

# Urban water resilience in Hindu Kush Himalaya: issues, challenges and way forward

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## Abstract

The urban population is expected to rise up to 68% by 2050, adding 2.5 billion people to the urban areas of the world. The majority of the rise is expected to be in the low-income countries of Asia and Africa. Several cities/towns in the Hindu Kush Himalaya (HKH) region are expanding at a rapid pace, putting additional pressure on water services and basic amenities for urban dwellers. Selected case studies undertaken by the authors suggest that the demand for water far exceeds municipal supply. Water governance in the HKH region remains a blind spot and challenges pertaining to urban water resilience are poorly understood. The paper is divided into three parts: the first outlines the development of towns and their water infrastructure through selected cases in the HKH, followed by key issues and challenges faced by urban systems and suggested measures to build urban resilience in order to deal with the projected rise in population, governance issues and anticipated changes in climate.

*Keywords:* Climate; Hindu Kush Himalaya (HKH); Population; Resilience; Urban; Water

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## Introduction

Water resources are gradually depleting and the issues related to water quality are taking an important space in the governance of the water sector (Srinivasan *et al.*, 2012). Currently, 55% of the population live in urban areas, which are expected to rise up to 68% by 2050, adding another 2.5 billion people to the urban areas (UNDESA, 2018). Ninety per cent of the growth is expected to be concentrated in the low-income countries (Shah & Kulkarni, 2015), posing serious challenges to water managers and city

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planners to build resilience against anticipated population and climate pressures. The term ‘resilience’ (Jalilov *et al.*, 2017) is defined as

*‘the capacity of urban water infrastructure to cope in the short term, and adapt and develop in the long term in the face of unforeseen changes such as major system failures, acute water infrastructure degradation, inadequate drinking water and wastewater infrastructure, and/or natural disasters.’*

In a broad sense, planning for sustainable water futures would require greater degrees of understanding around contemporary and future demand and supply (Cosgrove & Loucks, 2015). Development is the key concern of many low-income countries, which results in rapid and unprecedented urban growth (Stewart, 2017). This generates the need for larger supplies of resources, mainly water (Wakode *et al.*, 2018).

Approximately 1.3 billion people living in rural and urban areas across the Hindu Kush Himalaya (HKH) and downstream basin are affected by climate change (Eriksson *et al.*, 2009). The Himalayan region is warming at rates two to three times faster than the global average (Singh *et al.*, 2010). The towns and cities in the HKH are rapidly expanding and are subjected to extreme weather events as a result of climate change and unplanned urbanization (Sharma *et al.*, 2014).

Urban growth impacts several environmental components, i.e., land use change, hydrology, climate, biogeochemical cycle and biodiversity, which in turn, affects urban systems (Grimm *et al.*, 2008). The process of urbanization in the Himalayan region has largely been haphazard (Tiwari *et al.*, 2018), making it an important driver of environmental change (Walker, 2011). The fast rate of urbanization has impacted hydrological regimes and reduced groundwater recharge and decreased the availability of drinking water and sanitation (Tiwari *et al.*, 2018). The stress of climate change is manifested by an increase in extreme weather events in urban and rural areas of Himalaya (Balk *et al.*, 2009; Djebou & Singh, 2016).

In the HKH region, urbanization has largely remained outside the climate change debate, which has mostly been dominated by glacier melt and its consequences on river discharge (Hofer & Messerli, 2006). Water governance in mountains and hills remains a blind spot in the water governance literature. Compared to other geographies and water systems, mountain water and governance systems remain relatively unknown and largely unseen. In HKH states (Figure 1) and provinces of Bangladesh, India, Nepal and Pakistan, the urban population is growing between 3% and 5% (Singh *et al.*, 2019). This rapid pace of urbanization in the HKH raises important questions concerning the adaptive capacity of urban governance systems to changes in water availability and highlights the urgent need for crafting governance mechanisms for the management of a public good required by everyone. Floods and droughts, and the projected increase in extreme rainfall and storm events due to climate change in the region (Zhan *et al.*, 2018), pose serious challenges to urban water resilience.

This article will focus on cities/towns in the HKH region that are facing their own sets of challenges. In these towns, the influx of migrants, tourists, combined with the growth of the incumbent population, places considerable stress on the urban infrastructure to supply adequate clean water and sewage disposal, while the Himalayan towns are already grappling with issues and challenges for urban water resilience (Tiwari *et al.*, 2018), drawing on the limited information available and research and observations made by the authors. In order to build a holistic perspective, the paper is divided into three parts: the first part focuses on major urban centres and their water issues, followed by key issues and main challenges and issues facing urban water governance across selected case studies. We conclude with a number of recommendations concerning future strategies and actions that need to be taken to strengthen urban climate resilience in the region.



Fig. 1. Hindukush Himalayan region.

## Development of urban centres and water crises in major cities of HKH

Several cities in the larger HKH region, from Afghanistan to Bhutan, are suffering from water crises and have put severe pressure on existing water resources (Table 1).

The Indian Himalayan Region (IHR) occupies 14% of the area of the Indian subcontinent, spreading across ten states (administratively) of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, and the hill areas of the states of Assam and West Bengal.

### India

In Jammu and Kashmir, Srinagar is the most important city as it is the state capital as well as an important tourist destination. Leh is a very high-altitude settlement of Jammu and Kashmir, with a sparse population, but has grown in importance as a tourist destination. Likewise, Shimla and Manali in the state of Himachal Pradesh and Mussoorie and Nainital in the state of Uttarakhand are the most popular tourist destinations of Northern India. These urban centres have witnessed a high rate of urbanization. In

Table 1. Demand and supply and major issues in selected cities of HKH Himalaya.

S. no.	City	Supply (Million Liters Per Day (MLD))	Demand (Million Liters Per Day (MLD))	Major issues
1.	Kabul (Afghanistan)	52.14	–	Limited distribution due to high energy cost. Only 20% of total population is supplied with water
2.	Quetta (Pakistan)	106	170	Rapid population growth, low rainfall, ground water depletion, water deficit of 50%
3.	Shimla (India)	54.5	64.7	Lack of new sources, high tourist influx, leakages in pipelines. 84.2% demand is met
4.	Mussoorie (India)	7.67	14.4	Poor infrastructure, tanker economy, high tourist influx, recharge zones degraded
5.	Nainital (India)	20.5	18.2	Depletion of lake level which is the main source of water, encroachment over recharge zones, increase in impermeable areas
6.	Kathmandu (Nepal)	86	280	Rapid influx of migrants, tourist influx, poor infrastructure, poor governance
7.	Xining (China)	–	–	Water shortage deterioration water quality
8.	Thimpu	–	9.9	Water contamination and shortage of water increase in impermeable surface causing flooding

addition, in Uttarakhand, a large number of pilgrims visit the temples of Kedarnath, Badrinath, Gangotri and Yamnatri (Char Dham) across the country. As per the figures released by Uttarakhand police, approximately 2.7 million pilgrims visited the Char Dhams of Uttarakhand in 2018. This has created multiple forms of opportunities in the large and small towns of the state, i.e., expansion of hotel industry, eateries along the route, taxi services and others. Further, in many cases, e.g., the government of the Indian state of Uttarakhand's failure to create opportunities and develop basic infrastructure in rural areas has also led to migration to cities. For example, since the formation of Uttarakhand state in 2000, the state has posted an impressive growth rate of GSDP between 2004–05 and 2015–16, with a focus on secondary and tertiary sectors of economy. The primary sector, agriculture, upon which approximately 70% of the population of the state depends, is not within this story of successful growth. Given the urban nature of secondary and tertiary sectors, the urban population, at roughly 26%, emerges as the major beneficiary of growth, and the lack of focus on agriculture and allied activities and industry has led to persistent and continuing urban–rural disparities (Singh & Pandey, 2018).

### Nepal

It remains one of the least urbanized countries in South Asia and the world. The problems of definition in the study of Nepal's urbanization are considerable as the areas designated 'urban' have been defined and redefined over the years, and there is an evident lack of consistency in the definitions used (Devkota, 2018). Urbanization viewed cross three broad ecological regions – mountains, hills and Terai – shows enormous differences in urbanization volume and forms. In the hill region there is a stark difference between Kathmandu Valley, the traditional hub of Nepal's urbanization, and the rest of the hills. As a result of tourism, population pressure, poor infrastructure and governance, the demand and

supply gap is approximately 70%. Kathmandu valley on the whole faces a shortage of 210 MLD. The mountain ecological region has only recently acquired a meagre share of the urban population, while the number of urban centres in the Terai has grown rapidly (Ishtiaque *et al.*, 2017). The hill region of Nepal is the meeting place of people coming from the north and the south of the country with a population density of 167.1 persons per square kilometre and comprises 44.3% of the total population of the country (Suwal, 2013). This zone has 39 districts with many of the large urban centres of the country, which have grown in importance as tourist and commercial places. Pokhara, for example, has grown at a very rapid rate due to tourism (Tiwari, 2012). Shortage of water, ineffective water management practices and rising population are key concerns. Pokhara's water supply is managed by Nepal Drinking Water Cooperation. The current supply is only intended for 8,000 households, and the households in 2014 were 34,000 (Pokharel, 2014). Baglung municipality is a banking and financial hub of the region, with the presence of branches of several national banks and regional offices. A large number of people from Baglung are employed in India and further afield and, therefore, the town in particular and the region in general receives the highest amount of remittances from foreign employment in Nepal (Sharma *et al.*, 2014). The town experienced a rapid expansion after the completion of the Pokhara–Baglung highway in the mid-1990s and a summer highway connecting Baglung to Chaura.

*Xining in China*, the capital of Qinghai Province suffers from the dual challenges of water shortage and deteriorating quality. Severe degradation of the catchment area and pollution in the nearby Huangshui River have been major concerns. To meet the growing demands for water in the area around the city of Xining, the Qinghai Xining Water Environment Project, worth US\$150 million, is financed with an International Bank for Reconstruction and Development (IBRD) loan. The project aims to invest in storm and wastewater collection pipes, rejuvenate the environment along the banks of Beichuan River and strengthen the municipality's capacity in integrated water environment management.

### *Pakistan*

A study by the World Bank that analysed the water situation in Pakistan declared Pakistan to be one of the world's most arid and water-stressed (soon to be water-scarce) countries, on a par with those of the Sahara Desert (Khan, 2009). Quetta, the provincial headquarters of Baluchistan, is plagued by a growing water security crisis. Located at an elevation of 1,680 m, it is experiencing rapid population growth due to in-migration. The gap between demand and supply is widening and becomes acute during the low rainfall period (Kakar *et al.*, 2018). Approximately three million people residing in Quetta require some 170 MLD of water per day to meet their demands; however, the supply is only 106 MLD. Groundwater is the only source to meet this demand which has receded down to 300 m due to overexploitation. The Water and Sanitation Agency (WASA) could only manage to produce 100 million per day through 400 tubewells, thus creating a deficit of 50%. The residents rely heavily on tankers operated through informal arrangements. This has resulted in the overexploitation of the groundwater through some 2,000 tubewells, and this unchecked installation of tubewells is dangerously depleting the water resources of Quetta. The proposed Mangi Dam in Quetta district is likely to provide an additional eight million gallons per day, however this scheme will take time to become operational.

### *Afghanistan*

Kabul, the capital of Afghanistan, has a water crisis which is of major concern. The 4.5 million residents of Kabul (2010 data) suffer from water deficit on a daily basis. By 2050, the population of Kabul

is expected to reach nine million. Data from 2013 indicate that, currently, Afghanistan Urban Water Supply and Sewerage Company (AUWSSC) is able to provide 15 Lpcd of water, which is only able to supply less than 20% of its population (Mukherjee *et al.*, 2006). Despite having over 7,900 Lpcd of water in the basin, the distribution is limited due to high energy costs (Integrity Watch Afghanistan). Water-borne diseases and infant mortality are concerns due to the lack of sewerage network (only 3%) (Himmelsbach, 2010). Open wells and hand pumps are the only source of water for the majority of the population. As in the case of Quetta, Pakistan, illegal borewells are in abundance in Kabul, and residents have to pay a high price (0.36 USD) to procure water from tankers (Stanikzai, 2014). These illegal borewells have contributed to the unsustainable depletion of groundwater, and the water table dropped by 15 m from 2008 to 2012 (Snyder, 2014). The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP, 2008) estimated per capita water consumption in Afghanistan to be less than half that of other Central and West Asian countries. With an improving standard of living and a projected population of nine million by 2057, an estimated six-fold water consumption increase in the Kabul Basin was simulated in the groundwater-flow model described by Mack *et al.* (2010).

### *Bhutan*

Water is a means of subsistence for over 60% of the population (Dorji, 2016). The urban areas of Bhutan are facing drinking water and sanitation problems due to migration from rural areas. Cities, i.e., Thimou and Puentsholing, are finding it difficult to meet the demand and supply the gap (Bhujel, 2019). A limited supply of treated water, inadequate distribution systems, and flooding due to increase in non-permeable surfaces are primary issues faced by the two cities (Bhujel, 2019).

### **Key issues and challenges for urban water resilience in HKH**

The HKH region is characterized by a unique hydrogeology, in which springs play a crucial role (NITI Aayog, 2018). Aquifers feed into springs which are the main water sources for urban and rural areas. Springs also contribute to base flows in the streams and rivers. In many parts of the HKH, springs fed during the monsoon by groundwater or underground aquifers are reported to be drying up (NITI Aayog, 2018), threatening a whole way of life for local communities. A recent assessment by the Advanced Centre for Water Resource Development and Management (ACWADAM) for the Springs Initiative – through its research in various mountain regions of India, including the Indian Himalaya states of Ladakh, Himachal Pradesh, Uttarakhand, Sikkim, Nagaland and a few pilot areas in Nepal – has estimated that there are nearly four million springs in the Himalaya and that more than 60% of the population living in the IHR is directly dependent on springs (NITI Aayog, 2018). Springs are a safe source of drinking water for rural and urban communities, and with increasing population and urbanization there is an ever-increasing demand for spring water in the region.

Many towns are now turning to borewells for their water supply (Wankhade *et al.*, 2014). This has led to depletion of groundwater and further drying up of springs. Recharge ponds and lakes also play an important role in feeding springs, lakes and streams (MoWR, 2016), but many of these are being filled in or encroached upon due to unplanned and unregulated construction. In response to water scarcity, many towns/cities are sourcing water from distant sources, even including inter-basin transfers.

The cases of Shimla and Almora have shown that there has been very little focus on conserving the existing water sources which have sustained these towns since their existence. For example, the town of Almora used to depend on springs (more than 300 springs at one point in time), but now lifts water from the Kosi River. The capacity of pumps and the water extracted has increased over time, but when the river dries up in summer the town is left with no options (Sharma *et al.*, 2014). In Mussoorie, an ambitious scheme has been proposed to lift water from the Yamuna River approximately 18 km from the town through a process of four-stage pumping. Nainital, conversely, has shifted from complete dependence on springs to 95% dependence on lake bank filtration (Dimri & Dash, 2012). Most springs in the catchment have either become seasonal or have completely dried up. Only one spring remains which provides the remaining 5% of water (Shah & Tewari, 2009).

Pumping water from far distances is likely to be disrupted in extreme weather events, due to blockage, damage to pipes, electricity failure or changes in the source from where water is extracted. Such experiences repeatedly demonstrate that engineering solutions, wherein water is lifted from distant sources at great costs, will not alone be able to sustain the growing urban clusters of the Himalaya in the decades to come. Extremely heavy capital investment, high running costs and depletion of even these distant water sources due to catchment degradation and climate change make this mode of water supply unsustainable in the long run unless augmented by some alternative solutions that reflect local preferences and extant water practices. There is huge scope for undertaking nature-based local level measures such as springshed treatment, protection and rejuvenation of recharge zones of springs and lakes and tapping into indigenous knowledge, but these practices are hardly in use by governments and municipalities even where the scope is high and robust research exists.

Climate change impacts have already been manifested in an increased occurrence of floods and droughts in the region, which affect urban centres more because of the haphazard urban growth that is underway. The Uttarakhand floods of 2013 resulted in havoc for the residents of the urban areas of Chamoli and Rudraprayag and further downstream, while incessant rains for over 24 hours caused severe water logging in Srinagar city in Kashmir in 2014 and 2015. Rapid expansion of the population in urban centres in Afghanistan, Pakistan and low-lying cities of the IHR of India have resulted in severe groundwater extraction and depletion (Rodell *et al.*, 2009). A modest body of work on mountain and hill irrigation exists, but an overarching perspective on water governance in mountain areas is lacking. This is especially true for urban water governance in the mountains and hills of the HKH region, where cities/towns are rapidly growing and facing increasingly serious water challenges. The provision of basic infrastructure such as roads, power, drainage, water, sanitation, recreation, communication and trading facilities demands strong government investment/role.

Challenges pertaining to urban water resilience are poorly understood in the HKH region, although in recent years some attention has been received from researchers and policy-makers. However, huge gaps exist at research and policy level. The HKH region generally evokes the image of idyllic environs untouched by rapid urbanization taking place in plain areas. Hence, the majority of water augmentation/security schemes is focused on large metro-political cities or rural areas. However, contrary to this, 27% of the population in the IHR is urban, which is just 4% below the national average (Sharma *et al.*, 2014). The majority of towns in the HKH region depends on spring water to varying extents. Towns such as Shimla and Mussoorie depend entirely on spring water. Climate change is projected to reduce the spring discharge by increasing evapotranspiration loss, runoffs due to increased rainfall intensity and an increase in impervious surface due to concretization. The current practice of lifting water from distant sources is the norm which is expensive and technically challenging.

Changing climatic conditions combined with population rise, tourism pressure and unplanned developmental activities have also been noticed in several Indian Himalayan urban settlements like Shimla, Manali, Palampur, Almora, Leh and Gangtok, as shown by [Shah & Kulkarni \(2015\)](#). In Gangtok, for example, migration from the surrounding rural areas is leading to the possibility of Gangtok reaching a million inhabitants by 2025. In Dharamshala, reduced rainfall is developing into a water crisis, which is further exacerbated by the tourism industry. The town receives only 2 hours of water supply daily and there are several mismanagement issues which are primarily responsible for the growing crisis.

Of direct relevance to urban water resilience in the region is the widely reported drying up of springs, depleting groundwater resources on which many urban water systems depend ([Pandey, 2018](#)). Some towns also depend on surface water bodies whose catchment areas are being degraded due to urbanization and increases in built-up areas. This unregulated growth prevents aquifer recharge into the ground due to the concretization of what used to be waterways, and soil compaction which also increases runoff that can result in flooding and soil erosion. For example, Phew Lake near the city of Pokhara in Nepal is subject to heavy siltation and dumping of wastes, which affects water availability and quality for residents. Similarly, Lake Nainital is experiencing consistent decline during the summer season as a result of mismanagement of its ‘upstream’ recharge zone ([Dash \*et al.\*, 2008](#)). There is currently no practice or protocol to include hydrogeology in urban planning, therefore no concept of ‘protecting’ recharge zones.<sup>1</sup> Recent initiatives have provided promising approaches to spring water management and ‘springshed development’ activity ([Tambe \*et al.\*, 2012](#); [Mahamuni & Upasani, 2011](#)). Challenges and issues related to urban water are given in [Figure 2](#).

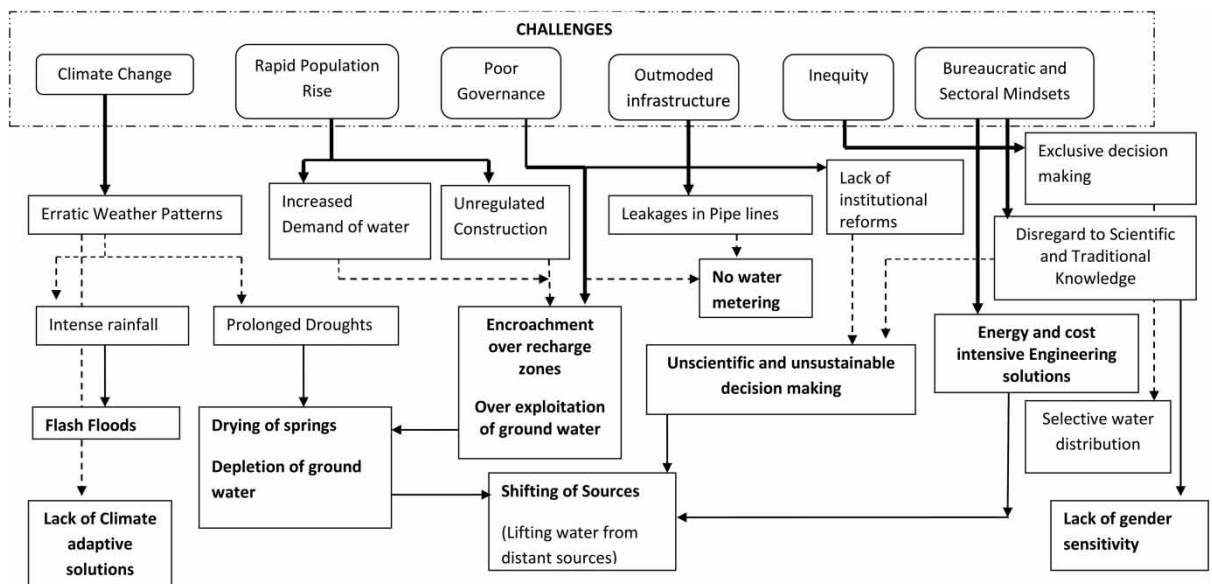


Fig. 2. Challenges and issues related to urban water management in HKH.

<sup>1</sup> Recharge zone is the area around an aquifer which replenishes water stored in an aquifer through precipitation or surface water.



## Recommendations

Promoting urban water resilience will require an understanding of the vulnerability of urban water users and ecosystems to water-related hazards (Romero-Lankao & Gnatz, 2016), which needs to involve planning, policy and action, keeping in mind the mountain characteristics to align urban sustainability and sustainable urban livelihoods. The capacity of urban water users to perceive risks and develop effective responses needs to be built.

In the context of the HKH region, climate change is an important factor that needs consideration in policy and practice through innovative approaches and tools that help create water-resilient cities and ensure quality water services. However, urban water systems cannot be looked at in isolation, hence, integrated multi-sectoral management will be required as industries, the environment and citizens pose competing demands within cities and catchments. These involve:

1. Mapping of water sources and important recharge, filtration or reservoir areas, understanding the demand and supply, keeping in mind the future population projections and changing climatic conditions.
2. Nature of the dependence of local communities on hydrological flows and developing a deeper understanding of recharge zones is also needed.
3. Research needs to be conducted in HKH towns to explore the links between urban and peri-urban water situations; to anticipate and understand possible future changes in water demand and supply with rising populations.
4. Document the links between climate-induced water issues at present and in the future, given the transforming pressures of urbanization in these towns; and to assess how far these towns have incorporated adaptive water governance in the context of changing climatic conditions and related extreme events.

In general, recharge areas of springs are also not well protected and Himalayan towns have generally not included spring protection and restoration in their planning process. Springs are further threatened by changing land use, ecological degradation, exploitation and climate change. Efforts to protect these vital water resources can help ensure water security for towns, but springs have not received adequate attention in the past and present. This has led to a significant data gap in terms of understanding spring water flow dynamics, watershed-related linkages, characteristics of local springs, and the factors leading to their decline in the HKH region.

The water supply of many cities in the HKH currently depends on or plans to source water from distant sources through emerging solutions which are cost and energy intensive and undesirable in the geologically and climate sensitive HKH.

5. Nature-based solutions such as rainwater harvesting, conservation of recharge zones and springshed management hold a great deal of promise; however, such practices have remained confined to municipal bye-laws.
6. Policies around conservation/protection of recharge zones, i.e., spring sheds, recharge areas of lakes and groundwater extraction and catchment areas of rivers catering to the urban populations need to be strengthened.

Governance structures across the urban centres in HKH seem weak and dominated by a certain section of society. Unregulated abstraction of groundwater has led to groundwater depletion in many urban centres of the region. The presence of an informal water market dominated by tanker mafia is seen across water-scarce cities of different countries in the HKH, due to which, water reserves have come under intense pressure. Ground water abstraction policies exist in municipal bye-laws in many cases, however they are seldom followed (Quetta, Kabul, Dehradun, Haldwani), and illegal borewells and overexploitation of groundwater resources remains a problem.

7. Ground water abstraction policies need to be developed/reassessed, keeping in mind the mountainous characteristics and emerging pressures. Groundwater extraction rules are seldom enforced due to the political clout of water-selling mafia to mint money.

Artificial low pricing of water has encouraged poor water management across countries in the HKH, promoting highly inefficient use in domestic, commercial, industrial and agricultural use.

8. Metering, differential pricing systems and incentivizing mechanisms need to be considered for promotion of the judicious use of water.

The cost at which water is supplied through tankers in most cases is extremely high, hence only the affluent members of the population are able to pay the premium. The poor and vulnerable are left at the mercy of government supply which is also not equitably distributed. Inequity in water distribution is a prominent issue across the cities and towns of the HKH. Socio-economically weaker areas within cities experience a 'zero day' at regular intervals, even in cases where water scarcity is not high. Gender sensitivity in terms of planning and community needs is limited to symbolism.

9. Equitable distribution of water and gender sensitive water management practices to benefit the population at the base of the pyramid.

Institutional capacities and urban governance mechanisms to manage water are generally low and poor. Moreover, multiple institutions/departments are involved in supply, management and maintenance of infrastructure related to water, which work in silos, and the lack of engagement within institutions/departments leads to unconnected decisions and actions, only aggravating the problem.

10. Strengthening institutional capacities and improved coordination between departments.

Strong cultural links and the peri-urban nature of many mountain towns helps citizens maintain stronger links with their natural environment than can be seen in larger cities. This has led to successful efforts led by citizens, for example, in Nainital, a group 'citizens for Nainital' have been constantly influencing decision-makers to make sustainable choices for lake conservation. Such efforts can be sustained for long periods. An aware and interested citizenry also lends itself well to citizen science efforts. People in towns like Mussoorie, Haldwani and Dehradun have shown an interest in long-term monitoring, collecting data and compiling long-term records which will reflect trends and changes. Citizen science could play a key role in data gathering; required are productive linkages between scientists, citizen groups and policy-makers. Although a significant amount of awareness exists among scientists and

policy-makers, urban water management from the climate change perspective has not really received enough attention in policy documents, i.e., state action plans for climate change.

#### 11. Strengthening links between scientists, policy-makers and citizens.

Behavioural change through awareness programmes, knowledge empowerment and citizen/stakeholder engagement in data collection and inclusiveness in decision-making is necessary to build robust and equitable policies around water management in urban centres. Several projects have also focused on sensitization at different levels, building awareness, generating a substantive database in different countries at different levels, involving communities as well as water utilities and municipal governments. Data deficiency is another issue; basic data on rainfall, temperature is not available even for established urban centres, and researchers have to rely on regional data which seldom provide accurate results, given the heterogeneity of HKH and the mountains and microclimatic conditions of the towns.

#### 12. Knowledge empowerment and involving citizens in data collection and decision-making.

Today, people have access to better tools to connect, and the translated information may result not only in sharing of information but also experiencing citizens' knowledge. Networking of citizens may create an active role for them to participate in science and decision-making. The internet has opened up space for citizens to seek scientific empowerment through the web. Large amounts of technical data exist within institutions; however, it is seldom translated to a wider audience. Using apps and the internet is a possible way to disseminate information to achieve smart water management practices, and smart citizens.

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### References

- Balk, D., Montgomery, M. R., McGranahan, G., Kim, D., Mara, V., Todd, M. & Dorélie, A. (2009). Mapping urban settlements and the risks of climate change in Africa, Asia and South America. *Population Dynamics and Climate Change* 80, 103.
- Bhujel, G. D. (2019). *Water Woes: Investments, Infrastructures, Policies and Advocacies*, *Kuensel*. Available at: <http://www.kuenselonline.com/water-woes-investments-infrastructures-policies-and-advocacies/>.
- Cosgrove, W. J. & Loucks, D. P. (2015). *Water management: current and future challenges and research directions*. *Water Resource Research* 51, 4823–4839. <https://doi.org/10.1002/2014WR016869>.

- Dash, R. R., Mehrotra, I., Kumar, P. & Grischek, T. (2008). Lake bank filtration at Nainital, India: water quality evaluation. *Hydrogeology Journal* 16, 1089–1099. doi 10.1007/s10040-008-0295-0.
- Devkota, K. (2018). Challenges of inclusive urbanization in the face of political transition in Nepal. In: *Handbook of Research on Urban Governance and Management in the Developing World*. Makerere, J. M. & Katusimeh, M. W. (eds). IGI Global, Hershey, PA.
- Dimri, A. P. & Dash, S. K. (2012). Wintertime climatic trends in the western Himalayas. *Climatic Change* 111(3), 775–800.
- Djebou, D. C. S. & Singh, V. P. (2016). Impact of climate change on precipitation patterns: a comparative approach. *International Journal of Climatology* 36(10), 3588–3606.
- Dorji, Y. (2016). *Water Securing Bhutan's Future*. Asian Development Bank/National Environment Commission. The Asian Development Bank/National Environment Commission Royal Government of Bhutan Thimphu, Bhutan. [www.adb.org/](http://www.adb.org/) [www.nec.gov.bt](http://www.nec.gov.bt).
- Eriksson, M., Xu, J., Shrestha, A. B., Vaidya, R. A., Santosh, N. & Sandström, K. (2009). *The Changing Himalayas: Impact of Climate Change on Water Resources and Livelihoods in the Greater Himalayas*. International Centre for Integrated Mountain Development (ICIMOD), Lalitpur, Nepal.
- Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X. & Briggs, J. M. (2008). Global change and the ecology of cities. *Science* 319(5864), 756–760.
- Himmelsbach, T. (2010). Groundwater Resources at Risk – Kabul Basin, Afghanistan – Assessment of the present situation and consequences for the future. In: *International Conference, Integrated Water Resources Management*, Karlsruhe, Germany, pp. 24–25.
- Hofer, T. & Messerli, B. (2006). Floods in Bangladesh: history, dynamics and rethinking the role of the Himalayas. *Ecology* 29, 254–283.
- Ishtiaque, A., Shrestha, M. & Chhetri, N. (2017). Rapid urban growth in the Kathmandu Valley, Nepal: monitoring land use land cover dynamics of a Himalayan city with Landsat imageries. *Environments* 4, 72.
- Jalilov, S.-M., Masago, Y., Nishikawa, J., Bai, X., Elmqvist, T., Takeuchi, K. & Fukushi, K. (2017). Enhancing Urban Water Resilience: Science-based Approaches and Strategies for Asian Megacities. Policy Brief (No. 9, 2017).
- Kakar, Z., Shah, S. & Khan, M. (2018). Scarcity of water resources in rural area of Quetta District; challenges and preparedness. In: *IOP Conference Series: Materials Science and Engineering*, Quetta, Pakistan, p. 414. doi:10.1088/1757-899x/414/1/012013.
- Khan, F. (2009). *Water Governance and Corruption in Pakistan. Running on Empty: Pakistan's Water Crisis*. Woodrow Wilson International Centre for Scholars, Asia Program, Washington, DC.
- Mack, T. J., Akbari, M. A., Ashoor, M. H., Chornack, M. P., Copen, T. B., Emerson, D. G., Hubbard, B. E., Litke, D. W., Michel, R. L., Plummer, L. N., Rezai, M. T., Senay, G. B., Verdin, J. P. & Verstraeten, I. M. (2010). *Conceptual Model of Water Resources in the Kabul Basin, Afghanistan*. U.S. Geological Survey scientific investigations report 2009–5262, 240 pp. Available at: <http://pubs.usgs.gov/sir/2009/5262>.
- Mahamuni, K. & Upasani, D. (2011). *Springs: A Common Source of A Common Resource, IASC-2011, Digital Library of The Commons*. Indiana University, Bloomington, IN.
- MoWR (2016). Repair, Renovation and Restoration of Water Bodies – Encroachment on Water Bodies and Steps Required to Remove the Encroachment and Restore the Water Bodies. In: *10th Report, Sixteenth Lok Sabha Standing Committee on Water Resources, Ministry of Water Resources, River Development and Ganga Rejuvenation*, New Delhi, India.
- Mukherjee, A., Sengupta, M., Hossain, M., Ahamed, S., Das, B., Nayak, B., Lodh, D., Rahman, M. M. & Chakraborti, D. (2006). Arsenic contamination in groundwater: a global perspective with emphasis on the asian scenario. *Journal of Health, Population and Nutrition* 24(2), 142–163. Available at: <http://www.jstor.org/stable/23499353>.
- NITI Aayog (2018). *Report of Working Group I Inventory and Revival of Springs in the Himalayas for Water Security*. Available at: [http://niti.gov.in/writereaddata/files/document\\_publication/doc1.pdf](http://niti.gov.in/writereaddata/files/document_publication/doc1.pdf)
- Pandey, K. (2018). Crisis in the Himalayas: nearly 50% perennial springs in the region have dried up. *Down to Earth*. Available at: <https://www.downtoearth.org.in/news/india/crisis-in-the-himalayas-nearly-50-perennial-springs-in-the-region-have-dried-up-61482>.
- Pokharel, S. (2014). Pokhara making do with three decades old water supply system. *Republica*. Nepal Republic Media, 25 May 2014. Web. 16 August 2014.
- Rodell, M., Velicogna, I. & Famiglietti, J. S. (2009). Satellite based estimates of groundwater depletion in India. *Nature* 460, 999–1002.

- Romero-Lankao, P. & Gnatz, D. M. (2016). Conceptualizing urban water security in an urbanizing world. *Current Opinion in Environmental Sustainability* 21, 45–51.
- Shah, M. & Kulkarni, H. (2015). Urban water systems in India typologies and hypotheses. *Economic and Political Weekly* 50, 57–69.
- Shah, S. & Tewari, A. (2009). Impact of human disturbance on forest vegetation and water resources of Nainital Catchment. *Nature and Science* 2009, 74–78. Available at: <http://www.sciencepub.net/nature>.
- Sharma, D., Singh, R. & Singh, R. (2014). Building urban climate resilience: learning from the ACCCRN experience in India. *International Journal of Urban Sustainable Development* 6(2), 133–153.
- Singh, V. & Pandey, A. (2018). Climate and development; a diagnostic assessment since the formation of uttarakhand. In: *Development Dynamics of Himalayan State*, Vol. 1. Nutiyal, R. R. & Datta, R. (eds). Kalpraz Publications, New Delhi, India, pp. 157–179.
- Singh, S. P., Singh, V. & Skutsch, M. (2010). Rapid warming in the Himalayas: ecosystem responses and development options. *Climate and Development* 2(3), 221–232.
- Singh, S., Hassan, S. T. M., Hassan, M. & Bharti, N. (2019). Urbanisation and water insecurity in the Hindu Kush Himalaya: insights from Bangladesh, India, Nepal and Pakistan. *Water Policy* wp2019215. <https://doi.org/10.2166/wp.2019.215>.
- Snyder, A. (2014). *Shortage in the Mountains of Plenty: Water Supply in Mountain and Hill Cities Throughout the Hindu-Kush Himalayan Region*, ICIMOD and The World Food Prize. Available at: [https://www.worldfoodprize.org/documents/filelibrary/images/youth\\_programs/2014\\_interns/2014\\_br\\_research\\_papers/SnyderAbigail\\_LONGReport\\_56ED38F157B76.pdf](https://www.worldfoodprize.org/documents/filelibrary/images/youth_programs/2014_interns/2014_br_research_papers/SnyderAbigail_LONGReport_56ED38F157B76.pdf)
- Srinivasan, V., Lambin, E. F., Gorelick, S. M., Thompson, B. H. & Rozelle, S. (2012). The nature and causes of the global water crisis: syndromes from a meta-analysis of coupled human-water studies. *Water Resources Research* 48(10), 1–16.
- Stanikzai, J. (2014). Illegal wells hurting Kabul's water supply. *Tolo News* 14 August 2013.
- Stewart, J. (2017). *Growth for Low-Income Countries?* United Nations University. Available at: <https://unu.edu/publications/articles/growth-for-low-income-countries.html>.
- Suwal, B. R. (2013). *Internal Migration in Nepal*. UNESCO Gender and Youth Migration. A UNESCO online initiative on migration. Available at: <http://www.unescogym.org/>.
- Tambe, S., Kharel, G., Arrawatia, M., Kulkarni, H., Mahamuni, K. & Ganeriwala, A. (2012). Reviving dying springs: climate change adaptation experiments from the Sikkim Himalaya. *Mountain Research and Development* 32(1), 62–72.
- Tiwari, A. (2012). Water quality and quantity analysis in Sikkim, North Eastern Himalaya. *Current Science* 103, 41–45.
- Tiwari, P. C., Tiwari, A. & Joshi, B. (2018). Urban growth in Himalaya: understanding the process and options for sustainable development. *Journal of Urban and Regional Studies on Contemporary India* 4(2), 15–27.
- UNDESA (2018). *Revision of World Urbanization Prospects*. UN Department of Economic and Social Affairs, New York, p. 16.
- United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) (2008). *Statistical Yearbook for Asia and the Pacific 2007*. UNESCAP. Available at: <http://www.unescap.org/stat/data/syb2007/ESCAP-SYB2007.pdf> (Accessed 5 September 2012).
- Wakode, H. B., Baier, K., Jha, R. & Azzam, R. (2018). Impact of urbanization on groundwater recharge and urban water balance for the city of Hyderabad. *India. International Soil and Water Conservation Research* 6(1), 51–62.
- Walker, B. (2011). *Urban Peaks in the Himalayas*. *China Dialogue*. Available at: <https://www.chinadialogue.net/article/show/single/en/4306Urban-peaks-in-the-Himalayas>.
- Wankhade, K., Krishnachandran, B. & Vishnu, M. J. (2014). *Sustaining Policy Momentum, Urban Water Supply & Sanitation in India*. IIHS RF Paper on Water Supply and Sanitation, IIHS, Bangalore.
- Zhan, M., Li, X., Sun, H., Zhai, J., Jiang, T. & Wang, Y. (2018). Changes in extreme maximum temperature events and population exposure in China under global warming scenarios of 1.5 and 2.0 °C: analysis using the Regional Climate Model COSMO-CLM. *Journal of Meteorological Research* 32(1), 99–112.

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