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Water scarcity and excess: water insecurity in cities of Nepal

Gyanu Maskey [a,b,*], Chandra Lal Pandey[a] and Monika Giri[b]

[a] Department of Development Studies, Kathmandu University School of Arts, Kathmandu, Nepal
[b] Southasia Institute of Advanced Studies, Kathmandu, Nepal
*Corresponding author. E-mail: maskeygyanu@gmail.com

GM, 0000-0002-1047-1776

ABSTRACT

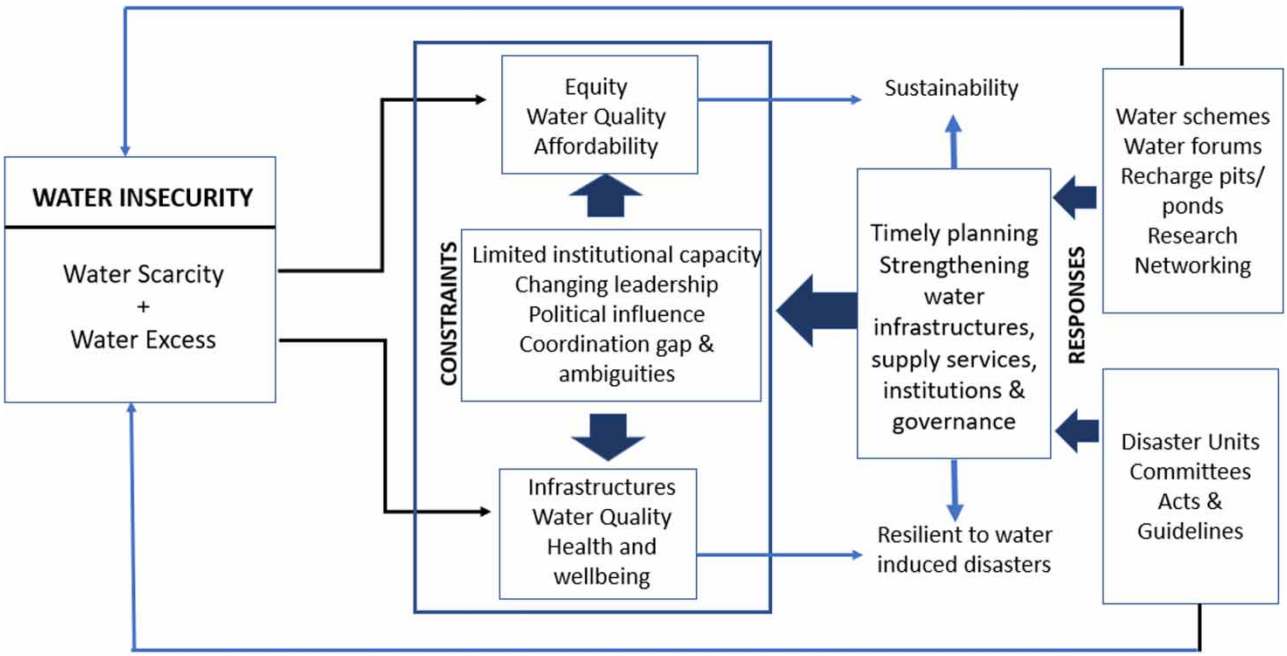
The world is facing the greatest and most complex twin challenges of water insecurity: scarcity and excess, with their adverse consequences on health, well-being, and developmental outcomes. Against this backdrop, we analyzed the challenges households face due to 'too much and too little water'. The research employed a qualitative methodology in which data were collected through 40 key informant interviews, informal conversations, and observations during 2020–2021 including a relevant literature review. We note that both 'too much and too little water' pose risks to water insecurity. Also, water security cannot be ensured by only dealing with water inadequacy without building a resilient water system and robust institutions. We found that water scarcity has affected other components of water security such as equity, quality, and affordability. Excess water has impacted water infrastructures, degrading the water quality, and risking human health and well-being. The responses to the water challenges were hindered by several constraints such as the limited capacity of the water institutions, frequent leadership changes, political influence, and emerging challenges in the federal context. We suggest timely planning and adopting site-specific innovations to address water scarcity and excess challenges, which include strengthening water services, infrastructures, institutions, and governance.

Key words: excess water, Nepal, urban water security, water insecurity, water institutions, water scarcity

HIGHLIGHTS

- 'Water scarcity and excess water' are twin challenges of water security.
- Water scarcity has affected equity, quality, and affordability, and excess water has impacted water infrastructures.
- Institutional responses for urban water security are inadequate and aggravated by multiple constraints.
- Timely planning and strengthening of water supply services and institutional capacity are crucial.

GRAPHICAL ABSTRACT



1. INTRODUCTION

While a billion people live in areas of physical water scarcity, an excess of water resulting in floods and landslides has also affected millions of lives across the world (Majumder 2015; Su *et al.* 2020). Urban areas have particularly realized the effects of 'water scarcity and excess' in terms of quality, quantity, and water-related disasters (Hoekstra *et al.* 2018). Recent studies demonstrate that haphazard urbanization, rapid urban population growth, water and energy-intensive lifestyles, socio-economic–agricultural practices, and weak water governance have put water resources systems under unprecedented stress (Mishra *et al.* 2021; Pandey 2021). Additionally, climate change is altering global temperature patterns and transforming the global hydrological regime, affecting the Himalayan Water Towers and natural water systems (Hussain *et al.* 2021). Climate-influenced water scarcity and excess have impacted people's lifestyles and livelihood, culture and social systems, agriculture, mining, and hydropower industries (Gao *et al.* 2017; Sithirith 2021). Cities in the Himalayan region have also experienced water issues, making them water insecure (Singh *et al.* 2020). The increasing mismatch of water supply and demand in the era of climate change has deepened the water crisis in the cities of Nepal (Dahal *et al.* 2019; Prakash & Molden 2020; Singh *et al.* 2020). Therefore, understanding water availability at sources as well as discharge variability is imperative for devising robust water management strategies (Kumar & Sen 2018).

With the world heading toward a global water crisis, the developing and least-developed countries suffer the most from water scarcity, excess, and contamination (Grey & Sadoff 2007) and are disproportionately affected by extreme weather events (Watson *et al.* 2007). The developed countries encompass strong institutional, engineering, technological, and economic ability to develop and operate complex water resources systems to adapt to climate and population changes (Garrote 2017). Developed cities are adopting innovative approaches, infrastructural investments, and policies in addressing water insecurity. Grecksch & Landström (2021) discuss participatory approaches such as Environmental Competency Groups that enable the co-production of new knowledge incorporating scientific and experience-based local perspectives. Others include adaptive and integrated paradigms in water governance (Johannessen *et al.* 2019), smart water systems, water infrastructures for storage, stormwater management, filtration, groundwater recharge, and policy incentives (IPCC 2022). However, global South countries including Nepal are facing severe constraints associated with urban water security related to resources, capacity and infrastructure deficit, and lack of integrated urban, water, and climate policies and programs (Maskey *et al.* 2020; Talat 2021).

The recent literature is focused on addressing scarcity and ensuring water access (Mitlin *et al.* 2019; Tzanakakis *et al.* 2020; He *et al.* 2021) that suggests potential solutions by augmenting the water supply. 'Resilience' has been typically linked with the ability of water systems to maintain continuous water supply services and ensure water access (Rodina 2019), while other studies have focused on the impacts of excess water (Hungerford *et al.* 2019; Shen *et al.* 2019; O'Donnell *et al.* 2020). Except for a few studies (Pradhan *et al.* 2012; Sithirith 2021) that have focused on both the water scarcity and excess risks, there is a dearth of literature integrating both water scarcity and excess aspects for securing water, particularly in regard to drinking water and how institutions respond. In this backdrop, we analyzed the challenges that urban households were facing in meeting their domestic water needs in the context of 'too much and too little water'. In doing so, we explored the two fundamental issues of urban water insecurity: water scarcity and water excess. Connected to this exploration, we investigated the following two interconnected research questions: (a) how does 'too little' and 'too much' water challenge urban water security? and (b) how are urban water governance and institutions responding to manage urban water security?

The following section discusses the water security literature and provides a conceptual review of urban water security. Section 3 gives a brief background of water insecurity challenges in Nepal, followed by the methodology in section 4. Section 5 presents the research findings and discussion. We sum up the paper and present the conclusion in section 6.

2. URBAN WATER SECURITY: A CONCEPTUAL REVIEW

The concept of water security has broadened from a human-centric approach to include ecological concerns, risk perspective, and nexus approach, and from a quality, availability, and quantity focus to accessibility, affordability, sustainability, and institutional and governance aspects (Cook & Bakker 2012). The definitions of water security were linked to specific human security issues such as military security, food security and more rarely environmental security. It was only in 2000 that the environmental value and sustainability issues were incorporated. The term was further widened to include environmental, economic, and social issues connecting to food security since the 1960s, energy security since the 1970s, health security since the 1980s, and the nexus of water, energy, and food since 2009.

Scholars note that the water security conceptual framing has been conventionally centered on themes such as availability, accessibility, affordability, and fulfillment of human needs or meeting the water demand and supply (Cook & Bakker 2012; Brears 2017). The traditional paradigm for water security emphasized physical availability or quantity, however, water security is considered to exist when an individual has access to sufficient, safe, and affordable water to satisfy their drinking, washing, and livelihood needs (Rijsberman 2006). The literature on water security notes that a country is water secure if there is a balance between the supply and demand of water (Sullivan 2002). However, it is also noted that the scarcity of water is only one focus, with little consideration of excess water including flood risks and environmental ecosystems (Su *et al.* 2020).

Urban water security has been divided into three pillars: water resource security, water environment security, and water disaster security inter-relating to quantity and quality aspects (Su *et al.* 2020). Water stress and availability, human development needs, food security, sustainability, and vulnerability of the water systems to hazards are also recognized as important dominating themes (Cook & Bakker 2012). Grey & Sadoff (2007) note that '*water security refers to the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies*' (refer to Figure 1). This definition highlights both scarcity and excess that are referred to by multiple scholars (Beck & Walker 2013; Grey *et al.* 2013).

The paper has adopted the water security framework incorporating both the scarcity and excess components that pose risks to urban water security. We define **urban water security** as a condition in which a city is sustainably able to manage a sufficient quantity of good quality water; distributes equitably at an affordable cost; and at the same time, the water infrastructures are resilient to water-induced disasters such as floods and landslides. Therefore, in the water scarcity part, we referred to the water security components as availability or quantity, quality, sustainability, equity, affordability, and in the excess part, resilience of water systems to water-induced disasters. We believe that scarce water and excess water in the form of water unavailability, floods and landslides can severely disrupt the normal life system of communities and bring unexpected shocks.

3. WATER INSECURITY IN NEPAL

Despite plentiful water resources, water insecurity in Nepal is ubiquitous (Pandey 2021). According to the Department of Water Supply and Sewerage Management (DWSSM), only 51.69% of the population have piped water coverage while 48.31% rely on non-piped locally and privately managed systems such as private tube wells (DWSSM 2019). The

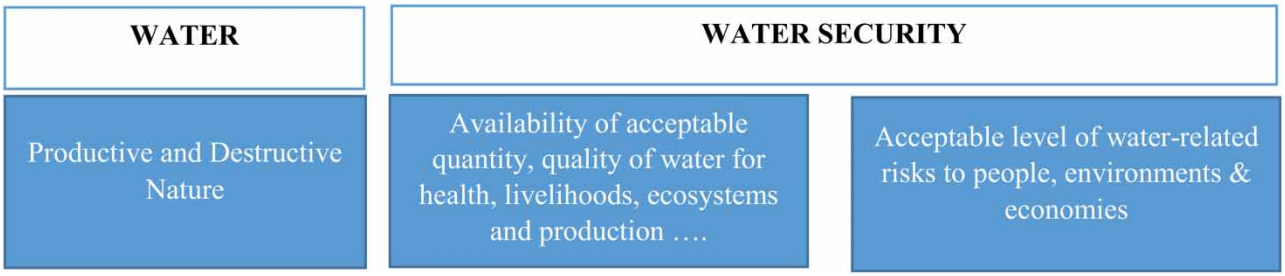


Figure 1 | Water security: highlighting both scarcity and excess water (Adapted from Grey & Sadoff, 2007).

WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply, Sanitation, and Hygiene report of the 20 years (2000–2020) noted that safely managed improved water supply sources have dropped to 18% from 24% with an increase in non-piped coverage from 36% in 2000 to 44% in 2017 (JMP 2021). While water demand is increasing significantly in urban areas such as Kathmandu valley (Saraswat *et al.* 2017), excess water causing floods, landslides, GLOF (glacial lake outburst flood), and soil erosion have led to destructive impacts in Nepal.[1]

Studies have shown that the impacts of climate change have caused water stress during this century and influence water resource availability in the future (Gurung *et al.* 2019; Dahal *et al.* 2020). The situation of scarce and excess water already persistent is exacerbated by climate change with changes in monsoon patterns and temperature. The average annual maximum temperature of Nepal has increased by 2.4 °C (0.056 °C/year) over the 44 years from 1971 to 2014 (DHM 2017). Precipitation has also become more variable, with an increase in extreme precipitation events (Karki *et al.* 2017), while the mean rainfall has been decreasing by 3.7 mm (−3.3%) per month per decade (GoN 2017), indicating more droughts and depletion of water resources. Toward the end of the century, the climate-change scenarios for Nepal suggest a significantly wetter and warmer climate (MoFE 2019). Climate-related changes have already impacted many sectors, including water, disaster management, forests, energy, biodiversity, agriculture, health, urban planning, and livelihood-related activities (MoFE 2019). They also affect the quantity, quality, and timing of water availability and thus exacerbate water insecurity (Nepal *et al.* 2021).

In addition, climate-induced disasters have increased the frequency of landslides and soil erosion in the hills, and floods and inundations in Terai (Ahmad *et al.* 2018). Flooding impacts on drinking water can be observed ranging from physical damage to water infrastructures having implications in water distribution, quantity, and quality aspects. The impact of flood-water accumulation poses risks to household drinking water structures specifically in the lowlands, causing inundation of wells, tube wells and community water systems.

4. METHODOLOGY

4.1. Research approach

The research applies a qualitative approach to analyze the challenge in domestic water supply led by too little and too much water. The study sites are Dhulikhel, Dharan, and Khairahani Municipalities. The sites represent a diverse geographical coverage and have the issues of water scarcity and excess. While Dhulikhel is a hilltop town, Dharan and Khairahani are located in Terai region, struggling for water security.

The data collection was done during 2020–2021. Primary data have been collected through 40 key informants' interviews conducted on both water scarcity- and excess-related issues in three study sites. The key informants included the local elected representatives, water and disaster management officials, representatives from water management institutions,[2] drinking water project officials, and community people. Insights from informal conversations, transect walks, and participatory observations were also captured. Primary data on water scarcity and excess were triangulated using secondary reviews. Also, primary data collected from certain stakeholders (for instance, communities) were verified with other stakeholders (local elected representatives and municipal officials). The research was conducted complying with the research ethics of

[1] Koshi flood in 2008, the Far-west flood in 2008, and the Terai flood in 2017.

[2] Water Users Committee, Water Board, Nepal Water Supply Corporation, non-governmental organizations.

anonymizing the key informants' identity, avoiding disclosing harmful information and obtaining prior consent for recording interviews.

Field insights were captured in the detailed notes and transcriptions of the interviews were done. The primary data were analyzed using thematic coding and primary themes identified included, for instance, the issues of water scarcity and water excess, impacts of water scarcity and excess, institutional responses in securing water, institutional constraints, and others. Secondary data consisted of, inter alia, water-related policies, journal articles, books and municipal programs, and policies.

4.2. Case study sites

The study focuses on three municipalities of Nepal, Dharan in eastern Nepal, and Dhulikhel and Khairahani in central Nepal (Figure 2). Dhulikhel is a hilltop and Dharan and Khairahani are Terai towns, facing water scarcity and also prone to water-induced disasters. From a disaster vulnerability point of view, Dharan and Khairahani are more susceptible to increased stormwater runoff and floods during monsoons. Dhulikhel brings water from the distant Roshi River beyond its local jurisdiction and is susceptible to damage to water infrastructures due to floods and landslides during monsoon. The populations in Dharan, Dhulikhel, and Khairahani municipalities are 200,000, 32,026, and 56,094, respectively.

5. RESEARCH FINDINGS AND DISCUSSION

This section presents the findings of the research focusing on how too little and too much water is challenging urban water security. Further, it also discusses how urban water institutions are responding to manage urban water security and the related challenges.

5.1. Water scarcity and excess in the case study sites

Our analysis showed Dharan and Dhulikhel experience severe water scarcity while Khairahani Municipality is more impacted by floods and landslides. Drinking water is supplied in Dhulikhel by the exemplary community-managed Dhulikhel

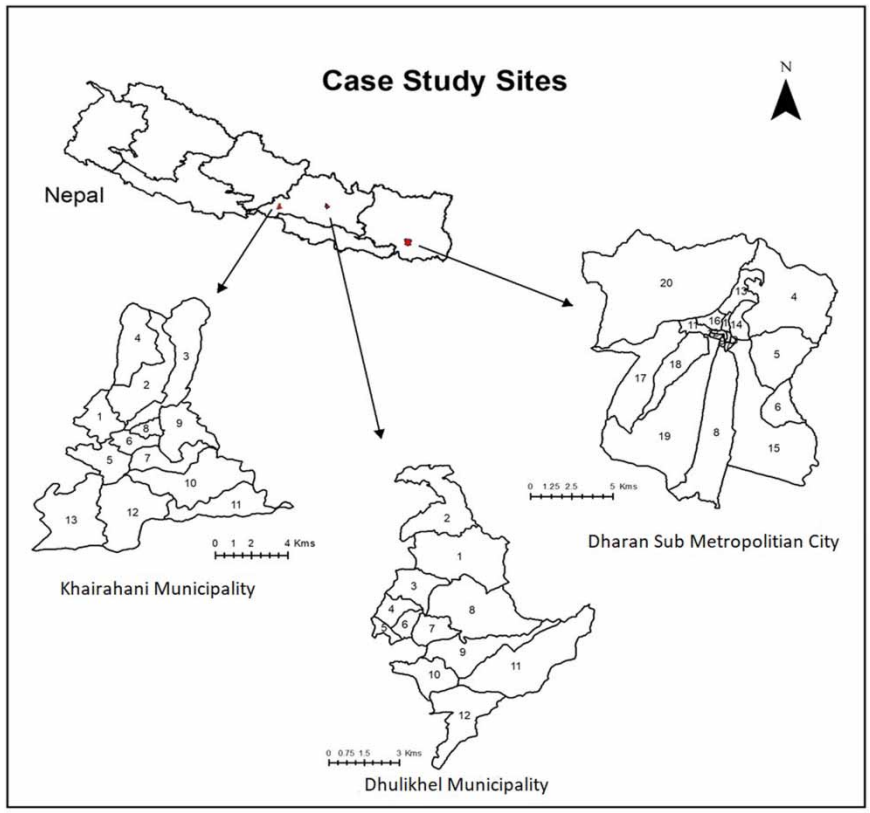


Figure 2 | Map showing the case study sites: Khairahani Municipality, Dharan Sub Metropolitan City, and Dhulikhel Municipality with their respective ward numbers. *Note:* ward is the lowest administrative unit.

Drinking Water and Sanitation Users Committee (DDWSUC) funded by German aid. According to the project representatives, the Asian Development Bank-funded scheme Kavre Valley Integrated Water Supply Project (KVIWSP)[3] is near completion. The water supply in Dhulikhel is 1.8 MLD, whereas the demand is 3.9 MLD (McManus *et al.* 2021).

Dharan, situated at the foothills, has limited surface runoff from the catchment areas. Koshi River is situated at a distance of 14 km from the city and Tamor at 25 km. Despite these high-volume rivers, more than 2,000 mm mean annual rainfall and porous geology supporting rapid infiltration, the steep gradient leads to rapid drain-out of rainwater. Only about half of its water demand is fulfilled during the dry months. The current water supply is 15 MLD while the demand is 30 MLD. The city water supply system consists of tapped water from multiple sources – mainly upstream catchment flows and groundwater extraction. In Dharan, drinking water problems are more severe in the slum settlements.[4] Compared with Dharan and Dhulikhel, domestic water scarcity is not a problem in Khairahani Municipality due to groundwater dependency (mostly tube wells). Drinking water is supplied partly by the Small Towns Water Supply and Sanitation Sector Project[5] and also by Nepal Water Supply Corporation (NWSC), small water supply projects and the water users committee. However, most people use tube-well water as the source and those with piped water supply also use it as an alternative source.

On the excess part, Khairahani Municipality is more prone to flooding during the monsoon although all three sites are vulnerable to multiple disasters including floods and landslides. Dhulikhel lies in Kavrepalanchok district, which is one of the most landslide-prone districts and is identified as a 'Landslide Hazard Hotspot' in Nepal (MoFE 2021). In Dharan, the squatter settlements along the banks of the Sardu and Seuti rivers are at high risk due to continuous floods and wet landslides during monsoon. Floods affect Khairahani communities almost every year, causing human casualties, crop damage, property loss, and displacement.[6]

5.2. Too little and too much water challenging urban water security

Our research found that the urban water security of the study sites is challenged by too little and too much water. Water scarcity and excess have affected other components of water security (such as equity, quality, and affordability) while the sustainability component has not received proper attention in the study sites.

Firstly, our research showed that the scarcity of water is leading to inequitable water distribution between core and peripheral areas of the study sites and the peripheral communities are facing the challenge of poor-quality water. Water institutions such as NWSC, Water Board, DDWSUC, and drinking water schemes in the research sites supply piped water only to the core wards or the city area while the annexed peripheral wards (due to restructuring) are dependent on natural water sources and are under the municipal program of one-house–one-tap. This was because the water projects were designed to supply water to the core areas only and it is very challenging to extend the water service areas with limited water sources. While people at the core city enjoy the drinking water supplied through larger drinking water schemes with filtration facilities, the marginal annexed areas and slum settlements suffer quality-related issues. The annexed areas are inhabited by economically marginalized populations and present health risks such as waterborne diseases. In Khairahani, there is a concern over arsenic in groundwater, but many of the locals are unaware about this and consume the water without any treatment, assuming that the groundwater is always clean and safe to drink. One of the respondents from ward number 13 said,

> *'Water from tube well is not fit for drinking in some places. When we boil water, some white substance settles at the bottom so we are not fully sure about water quality. I heard before 1993, this was not there but now it may be due to the pollution and the chemicals used in the agricultural field.'*

Out of 36,000 households in Dharan, 10,000 households depend on unsafe water sources. Likewise, in Khairahani, water connections have not yet reached all the Chaudhari communities residing in rural/peripheral areas and they are using water from tube wells. These communities including the peripheral communities in Dhulikhel and Dharan and slum

[3] Water supplies in three towns of Kavre including Dhulikhel (Banepa, Panauti and Dhulikhel).

[4] Supply in wards 11, 18 and 17.

[5] Supply in wards 6, 8, 5, 9, 3, 12 and 13.

[6] The flooding risk has also increased after the formation of dams in the Narayani-Gandaki river basins in 1979, which has elevated challenges associated with flooding in the areas where floods were not experienced before.

settlements in Dharan are unable to afford piped water connections. In the three study sites, limited water availability has ignited water conflicts among core–periphery, upstream–downstream, and rich and poor settlements due to increased issues of inequitable and unaffordable access to water. We concur with other studies' findings that competing use of water and inequitable water distribution within towns aggravate the conflicts (Ranganathan 2014). At the same time, water quality has been compromised in the peripheral communities and among the poor and marginalized people (Grasham *et al.* 2019; Maskey *et al.* 2021).

We also found that the water scarcity has led water users to extract groundwater through deep-boring wells in all three sites; however, the sustainability aspect has received limited attention. In Khairahani, the plan for long-term water supply is not a concern at all since they shared that they did not have a water scarcity problem. An environmental officer of the municipality shared,

> *'We have not done any planning as such. As our area falls in the Chure,*[7] *we have to take permission for every small activity we do from the President Chure Terai Madhesh Conservation Board. There are many water sources here so much of the interest is not given in the conservation aspect. Even if we try to do some activities here, it is very difficult to convince people here as they do not think they have to worry much about water now.'*

Although the Himalayan mountains are considered the 'Water Towers' of South Asia, the Himalayan towns have been encountering a water scarcity crisis due to multifaceted pressures such as increasing population, unplanned urbanization, intensifying impacts of climate change, changing lifestyles and mismanagement of water institutions. These pressures are leading toward urban water scarcity, resulting in inequitable water distribution and driving toward urban water insecurity (Hoekstra *et al.* 2018; Maskey *et al.* 2021; Pandey 2021).

Secondly, our findings showed that **too much water** has impacted all three case-study sites, primarily disrupting the water supply and polluting water. The participants noted the susceptibility of water infrastructures to floods and landslides in every monsoon season. During the floods, the poor water infrastructure further degraded and lowered the quality of filtration and water distribution. Before the merging of NWSC with the Water Board and implementation of the ADB project, NWSC supplied water in Dharan with degraded water infrastructures as it has been supplying water for the last 35 years. An NGO representative shared:

> *'Previously, the pipes, filtration and tanks of NWSC–overall infrastructures were in poor condition and the intakes were temporary that were damaged during the floods each year. Even the permanent structures were of a poor system and often required repair and maintenance.'*

The recent change in the institutional mechanism of water governance through the merging of NWSC to the Water Board has upgraded the water infrastructure. Likewise, in May 2020, the water pipeline of Dhulikhel was damaged by the pre-monsoon flood of Kharkhola and Punyamata rivers. The damage to these pipelines disrupted the water supply for few days until the infrastructures were repaired. The Chair of the small water users committee in Dharan shared that the pipes are managed by hanging through poles which are damaged by floods every year in monsoon. The supply of piped water in areas across the river in Khairahani has proven to be challenging due to the high risk of pipe damage during floods. The monsoon season poses a particular threat, as the pipes are often swept away, inundating the entire bazaar area and adversely affecting the drinking water system. However, in contrast to the hills, Khairahani is a flat area where water is primarily collected from the ground, therefore there are fewer issues with infrastructure damage in the municipality. We also found that the water brought from distant sources experienced damage at a larger scale and required additional efforts to resume the supply. Similar to our findings, other studies have also highlighted the impacts of floods causing damage to water infrastructures (Abbas & Routray 2014; Sithirith 2021).

Another distinct impact of too much water was poor water quality due to pollution. Contamination of drinking water has been considered the most serious consequence of flooding (Sun *et al.* 2016). During heavy rainfall, high runoff combined with pollution at the source contributes to water pollution. The key participants reported that even animal carcasses and faeces are

[7] The Chure Region, foothills of the Himalayas, spreads east–west parallel to the high mountains covering 12.8% of Nepal.

carried along with the water during floods in the Shardu River of Dharan. Furthermore, the chair of the community-managed water supply committee noted a significant increase in pollution at the Shardu source during the COVID-19 lockdown period, as people indulged in bathing and swimming in the area. In Khairahani, flood water inundated houses, causing septic tanks to overflow and mix with tap water. The key informants shared that flood water also swept through waste, dumping sites and toilets, polluting the water. An excerpt from the community in Khairahani illustrates this:

> *'Mixing of toilet waste is another problem during monsoon. Flood water enters everywhere be that toilets or houses and are logged in the fields anytime. Water enters septic tanks also and fills the tanks and overflows. That is normal for people here during the monsoon season.'*

Flood water also brought debris and dirt with it, causing waterlogging in the flat land. Eventually, the seeping of polluted water into the ground led to groundwater pollution, causing waterborne diseases. According to studies, use of contaminated water bears a high risk of health implications including waterborne illnesses (Bariweni *et al.* 2012).

5.3. Responses and constraints of water institutions in securing water

This section discusses the responses made by water institutions in dealing with both the water scarcity and excess issues in the study sites and the constraints faced by them. The Constitution of Nepal 2015 and the Local Government Operation Act 2017 have provided full authority of local water management to local government. The Water Board has emerged as a new institution in Dharan with the merging of NWSC amid the reluctance from NWSC. In Dhulikhel, DDWSUC is expected to merge with KVIWSB[8] but they too are reluctant. This came into formation with the implementation of the ADB-funded drinking water project as a response to fulfill the water demand–supply gap. In Khairahani, the Small-Towns Water Supply Project and NWSC are partly supplying water.

Further, these institutions have been responding to secure water in the study sites through several efforts and engagements (as shown in Table 1). For instance, Dharan Municipality has adopted a subsidy policy to rebate building construction permission revenue. The municipality has encouraged rainwater harvesting by providing a 30% subsidy on building permit revenue for households that install a rainwater harvesting system during the construction of a house (Rai *et al.* 2019). Around 13,000 households in Dharan have rainwater harvesting structures installed and almost one-fifth of the households were found to have collected rainwater as a coping strategy for water scarcity (Rai *et al.* 2019). Also, the building of recharge pits is a requirement set forth by the Dharan Municipality for the construction of new private and public structures. Similarly, Dhulikhel Municipality has adopted the policy of 'one house, one tap' which aims to provide drinking water access to all households. The municipality has also collaborated in various water conservation initiatives, including recharge ponds. Both municipalities have also engaged in research and collaboration, and organized water forums such as 'Paani Chautari'. This forum, which is comprised of water-related stakeholders, was established as an informal platform to promote knowledge-sharing on water-related issues and fostering collaboration between different water users. Nonetheless, there exist several challenges to sustainability and ownership of such initiatives and leadership-related challenges. In Khairahani, water scarcity is not a significant concern due to greater reliance on groundwater, and therefore, water conservation initiatives have not received a priority.

In dealing with disasters due to excess water like floods and landslides, we found that separate disaster units have been established in all the three municipalities. These units are responsible for implementing flood-related early-warning systems, constructing embankments, distributing relief aid and carrying out rescue operations. The municipalities have also formed Palika-level disaster management committees, established disaster management funds and formulated local-level disaster management Acts/Guidelines.

However, the damage to water-related infrastructures during floods and landslides comes under the purview of institutions managing water distribution. For instance, although Dharan has an Environment and Disaster Unit, the impacts of floods in the water supply are managed through the Water Board. It deploys technicians to repair the infrastructure. Likewise, water management institutions have been managing such situations. For instance, the Water Board has upgraded the old water infrastructures of NWSC (with flocculation and good filtration capacity). In response to the water supply disruption

[8] As per the provision in Drinking Water Supply Management Board Act (2006).

Table 1 | Responses to water scarcity and excess

SN	Responses in research sites to address water scarcity	Policy significance
1.	ADB-funded drinking water projects in Dharan and Dhulikhel; a small-town water supply and sanitation project in Khairahani	Water supply projects bring in opportunities to augment the water supply. However, large-scale water schemes need to ensure source sustainability (surface and groundwater) and the conservation of locally available water sources.
2.	Water forums termed 'Pani Chautari' in Dharan and Dhulikhel	Participatory approaches and forums amongst local government, community and researchers can collectively opt for context-specific solutions to address water insecurity. Municipal leadership in continuing such discussions is crucial.
3.	Rainwater harvesting promotion in Dharan by the municipality; mandatory provision of recharge pits to build new houses in Dharan and recharge ponds in the forest area in Dhulikhel	Mandatory municipal policy provisions in implementing nature-based solutions help address water crisis and manage stormwater runoff as well as groundwater recharge. Hence, integrating climate-adaptive water systems and proper monitoring of policies' implementation is key to action.
4.	Research and awareness on watershed conservation by CETD[a] in Dharan, a local NGO with INGOs IUCN and ICIMOD; and municipal partnerships and collaborations with Kathmandu University, and other institutions in water-related research and engagements in Dhulikhel	Research and institutional collaboration on addressing water security challenges by the local government can strengthen planning and evidence-based policymaking. It also facilitates the exchange of innovative ideas and best practices among cities, both nationally and internationally. Municipal leadership and continuous engagement seeking collaborative approaches is important.
	Responses in research sites to address excess water	**Policy significance**
5.	A separate disaster management unit set at variable capacity in the study sites	A separate disaster management unit at the municipal level and ward levels ease focused responses. Institutional strengthening with human resource expertise, and further focus beyond providing instant relief to managing drinking water issues brought about by climate-induced disasters, is necessary.
6.	Local disaster acts and guidelines	Local governments' initiatives toward formulating disaster acts and guidelines are facilitating efficient disaster response. However, forthcoming policies need to tailor context-specific needs, be practical in implementation, and enhance the expertise of municipal staff.
7.	Disaster management fund established	A disaster management fund established is a positive step but the amount deposited in the fund is insufficient. To ensure community resilience before, during and after disasters, an adequate fund is needed.

[a]Center for Environment and Tourism Development.

caused by the severe floods in Khar Khola of Bhumidanda which serves as the source of drinking water in Dhulikhel, DDWSUC employed various measures. They resorted to using groundwater extraction, stored water and supply through water tankers, reduced the time of water supply and appealed to the public to reduce their water consumption through social media announcements. In addition, they also sourced water from the nearby forest water source and supplied it through public taps. Despite the considerable expenses incurred by DDWSUC for repairs and water infrastructure maintenance damaged by floods, the committee claims to have received no support from the municipality for handling water-related disasters.

We observed the municipal responses are primarily focused on instant relief distribution, awareness raising, arranging safe shelters and providing compensation for damage from disasters.[9] Khairahani Municipality also ensured that the blocking of roads did not persist for a long time, for which they mobilized tractors from the municipality or rented them. While most of

[9] For instance, Khairahani Municipality provided instant support of USD 23–76 and USD 76 for the total loss for house damage and USD 23–54 for the partial damage of the house or the animal shed.

the municipal budget is spent on infrastructure development, the municipalities have not provided support to the water user committee, who manage the water themselves (in peripheral and slum settlements in Dharan and Dhulikhel). Even rescue areas such as schools and public buildings during disasters lacked basic sanitation and drinking water.

While responding to securing water, the water institutions faced an array of constraints. The key respondents have also shown concern over several constraints in disaster response effectiveness such as a lack of expertise in disaster response. For instance, the unfilled position of the environmental engineer was noted in Dharan. The Deputy Mayor of Dharan also highlighted lack of expertise in formulation of disaster-related acts, policy, and institutional mechanisms. The municipal representatives shared the need for capacitating the local government in human and financial resources. We found that there is a difference in the capacity of the three municipalities with Dharan in a better position with the environmental inspector and three persons dedicated to the Forest, Environment, and Disaster Unit (along with 70 staff in sanitation). Dhulikhel and Khairahani have a separate Disaster Unit with one officer-level member of staff and civil engineer assigned to the role of disaster management in Dhulikhel and Khairahani, respectively.

In Dharan and Dhulikhel municipalities, we found an inimical relationship between existing water-related institutions and the municipality. For instance, DDWSUC members shared the tussle with the municipality and on the other hand, the municipal authorities including Mayor/Deputy Mayor blamed DDWSUC for not cooperating with them. DDWSUC often claimed a weak financial situation with no contribution or support from the municipality. In the Federal context, the issue of overlap of authority was also stressed by the representative of the Disaster Unit in Dharan who explained the municipality's resistance or denial with district authorities of the Ministry of Home Affairs. Additionally, according to the key informants, change in municipal leadership has made conservation initiatives challenging. For instance, the formation of the watershed conservation committee and initiation of the payment for ecosystem services mechanism by engaging and convincing the municipal leadership became futile with change in leadership.

Conjointly, ineffective water governance was linked to the political appointment of the members of the Water Board, for which concerns were raised for the transparent selection of Water Board members. A former Water Board member claimed that he represented an NGO working in the water sector but was replaced with a ward chair. He was disappointed with this recruitment as he came to know that the ward chair registered the watershed conservation committee and took the chair position merely to become a member. Further, women's representation in the Water Board is not mandatory and the Dharan Water Supply Management Board (DWMB) has not made any provision to include women on the board.[10] The policy provision of having 30% women in the Water Act (Water Supply Management Board Act 2006) is limited to community-managed water projects and the DWMB is silent on the inclusion of women in municipal-level water management boards. The Deputy Mayor (female) was represented previously in the absence of the Mayor, but now the (male) Mayor is elected and the Deputy Mayor and municipal executive officer are invitees to the Board's meetings. There have been demands for the representation of women and indigenous people in the Water Board by the drinking water struggle committee.

Prior studies on water institutions and policy have also noted similar challenges hampering efficient and equitable urban water management (Ojha *et al.* 2019; Pandey *et al.* 2019). While institutions play a major role in responding to crises of water scarcity and excess, there is limited institutional capacity to adapt to the situation during scarce and excess water. The constraints on local governments' capacity include inadequate information, lack of resources, technical capacity, and skills for responses in the water sector and lack of transparency and citizen trust in water service delivery (Naidoo *et al.* 2016). Studies in Nepal have also reported that water governance and management challenges exist with local governments including the efficiency and effectiveness of water services through enhanced capacity of staff, water utility reform, reduction of leakage and elimination of non-revenue water (NIUA 2015). Furthermore, the water institutions are facing challenges in developing climate-adaptive measures to combat climate risks due to inadequate knowledge (Pandey 2021).

6. CONCLUSION

We discussed the key challenges posed by both 'too little and too much water' in the three study sites. We also reflected on the constraints faced by water institutions and their responses for urban water security.

[10] DWMB has the provision of all the seven-member board formed under the leadership of the mayor; however, none of the representing organizations in the board are headed by women, which excluded women from being members of the board.

Firstly, our analysis revealed that Dharan and Dhulikhel are facing a dual challenge of coping with acute water scarcity and excess water, whereas Khairahani Municipality is primarily affected by floods. Likewise, the water systems in the cities of the Terai region face the challenges of floods while the hills are susceptible to landslides, causing disruptions in water supply and distribution. The findings hence show that the Himalayan cities are prone to both aspects of water security: scarcity and excess determined by their geographical location, nature and distance of water sources, water infrastructure and institutional capacity of the water institutions. Further, water scarcity is found to affect other components of water security such as equity, quality and affordability; and excess water has impacted water infrastructures, degrading the water quality, risking human health and well-being. Hence, variable context-specific responses considering both scarcity and excess aspects are to be incorporated in planning and responses by water institutions.

While augmenting water supply, ensuring access and source sustainability are imperative for meeting the growing water need and declining water, it is equally important alongside this to prioritize the responses toward the development of resilient water infrastructures and assessment of the potential impact of excess water, particularly on drinking water. It is thus crucial to take into consideration disaster vulnerability and its implications on water-related infrastructures particularly for the large-scale donor-funded water projects bringing water from distant sources, beyond their jurisdictions, as in Dhulikhel. All aspects of the water supply system need to be carefully examined, which include protection of water sources or catchment, efficient water collection, treatment, affordable pricing, and an equitable distribution system.

Secondly, our findings revealed that strengthened institutional capacity is key to urban water security. In the study sites, the responses to water-related challenges were further hindered by several constraints such as the limited capacity of the water institutions, frequent leadership changes, political influence, and emerging challenges in the federal context. Additionally, there was a lack of municipal support in addressing drinking water issues during floods, and the disaster responses were also not prompt. The municipal responses followed an 'event driven' pattern, without thorough assessment of actions prior to implementation. It is thus essential to ensure that water institutions are more responsive and overcome the constraints and risk factors to ensure a robust water governance system. To achieve this, the institutions must prioritize strategies, and climate monitoring should form an integral part of local development planning. In addressing the impact of excess water and disruptions to drinking water, engineering solutions are often favored as a first option. However, it is crucial to strengthen water supply and sanitation services and institutional capacity prior to the disaster event.

In sum, to ensure urban water security, a holistic approach is necessary. This entails addressing both scarcity and excess, as these factors can impact other components of water security discussed above. It is important to note that living in a water-rich environment does not necessarily guarantee water security. Access to quality water, affordable water and resilient water infrastructures that can withstand water-induced disasters are also the crucial determinants of water security. We suggest timely planning and adopting contextual and site-specific innovations to address water scarcity and excess. This can include improving water services, quality, and its equitable distribution, bolstering water infrastructures, strengthening water institutions, and enhancing water governance.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Abbas, H. B. & Routray, J. K. 2014 Vulnerability to flood-induced public health risks in Sudan. *Disaster Prevention and Management* **23** (4), 395–419.

Ahmad, T., Shrestha, A. M., Das, S. K., Darnal, K., Neupane, R., Pote, R., Dangol, B., Shakya, R. & Paudel, D. 2018 Impact of climate change on WASH services: a case from Nepal. In: *Proceedings of 41st WEDC International Conference*, Egerton University, Nakuru, Kenya.

Bariweni, P. A., Tawari, C. C. & Abowei, J. F. N. 2012 Some environmental effects of flooding in the Niger Delta region of Nigeria. *International Journal of Fisheries and Aquatic Sciences* **1** (1), 35–46.

Beck, M. B. & Walker, R. V. 2013 On water security, sustainability, and the water-food-energy-climate nexus. *Frontiers of Environmental Science & Engineering* **7**, 626–639.

Brears, R. C. 2017 *Urban Water Security*. Wiley & Sons, Singapore.

Cook, C. & Bakker, K. 2012 Water security: debating an emerging paradigm. *Global Environmental Change* **22**, 94–102.

Dahal, N., Shrestha, U. B., Tuitui, A. & Ojha, H. R. 2019 Temporal changes in precipitation and temperature and their implications on the streamflow of Rosi River, Central Nepal. *Climate* **7** (1), 3.

Dahal, P., Shrestha, M. L., Panthi, J. & Pradhananga, D. 2020 Modeling the future impacts of climate change on water availability in the Karnali River Basin of Nepal Himalaya. *Environmental Research* **185**, 109430.

DHM 2017 *Observed Climate Trend Analysis in the Districts and Physiographic Regions of Nepal (1971–2014)*. Department of Hydrology and Meteorology, Government of Nepal, Kathmandu, Nepal.

DWSSM 2019 *Drinking Water and Sanitation Status – 2075 BS* Government of Nepal, Kathmandu, Nepal.

Gao, L., Bryan, B. A., Liu, J., Li, W., Chen, Y., Liu, R. & Barrett, D. 2017 Managing too little and too much water: robust mine-water management strategies under variable climate and mine conditions. *Journal of Cleaner Production* **162**, 1009–1020.

Garrote, L. 2017 Managing water resources to adapt to climate change: facing uncertainty and scarcity in a changing context. *Water Resources Management* **31**, 2951–2963.

GoN 2017 *National Climate Change Impact Survey 2016: A Statistical Report*. Central Bureau of Statistics, Kathmandu, Nepal.

Grasham, C. F., Korzenevica, M. & Charles, K. J. 2019 On considering climate resilience in urban water security: a review of the vulnerability of the urban poor in sub-Saharan Africa. *Wiley Interdisciplinary Reviews: Water* **6** (3), 1344.

Grecksch, K. & Landström, C. 2021 Drought and water scarcity management policy in England and Wales – current failings and the potential of civic innovation. *Frontiers in Environmental Science* **9**, 574975.

Grey, D. & Sadoff, C. W. 2007 Sink or swim? Water security for growth and development. *Water Policy* **9**, 545–571.

Grey, D., Garrick, D., Blackmore, D., Kelman, J., Muller, M. & Sadoff, C. 2013 Water security in one blue planet: twenty-first century policy challenges for science. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* **371**, 20120406.

Gurung, A., Adhikari, S., Chauhan, R., Thakuri, S., Nakarmi, S., Ghale, S., Dangol, B. S. & Rijal, D. 2019 Water crises in a water-rich country: case studies from rural watersheds of Nepal's mid-hills. *Water Policy* **21** (4), 826–847.

He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J. & Bryan, B. A. 2021 Future global urban water scarcity and potential solutions. *Nature Communications* **12** (1), 4667.

Hoekstra, A. Y., Buurman, J. & van Ginkel, K. C. H. 2018 Urban water security: a review. *Environmental Research Letters* **13**, 053002.

Hungerford, H., Smiley, S. L., Blair, T., Beutler, S., Bowers, N. & Cadet, E. 2019 Coping with floods in Pikine, Senegal: an exploration of household impacts and prevention efforts. *Urban Science* **3** (2), 54.

Hussain, S., Aslam, M. U., Javed, M., Zahra, M., Ejaz, H., Kubra, K. & Mushtaq, I. 2021 Impact of climatic changes and global warming on water availability. *Anthropogenic Pollution* **5** (2), 57–66.

IPCC 2022 *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.

JMP 2021 *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2020: Five Years into the SDGs*. World Health Organization (WHO), Geneva, Switzerland and the United Nations Children's Fund (UNICEF), New York, USA.

Johannessen, Å., Gerger Swartling, Å., Wamsler, C., Andersson, K., Arran, J. T., Hernández Vivas, D. I. & Stenström, T. A. 2019 Transforming urban water governance through social (triple-loop) learning. *Environmental Policy and Governance* **29** (2), 144–154.

Karki, R., Hasson, S., Schickhoff, U., Scholten, T. & Böhner, J. 2017 Rising precipitation extremes across Nepal. *Climate* **5** (1), 4.

Kumar, V. & Sen, S. 2018 Evaluation of spring discharge dynamics using recession curve analysis: a case study in data-scarce region, Lesser Himalayas, India. *Sustainable Water Resources Management* **4** (3), 539–557.

Majumder, M. 2015 *Impact of Urbanization on Water Shortage in Face of Climatic Aberrations*. Springer, Singapore.

Maskey, G., Pandey, C. L. & Shrestha, K. K. 2020 Securing water in the rapidly urbanising global South: insights from critical analysis of 'sectoral policies' in Nepal. *New Angle: Nepal Journal of Social Science and Public Policy* **6** (1), 9–31.

Maskey, G., Pandey, C., Bajracharya, R. M. & Moncada, S. 2021 Inequity in water distribution and quality: a study of mid-hill town of Nepal. *World Water Policy* **7** (2), 233–252.

McManus, P., Pandey, C., Shrestha, K., Ojha, H. & Shrestha, S. 2021 Climate change and equitable urban water management: critical urban water zones (CUWZs) in Nepal and beyond. *Local Environment* **26** (4), 431–447.

Mishra, B. K., Kumar, P., Saraswat, C., Chakraborty, S. & Gautam, A. 2021 Water security in a changing environment: concept, challenges and solutions. *Water* **13** (4), 490.

Mitlin, D., Beard, V. A., Satterthwaite, D. & Du, J. 2019 *Unaffordable and Undrinkable: Rethinking Urban Water Access in the Global South*. Working Paper, World Resources Institute, Washington, DC, USA.

MoFE 2019 *Climate Change Scenarios for Nepal for National Adaptation Plan (NAP)*. Ministry of Forests and Environment, Government of Nepal, Kathmandu, Nepal.

MoFE 2021 *Vulnerability and Risk Assessment and Identifying Adaptation Options: Summary for Policy Makers*. Ministry of Forests and Environment, Government of Nepal, Kathmandu, Nepal.

Naidoo, S., Rodda, N., Stenström, T. A., Schmidt, S., Dent, M., Bux, F., Hanke, N., Buckley, C. A. & Fennemore, C. 2016 Water security in South Africa: perceptions on public expectations and municipal obligations, governance and water re-use. *Water SA* **42** (3), 456–465.

Nepal, S., Neupane, N., Belbase, D., Pandey, V. P. & Mukherji, A. 2021 Achieving water security in Nepal through unravelling the water-energy-agriculture nexus. *International Journal of Water Resources Development* **37** (1), 67–93.

NIUA 2015 *Compendium of Global Good Practices – Urban Water Supply*. National Institute of Urban Affairs in association with Cities Alliance, New Delhi, India.

O'Donnell, E., Thorne, C., Ahilan, S., Arthur, S., Birkinshaw, S., Butler, D., Dawson, D., Everett, G., Fenner, R., Glenis, V., Kapetas, L., Kilsby, C., Krivtsov, V., Lamond, J., Maskrey, S., O'Donnell, G., Potter, K., Vercruysse, K., Tudorel, V. & Wright, N. 2020 The blue-green path to urban flood resilience. *Blue-Green Systems* **2** (1), 28–45.

Ojha, H., Kovacs, E. K., Devkota, K., Neupane, K. R., Dahal, N. & Vira, B. 2019 Local experts as the champions of water security in the Nepalese town of Dhulikhel. *New Angle: Nepal Journal of Social Science and Public Policy* **5** (1), 165–176.

Pandey, C. L. 2021 Managing urban water security: challenges and prospects in Nepal. *Environment, Development and Sustainability* **23** (1), 241–257.

Pandey, C. L., Maskey, G., Devkota, K. & Ojha, H. 2019 Investigating the institutional landscape for urban water security in Nepal. *Sustainability: The Journal of Record* **12**, 173–181.

Pradhan, N. S., Khadgi, V. R., 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*. ICIMOD, Kathmandu, Nepal.

Prakash, A. & Molden, D. 2020 Editorial mapping challenges for adaptive water management in Himalayan towns. *Water Policy* **22** (S1), 1–8.

Rai, R. K., Neupane, K. R., Bajracharya, R. M., Dahal, N., Shrestha, S. & Devkota, K. 2019 Economics of climate adaptive water management practices in Nepal. *Heliyon* **5** (5), e01668.

Ranganathan, M. 2014 'Mafias' in the waterscape: urban informality and everyday public authority in Bangalore. *Water Alternatives* **7** (1), 89–105.

Rijsberman, F. R. 2006 Water scarcity: fact or fiction? *Agricultural Water Management* **80** (1–3), 5–22.

Rodina, L. 2019 Defining 'water resilience': debates, concepts, approaches, and gaps. *Wiley Interdisciplinary Reviews: Water* **6** (2), e1334.

Saraswat, C., Mishra, B. K. & Kumar, P. 2017 Integrated urban water management scenario modeling for sustainable water governance in Kathmandu Valley, Nepal. *Sustainability Science* **12** (6), 1037–1053.

Shen, Y., Morsy, M. M., Huxley, C., Tahvildari, N. & Goodall, J. L. 2019 Flood risk assessment and increased resilience for coastal urban watersheds under the combined impact of storm tide and heavy rainfall. *Journal of Hydrology* **579**, 124159.

Singh, S., Tanvir Hassan, S. M., Hassan, M. & Bharti, N. 2020 Urbanisation and water insecurity in the Hindu Kush Himalaya: insights from Bangladesh, India, Nepal and Pakistan. *Water Policy* **22** (S1), 9–32.

Sithirith, M. 2021 Downstream state and water security in the Mekong region: a case of Cambodia between too much and too little water. *Water* **13** (6), 802.

Su, Y., Gao, W., Guan, D. & Zuo, T. 2020 Achieving urban water security: a review of water management approach from technology perspective. *Water Resources Management* **34**, 4163–4179.

Sullivan, C. 2002 Calculating a water poverty index. *World Development* **30** (7), 1195–1210.

Sun, R., An, D., Lu, W., Shi, Y., Wang, L., Zhang, C., Zhang, P., Qi, H. & Wang, Q. 2016 Impacts of a flash flood on drinking water quality: case study of areas most affected by the 2012 Beijing flood. *Heliyon* **2** (2), e00071.

Talat, N. 2021 Urban water-supply management: indirect issues of climate change leading to water scarcity scenarios in developing and underdeveloped nations. In: *Water Conservation in the Era of Global Climate Change* (B. Thokchom, P. Qiu, P. Singh & P. K. Iyer, eds), Elsevier, Amsterdam, The Netherlands, pp. 47–71.

Tzanakakis, V. A., Paranychianakis, N. V. & Angelakis, A. N. 2020 Water supply and water scarcity. *Water* **12** (9), 2347.

Watson, J. T., Gayer, M. & Connolly, M. A. 2007 Epidemics after natural disasters. *Emerging Infectious Diseases* **13** (1), 1.

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