus within the HKH. In a critical mode, we question conventional wisdom on the existence of the nexus at the micro scale within the HKH. Scaling up to meso and macro levels, we then critically examine prospective approaches to both basin-scale management within the region and to management of transboundary water conflicts at the subnational and national scales. We conclude this section with a consideration of pathways toward improved water-related decision making in the HKH, across micro, meso, and macro scales.

For the purpose of this discussion, water governance is understood to be the mechanism for addressing questions of water access, use, and distribution among social actors, sectors, and across geographical scales. The outcome of good water governance should be social equity and political stability enabled by environmental quality across the HKH. A key premise of our discussion is that water governance is a deeply political enterprise — and deeply political it is, indeed. If water is life, and human life is steeped in politics, then water use and distribution are inevitably steeped in politics as well. This section is organized around geographical scales, not only to illustrate how politics impact water governance at the micro, meso, and macro scales, but also how water politics might be moderated and informed by evidence-based policy.

### 8.4.1 Characterization of existing water governance institutions

The HKH is characterized by relatively weak penetration of formal state (national) institutions. This is due to the region’s topography and its weaker state structures. Water is no exception to this general lack of strong state presence, although modern state institutions have recently started becoming more influential, especially in terms of infrastructure development at the meso and macro scales. Informal customary water governance at the micro-scale, with its marked gender inequality, has been the predominant institutional norm in the region. The recent rise in state penetration has not replaced existing governance mechanisms, but it has spawned hybrid governance regimes with informal structures heavily mediating state intervention, rather than the reverse. The state has, however, indirectly contributed to profound transformation of informal water governance through the provision of energy and technology for harnessing and managing water supply and through investments in infrastructure for irrigation and for energy (particularly hydropower).

The region’s political geography is dominated by nation-states, which must be the arbiters of any water governance at the country level. At the moment, there are no multilateral or regional water-governance structures. Two regional multilateral institutions — South Asian Association for Regional Cooperation (SAARC) and the International Centre for Integrated Mountain Development (ICIMOD) — have not been involved in water governance. In fact, SAARC has maintained strict neutrality and a studied silence on the subject. On the other hand, ICIMOD has been quite proactive in generating knowledge on water governance and related issues in the region, but it has limited its activities to research and dissemination. This lack of a multilateral or regional governance framework for water is largely a result of the nationalization of water by the HKH countries, as the power disparities among these countries cause them to guard individual sovereignty over water.
Sovereign control over water has not prevented some countries in the region from entering bilateral treaties, which require regulating the exercise of sovereignty over domestic water resources to satisfy treaty obligations. Such treaties and their accompanying institutional structures are discussed in 8.3.2. At the subnational scale, Shah (2009) describes the existing water management structures in northern Afghanistan as community-based water-management systems that pivot around the institution of an elected or selected mir-e-aab (water master) with minimal or absent state presence in managing most canal and karez systems (underground aqueduct, also known as qanat in west Asia). Local water-allocation systems were largely disrupted during the long Afghan civil war, and the inability of the post-Taliban regime to restore to original claimants their abandoned or appropriated water rights is a source of considerable resentment among the Afghan populace.

Since 2003, through the Ministry of Rural Rehabilitation and Development, the Afghan government has inserted itself into local-level water management by availing funds for participatory water-infrastructure development through Community Development Councils operating under the National Solidarity Programme. This has led to more of a hybrid institutional regime, with the balance of power resting with the local informal regime more than the state. Due to the contours of local power relations, the results of these hybrid management systems have not been entirely equitable in terms of gender or class (McCarthy and Mustafa 2014).

In the Pakistani-administered part of the Karakoram range, constituting Gilgit-Baltistan, water-management institutions have also been largely local and community-based — and they have gotten a considerable boost from the investments in community organization and water-infrastructure development undertaken by the Aga Khan Rural Support Programme (AKRSP) and comparable NGOs (See Box 8.3.1).

**BOX 8.3.1: Aga Khan Rural Support Programme**

AKRSP provides illustrative evidence of a productive and cooperative relationship between state and non-state (or more informal) actors. The AKRSP’s primary approach is to promote the participation of local stakeholders in water management through the creation and support of village organizations, which then provide the structure and resources necessary for these villages to effectively manage their own water supplies. This model has enjoyed some success in promoting water access, particularly in more rural and difficult-to-access areas. One of the biggest successes of the program, however, has been its relatively extensive engagement with state authorities providing logistical, financial, and technical resources in support of these activities (De Spoelberch 1987; Ehsan-ul-Haq 2007). This example illustrates the potential for greater state cooperation with a variety of actors in promoting effective and sustainable water-management activities.

Gilgit-Baltistan might be an exception in the HKH, as it demonstrates synergy and cooperation between state and non-state actors, including the AKRSP, Aga Khan Foundation (AKF), and other related institutions. By contrast, in most of the HKH, typical relations between state and non-state water managers are indifferent, if not downright hostile. In Pakistan, as in India, water is primarily a provincial/state subject, with the central governments only intervening in the financing of large-scale infrastructure projects deemed to be of national interest, such as hydropower. However, within the
HKH areas of both countries, water management, for all practical purposes, remains local and community-based.

Many of these local-scale water-management systems limit gendered access to safe water, causing serious consequences for women and the health and well-being of girls. In Nepal, Udas and Zwarteveen (2010) documented that the central irrigation bureaucracy is unable to systematically address issues of gendered access to water because of the country’s entrenched patriarchal ethos, confirming the earlier review by Chandra and Fawcett (1999), who documented how lack of participation by women in water-supply projects ultimately increased their workloads and diminished their prospects of benefiting from improved water infrastructure.

In the Indian Himalaya, the central government’s Ministry of Water Resources and Central Water Commission play strong, engineering-focused, state-led roles in the development of water resources, investment in infrastructure, and data collection and monitoring. As previously indicated in this section, national involvement does not negate local water management or meso- to micro-scale water extraction and allocation practices — especially in the case of FMIS, which have a centuries-long tradition and form the backbone of livelihoods and food-security in rural mountain communities. Nevertheless, globalization, market integration, the penetration of contract farming, and seasonal to permanent outmigration (especially of working-age males) are having profound impacts on irrigated agriculture.

Within the region, Himachal Pradesh and Sikkim present more dynamic and transformative instances of active state involvement in water-management — ranging from irrigation and potable-water supply to hydropower. By contrast, the states of Jammu and Kashmir and Uttarakhand have resorted to a more conventional approach with central government making a strong imprint on infrastructure and water management. This is due, in part, to territorial and strategic concerns — in J&K, concerns ostensibly include the integration of local communities into mainstream Indian polity; in Uttarakhand, there are governmental concerns over nationalist sentiments for Mother Ganga and for the historical marginalization of hill districts, which formed part of Uttar Pradesh state before breaking off as the new state of Uttarakhand (previously Uttaranchal).

The states of Northeast India present an entirely different picture, with local practices and traditions holding sway, marking a governance system that is less of a hybrid than one in which state and central government institutions are largely absent. With the advent of hydropower in the Northeast — and the perception of a large gap between generation potential and installed capacity on high-volume tributaries to the Brahmaputra — the region is witnessing greater involvement of central government, including investments in infrastructure through public and private capital, as well by multilateral institutions, including the Asian Development Bank.

In terms of domestic water supply, the expanding urban areas of the HKH are largely serviced by either centrally or provincially controlled agencies (such as the centrally controlled Kathmandu Valley Water and Sanitation Board). In HKH rural areas, the main government agency responsible for domestic water supply is Public Health Engineering (PHE), however, most of the time the domestic water supply is actually serviced through community-based initiatives. PHE has an infrastructure bent and often assumes responsibility for supplying domestic water to larger and medium sized cities in the region, such as Gilgit, Muzaffarabad, and Srinagar.
In all of the urban water-supply situations, the emphasis is on networked, piped water systems, replicating the infrastructure and institutional models of the western and plains cities of South Asia — but without regard to topography, cultural particularities, or the institutional history of water supply in HKH cities. The consequences go beyond an uneven water supply inequitably rendered in terms of class and location across the urban areas of the HKH; serious health hazards also arise from water-supply contamination.

In sum, the key features of the institutional water landscape in the HKH are as follows:

- Water management is characterized by a hybrid formal-informal regime, with the balance of power in favor of informal institutions, particularly at the local level.
- At the macro scale — and certainly for meso- and macro-scale infrastructural development — the balance of power is in favor of formal state institutions.
- There is a disconnect between the macro/national, meso/regional, and micro/local water-governance institutions, which is largely a function of the political marginality of national terrain within the HKH. This is especially true of larger nation-states, with the exceptions of Nepal and Bhutan, the boundaries of which fall predominantly within the HKH.
- There is a need for greater synergy between state and informal water-management institutions without the strict institutional boundaries that exist at present. Local water management and its informal institutions could benefit from state support instead of the antagonism that is present today.
- The gender inequities often witnessed in informal and formal institutions are a matter of serious concern and should be a priority area for reform.
- The urban water-supply systems in emerging cities in the HKH need to be more attuned to the particularities of the topography and the organic growth of the cities where formal institutional regimes uncomfortably preside over the informal institutional landscape, with deleterious consequences for water quality and quantity.

These characteristics of local and national water institutions exist in juxtaposition to governance at the level of transboundary river basins; thus, we turn to conflict and cooperation across geographical scales in the HKH.

### 8.4.2 River-basin approaches and transboundary conflict and cooperation

Countries throughout the HKH face similar challenges of increasing water demand due to economic growth. Availability of and access to water resources vary dramatically throughout the region due to seasonal precipitation patterns, the geographic distribution of glaciers, and, importantly, a lack of adequate governance. In addition, rising uncertainty in water availability and increases in extreme weather are both likely, due to climate change (Molden et al. 2014). Management of water resources at a river-basin scale may help in maximizing benefits of infrastructure projects, negotiating competing water and energy uses, and minimizing risk of water-related hazards. However, a river-basin approach is challenging at macro (or meso) scales that are either international or interstate (subnational).

At both transboundary and subnational levels, coordination throughout shared river basins requires increased institutional capacity, particularly across scales, and may require a decoupling of national political aims from shared resource-management objectives. The river-basin approach is particularly
relevant in the context of upstream–downstream benefit sharing between HKH areas and downstream populations in the plains. Within the HKH, however, much of the demand for water, especially for drinking-water, is met by groundwater from springs, where the most relevant geographical unit for effective management is not the river basin but the springsheds, which do not follow the river valley contours. Springs draw upon mountain aquifers, which may be shared among multiple valleys; therefore, holistic water management must integrate mechanisms across river basins and springsheds in order to better coordinate surface and groundwater resource management.

In the HKH, a river-basin approach helps harness the full potential of water resources while managing competing uses in the face of rising demand and increasing uncertainty (Shrestha et al. 2015b). Both infrastructure and institutional water-management approaches benefit from a river-basin perspective. Building institutional capacity at a river-basin scale can improve coordination between upstream and downstream areas — and improve cross-sectoral policies for water and energy. However, the river basins originating in the HKH often cross state or national borders, making coordinated basin-wide water management difficult.

Building transboundary institutional capacity is challenging due to the different needs and priorities of riparian states. River-basin management can even be difficult at the subnational level due to a lack of interstate institutional mechanisms, a predominance of local and community-based water-management schemes, and a lack of alignment among hydrologic boundaries and administrative management units.

At the local scale, much of the agricultural and domestic water supply is dependent is upon mountain springs, whose aquifers do not necessarily follow the basin’s surface boundaries. The basin approach may be useful at the meso and macro scales, but at the micro/local scale, formal institutions can prove useful by helping to link micro water-management institutions across valleys in order to address common issues of spring recharge, zone protection, and water quality. However, at the international transboundary level, the rivers originating within the HKH continue to be strongly contested, as outlined in 8.3.2.1.

8.4.2.1 Transboundary waters

Transboundary resource sharing in South Asia has historically been fraught with contentious relationships, a focus on national interests, a lack of trust, and hegemonic players. National interests and international power relations have played a significant role in hydro-politics in the region (Asthana and Shukla 2014). Despite being connected by hydrologic flows (seven of the major river basins in the HKH cross national borders), states have often taken unilateral action on water-management decisions, leading to fragmented management of transboundary resources, narrow (albeit understandable) focus on national interests, and negative consequences for downstream countries and communities (Asthana and Shukla 2014; Rasul 2014; Giordano et al. 2016).

Where international cooperation on water management exists, agreements are typically made between only two countries, and water disputes are often entangled with other political issues (Shah and Giordano 2013; Giordano et al. 2016). Several governments in the region are weak and unstable, whereas others are seen as regional hegemons. Bilateral water treaties often involve nation-states with disparate levels of political power. For example, in the Ganges-Brahmaputra-Meghna basins, India holds separate bilateral treaties with Nepal and Bangladesh, despite the fact that these three countries...
are all part of a larger shared basin. These water treaties are often inflexible and lack adequate mechanisms for negotiation of inter-party conflicts.

Bilateral water treaties in the region have resulted in varied outcomes for downstream states. Sometimes, transboundary water treaties have improved shared-resource management, but in other cases, the lack of an adequate — or any — agreement has contributed to contentious state relations. The Indus Water Treaty, signed by India and Pakistan in 1960 and currently in effect, secured a significant apportionment of 80% of Indus River Basin flows for Pakistan, the lower riparian state (Shah and Giordano 2013). India and Bhutan were able reach a mutually beneficial agreement on hydropower development in shared river basins; Bhutan earns over 60% of its national GDP from hydropower sales to India (Shah and Giordano 2013).

By contrast, treaties developed for joint hydropower projects on the Gandak, Koshi, and Mahakali Rivers (in 1952, 1954, and 1996, respectively) have tended to exacerbate tensions between India and Nepal. The Koshi agreement provided compensation to Nepal for land inundation, irrigation flows, and benefit sharing from a hydropower and flood-control project constructed by India within Nepalese territory. However, Nepal does not feel that the agreement has been upheld fairly (Shrestha et al 2012; Giordano et al. 2016). Further, lack of bilateral agreement on required modifications of the Koshi project led to failure of the embankment of 2008, causing major flooding with severe damage and loss of life — and compounding the existing mistrust between these nations.

Water projects within the Brahmaputra and Ganges basins have also led to increased tensions between India and Bangladesh. India constructed the Farakka Barrage on the Ganges to divert dry-season flows for drinking-water and irrigation and to prevent sedimentation in Kolkata port, however, the project negatively impacts downstream flows in Bangladesh.

Other projects have been developed unilaterally. India constructed a series of run-of-the-river hydropower projects and a diversion barrage on the Teesta River. Both projects impact downstream flows in Bangladesh. Although agreements on minimum flows and dispute resolution were reached between India and Bangladesh on these projects in 1996 and 1998, in both cases, Bangladesh remains dissatisfied with India’s fulfillment of the terms of the agreements. To further complicate international agreement on water sharing, domestic protests within India have weakened the central government’s ability to achieve an equitable arrangement with Bangladesh over the Farakka Barrage, an example of how international water cooperation is subverted by domestic political aims (Giordano et al. 2016).

To redirect water management from conflict among international riparian states toward productive cooperation, joint water projects and research efforts are two ways to engage multiple players and build trust — while also serving to increase the knowledge base on resource issues, improve evidence-based decision making, identify mutually beneficial goals, and leverage cooperation within the scientific community to promote cooperation at other levels (Asthana and Shukla 2014). Cooperation will also lead to better planning of infrastructure projects, reducing impacts on resources, livelihoods, and ecosystems (Giordano et al. 2016). Finally, regional information-sharing systems need to be established to facilitate open data exchange within river basins. Data sharing will help facilitate disaster management, increase capacity for information dissemination, improve regional resilience to climate change, and improve early-warning systems for floods — especially for glacial lake outbursts. However, questions about conflict and cooperation at multiple scales must also take into account
interdependent resource systems, illustrated through the WEF security nexus and its unique manifestations within the HKH.

### 8.4.3 The water-energy-food security nexus

There is growing recognition of the important links between water, energy, and food, and this triad is such that the security of one is impacted by or influences the others. This so-called WEF security nexus has emerged as an important conceptual paradigm for sustainable resource management. The nexus is considered to be a set of tradeoffs resulting from the competing demands (such as water for food versus water for energy through biofuels) and the synergistic relations between resource use and development, whereby interconnections can allow multiple needs to be addressed simultaneously. The tradeoffs and synergies are multi-dimensional, spanning physical and social spheres across multiple scales (Rasul 2014) both rural and urban (Scott et al. 2016).

The critical links among groundwater, energy, and irrigation have been highlighted in a number of studies. The proliferation of electric pumps for extracting groundwater in India (Mukherji 2007; Shah 2009) and of diesel pumps in Pakistan (Siddiqi 2013) has led to an extensive increase in energy consumption for agricultural production in the plains. Policy instruments, such as power tariff reforms, have been identified as interventions that can simultaneously reduce power demand (thereby improving energy supply for non-farm power needs), improve agricultural productivity, promote equity, and allow for more sustainable use of groundwater in agriculture (Kumar et al. 2013).

Within the mountainous regions of the HKH, the key linkages within the WEF nexus are through hydropower—electricity generation, fuelwood for heating and cooking, and rainfed agriculture for food production (although these vary across socio-economic levels and geographical scales). In the case of hydropower, off-grid, small-scale systems serving local communities have played an important development role in some areas (Pervaz and Rahman 2012). On the other hand, large, grid-connected hydropower systems serve regional energy demands with a distinct advantage for downstream agriculture and urban demands. In 2013, hydropower constituted a significant portion of total electricity production (~77% in Nepal; 32% in Pakistan; and 12% in India (IEA 2016)).

Overall, the WEF nexus at the micro/local scale in the HKH is not constituted by critical tradeoffs; rather it exists due to the essential need for water in both the energy and agricultural sectors. However, the prevailing system of access to and use of resources is vulnerable to disturbances in climate — and WEF security in rural areas will be significantly impacted (with the poor being exposed to higher risks). Small-scale hydropower systems will likely be the first affected by changes in streamflow due to climate change (as compared to large systems with significant storage capacity). Furthermore, landslides and floods that disrupt road connectivity in remote mountains will impact food imports and distribution to local markets. In the HKH, recent vulnerability assessments already show that yields in important crops have declined in over 40% of households in the mountain regions due to droughts, floods, frost, hail, and disease (Kurvits and Kaltenborn 2015).

The HKH has extensive hydropower-generation potential (estimated at 500 GW), and several large-scale systems are in operation or in stages of planning and development (Vaidya 2012). Power-generation revenue accrues at the provincial level (where power plants are situated); however, the electricity generated is largely used in the densely populated plains — as is stored water (for irrigated
agriculture). For instance, Khyber Pakhtunkhwa (KPK) and Gilgit-Baltistan collectively host 76% (46 GW) of the 60 GW total estimated hydropower potential in Pakistan.

The irrigation benefits of the Indus waters are largely derived in the plains of Punjab and Sindh, whereas energy-generation revenues are accrued in KPK and Gilgit-Baltistan (Siddiqi 2013). An improved evaluation of the distribution of costs and benefits can allow for creating inclusive and equitable arrangements. For instance, a fraction of hydropower revenue could be provisioned for rural development of the province, and some of the new development projects could be directed toward adaptations for climate change impacts, such as deployment of photovoltaic (rather than micro-hydro) systems.

System-level modeling and analysis have largely focused on meso/basin- or macro/national-scale profits and benefits (Yang et al. 2014). As large projects are planned and funded by national agencies, the relevant scale of analysis has been at the provincial (meso) or national (macro) level. These approaches can be improved by incorporating methods and metrics that compute national-level net benefits in conjunction with local costs borne at smaller levels.

Modeling higher spatial resolution is more complex, and lack of sufficient data makes evaluation difficult. Nonetheless, advances in data collection, computation, and methodological tools now make it possible to increase the sophistication of evaluation and improve decision making for development that provides net benefits across micro/local, meso/regional, and macro/national/international scales. Ultimately, governance and institutions will have to be adapted and reformed (Matthew 2012) — a tall order, given the region’s history and political complexity, yet one that must be fulfilled to effectively address the interconnected challenges.

### 8.4.4 Decision-making improvements

Water-related decision making across micro, meso, and macro scales is mediated by the relative social and political power of stakeholders and interest groups — and by complex and often involved institutional histories and designs. At the micro level, the main conduits for decision making are informal local institutions. These institutions are embedded in the local-level geographies of power organized around class, ethnicity, and gender. To facilitate more inclusive decision-making structures, there is a need for greater synergy between the formal state and informal local institutions. The key political challenge is to make the informal local-level institutions accountable and equitable, without undermining their efficacy or legitimacy. Decision making by informal institutions at the local level is, indeed, based on local knowledge; therefore, there is a need for formal state institutions to learn from the local decision-making bodies.

At the meso/subnational scale, the balance of power is in favor of formal state institutions. Here, the key challenge is to steer what is generally highly politicized decision-making toward evidence-based decision making appropriately informed by science and local knowledge. At this scale, the importance of research and knowledge-generating actors cannot be over emphasized. Scientifically rigorous, socially informed, and locally relevant research could be made available to local level decision-makers, who, in turn, could also be made more accountable. As science points the way toward ecological and economic sustainability, accountability will ensure that attention is paid to social justice and sustainability.

At the macro/international scale, there is an obvious need for greater trust between the nation-states
of the HKH. Water conflicts rarely play out in isolation from the range of other issues between nation-states — but water can be a conduit for trust-building. Again, development that goes beyond design and construction could bring dimension to the largely engineering-focused perspective of the national water bureaucracies in the countries of the HKH.

Educating citizens and the press on water issues within the HKH could also provide a counterpoint to the focus on infrastructure and engineering that is currently predominant in addressing water problems in the region. National water policies informed by multidisciplinary perspectives could help both national and regional initiatives find innovative solutions to seemingly intractable water conflicts, serving such programs as ICIMOD’s Himalayan Adaptation, Water, and Resilience; Consultative Group for International Agricultural Research (CGIAR) Water, Land, and Ecosystems: Ganges; and the South Asia Water Initiative. Finally, the link between subnational and national water politics cannot be overlooked. The aforementioned regional-level interventions could also serve to make national water policies more regionally and ecologically sensitive and less narrowly nationalistic.

8.5 CHALLENGES AND WAYS FORWARD

In the conceptual Figures 8.4.1 to 8.4.6, we illustrate possible future trends in water availability and use; in corresponding comments, we present the governance possibilities these figures suggest. The starting points of the curves are the notional present state of each variable. Refer to Chapter 5 for more information on future scenarios.

In general, annual river flows across the HKH during this century will not undergo great change because increased precipitation and runoff will tend to counteract reduced flow from glacial melt (Figure 8.4.1), except in the Indus Basin where contributions from monsoon precipitation are low. In general, however, pre-monsoon flows are expected to decline, impacting irrigation, hydropower, and ecosystem services. Data uncertainties are high, as is spatial and temporal heterogeneity. Projections indicate that intra-annual variability in surface water will increase (Figure 8.4.2). There is anecdotal evidence that springs in the mid-hills of the Himalaya are drying up (Figure 8.4.3); these contribute to lean season baseflow in local streams, which constitute the primary source of drinking water in the HKH mid-hills before joining the rivers fed by glacial melt.
Figure 8.4.1: Schematic of the generalized trend in runoff from precipitation, runoff from glacial meltwater, and total runoff for the HKH over the next century.

Figure 8.4.2: Schematic of the generalized trend in intra-annual variability of runoff from precipitation, runoff from glacial meltwater, and total runoff for the HKH over the next century.

Figure 8.4.3: Schematic of the generalized trend in springflow for the HKH mid-hills over the next century.

Figure 8.4.4: Schematic of the generalized trend in urban water use in the HKH over the next century.
Urbanization is occurring rapidly throughout the HKH. Increased demand for water is driven by population growth and the concentration of economic and political power in cities and towns (Figure 8.4.4). This already puts unprecedented pressure on water resources in cities. In the future, it is likely that larger cities in and around the HKH will resort to long-distance water transfers from HKH highlands to satisfy increasing demand, possibly designing suitable institutions for payment to upstream communities for ecosystem services. It is also likely that some of the bigger cities will invest in workable wastewater-treatment infrastructure. However, the real crisis will occur in smaller emerging towns, which have inadequate funds for infrastructure upgrades and lack suitable governance institutions.

Reduced lean-season river flow coupled with increasing urban and upstream demand will result in less surface water available to downstream farmers for irrigation. Agriculture and irrigation will become increasingly feminized, and institutions must respond to this reality or mountain agriculture and irrigation systems will stagnate or shrink. For example, most FMIS still consider members to be landowners, who are men, many of whom have migrated. If institutions become inclusive, and if remittance money is invested in agriculture, then it is possible that the shift to remunerative crops like coffee, orchards, and mountain niche crops (instead of rainfed cereals) will become even more pronounced.

Further, hydropower is rapidly emerging as the main source of energy and revenue for Himalayan states, but changing river flow regimes will require hydropower projects to be constructed and managed in order to account for pre-existing water use for irrigation. Without mechanisms to negotiate water sharing
between existing agricultural and emerging hydropower uses, the water available for agriculture will
decline in localized areas (Figure 8.4.5). There is a need for improved benefit-sharing norms that enable
the preservation of water flows for agricultural use while allowing substantial, but mediated, hydropower
development (Figure 8.4.6).

Ecosystem flows in Himalayan rivers and streams are subject to flow regimes that are heavily impacted by
human water uses. Although inter-annual variability in flood and drought cycles does affect riparian
ecosystems, the increasing intra-annual variability that will have the greatest impacts on fish, macro-
invertebrates, and other riverine flora and fauna. Increasing intra-annual variability will reduce lean-
season flows and diminish the high-monsoon flows characteristic of HKH regimes (Figure 8.4.7).

Figure 8.4.7: Schematic of the generalized intra-annual variability in streamflow under natural regimes and regimes
heavily impacted by human development (hydropower and agriculture or energy transition with climate-induced
glacial melt)
REFERENCES


Bajracharya, SR; Maharjan, SB; Shrestha, F; Bajracharya, OR; Baidya, S (2014) Glacier status in Nepal and decadal change from 1980 to 2010 based on landsat data. Kathmandu: ICIMOD


Bastakoti, R.C, N. Maskey, P. Drechsel and S. Prasad, 2014. Wastewater irrigation in urban agriculture:


Ehsan-ul-Haq, 2007, Community Response to Climatic Hazards in Northern Pakistan, Mountain Research and Development, Vol. 27, No. 4, pp. 308-312


IWMI. Status, constraints and prospects in Kathmandu Valley, Unpublished report, International Water Management Institute, Colombo


Mahamuni, K., and H. Kulkarni (2012), Groundwater Resources And Spring Hydrogeology In South Sikkim, With Special Reference To Climate Change, Climate Change in Sikkim Patterns, Impacts and Initiatives. Information and Public Relations Department, Government of Sikkim, Gangtok.


Nadeem, S; Elahi, I; Hadi, A; Uddin, I (2009) Traditional knowledge and local institutions support adaptation to water-induced hazards in Chitral, Pakistan. Kathmandu: ICIMOD


Ostrom, E. and R. Gardner, Coping with Asymmetries in the Commons: Self-Governing Irrigation Systems Can Work Journal of Economic Perspectives- Volume 7, Number 4-Fall 1993-Pages 93-112


Pradhan, NS; Khadgi, VR; Schipper, L; Kaur, N; Geoghegan, T (2012) Role of Policy and Institutions in Local Adaptation to Climate Change – Case studies on responses to too much and too little water in the Hindu Kush Himalayas. Kathmandu: ICIMOD


Rana, S., and V. Gupta (2009), Watershed Management in the Indian Himalayan Region: Issues and Challenges, paper presented at World Environmental and Water Resources Congress 2009@ sGreat Rivers, ASCE.


Sharma, E; Chettri, N; Tse-ring, K; Shrestha, AB; Fang Jing; Mool, P; Eriksson, M (2009) Climate change impacts and vulnerability in the Eastern Himalayas. Kathmandu: ICIMOD


