CHAPTER 5

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Cryospheric change, adaptation, and sustainable development in the mountain societies of the Hindu Kush Himalaya

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Chapter overview

KEY FINDINGS

Improvements in the lives of mountain people have generally followed increased accessibility and economic development. Despite this, their marginal and vulnerable status has hardly changed (*medium confidence*). In fact, marginality and vulnerability have probably worsened as the climate changes and the cryosphere changes with it (*medium confidence*). Mountain societies dependent on agriculture, livestock, and medicinal and aromatic plants are facing the serious adverse effects of cryospheric change (*high confidence*). Cryospheric change will continue to have significant implications for societies, particularly those that rely on high mountain freshwater (*high confidence*).

Intensifying cryospheric change, population growth, and infrastructure development in mountainous areas have exposed communities to increased cryosphere-related hazards (*medium confidence*). The risks posed by cryosphere-related hazards are becoming more unpredictable, and future cryosphere-related disasters will be costlier and deadlier (*medium confidence*). Risk perception among mountain societies – whether communities over- or underestimate potential cryosphere-related hazards and disaster risks – is a significant determinant of how cryospheric change and the associated adverse consequences will be identified and prioritised (*medium confidence*).

The adaptation approaches undertaken by mountain societies so far have been largely autonomous and incremental in nature, mostly limited to the household and community levels (*high confidence*). There are large gaps between the adaptation needs of communities and their access to or the provision of the necessary adaptation support (*high confidence*). There are soft as well as hard limits to adaptation, which constrain responses and make mountain livelihoods highly vulnerable to a changing cryosphere (*high confidence*).

POLICY MESSAGES

It is urgent to address adaptation needs through synergised sectoral policies. Effective adaptation is key to maintaining sustainable mountain development, which increases the capacity of mountain societies to adapt – with enhanced speed, scope, and depth. To facilitate sustainable development in the mountains, policies across multiple sectors need to address the myriad pressures faced by mountain societies, taking into consideration their needs and aspirations, including the need to adapt to a changing cryosphere. Sectoral policies need to examine the nature, extent, and implications of the soft and hard limits to adaptation and guide the development of synergised adaptation actions. This is particularly important in the context of socioeconomic and political marginalisation and warming beyond 1.5°C. There is also the need to plan anticipatory responses to potentially irreversible changes in the cryosphere of the Hindu Kush Himalaya (HKH).

Implementing inclusive adaptation policies and practices is critical for sustainable mountain development in the HKH. The tenets of social and environmental justice and sustainable development must be incorporated into adaptation policies and practices if vulnerable and marginalised communities are to respond effectively to changes in the cryosphere. Policies need to ensure the protection of the non-economic assets of mountain societies – cultural heritage and spiritual and religious beliefs, for instance, which are critical for societal well-being, but are threatened by cryospheric change.

Strengthening regional and global cooperation and collaboration is urgently needed to address the impacts of cryospheric change. There is an urgent need to cultivate cooperation in the generation, exchange, and sharing of knowledge among global, regional, national, and local actors in the common interest and for co-benefits. Collaborative efforts to understand the transboundary implications of cryospheric change can not only help fill existing knowledge gaps but also strengthen cooperation on data and information sharing, cross-learning, and scaling of adaptation options from one location to another. Regional and global cooperation are needed for technical and financial assistance to facilitate adaptation and mitigation, and to advocate for matters of common interest to mountain societies.

CHAPTER SUMMARY

The HKH region is experiencing non-climatic as well as cryospheric drivers of change (*high confidence*). Cryospheric change in the region has implications for the lives and livelihoods of more than 1.9 billion people. Understanding the intersections between cryospheric change and societies is essential to undertaking effective adaptation policies and practices to achieve the Sustainable Development Goals.

Impacts of non-climatic drivers of change

People in the HKH region are experiencing multiple climatic and non-climatic drivers of change. These drivers of change are interwoven and have significant impact on the lives and livelihoods of mountain people as well as their capacity to respond or adapt to these changes. Mountainous areas in the region have witnessed economic growth and infrastructural and technological development, which is expected to continue (*high confidence*). Access of local communities to governmental institutions and their services is improving (*high confidence*), but this is also resulting in a weakening of traditional institutions (*high confidence*), with implications for adaptive capacity.

Impacts of cryospheric change on society

The major livelihoods of mountain communities are agriculture, livestock, tourism, and the collection and trading of medicinal and aromatic plants. The contribution of cryospheric services to these mountain livelihoods is high (*high confidence*). Cryospheric change, particularly changes in snowfall pattern, have adversely affected the livelihoods of communities (*high confidence*). Major adverse impacts include crop loss and failure, fodder shortage, livestock deaths, decrease in the availability of medicinal and aromatic plants, and degradation of aesthetic experiences. In many areas, communities have abandoned agriculture and pastoralism in response to cryospheric change and other non-climatic drivers of change (*medium confidence*). These impacts have increased the socioeconomic vulnerability of mountain communities (*high confidence*), including food and nutrition insecurity. However, there are a few short-term positive impacts of cryospheric change on agriculture, pastoralism, and tourism – such as improved access to previously inaccessible sites for animal grazing and tourism. As the cryosphere changes along with the social, economic, and political dynamics in mountain societies, these cryosphere–livelihood linkages may gradually decrease (*low confidence*).

High mountain communities in the HKH region are heavily dependent on snow and glacial meltwater to meet their water needs (*high confidence*). This reliance is not limited to mountainous areas. Water supply systems in downstream regions, including in densely populated urban settlements, are dependent on meltwater for domestic and commercial purposes (*high confidence*). Along with growing demand, poor management, and insufficient infrastructure, cryospheric change is likely to further exacerbate water shortages in the region (*high confidence*). Water stress in transboundary river basins in the HKH region – particularly the Indus, Ganges, and Amu Darya – have led to both conflicts as well as cooperation for managing water resources among the countries sharing the river basins (*medium confidence*).

Components of the cryosphere also play a major role in the cultural, religious, and spiritual beliefs and practices of high mountain societies and influence their well-being (*medium confidence*). Human societies have ascribed spiritual relevance to the high mountains since ancient times; pilgrimages to the mountains have been made since the beginning of recorded human history. Tied to the spiritual reverence Indigenous communities hold for their natural environs is the understanding that there is a need to protect the local environment, including its cryospheric components (*low confidence*). Loss of the aesthetic properties of the mountains, glaciers, and snow cover could be perceived as a loss of honour and pride and be interpreted as consequences of diminished morality and ethics (*low confidence*). These effects could potentially decrease the attractiveness of high mountain sites for tourists, impacting local livelihoods (*low confidence*).

Cryosphere-related hazards in the region have caused significant losses and damages of property, infrastructure, and lives, including tangible and intangible cultural heritage (*high confidence*). These disasters have led to a loss of traditional knowledge, increased social and economic burdens, and caused psychological stress and displacement (*high confidence*). People's perceptions of cryosphere-related risks are shaped by socioeconomic, cultural, religious, and political factors, all of which determine their responses (*low confidence*). Cryosphere-related hazards are becoming more complex and devastating as they are increasingly interlinked with other environmental extremes (e.g., landslides, rockfall, seismic activity, and heavy rain), creating cascading hazards (*medium confidence*). The exposure of people and infrastructure to these hazards has increased due to a rise in population and an intensification of economic activities in the region (*medium confidence*). Cryosphere-related hazards are projected to increase in the HKH region in the future, adding investment burdens with long-term implications for national and regional economies (*medium confidence*).

Understanding of the implications of cryospheric change on livelihoods, water supply, and cultural heritage in upstream and downstream communities remains inadequate for robust adaptation action and effective sustainable development (*high confidence*).

Adaptation to cryospheric change

Adaptation measures adopted by households and communities in response to cryospheric change can be broadly categorised as behavioural, technological, infrastructural, financial, regulatory, institutional, and informational. Behavioural and technological measures are the most reported across different sectors. These measures are mostly reactive, autonomous, and incremental in nature, and unable to fulfil the necessary speed, depth, and scope of adaptation (*high confidence*). With cryospheric change possibly taking on unprecedented trajectories, these measures may not be effective in the long term. There are concerns that communities may not be able to cope with an increased magnitude and complexity of extreme events as they try and navigate persistent socioeconomic challenges (*high confidence*).

Local communities are already abandoning their traditional livelihoods and settlements, pointing towards an evident adaptation deficit to cryospheric change (*medium confidence*). Constraints and limits to adaptation, along with insufficient understanding of the interactions between cryospheric and non-climatic drivers and the associated impacts on mountain societies, could potentially hinder the overall target of achieving the Sustainable Development Goals (*medium confidence*). To address this, there is an urgent need to integrate adaptation to cryospheric change with sustainable development, specifically in the high mountains (*high confidence*).

KEY KNOWLEDGE GAPS

The interactions between the cryospheric and non-climatic drivers of socio-ecological changes and their respective influence on the lives and livelihoods of mountain societies – including non-economic aspects such as spiritual practices and belief systems – remain insufficiently understood. Without better understanding of the cascading consequences of cryospheric change and associated adaptations, the extent of actual or potential maladaptation – responses that shift the burden of addressing cryospheric change to other places (downstream as well as transboundary), systems (ecosystems), or times (future) – will be difficult to anticipate and avoid. There is an urgent need to improve understanding of the complex nature of cryosphere-related hazards, including their transboundary consequences and implications for losses and damages.

Interdisciplinary studies examining the nexus of changes in the cryosphere, hydrosphere, biosphere, and society will help inform adaptation measures that attend to the myriad pressures faced by mountain societies. Greater involvement with local and Indigenous communities, including greater respect for diverse knowledge systems, is essential to identifying adaptation options that attend to context-specific experiences of the interlinked processes of change.

Both the effectiveness and inclusiveness of exiting adaptation measures remain poorly understood. Evaluation of the effectiveness of adaptation should be informed by tenets of social and environmental justice and, more broadly, of sustainable development.

Given the significant shortfalls in existing adaptation efforts, there are concerns about what global warming beyond 1.5°C will mean for cryosphere-dependent socioeconomic systems in the HKH. There is an urgent need to initiate research that examine the nature, extent, and implications of the hard limits to adaptation associated with warming beyond 1.5°C. Such studies should be undertaken with the aim of informing anticipatory responses to projected reductions in the cryosphere of the HKH.

Contents

5.1. Introduction

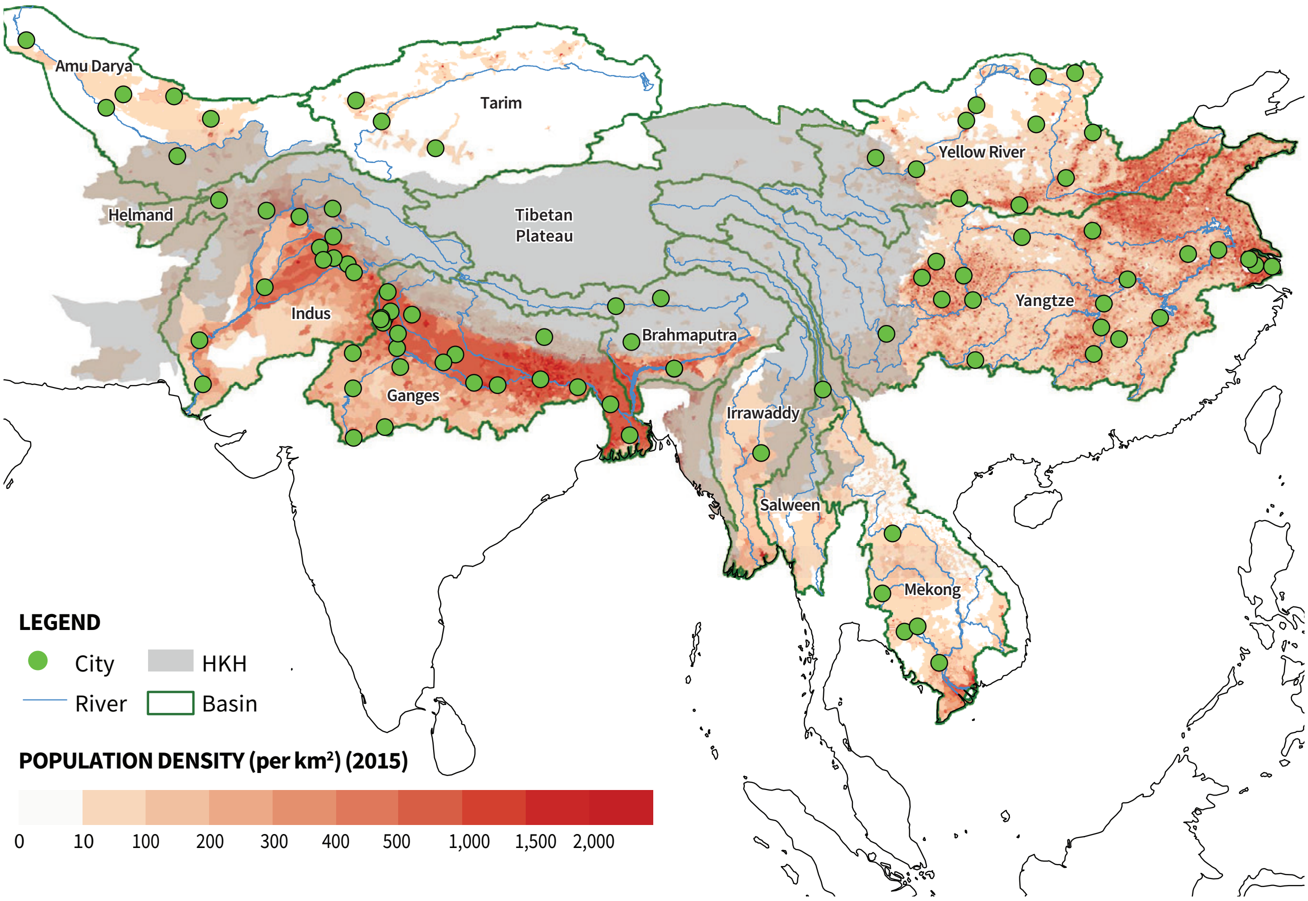
The Hindu Kush Himalayan (HKH) region, which is part of the Asian Water Tower and widely regarded as the Third Pole, is home to the largest cryospheric systems outside the Antarctic and Greenland (Yao et al., 2020). The region is also the most densely populated mountain range in the world (see Figure 5.1), with an estimated 240 million (E. Sharma et al., 2019) people comprising hundreds of ethnic groups and living languages. A further 1.65 billion people living in the 12 river basins – including 10 major transboundary rivers that flow through 16 countries – depend directly or indirectly on the natural resources and ecosystem services (i.e., food, water, energy) provided by the mountains (E. Sharma et al., 2019; also see Chapter 4, section 4.4). Accordingly, changes in the mountains of the HKH region, including changes in the mountain cryosphere – glaciers, snow cover, permafrost, and river and lake ice – have the potential to impact lives and livelihoods in mountain and downstream communities. Meanwhile, mountain people often live in poverty; one-third of the region's mountain population live below the poverty line, a figure considerably higher than the national average for the respective countries of the HKH region (Gioli et al., 2019). This makes both the mountain ecosystems and people living therein more likely to be vulnerable to changes occurring in the HKH, where multiple spheres interact with each other (Y. Wang et al, 2019).

The physical dimension of interactions between the cryosphere and hydrosphere are routinely studied in the HKH region. However, less is known about connections between the social conditions and environmental processes and changes, in particular, how cryospheric change interacts with mountain livelihoods, cultures, economies, and institutions. This relative knowledge deficit impedes the development and implementation of robust responses to changes in mountain systems and could undermine efforts to address the vulnerability of mountain populations across the HKH region (C. Singh et al., 2022).

In general, while the high mountains supply crucial freshwater, maintain biodiversity, and deliver essential goods and services to mountain societies[1], the difficult topography and remoteness mean that mountain communities are often isolated – economic and infrastructural development in the mountains are hindered and there is limited access to quality education. The impacts of cryospheric change exacerbate these challenges, making already difficult livelihoods more precarious. Traditional practices, although often ingenious and time tested, still struggle to keep pace with the rapid pace of climate change (Orr et al., 2022). Furthermore, existing adaptations are mostly reactive and incremental (Adler et al., 2022), hindering progress towards sustainable development in the HKH. This situation highlights

[1] While HKH societies refer to the population and their activities as a whole in the HKH basins (including mountain areas and the downstream), mountain societies refer only to the population in the mountain areas and their activities.

FIGURE 5.1 POPULATION DENSITY MAP OF THE HKH REGION



Data source: WorldPop (2018).

the importance of understanding the linkages between cryospheric change, human adaptation, and sustainable development in the region.

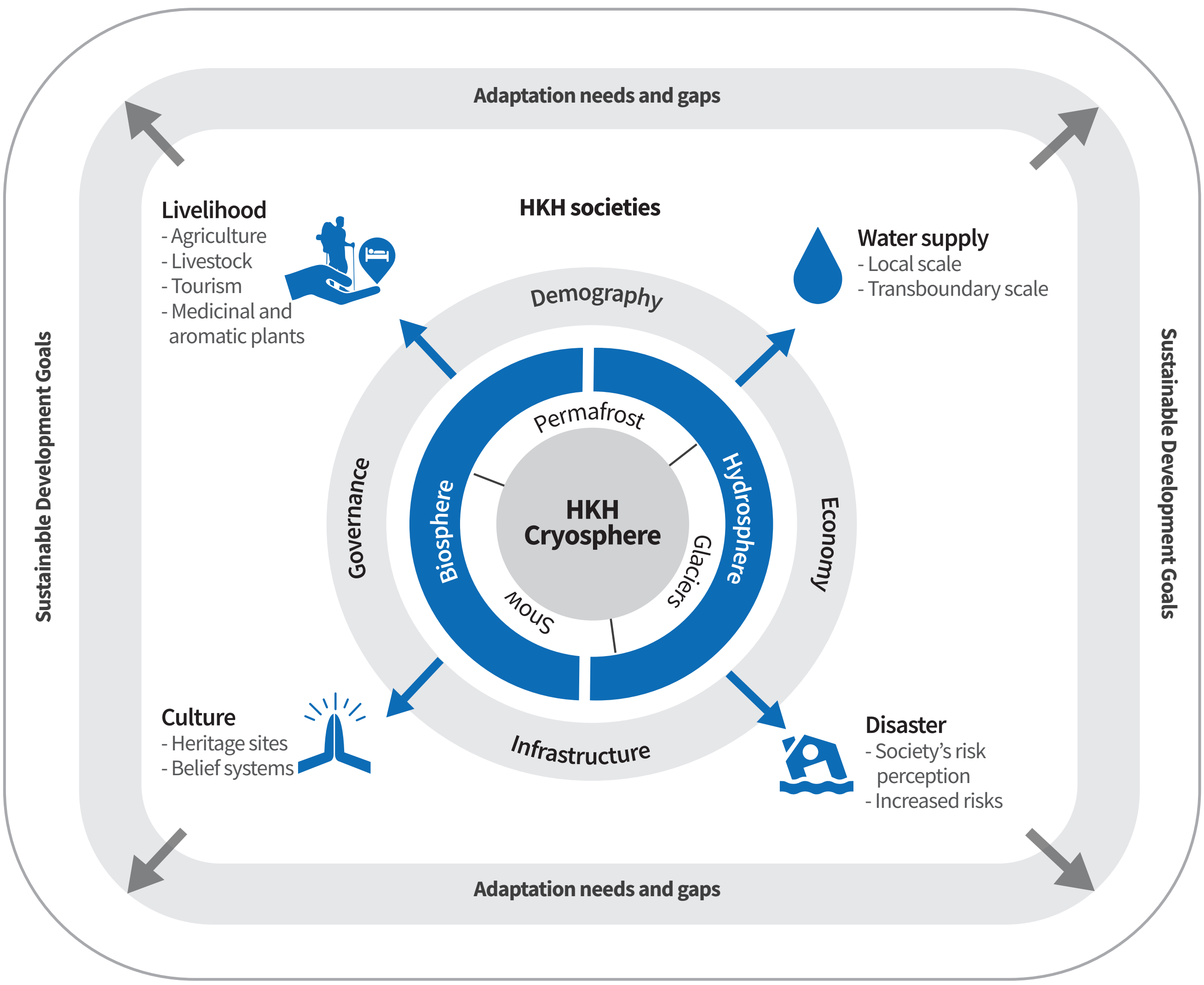
The importance of sustainable development in mountain areas such as the HKH is well established. For example, the 13th chapter of Agenda 21 is focused on sustainable mountain development (SMD), which is defined as "a regionally-specific process of sustainable development that concerns both mountain regions and populations living downstream or otherwise dependent on these resources" (Price & Kim, 1999, p. 205). Furthermore, the 2012 UN Convention on "The future we want", recognises mountains as playing an essential role in overall sustainable development; it also calls for strengthened multi-stakeholder cooperative actions and the inclusion of mountains in national sustainable development agendas (UN, 2012). Finally, in the 2030 Agenda for Sustainable Development (UN, 2015), three targets are explicitly associated with mountains:

- Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes.
- Target 15.1: By 2020, ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular, forests, wetlands, mountains, and drylands, in line with obligations under international agreements.
- Target 15.4: By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.

In high mountains such as the HKH, mountain specificities require a better understanding of the linkages between the remote and more disadvantaged mountain societies and the highly interwoven nexus of the high mountain cryosphere, hydrosphere, and biosphere. This would help in addressing the concerns of mountain communities (Figure 5.2) and identify effective ways to meet SMD goals. More recently, there has been a growing emphasis on connections between cryospheric change, human adaptation, and sustainable development (Adler et al., 2022; Hock et al., 2019; McDowell et al., 2020 & 2021a; Rasul et al., 2020; Wester et al., 2019), a topic that this chapter examines in the context of mountain societies in the HKH region.

It is important to note that role of adaptations in supporting SMD depends considerably on the approaches to adaptation, which can include autonomous or planned, reactive or anticipatory, and incremental or transformational. Contextually appropriate approaches can improve the resilience of natural and socioeconomic systems, reduce the overall vulnerability and risks of high mountain societies, and advance levels of sustainable development. For example, incremental or autonomous adaptations by high mountain societies may no longer be effective in the context of the increasing magnitude and complexity of cryospheric change and persistent socioeconomic challenges (see Chapter 3, section 3.1.2). In this context, proactive

FIGURE 5.2 **IMPACTS OF CRYOSPHERIC CHANGE, ADAPTATION, AND SUSTAINABLE DEVELOPMENT IN THE HKH SOCIETIES**



responses informed by the tenets of SMD are needed to secure the well-being of mountain communities affected by a changing cryosphere (Adler et al., 2022).

This chapter presents the current state of knowledge regarding the impacts of cryospheric change on high mountain societies as well as observed adaptations to associated challenges and the contributions these responses make to SMD. It then identifies knowledge and action gaps, before presenting options for advancing sustainable development in the HKH region.

The chapter first identifies cryospheric impact drivers (CrIDs), which are the cryospheric conditions or changes that can influence high mountain societies, such as changes to glacier mass, meltwater, and snow cover. We identify the effects of CrIDs on four key dimensions of mountain societies:

- Livelihoods: agriculture, livestock, tourism, and medicinal and aromatic plants;
- Water security: water resource availability, scarcity, and quality;
- Culture: cultural heritage and mountain sacredness;
- Disaster risk: loss and damage, exposure, vulnerability.

The effects of CrIDs on high mountain societies are mediated by societal factors or non-climatic impact drivers (nCIDs), such as socioeconomic factors, land use, and governance. The chapter will, therefore, address the following questions:

- What are the primary CrIDs and nCIDs relevant to mountain societies in the HKH, and what are their effects on the four key dimensions of mountain societies as described above?
- Who is vulnerable to the effects of CrIDs and nCIDs, and how are they impacted?
- What adaptations are being undertaken to address vulnerabilities, how are these responses integrated with tenets of sustainable development, and are limits to adaptation constraining necessary progress towards SMD?

The chapter began with a short introduction to cryospheric change, mountain societies, and adaptation in the HKH region. It also discussed the importance of sustainable mountain development in a changing climate and outline the chapter objectives. The second section of the chapter explains key CrIDs and nCIDs, and their association with increasing vulnerability in mountain societies of HKH. Observed impacts of CrIDs and nCIDs on the four key dimensions of mountain societies are explained in section 3. This section also examines CrIDs and nCIDs in a transboundary context, particularly as they relate to the potential for transboundary water conflicts and disasters. Adaptations to such impacts and important limits to adaptation are presented in section 4. Section 5 discusses how the effects of CrIDs and nCIDs hamper progress towards SDGs despite considerable adaptation efforts. The last section (6) summarises the chapter's major findings and identifies key knowledge gaps that must be addressed to better integrate adaptation with sustainable development in the region.

5.2. Changes in cryospheric and non-climatic impact drivers in the region

5.2.1. Cryospheric impact drivers

CrIDs are part of climatic impact drivers (CIDs) introduced in the Working Group I Assessment Report 6 of the Intergovernmental Panel on Climate Change (IPCC) as the "physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems" (Chen et al., 2021; p. 201). They are more specifically linked to the cryosphere and their changes can have a detrimental, beneficial, neutral, or mixed effect on mountain societies. CIDs are value-neutral in characterisation as opposed to hazards – understood as adverse conditions – for the purpose of highlighting the beneficial outcomes of some impacts (Chen et al., 2021).

In the HKH, the CrIDs signify glacial retreat, which is more significant in the Central and the Eastern Himalaya than in the Karakoram and West Kunlun regions (see Chapter 2, section 2.3). Rapid glacial retreat led to an increasing number and area of glacial lakes during 1990, 2000, and 2020, while increasing the risk of GLOFs, particularly in the Eastern Himalaya (see Chapter 2, section 2.4). Meanwhile, barring a few exceptions in the Karakoram, CrIDs have also led to a widespread decline in the extent of snow cover and snow days across the region (see Chapter 2, section 2.4). Furthermore, the rise in average permafrost temperature has led to permafrost degradation, putting more pressure on ongoing environmental changes and increasing the risks of hazards (see Chapter 2, section 2.5). Similarly, as a consequence of the warming climate, the contribution of cryospheric meltwater to the annual streamflow is increasing in the high-altitude areas. It is the highest during the snow- and ice-melting seasons, namely, spring, summer, and early autumn. Moreover, it is higher in the western river basins than in the eastern river basins (see Chapter 3, section 3.1). Though the number of studies is limited, they indicate that the contribution of meltwater and permafrost thaw to groundwater recharge and spring discharge is high, particularly in high-altitude areas (see Chapter 3, section 3.1.2).

Apart from scientific findings, understanding how people perceive and comprehend climate change and its impacts is important for identifying and implementing suitable adaptation measures in order to enable them to transit to a better state in the midst of the ongoing changes (Negi et al., 2017; A. Sharma et al., 2020). While the geophysical changes in the cryosphere have been monitored and extensively analysed, less is known about how people and communities live through these changes and how they perceive the changes and associated risks (Carey et al., 2021). This chapter emphasises the importance of the lived experiences of the HKH communities and explores these experiences in the context of cryospheric change.

One of the most visible signs of climate change in the HKH and among the most documented is the rapid melting of glaciers (Kargel et al., 2011; National Research Council [NRC], 2012; A. B. Shrestha & Aryal, 2011). The disappearance of glaciers has exposed the underlying rocks and darkened the peaks that embody cultural framings and attributions (Adler et al., 2022; Orlove, 2009). Perceptions of high mountain communities in the HKH about the snow cover also attest to its decline both temporally and spatially (Bacha et al., 2021; HI-AWARE, 2018).

In a context of increasing climatic variability and uncertainty, people make decisions based on available information and alternatives to reduce risks and secure their lives and livelihoods (Berkes, 2007). Although weather-related information and scientific evidence of climate change are disseminated by external sources, communities' social memory of climatic events (such as avalanches, floods, and droughts), their traditional ecological knowledge, and cultural values and belief systems are also equally important when it comes to making decisions (T. Byers et al., 2019; Butcher, 2013). Moreover, oral narratives of individuals who have survived past hazard events can add value to remotely sensed data and complement scientific hazard assessments (T. Byers et al., 2019; Lennartz, 2013). Such shared cultural knowledge and rules have been key to survival and adaptive strategies in this high mountain region that has been historically influenced by a set of socioeconomic, cultural, political, and institutional factors spanning from the household to the global scale (Nüsser et al., 2012; Nüsser and Schmidt, 2017).

5.2.2. Non-climatic impact drivers

Apart from cryospheric change, the region is also facing important changes in the sociocultural, economic, and political realms with direct and indirect impacts on the lives and livelihoods of mountain communities as well as the sustainability of mountain systems. These non-climatic changes that can influence the impact of CrIDs are referred to as non-climatic impact drivers or nCIDs. Some changes in nCIDs are global in nature (e.g., globalisation) whereas others are regional (e.g., air pollution) and local (e.g., infrastructure growth) in nature.

It is well established that the effects of CrIDs are shaped by the nature of the climatic or cryospheric conditions as well as changes in the socioeconomic and political dynamics or nCIDs. Such understanding has been shaped by existing literature that has focused on the idea that experience of climate change is always mediated by pre-existing social constraints and opportunities with differential consequences for different segments of the population, namely, women (Goodrich et al., 2019; Resurrección et al., 2019), the poor (Dilshad et al., 2019; Gentle et al., 2014), and other marginal groups such as migrants (Samui & Sethi, 2022).

ECONOMIC GROWTH

Economic growth is a major policy goal for all countries and more so for developing nations. At present, five of the eight countries in the HKH region fall under the least developed country category based on their low levels of income and structural impediments to growth. Out of these three countries – Bangladesh, Bhutan, and Nepal[2] – are in the process of graduating to low middle-income countries status (UNCTAD, 2021). Although monetary poverty is declining across the HKH countries except Afghanistan, signifying thereby betterment of life, around 15% of the population continues to remain in poverty, with almost 260 million people living in extreme poverty[3] (Islam et al., 2021). Poverty is also linked with age, gender, caste, ethnicity, education, and access to services and accessibility. Thus, understanding multidimensional poverty[4] is vital because it remains high in the mountainous areas of the HKH countries (Gerlitz et al., 2015; Hunzai et al., 2011; Mohanty et al., 2018) due to mountain specificities (Jodha, 2007). Multidimensional poverty constitutes a major bottleneck to sustainable mountain development, and adaptation to climate and cryospheric change in the mountains.

Despite economic growth, food security is still a concern in the HKH countries with about 12% of the population (390 million) suffering from undernourishment (FAO et al., 2022). The severity of food insecurity is higher among the mountain population than among those in the lowlands. In the HKH countries, around one-third of the population is food insecure, and half is suffering from malnutrition with children (under 5 years of age) and women among the most nutrition-insecure groups (Rasul et al., 2019). The need for rapid economic growth to meet the target of poverty and food insecurity reduction has increased the demand for natural resources, often leading to their overexploitation, significant land use and land cover changes, and unsustainable socioeconomic activities (Ali et al., 2021; Rasul et al., 2019).

DEMOGRAPHIC SHIFTS

The HKH region is one of the most populated mountainous areas of the world. The overall population in the region is still increasing though the population growth rate is decreasing due to decline in fertility rates. Within the region, China has a lower population density than Pakistan, India, Nepal, and Bangladesh.

Another observable demographic shift in the region is the growing concentration of the population in towns and cities, leading to rapid urbanisation (Dame et al., 2019; Mukherji et al., 2018), including in the

[2] The Committee for Development Policy (CDP) is a group of independent experts that report to the Economic and Social Council (ECOSOC) of the United Nations. CDP's 2021 triennial review considered some countries including Bangladesh, Nepal, and Myanmar for graduation from LDC status and recommended Bangladesh and Nepal for graduation from the LDC category. Taking into consideration the special conditions created by the COVID-19 pandemic, the Committee recommended an extended preparatory period as well as careful monitoring and analysis of the impacts of the pandemic, with specific transition support. The Committee decided to defer its decision on Myanmar to the CDP's 2024 triennial review. Bhutan is already scheduled for graduation in 2023 (UNCTAD, 2021).
[3] 'Poor' refers to those who earn less than USD1.90 a day (2011 PPP).
[4] The multidimensional poverty index (MPI) measures poverty in terms of three broad dimensions of human development: education, health, and living standards. However, to capture the geographical dimension (mountain specificities), the two dimensions of accessibility and resource endowment are added to the calculations.

sparsely populated Tibetan Plateau range (Qi & Yi, 2021). Lack of access to basic services such as education and health care as well as economic opportunities are major reasons for the migration of people from rural to urban areas (Dame, 2018; Pathak et al., 2017). Cryospheric change, both slow-onset and extreme events, also contribute to out-migration from the high mountain areas (Prasain, 2018; Rasul & Molden, 2019). Often, male members of households migrate outside the village for work purposes, leaving the immobile populations, namely, women, children, and the older generation behind (Maharjan et al., 2020). Multilocality and translocal livelihoods have become an integral part of household livelihood strategies (Benz, 2016; Dame, 2018). But the ability to migrate to towns/cities or international destination is dependent on the socioeconomic situation of households. Households with better education and economic opportunities, and of higher social classes find it easier to move as compared to vulnerable groups. This has resulted in changes in the social composition and vulnerability of immobile populations (Pathak et al., 2017). These changes leading to depopulation in rural areas and urbanisation in selected pocket areas have had an impact on land use and land cover changes (Dame et al., 2019; Maharjan et al., 2020; Parveen et al., 2015).

INFRASTRUCTURE AND TECHNOLOGICAL DEVELOPMENT

The mountain communities are becoming increasingly accessible, both physically and virtually. Governments have focused on connecting remote mountain areas with national road networks, thereby meeting aspirations of the local communities as well (Lennartz, 2013; A. Pandey et. al., 2021). In addition, rapid growth in road networks in the Tibetan Plateau has improved transboundary connections easing the trade in goods and services and enabling economic development in the mountain areas (Ali et al., 2022; Saxer, 2017; Zhao et al., 2022). Increase in access to information technology has virtually connected mountain communities with other areas although disparities exist in accessibility and quality of connections. Table 5.1 shows access to electricity, roads, and information and communication technology in the HKH countries, which clearly illustrates rural–urban disparities in accessibility and quality of services. As most mountain areas continue to remain rural, not only is access to services poor but also the quality of service, with implications for the adaptive capacities of mountain communities.

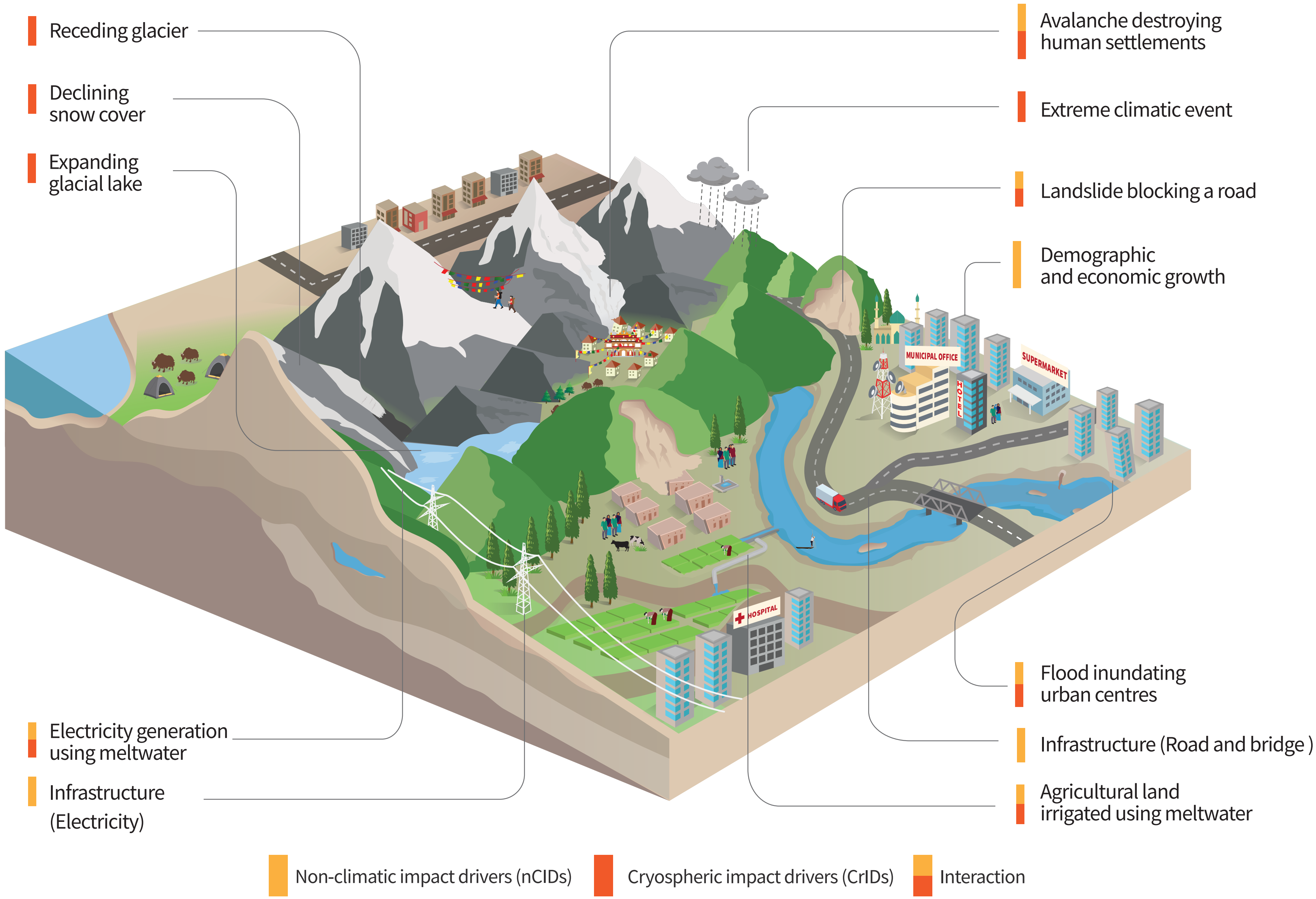
TABLE 5.1 INFRASTRUCTURE DEVELOPMENT IN THE HKH COUNTRIES

Infrastructure	Electricity				Rural roads		Information and communication (country level)	
	Access				Access %	Quality	Internet use[a]	Mobile subscription[b]
	Urban %	Rural %	Total %	Quality				
Afghanistan	99.5	97.1	97.7	Poor	20.3		18	58
Bangladesh	99.5	81.3	88	3.7	47	3.1	25	107
Bhutan	99.1	96.8	97.7	5.8	34.2		86	100
China	100	99.9	100	5	57.4	6	73	122
India	99.2	89.3	92.6	4.7	42.8	4.4	43	82
Myanmar	92.5	59.9	69.8	Poor	38.3		35	126
Nepal	98.7	94.7	95.5	2.8	51.7	2.6	38	130
Pakistan	100	54.1	70.8	2.9	39.9	3.9	25	82

Notes:
Access to electricity: Percentage of population (total, rural, urban) with access to household electricity services; Access to rural roads: Percentage of rural population with access to all-season roads (within two kilometres); Quality of infrastructure: 1-7 (from worst to best); Internet use: Percentage (%) of population using internet; Mobile cellular subscription (per 100 people)
[a]Afghanistan, Bangladesh, India, Myanmar, Nepal & Pakistan (2020), Bhutan & China (2021)
[b]Afghanistan & Nepal (2020), Bangladesh, Bhutan, China, India, Myanmar & Pakistan (2021)

Source: World Bank (2020); World Bank (2022)

FIGURE 5.3 CrIDs, nCIDs AND THEIR INTERACTIONS IN THE HKH SOCIETIES



GOVERNANCE SYSTEMS AND INSTITUTIONS

Historically, high mountainous communities have remained disconnected from and beyond the reach of formal governmental institutions. Local communities have, therefore, followed traditional customary laws to govern their natural resources as well as social relations (Ojha et al., 2019). But the local communities' access to governmental institutions and their services is improving with growing physical and virtual connectivity as well as the implementation of decentralised policies by countries in the region (Shah & Thompson, 2004). Despite the growing reach of formal governmental institutions, public service delivery has not met the locals' expectations due to lack of human, financial, and technical resources (Ehsan, 2021; Khan, 2021; Kharel & Pasa, 2021). Moreover, the introduction of formal institutions has undermined customary institutions, sometimes even leading to clashes between them.

In other instances, traditional customary governance mechanisms have been recognised and integrated into formal governance mechanisms (Chhetri, 2008). Overall, a shift towards decentralisation and community participation in natural resource management (i.e., forest and water) is evident in the region (Ojha et al., 2019). While this is a positive development in meeting the needs and aspirations of local communities, the decentralisation processes still face multiple challenges such as a deep-rooted centralised governance mindset, high central dependency, inadequate resource mobilisation, absence of coherent legal frameworks, sub-national conflicts, and the limited capacity of local institutions (Ehsan, 2021; Nixon et al., 2013).

In sum, rapid economic growth, technological and infrastructure development, and newer forms of governance have increased the connectivity of mountain societies to other parts of their respective countries as well as the rest of the world. With the commercialisation of the agriculture sector, changes in land use, and more intense use of natural resources, rural mountain societies are gradually shifting from subsistence to market economies, and are being increasingly integrated into regional, national, and global markets (Kreutzmann, 1991; Mizushima, 2016; Y. Wang et al., 2019). This has contributed to a general rise in income levels and enhanced livelihoods, although not uniformly, across the region and across all population groups. On the other hand, it has also led to a decline in traditional livelihood practices, ways of life, social structures, and local knowledge systems (Dame & Mankelow, 2010).

5.2.3. Intersection of CrIDs and nCIDs

As highlighted in the earlier sections, the HKH is undergoing changes in both CrIDs and nCIDs. When they intersect, the result can be either exacerbated vulnerabilities, albeit differentiated, or increased opportunities for mountain societies. With improved access alongside other infrastructure development, tourism has increased leading to improvements in the local economy although also leading to increased food imports and decreased social bonding (Tuladhar et al., 2021). On the other hand, cryospheric change have also increased the risks of cryospheric hazards (see Chapter 3, section 3.2). These simultaneous socioeconomic and cryospheric changes have increased the overall vulnerability of the mountain inhabitants (see Chapter 3, section 3.2). Similarly, the decline in caterpillar fungus production across four HKH countries (China, India, Nepal, and Bhutan) is attributed to climate change, habitat degradation, and overexploitation (Hopping et al., 2018), which highlights the intersection between CrIDs and nCIDs. Figure 5.3 shows how the CrIDs and nCIDs interact and influence mountain societies, particularly mountain livelihoods, water security, culture, and disaster risk.

Adaptation to impacts of cryospheric change occurs mostly in the form of behavioural changes, infrastructure and technology access, and institutional, financial, and regulatory support (Rasul et al., 2020). Therefore, the adaptive capabilities of communities are directly linked with their socioeconomic situation and locality. All this highlights the importance of looking into the combined effect of both CrIDs and nCIDs when it comes to impacts and adaptations.

5.3. Implications of cryospheric impact drivers on mountain societies

Both CrIDs and nCIDs influence mountain livelihoods such as agriculture, livestock, tourism, water security, and culture (Biemans et al., 2019; Carey et al., 2017; Mukherji et al., 2019; Pasakhala et al., 2021; Tuladhar et al., 2021). The population living in the HKH as well as downstream are directly and indirectly dependent on meltwater run-off to meet their water needs (Nie et al., 2021; Rasul & Molden, 2019; Xiao et al., 2015). Therefore, cryospheric change will have an impact on the supply of water (see Chapter 3, section 3.1.5) for several sectors (Rasul et al., 2019; 2020) while also increasing the disaster risk (Allen et al., 2019; Stäubli et al., 2018; Vaidya et al., 2019). This will, in turn, have a cascading effect on the social, economic, cultural, and environmental dimensions at multiple spatial and temporal scales (Pasakhala et al., 2022; Rasul & Molden, 2019). Water-induced hazards and other climatic stressors are estimated to have caused losses to the tune of USD 45 billion in the HKH region during the 1985–2014 period (Stäubli et al., 2018).

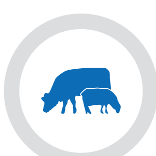
5.3.1. Impacts on livelihoods

Agriculture, livestock production, tourism, and the collection and trading of medicinal and aromatic plants (Figure 5.4) are the major income sources closely connected with the cryosphere. Cryospheric change will, therefore, carry implications for these livelihood options. For example, in the Kashmir Valley of India, the decreasing trend in snowfall, along with increasing temperature, poses a challenge to the social and economic development of the valley (A. K. Mishra & Rafiq, 2017). Labour migration is the other major income source in the mountains. Although not directly affected by cryospheric change, it is a result of CrIDs on traditional livelihoods, which have been adversely impacted by them (R. Pandey, 2021; Sati, 2021).

FIGURE 5.4 ADVERSE IMPACTS OF CRYOSPHERIC CHANGE ON LIVELIHOODS IN THE HKH

Agriculture

- Decrease in soil moisture
- Disruption in irrigation water supply
- Decrease in soil fertility/nitrogen cycling in soil
- Phenological changes in crops
- Changes in land use practices and cropping patterns
- Increased crop loss due to extreme events



Livestock

- Decrease in soil moisture and nutrients necessary for fodder/forage crops
- Shorter vegetation growing season
- Changes in the seasonal mobility of transhumance herders
- Shrub encroachment and shrinking of grazing areas
- Livestock loss due to extreme events

Tourism

- Degrading aesthetics
- Limited amenities due to scarcity of water and energy
- Increase in disaster risk

Medicinal and aromatic plants

- Decreasing soil moisture
- Decreasing water availability
- Disruption in collection season
- Changes in plant phenology and growing season
- Habitat alteration
- Risk to life of collectors due to extreme events

AGRICULTURE

Agriculture is the primary source of livelihoods in the HKH region, providing food, nutrition, and employment opportunities to people. Despite the rising importance of non-farm income opportunities, more than 80% of the mountain people in the region still partially or significantly depend on agriculture (Hussain et al., 2016).

Glacier and snow meltwater are the major water sources of irrigation as well as soil moisture in the high mountain areas (Nüsser et al., 2019; Parveen et al., 2015). Farmers drain glacier and snow meltwater through irrigation channels to agricultural fields and settlements (Nüsser & Schmidt, 2017; see Chapter 3, section 3.3.1). In Gilgit-Baltistan (Pakistan), glacier and snow meltwater irrigate more than 85% of the agricultural land through traditional and improved irrigation systems (Ashraf & Akbar, 2020). Destruction of such traditional irrigation systems could result in large-scale agricultural land abandonment (see Chapter 3, section 3.3.1). Many irrigation systems in the downstream also rely on the glacier- and snow-fed rivers (Kreutzmann, 2012; Molden et al., 2022; Mukherji et al., 2015) as Indus, Jhelum, and Chenab rivers feed the Indus Basin Irrigation System (Qureshi, 2011), Satluj and Beas rivers the Indira Gandhi Nahar Paryojana (Amarasinghe et al., 2012), and Bhagirathi river the Tehri dam (R. C. Sharma et al., 2008).

About 129 million farmers in the Indus and Ganges river basins are dependent on glacial and snow melt (Biemans et al., 2019). In the Indus Basin, meltwater contributes to 9% of the ~46 megatons (MT) of wheat, 15% of the 19 MT of rice, 28% of the 4 MT of cotton, and 17% of the 53 MT of sugarcane (Biemans et al., 2019). Besides irrigation, the snow coating on agriculture and tree debris helps in-situ decomposition adding to soil fertility. Winter climate change can thus influence nitrogen cycling in soils by changing the freeze–thaw cycles in the temperate forest ecosystems (Urakawa et al., 2014).

Changes in the cryosphere are also likely to impact the hydrological regimes of major river systems in the HKH region (Immerzeel et al., 2010; see Chapter 3) as well as the irrigation systems fed by those rivers. Erratic snowfall patterns (i.e., timing, duration, and amount) have been reported to cause crop failure and loss (Aggarwal, 2008; Dilshad et al., 2019; Sujakhu et al., 2016; Tuladhar et al., 2021). In 2018, an early snowfall (late September) in Himachal Pradesh, India, adversely impacted the summer harvest of potatoes, cauliflower, cabbage, apples, pears, plums, and cherries causing losses in the range of USD 4 million (Pinto, 2018).

Increasing temperature also affects crop phenology. Most highland horticulture crops require low temperatures to be maintained for a long period of time, during which the plants remain dormant only to emerge when the conditions are favourable for growth (Rautela & Karki, 2015). Studies have reported phenological changes such as early sprouting and maturation of seeds (Deng et al., 2011), flowering, and fruiting of cereal (rice and wheat) and fruit crops (apple and cherry) (Sujakhu et al., 2016; Vedwan, 2006) as a result of increasing temperature. Temperature increase, together with water scarcity, have been reported to result in changes in land use practices and cropping patterns (Aggarwal, 2008; Rashid et al., 2020). For instance, in Jammu and Kashmir, summer varieties of rice and traditional Kashmiri apples have vanished, and paddy land has been converted to rainfed dry land in some areas due to increasing temperature and untimely snow and rainfall (R. C. Sharma et al., 2017). In Mustang and Manang, Nepal, higher temperatures and increased meltwater availability have created a conducive environment for growing fruits, vegetables, and other cash crops (Manandhar et al., 2011; Konchar et al., 2015), which were hitherto unsuitable given climatic conditions.

The adverse impacts of cryospheric change can be devastating for food production in the long run. In the downstream areas of the river basins – the food basket for a large population – decline in water availability may result in drastic reductions in food production, putting the food and nutrition status of poor people in jeopardy (Molden et al., 2022). Similarly, in upstream areas, the food and livelihood security of people is under threat due to impacts of cryospheric change, such as glacier retreat, and thinning and changing snow dynamics, on cryosphere-fed irrigation systems (Nüsser et al., 2019a; also see Chapter 3, section 3.3.1). This might increase dependency on imported food. In the mountains, characterised by remoteness, political marginalisation, low market integration, and limited agricultural land, availability and access to food for purposes of food security remains a challenge (Dame & Nüsser, 2011). The decline in consumption of nutritious traditional crops, abandonment of farmlands, and the limited capacities of the immobile population (women and older generation) are bound to adversely impact the food and nutrition security of the mountain communities (Rasul et al., 2019; P. C. Tiwari et al., 2018).

LIVESTOCK

Livestock production plays an integral role in the livelihoods of 25 to 30 million agro-pastoralists and pastoralists living in the region (Shaoliang & Sharma, 2009). Livestock contributes to food production and food security and provides a wide range of services, among them, buffering against climatic and economic shocks (Godde et al., 2021). Sedentary, transhumance and nomadism are the major livestock production systems in the region, which are dependent on cryospheric services.

Snow meltwater is a major source of moisture and nutrients for vegetation in the high altitudes (Walker et al., 1993). The timing of snowfall and snowmelt and the depth of snow cover play vital roles in vegetation distribution, growth, and productivity (Walker et al., 1993) as well as the seasonal mobility of transhumance herders and their livestock (Ahmad et al., 2021; Namgay et al., 2013; R. Singh et al., 2020).

Studies on the perceptions of local communities, particularly herders, in the region have reported a decrease in the amount of snowfall and an upward shift of the snowline (Aryal et al., 2014; Klein et al., 2014; Luxom et al., 2022; Negi et al., 2017; Pasakhala et al., 2021; Y. Wang et al. 2014). Rapid melting of snow and glaciers as well as permafrost degradation have caused an expansion in high-altitude lakes in the Tibetan Plateau, resulting in the loss of grazing areas for livestock (Hopping et al., 2016; Nyima & Hopping, 2019). Increase in temperature and shifting of the snowline have also provided a conducive environment for shrub encroachment in the alpine meadows, which further shrink the grazing areas for animals (Dong et al., 2011). With the decrease in the amount of snowfall, the number of watering points for animals has also reduced, leading to a higher concentration of animals and increased grazing pressure around the remaining water points (Paudel & Andersen, 2010). These cryospheric changes in conjunction with temperature increase and overgrazing have led to rangeland degradation (Wu et al., 2015), adversely affecting the quality and amount of forage available for livestock (Gentle & Thwaites, 2016; Rayamajhi & Manandhar, 2020). The changes listed above have combined to create a reduction in livestock productivity (Manandhar et al., 2011).

Decrease in snow cover and snowfall has allowed herders to access previously unavailable pastures for grazing their animals (Pasakhala et al., 2021). In the short-term, access to new pastures compensates for reduction in forage quality and quantity. However, continual decline in snowfall and frequent occurrence of snow drought will shorten the growing season, degrading rangelands further in the long-term (Paudel & Andersen, 2013; Shang et al., 2012).

Livestock production in the region is also vulnerable to cryosphere-related disasters. Heavy snowfall and snowstorms that bury rangelands for prolonged periods of time deprive livestock of food as well as water (Shang et al., 2012). These snow-related disasters also impair the mobility of animals in search of food. The erratic snowfall pattern has disrupted the movement of herders and their animals and increased the risk of losses due to snowstorms (Luxom et al., 2022; Namgay et al., 2013). These weather-related occurrences have led to mass death of livestock from both starvation and severe cold in several areas of the HKH (Dollfus, 2013; Joshi et al., 2013; Luxom et al., 2022; Tuladhar et al., 2021; Yeh et al., 2014). For example, snow-related disasters between 1974 and 2009 killed 18 million animals in the eastern Tibetan Plateau (Y. Wang et al., 2014). Avalanches, too, cause heavy loss of animals as in the case of Manang, Nepal, in 2018, which killed 250 animals (K. R. Tiwari et al., 2020). These deaths incurred huge economic losses to the herding community (Shang et al., 2012; K. R. Tiwari et al., 2020). In conjunction with other socioeconomic drivers of change, the growing adverse impacts of cryospheric change and forage shortages have discouraged herders from continuing with livestock production (Luxom et al., 2022; Pasakhala et al., 2021).

Under observed and projected cryospheric change, livestock-based livelihoods are likely to become more vulnerable in the future, and hence, untenable. As livestock is a form of liquid asset for mountain communities, these changes can have significant implications for poverty in the region. Livestock products (diary and meat) are also an important source of protein for the households. Thus, decrease in or abandonment of livestock keeping, because of fodder shortage and loss of interest in the younger generation, might have implications for the nutritional security of household members.

MEDICINAL AND AROMATIC PLANTS

Medicinal and aromatic plants (MAPs) play an important role in the health and livelihoods of the communities in the region. Plants are traditionally used for treating various ailments of humans as well as livestock and is often a cheap alternative to costly medicines (Applequist et al., 2019; Bergmann et al., 2008). In remote mountain villages, access to modern medicines and medical services is limited and the traditional knowledge of medical plants is often the only option available for local communities (M. Kumar et al., 2021; Phondani et al., 2014). Moreover, the harvesting of and trading in these plants is a major source of cash income (Pradhan et al., 2020; U. B. Shrestha & Bawa, 2014; Wallrapp et al., 2019).

Soil moisture is an important limiting factor in the distribution of high-altitude plant species (M. Müller et al., 2016). Snow meltwater provides soil moisture for vegetation, including MAPs, growing in the subalpine and alpine meadows (Paudel & Andersen, 2013). But the decrease in snowfall and receding of glaciers threaten water availability for plant species that grow in cool and moist conditions. For example, the rapid melting of the Braga glacier and the Gangapurna glacier in Manang, Nepal, threatens water availability for *Neopicrorhiza scrophulariiflora* (B. B. Shrestha & Jha, 2009). Decrease in snowfall has been perceived as a major factor in the decrease in availability of MAPs such as the highly valued *Ophiocordyceps sinensis*, colloquially referred to as the caterpillar fungus (Hopping et al., 2018; U. B. Shrestha & Bawa, 2013). Untimely heavy snowfalls during April and May have, moreover, begun to disrupt and delay its collection season in Bhutan, India, and Nepal (A. C. Byers et al., 2020), with serious adverse impacts on mountain livelihoods.

Studies have also reported changes in plant phenology and growing seasons due to shifts in snowfall patterns and warming conditions (Zeng & Jia, 2013). The decline in snow cover favours the growth of shrubs in alpine conditions (Brandt et al., 2013; Wipf & Rixen, 2010) which, in conjunction with decreased meltwater, will lead to habitat alterations of ecologically sensitive medicinal plant species (Choden et al., 2021). All these are likely to have negative implications on the livelihoods of communities dependent on the collection and trading of MAPs.

TOURISM

Tourism is an important contributor to the national as well as the local economy of countries in the region (Ingty, 2017; Tuladhar et al., 2021). International tourism contributed about 4% of the total Gross Domestic Product (GDP) of Nepal in 2017 (Khanal, 2020) and 10% of that of Bhutan in 2019 (Tourism Council of Bhutan [TCB], 2022). The majority of international tourists arriving in Nepal have stated their purpose as mountaineering and holiday/pleasure (Ministry of Culture, Tourism & Civil Aviation [MoCTCA], 2020). In Solukhumbhu, Nepal, the gateway to Mount Everest, the number of seasonal tourists doubled between 1994 and 2014 (Aubriot et al., 2019). Similarly, the Yolung Snow Mountain range of Yunnan province in China, which is a popular destination for glacier tourism (offering sightseeing by train, car and helicopter as well as hiking, skiing, ice cave tourism, ice climbing, etc.), attracted a large number of tourists, the recreational value of which ranges from 1.97 to 8.17 billion CNY (1 USD=6.93 CNY as of August 2020) (Shijin et al., 2020).

Cultural and spiritual services of the cryosphere also attract hundreds of thousands of tourists to the region every year (Hong-Min et al. 2021; Mukherji et al. 2019; Nepal & Chipeniuk 2005). There is an abundance of sacred sites for different religious groups, among them, Hindus, Jains, Sikhs, and Bons, who travel across the HKH to visit them (Pathak, 2016; Piasecki, 2019). Culture and spirituality are important determiners of the satisfaction levels of the tourists visiting the Himalaya (Bagri & Kala, 2015). In the Indian Himalaya of Garhwal, the spiritual *char dham yatra* circuit received around 2.2 million tourists in 2017 alone (Nath, 2018). Cultural and spiritual tourism centred on people, places, and events can be marketed as niche high-mountain tourism products in the international tourism market and would contribute significantly to economic and social development goals (Haq & Medhekar, 2020). Along with cultural and spiritual tourism, adventure tourism (winter sports, mountaineering, and trekking) is a major attraction related to the cryosphere (MoCTCA, 2020; Shijin et al., 2020; Zhang et al., 2022).

Cryospheric change has both positive and negative impacts on the tourism industry. From a positive angle, cryospheric change has improved access to formerly inaccessible areas due to the melting of glaciers generating ice-free routes (Lama, 2010; Palomo, 2017). Access is also a major concern in the transit destinations leading to high mountain areas (Apollo, 2017). In Qinghai Tibetan Plateau, increase in the annual cumulative number of thermally favourable days has had a positive impact on tourism (L. E. Wang et al., 2017). Tourist arrivals are likely to increase in colder areas as they become warmer (Bigano et al., 2008; Ramasamy & Swamy, 2012) while a lengthened summer season has the potential to expand domestic and international tourism markets, thereby increasing tourist receipts (D. Scott et al., 2004). However, these positive impacts are likely to be short-lived, while the negative impacts will likely be long-lasting. The loss of glaciers and snow cover on the mountains not only spoil their aesthetically pleasing appearance (Becken et al., 2013; Mukherji et al., 2019) but also affect the cultural and belief systems of the local inhabitants and decreases the number of tourists, resulting in low employment and revenue generation for locals from the tourism sector (Shi-Jin & Lan-Yue, 2019). Moreover, warmer temperatures may restrict access to various high passes due to the thinning of the glacier surface, and the development of surface ponds and glacial lakes (Apollo, 2017; Watson & King, 2018). In Ladakh, the freezing of the Zanskar River creates a route that is popularly known as the Chadar trek, which is used by both locals and tourists. This route is now experiencing early melting and a shorter frozen period, hampering, thereby, access (Apollo, 2017; Raina & Koul, 2011; Shaheen et al., 2013).

Tourism is also affected by the fragile nature of mountain geography which makes it highly unstable and prone to numerous disaster events such as avalanches and snowstorms, landslides, and glacial lake outburst floods that endanger the lives of both locals and tourists as well as infrastructure. Cryosphere-related disasters claimed the lives of 372 mountaineers, guides, and locals between 1922 and 2020 in Nepal (Schweizer et al., 2003; Thakuri et al., 2020). Similarly, the 2013 mega-flood event, also referred to as the Himalayan Tsunami, in Kedarnath, one of the four most holy places in India for Hindus, caused a loss of over 4,000 human lives and affected about 1 million people, while damaging roads and other infrastructure (Bhambri et al., 2016). Such devastating disaster events adversely affect the number of tourist arrivals (NITI Aayog, 2018) as safety is of paramount importance to tourists (Šimková 2014; Hock et al., 2019).

Changes in temperature also influence mountain tourism by affecting water availability for tourists' use. In the Khumbu region of Nepal, cryospheric change has resulted in a decrease in stream flow, affecting water availability and impacting local ability to meet the demands for amenities of a growing number of tourists (Lama, 2010; McDowell et al., 2013). The rapid increase in the number of tourists in the high mountains has created competition for water between the traditional uses of water for water mill operations and new uses of water to host tourist operations (Aubriot et al., 2019). Similarly, in the Indus Basin, the changing cryosphere (loss of glacier mass and area) and resultant water scarcity are expected to carry implications for socioeconomic development, including tourism (Kulkarni et al., 2021; Romshoo et al., 2015).

5.3.2. Impacts on water security and their implications: Local to transboundary

IMPACTS AT LOCAL SCALE

The high mountain settlements are dependent upon water sources like springs, lakes, and streams fed by glaciers and/or snow meltwater for drinking and domestic use (Mukherji et al., 2019; Nüsser et al., 2019b; Parveen et al., 2015; C. Scott et al., 2019). They have been harnessing drinking water through local and traditional methods such as canals and pipes, or a complex array of channels from the source (Gagné, 2016; Lal & Verma, 2008; J. Müller et al., 2020; Prasad & Sharma, 2019; Rawat & Sah, 2009; Tuladhar et al., 2021).

The meltwater from glacier, snow, and permafrost contributes significantly to rivers in the region (Kaser et al., 2010; Prakash & Molden, 2020), which gradually reduces with decrease in elevation and increase in distance from the cryosphere (Siderius et al., 2013). High mountain communities are not the only ones dependent on snow and glacier meltwater. The water security of densely populated urban areas in the downstream are also dependent on this water, which is utilised for domestic and commercial purposes (R. Kumar & Sharma, 2019; Rasul & Molden, 2019). For instance, the Melamchi River in Nepal, fed by snow and glacier melt, provides 170 million litres of water for residents of the Kathmandu valley. Not only does it offer water security but it also prevents excessive groundwater extraction (Khadka & Khanal, 2008; Chinnasamy & Shrestha, 2019). The water supply systems in cities such as Haridwar, Varanasi, Patna, Delhi, and Islamabad are also partially dependent on meltwater (Rasul & Molden, 2019).

Although the warming climate is associated with an increase in meltwater that flows into downstream rural and urban settlements, these settlements are also facing scarcity in drinking water, mostly due to the decline in the available water supply sources such as springs, traditional spouts, etc. This is compounded by the rapidly growing demand for water, poor water management, and inadequate infrastructure in the region (Ranjan & Pandey, 2019; A. Sharma et al., 2020; Synder, 2014), particularly in the urban areas (Mondal & Roychowdhury, 2019; J. Müller et al., 2020; Ranjan & Pandey, 2019; Synder, 2014). Both the growth in population and economic activities such as tourism are aggravating water scarcity (Narain & Singh, 2019). For instance, in the Everest region, pressure on water is generated not only by domestic and agricultural use but also by the demand for water for electricity generation (Faulon & Sacareau, 2020). Water scarcity increases the workload of women and, consequently, the health risks as women are mostly responsible for fetching water from distant water sources for their families (Khanduri & Rawat, 2003; Prakash & Molden, 2020; Prasad & Sharma, 2019; Resurrección et al., 2019; Sidh & Basu, 2011).

The water quality of glacier and snow meltwater are usually within the safe limits for drinking (Nicholson et al., 2016; R. C. Sharma & Kumar, 2017). However, the rapid melting of glaciers and permafrost is releasing stored pollutants and pathogens into the river systems fed by meltwater (Kang et al., 2019; Yarzábal et al., 2021), which poses serious health risks for humans. Mercury and organic pollutants have already been detected in meltwater of the Bhagirathi and Alaknanda river basins and the Tibetan Plateau (Mu et al., 2020; B. M. S. Sharma et al., 2015; Sun et al., 2017).

IMPACTS AT TRANSBOUNDARY SCALE

The challenges posed by change in the water supply can have repercussions at the transboundary basin scale. The term transboundary is understood as an area that extends across the international political borders of two or more countries (Albrecht et al., 2017; Lorenz et al., 2001). As the rivers flow from upstream to downstream across different spatial scales, they create hydrosocial territories of people, institutions, and biophysical environments revolving around the control of water (Boelens et al., 2016; A. Pandey et al., 2020). In the HKH region, water resources and services are shared by eight countries. The water originating in the HKH is a lifeline for the economies of the region, which have been adversely impacted by cryospheric change. While the Tarim is largely an endorheic basin in China, other basins such as the Indus, Ganges, Brahmaputra, Amu Darya, and Syr Darya are all transboundary in nature.

Globally, it is understood that the river discharge in many basins will be impacted by future glacier mass loss under climate change, especially when glacier meltwater reaches a peak (Huss & Hock, 2018). In the meantime, the increasing demand for freshwater for rapidly growing economies and the rising dependence of the downstream on mountain water (A. Pandey et al., 2020; Viviroli et al., 2020) will lead to more imbalance between supply and demand. Often, the most vulnerable are those residing in transboundary basins such as the Indus Basin where there is dense population and large irrigation areas (Immerzeel et al., 2020). The rising imbalance between demand and supply leads to scarcity of freshwater while competition for the limited freshwater often leads to disputes (De Stefano et al., 2010) increasing, thereby, hydro-political tensions among countries of the transboundary river basins (Bernauer et al., 2012; Dinar et al., 2015; Vorosmarty et al., 2000).

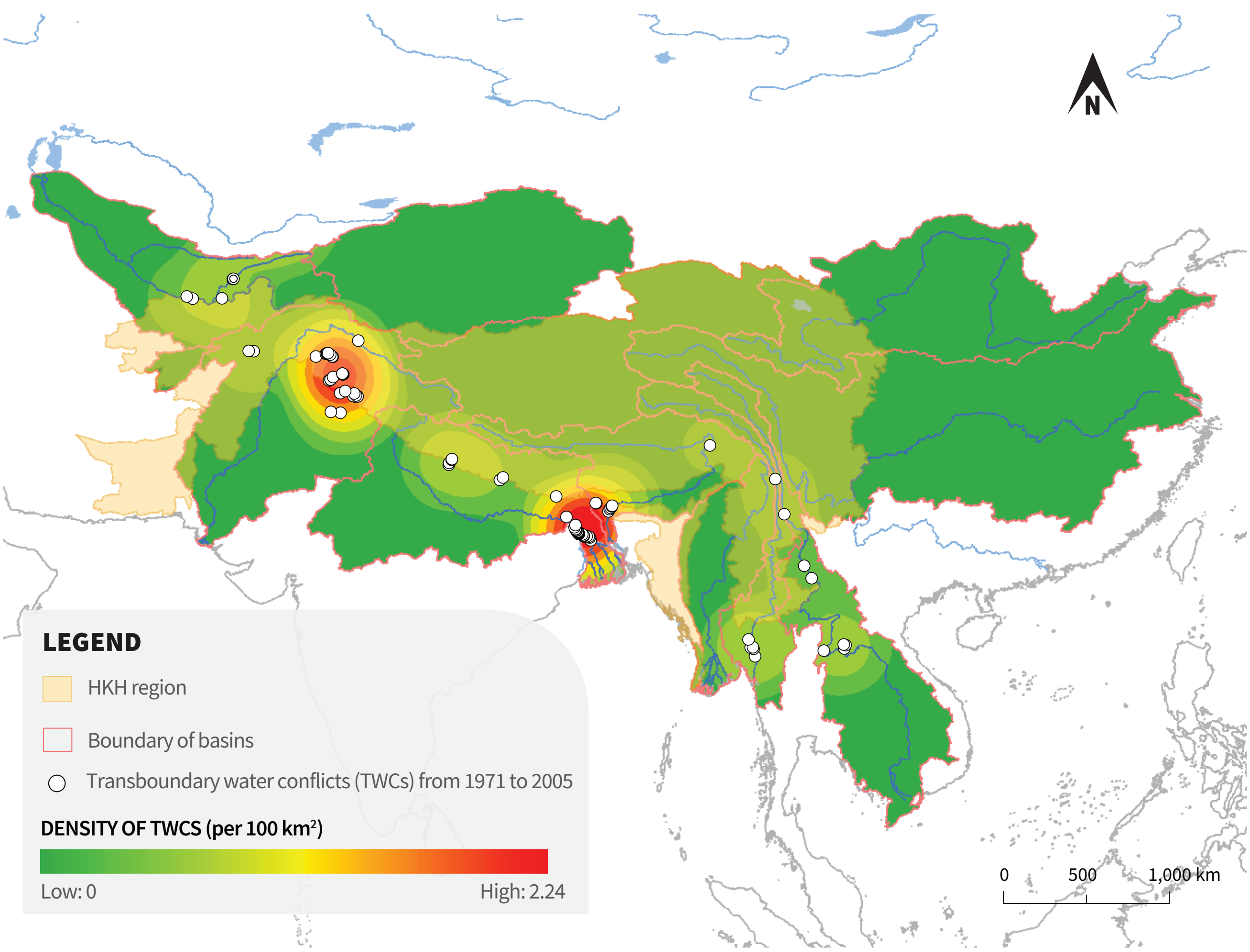
Freshwater is now often considered as a strategic resource, for which countries in transboundary basins would be willing more and more to extend their special protection and to compete for at international fora, even resorting to armed confrontation (Baghel

& Nüsser, 2015; Toset et al., 2000). Coupled with the lack of effective transboundary cooperation between upstream and downstream countries, these disputes could soon escalate into transboundary water conflicts (TWCs) (Brochmann & Gleditsch, 2012). In fact, there has been a rising risk of global TWCs in the latter part of the 20th century after World War II (De Stefano et al., 2010; Yoffe et al., 2003) with water crises ranked as one of the highest risks to world peace during the next decade (World Economic Forum, 2019).

A similar trend is observable in the HKH, especially in the Indus and Ganges-Brahmaputra basins where disputes over water have occurred during the 1971–2005 period as illustrated in Figure 5.5, based on the number of water conflicts recorded in the International Water Event Database in the Transboundary Freshwater Dispute Database (TFDD). According to the records, the disputes at Baglihar Dam, Wullar Barrage, and Kishan Ganga Dam of the Indus Basin located in Jammu-Kashmir all revolved around the issue of sharing river water. Similarly, in the Ganges-Brahmaputra basins, there have been frequent disputes over water between India and Bangladesh.

The causes of TWCs are complicated involving political, social, and economic factors, but one of the fundamental triggers is the increasing imbalance between freshwater supply and demand, or water stress, as defined by the ratio between water demand and supply in transboundary basins.

FIGURE 5.5 **HOTSPOTS OF TRANSBOUNDARY WATER CONFLICTS IN THE HKH FROM 1971 TO 2005**

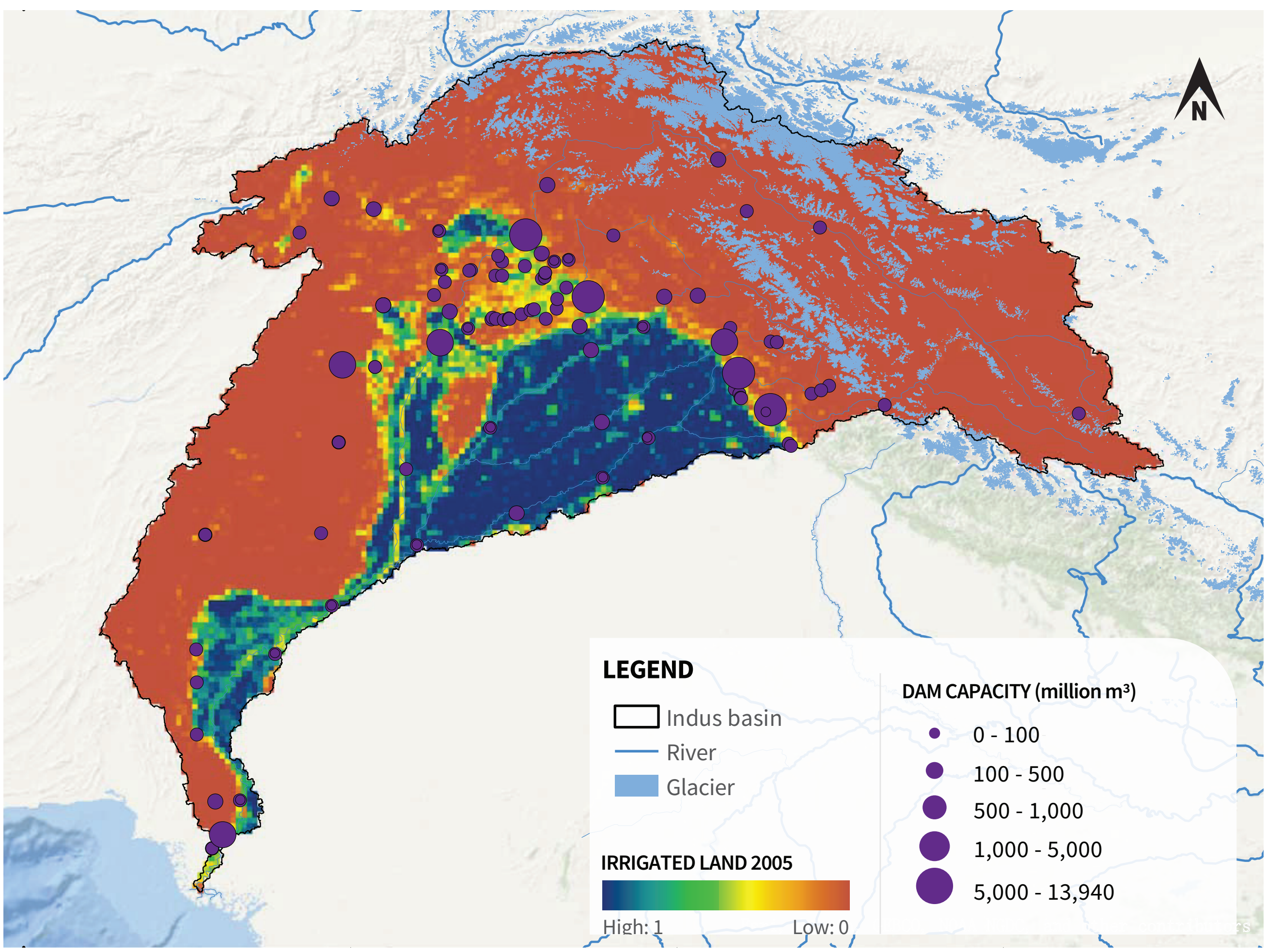


Data source: Transboundary Freshwater Dispute Database (n.d.)

Considering the reliance on the freshwater of the Indus Basin for irrigation in both India and Pakistan, (Figure 5.6), the importance of regional collaboration for sharing freshwater resources becomes paramount. The Indus Water Treaty, which was signed by India and Pakistan in 1960, is considered as one of successful cooperation to avoid severe conflicts between nations. According to the treaty, India has rights over the three eastern rivers, namely, Satluj, Beas and Ravi while Pakistan has control over the western rivers, Chenab, Jhelum, and Indus.

The Indus Basin Irrigation System (IBIS) is the largest contiguous irrigation system in the world, irrigating over 2.5 million acres and running over 90,000 km of watercourses (Muhammad et al., 2016). The irrigated land fraction for 2005 was extracted from ESACCI-LC dataset (Lamarche et al., 2017) based on the linear resample method as shown in Figure 5.6. It shows that about 77% of crop land was irrigated while the rest was rainfed. According to Simons et al. (2020), 76% of the annual average evapotranspiration for crop land in the Pakistani part of the IBIS was replenished by irrigation. The mountain water from the upstream high-mountain areas of the HKH is the main water source for irrigation (Biemans et al., 2019; Immerzeel et al., 2010; 2020; see also section 5.3.1.1). Notably, the Indus Basin shows high dependence on mountain water, not only due to the significant run-off contribution from mountain water but also due to the insufficient water supply in the lowland for the growing population (Viviroli et al., 2020). It has also been reported that the immense irrigation system leads to unsustainable use of local blue water resources because of heavy reliance on the mountain water surplus.

FIGURE 5.6 **IRRIGATION AREA AS PERCENTAGE OF THE TOTAL AREA IN THE INDUS BASIN**



Data source: ESA (2017)

When irrigation relies heavily on mountain water in transboundary basins, the importance of geo-collaboration to share the freshwater resources among the countries in the basins cannot be overemphasised. This is particularly true in the case of the Indus Basin. The issue is further compounded by ground water depletion, which comes to about 300 mm per year in the north-eastern Indus (Wijngaard et al., 2018). It is projected that both renewable and non-renewable groundwater abstraction would increase in the future (Lutz et al., 2022). Notably, the decline in the groundwater table could possibly be exacerbated by the transboundary impacts of extensive groundwater pumping on the Indo-Pakistan border (Cheema et al., 2014; Iqbal et al., 2017; Simons et al., 2020). In Pakistan, nearly half of the labour force is engaged in agriculture and one-fifth of the GDP is generated from agricultural production (Kreutzmann, 2011). Hence, the stakes involved in obtaining enough freshwater are high. It is even more critical when its cascading impacts, not only on the economy but also on poverty eradication, food security, and other aspects associated with sustainable development goals, are considered.

5.3.3. Impacts on cultural heritage

The physical changes in the cryosphere due to CrIDs and their impacts are described in the previous chapters. But the cryosphere is also inextricably linked with human societies as it provides material and non-material services towards societal well-being (Mukherji et al., 2019; Su et al., 2019) and, hence, cryospheric change also impacts these services. While the material services, especially the impacts on human lives, livelihoods, housing, and other infrastructure have received much attention, the impacts on non-material services such as culture and spirituality are not well understood and are hardly incorporated into the global knowledge generation process (Chakraborty & Sherpa, 2021). This is a significant lacuna in knowledge production as climate change also influences the cultural landscape and affects ethno-climatic rituals and the religious and symbolic relationships that societies form with the mountains around them (Allison, 2015; Becken et al., 2013; Brautigam, 2011). In Mustang Nepal, for instance, women especially have been found to be confused by the observed weaker correlations between religious rituals and climatic conditions and made anxious by the perceived indifference of the weather gods to their prayers (Becken et al., 2013).

The HKH, with its abundance of water and ice, and richness in flora and fauna have shaped human civilisation for millions of years (Tan, 2015), and the mountain systems have played a significant role in it (Zurick, 2014; Allison, 2015b). In all these cultures, snow- and glacier-covered mountains, for instance, have carried powerful mystical and symbolic meanings, attracting spiritual visitors on auspicious occasions from ancient times (Allison, 2015; S. Singh, 2004). The cryosphere components are seen as the sacred abode of deities and spirits protecting the local socio-ecological systems (Ikeda et al., 2016; Mukherji et al., 2019). For instance, *Lü* (the underwater spirits) of the Khumbu Valley (Bjønness, 1986; Spoon & Sherpa, 2008) and *Klu* in Ladakh (Gagné, 2019) protect the water bodies (lakes and rivers) while Mt. Langtang-Lirung in the Langtang Valley is the local protector deity (Pasakhala et al., 2022). In Bhutan, only religious monuments are allowed to be built in places believed to be the abode of the local deities while other land use and commercial or residential constructions are prohibited in those locations (Allison, 2015). These spiritual beliefs and the tendency to regard the cryosphere and mountains as sacred have directed the mountain societies towards the protection of geology, geography, and the natural environment, including flora and fauna (Ghimire et al., 2020). Moreover, spiritual practices in the high Himalaya have had positive impacts on people's mental, emotional, and social well-being (Arya et al., 2017). Generations of local inhabitants as well as artists and poets from elsewhere have regarded various elements of the cryospheric system as symbols of vibrant life and as sources of creative inspiration.

But the exposure of rocks due to the decrease in snow and glaciers has caused a darkening of the peaks, which locals perceive as a loss of honour and pride (Orlove, 2009; Diemberger et al., 2015). At the same time, the cryospheric disasters also threaten aspects of the tangible cultural heritage such as monasteries and temples (Bhambri et al., 2016). The recurring GLOFs in the Limi valley in northwestern Nepal threaten the eleventh-century Rinchenling Monastery (Kropacek et al., 2015). Therefore, the impact of cryosphere degradation on human well-being extends to the aesthetic, inspirational, religious, and spiritual as well as the educational, recreational, and cultural spheres (Su et al., 2019).

The discussion on the cultural impacts of cryospheric change in the HKH has also explored the question of morality and the ethics of care where the geophysical and cultural landscapes are perceived as an assemblage of people's intricate and interdependent relations with animals, plants, and lands (Butcher, 2017; Gagné, 2019 & 2020). It is widely believed in mountain societies that when people disregard the sanctity and sacredness of these natural bodies believed to be protected by the deities and spirits (e.g., glaciers, summits, lakes, and forests) and pollute them, these entities would, in return, avenge and punish those committing the infractions (Butcher, 2013; Gagné, 2019; Sherry & Curtis, 2017; Spoon & Sherpa, 2008). This moral and ethical viewpoint also recognises the value of tending to and caring for the non-human members as well as the other dharma in one's life and livelihood, which includes farming, herding, conservation, and avoidance of pollution. The observed cryospheric changes have been framed and interpreted by many societies as the consequence of diminished morality and ethics, mainly the result of irresponsible human actions against nature and the loss of the values of reciprocity and morality (Gagné et al., 2014; Pasakhala et al., 2022). Although the connections between the two may seem abstract or even superstitious, especially to outsiders, these moral and ethical perspectives guide local interpretations and influence perceptions and responses – to either adjust or shift adaptive measures, for example – of communities living in the glacierised region (Spoon & Sherpa, 2008).

5.3.4. Cryosphere-related disasters and society's perception of risks

CRYOSPHERE-RELATED DISASTERS

Cryospheric hazards such as glacial lake outburst floods, heavy snowfall, avalanches, rockfalls, and blizzards are common phenomena in the HKH (Vaidya et al., 2019; also see Chapter 3, Figure 5.3, for an overview of water-induced hazards in the HKH region since 2015). The growing population and infrastructure development in the mountainous area have increased the exposure of communities to cryospheric hazards. These developments are also likely to increase the magnitude of cryosphere-related disasters (Hewitt & Liu, 2013; Hewitt & Mehta, 2012; Vaidya et al., 2019). For decades, glacial lake outburst flooding (GLOF) received much of the attention as the ever-increasing size of glacial and supra-glacial lakes in the region have caught the attention of scientists and policy makers (Carrivick & Tweed, 2016; Hewitt & Liu, 2013). But there are other smaller and relatively unknown glacier-related floods that have not received as much attention. Only in recent years have some of these been documented (A. C. Byers et al., 2018; 2022; Veh et al., 2018). But if the recent episodes of devastating flood disasters such as the Chamoli and Kedarnath floods of India (Bhambri et al., 2016; Shugar et al., 2021), Melamchi, Seti, and Bhotekoshi River floods of Nepal (A. C. Byers et al., 2022; Cook et al., 2018), and the recent floods in Pakistan (Waqas, 2022) are any indication, cryospheric hazards in the region have grown more complex and devastating. The risks posed by the cryosphere-related disasters are becoming more unpredictable, costly, and deadly as the cryospheric elements (namely, snow melt, glacial lake outburst floods, and avalanches) are increasingly interlinked with and often compounded by other environmental extremes (namely, landslides, rockfalls, seismic activity, and heavy rains), often creating cascading hazards (A. C. Byers et al., 2017; Kirschbaum et al., 2019) and catastrophic disasters (see Chapter 3, section 3.2.1). In this section, we examine how changes in the HKH cryosphere have increased disaster risk in the region.

As shown in the chapter on high mountain areas in a recent IPCC special report (Hock et al., 2019), cryosphere-related disasters are projected to increase in the future requiring additional expenditure on risk-reduction measures, along with expenditure on the protection of infrastructure and possible relocation of communities to safer places. The societal costs of these cryospheric disaster risks are enormous as the exposure of people and infrastructure to cryospheric hazards and risks has also increased due to population growth, tourism, and socioeconomic development (Hock et al., 2019). Tourism, infrastructure (e.g., roads and hydropower plants), and other human activities have intensified in the high mountains, causing more disturbances to the already fragile mountain slopes, and increasing cryospheric disaster risks. All these in turn have increased the vulnerability of mountain people as well as their infrastructure.

The HKH region has experienced several GLOFs and other significant cryospheric hazards and risks, with long-term implications for the regional economy (Rasul et al., 2020; Richardson & Reynolds, 2000). Some of the major episodes are presented here to emphasise the intricate intersection between cryospheric change and associated disaster risks and their social implications. For instance, the Zhangzangbo GLOF in Tibet, China, killed 200 people and incurred an estimated economic loss of USD 456 million in 1981. It caused severe damage to the Nepal–China Highway, which cost USD 3 million to rebuild (Mool et al., 2001). Similarly, the Dig Tsho GLOF in the Khumbu Himal of Nepal damaged a hydropower plant and other properties in 1985, the estimated economic loss of which was USD 500 million (A. B. Shrestha et al., 2010). The GLOF risk in the Imja Tsho alone has been estimated to be over USD 11 billion as a major GLOF from this lake could significantly affect the tourism industry – the main source of revenue – as well as potentially damage roads, highways, several bridges, and three major hydropower stations, in addition to causing damage to dozens of settlements in flood zones (Bajracharya et al., 2007). Due to several GLOFs and the disruptions to irrigation canals, the entire village of Passu and the communities of Northern Borith and Ghulkin in northern Pakistan were forced to migrate to higher ground (Ashraf et al., 2012; Parveen et al., 2015). There have been other such forced relocations of populations due to GLOF hazards in several areas such as Uttarakhand, India (Jha & Khare, 2016; Maikhuri et al., 2017) and the Nagchu Prefecture in China (Diemberger et al., 2015).

Avalanches are another source of fatal hazards in the HKH. Snow and ice avalanches that occur at higher elevations can cause considerable loss of life as well as damage to property and infrastructure. Among such documented disasters are the following: the snow avalanches that caused 65 casualties in the Nepal Himalaya during the period of 2011-2019 (Thakuri et al., 2020), the two co-seismic avalanches which killed nearly 400 people after the Gorkha Earthquake in 2015 (Kargel et al., 2016), the rock and ice avalanche that killed more than 200 in Chamoli (Uttarakhand, India) in 2021 (Shugar et al., 2021), and the glacier detachment on the Tibetan Plateau that killed 9 people in 2016 (Kääb et al., 2018). A major avalanche from Mt Pumori into the Everest Basecamp, which was triggered by the Gorkha Earthquake in 2015, virtually closed the climbing season, bringing the local tourism industry to a virtual standstill (Moore et al., 2020; Thakuri et al., 2020).

SOCIETY'S RISK PERCEPTION

The above-mentioned disasters are only a few of the major disaster impacts recorded in the HKH region but they represent a much broader trend discernible in the region in recent decades and years. There is one area of the discourse on disasters that is relatively understudied in studies on the intersection between cryospheric hazards and society. It is societal perceptions and responses to hazards and risks. For people and communities experiencing cryospheric change, their decisions regarding risks can be influenced by their perceptions of the sources of risk. While scientific studies have helped tremendously to reduce objective uncertainty (e.g., mass balance, rate of glacier recession, and trigger factors of glacial lake outburst floods), more complicated (and less understood) are the ways people tend to view and calculate their exposure, and ability to adapt, to cryospheric hazards and risks (A. C. Byers et al., 2014; S. F. Sherpa et al., 2019). Among the key barriers and constraints in the way of the decision-making process are the structural biases (e.g., confirmation biases, cognitive dissonance) that people tend to live with in their lives, which either prompt them to overestimate or underestimate the risk they face. These would, in turn, depend on the socioeconomic, cultural, and political contexts of the people under reference (Slovic & Peters, 2006). For example, earthquakes and glacial lake outburst floods are often perceived to be more dangerous than landslides and droughts which occur more frequently and may not be perceived as catastrophic as the former even though the latter may cause more damage (S. F. Sherpa et al., 2019). In Khumbu, people's perceptions of cryospheric hazards were found to be influenced by livelihood sources, age, prior experiences of hazardous events, and geography (S. F. Sherpa et al., 2019). As this was the same area where a major GLOF event from the Dig Tsho occurred in 1985, which destroyed a newly built small hydropower station, farming land, and trails along the Dudh Koshi River Basin (Vuichard & Zimmermann, 1987), there has been a heightened sense of urgency, of late, among both scientists and the residents regarding the rapid expansion of the nearby Imja Tsho (A. C. Byers et al., 2017; Somos-Valenzuela et al., 2014).

Similar studies focusing on the Tsho Rolpa have also highlighted how people's perceptions of GLOF risks are shaped by socioeconomic, cultural/religious, and political factors that are not adequately articulated by outsiders such as government agents and researchers. The adverse implications of this disconnect are evident in the level of participation of the locals in the disaster risk mitigation measures in the Tsho Rolpa (Dahal & Hagelman, 2011; Sherry & Curtis, 2017), which is similar in nature to other such instances elsewhere in the region (S. P. Singh & Thadani, 2015). They also show that peoples' risk perceptions – whether underestimation or overestimation of the potential hazard and disaster risk – play a significant role in identifying and prioritising adaptation measures to address cryospheric change and associated risks (Thompson et al., 2020). All in all, this only underscores the need to move beyond the tendency to frame cryospheric changes and their risks as something to be solved by experts and expert (engineering) solutions and to develop an integrated and interdisciplinary understanding of and approach to disaster risks and hazards in which people's perceptions and complex local realities are given their due place, and complemented with scientific monitoring and assessments (Carey et al., 2021; S. P. Singh & Thadani 2015).

5.4. Adaptation measures: Successes and limits

The nexus of significant climate-related changes in the cryosphere and prevalent socioeconomic difficulties are leading to appreciable negative impacts for people living across the HKH (Adler et al., 2022; Carey et al., 2017; McDowell et al., 2013; A. Mishra et al., 2019). These challenges, however, are not decisive in shaping the fate of mountain communities as mountain people are displaying agency in adapting to the changes in diverse ways across the HKH. In fact, more adaptation actions have been recorded in the HKH than in any other mountain region globally (McDowell et al., 2014, 2019, & 2021a).

In this section, we examine the characteristics of the responses of mountain communities to the combined CrID and nCID impacts across four dimensions. The results presented here are based on the analysis of recent adaptation-focused systematic reviews that include the HKH region (McDowell et al., 2019 & 2021a; Rasul et al., 2020) as well as literature reviews by the chapter authors. Here, adaptations reported in the literature are used as a proxy to assess the adaptation actions in the region. However, because many adaptations go undocumented, the results below likely underrepresent the actual extent of adaptations taking place across the HKH region.

5.4.1. Adaptation to maintain livelihoods

AGRICULTURE

Most adaptation measures in the agricultural sector are being carried out at the household level by local communities (Table 5.2). Most of these responses are autonomous, in that they are carried out without a formal adaptation plan or specific adaptation support. Formal policies or programmes are rare in the region. Instead, behavioural, and technological responses are the most common adaptation measures in response to growing water scarcity due to the decline in snowfall and the receding of glaciers.

Responding to increasing uncertainty of snowfall, farmers have changed their crop sowing seasons and planted drought-resistant crops such as buckwheat (Chaudhary et al., 2011; Hussain et al., 2016; Onta & Resurrección, 2011). Crop failures due to delayed snowfall or snow drought have led farmers to organise themselves and advocate for compensation and support against crop failures, as seen in the case of the Apple Growers' Association in Himachal Pradesh (Vedwan, 2006). In a few areas, increased water availability due to increasing temperature and snowmelt have favoured the growth of vegetables as well as other new crops (Ingty, 2017; Macchi et al., 2014; Maikhuri et al., 2017; Manandhar et al., 2011; Negi et al., 2017; Nüsser and Schmidt, 2017; Nüsser et al., 2019a).

LIVESTOCK

Adaptations in the pastoralism sector follow a similar pattern as in agriculture, with most actions being carried out at the household level or community scale, with behavioural and technological responses being the most common (Table 5.3). However, in this sector, a modest number of responses is institutional in form.

Behavioural adaptations were observed amongst pastoral communities, who have changed their grazing locations and timing of animal movement to cope with snowfall uncertainty (Fu et al., 2012; Gentle & Thwaites, 2016; Rayamajhi & Manandhar, 2020). Fodder plantation, seeding of pastures, and purchasing of livestock feed are some of the measures adopted to improve food availability for livestock (Suberi et al., 2018; Wang et al., 2014; Wu et al., 2015). In response to impacts of cryospheric change on water and food shortages as well as other drivers of

TABLE 5.2 ADAPTATION IN AGRICULTURE

Form	Scale	Measures
Behavioural	Household	Planting new crops at higher elevations (Macchi et al., 2014); Planting less water-consumptive crops (Kelkar et al., 2008); Shifting to alternative livelihood options (Tuladhar et al., 2021)
	Single community	Agricultural diversification (Ingty, 2017)
	Multiple communities	Changes in the sowing season (Hussain et al., 2016)
Technological	Household	Replacement of traditional cultivars with high yielding ones (Maikhuri et al., 2017)
	Single community	Shifting from traditional crops to vegetables (Negi et al., 2017)
Institutional	Single community	Formation of the Apple Growers' Association to advocate for compensation and support against crop failure (Vedwan, 2006)

TABLE 5.3 ADAPTATION IN LIVESTOCK

Form	Scale	Measures
Behavioural	Household	Reduction in the number of animals (Hussain et al., 2016)
	Single community	Changes in the timing of animal movement (Fu et al., 2012; Gentle and Thwaites, 2016; Rayamajhi and Manandhar, 2020)
	Multiple communities	Replacing large-sized animals with small ones (Macchi et al., 2014)
Technological	Household	Purchase of livestock feed (Suberi et al., 2018); Plantations of fodder species (Suberi et al., 2018)
	Multiple communities	Reseeding of pastures (Wu et al., 2015)
Institutional	Single community	Pooling of resources and labour (Fu et al., 2012; Y. Wang et al., 2014)
	Multiple communities	Formation of herders' committees to regulate grazing (Joshi et al., 2013)
Infrastructural	Single community	Construction of sheds for the animals (Hussain et al., 2016)
	Multiple communities	Construction of sheds and fencing (Wu et al., 2015)

change, communities have reduced the number of animals they own (Hussain et al., 2016; Y. Wang et al., 2014) while some have abandoned livestock keeping altogether and shifted to other livelihood options (Negi et al., 2017; Tuladhar et al., 2021).

For ecological restoration of the rangelands affected by permafrost degradation, the provincial government of the Qinghai-Tibet Plateau has implemented 'Returning to grasslands from grazing' and 'Ecological protection in the Three Rivers' sources' (Huijun et al., 2009). Communities have also built sheds and fences to protect their animals against snowstorms (Hussain et al., 2016; Y. Wang et al., 2014; Wu et al., 2015).

TOURISM

Responding to the impacts of change to traditional livelihoods such as agriculture and pastoralism, as well as new income generation opportunities, many mountain communities have been gradually diversifying their activities to include tourism (Ingty, 2017; Tuladhar et al., 2021). However, the tourism sector is threatened by cryospheric change, complicating the livelihood diversification efforts for mountain societies. A few adaptive measures have been taken to safeguard against cryospheric risks albeit mostly by the private sector (Table 5.4).

In the case of the Yulong Snow Mountain in southwestern China, the government and the private sector have jointly developed and implemented an environmental protection plan, which includes restricting the number of tourists visiting the area, along with financial incentives to tourism entrepreneurs, to avoid damage to Baishui Glacier No. 1 (S. Wang et al., 2010). In Langtang Nepal, the local communities and the private sector have come together to promote 'disaster tourism' to support the recovery of the village devasted by the earthquake-triggered avalanche (Kunwar et al., 2019). Installation of hazard signposts and construction of shelters for tourists along the trekking routes, weather forecasting, and early warning communication are among the major measures undertaken to reduce risks in Nepal (Ziegler et al., 2021). Countries in the region have also introduced regulatory measures and guidelines to control the number of visitors, limit the tourist season, implement rescue operations, and introduce other disaster risk preparedness measures (Burtscher, 2012).

MEDICINAL AND AROMATIC PLANTS

There is limited documentation about the adaptation measures adopted with regard to the collection of MAPs (Table 5.5). Delayed collection of MAPs,

TABLE 5.4 ADAPTATION IN TOURISM

Form	Scale	Measures
Infrastructure	Single region	Construction of shelters (Ziegler et al., 2021)
Technological	Single region	Use of environment-friendly vehicles (S. Wang et al., 2010)
Financial	Single region	Diversification of tourism products and use of financial measures to restrict the number of tourists (S. Wang et al., 2010)
Regulatory	Single community	Implementing environmental protection rules and guidelines for controlling the number of visitors (Burtscher, 2012; Ingty, 2017)
	Single region	Implementing environmental protection rules (S. Wang et al. 2010)
Informational	Single region	Establishing a glacier museum and educating tourists about the need for glacier protection (S. Wang et al., 2010); Installation of signposts (Ziegler et al., 2021)

TABLE 5.5 ADAPTATION IN THE COLLECTION OF MEDICINAL AND AROMATIC PLANTS

Form	Scale	Measures
Behavioural	Single community	Changes in the timing of collections (A. C. Byers et al., 2020) Conservation of MAPs (Koul et al., 2005)
Technological	Multiple communities	Propagation of MAPs (Koul et al., 2005; Rokaya et al., 2017)

particularly caterpillar fungus, has been reported in response to delayed snowfall (A. C. Byers et al., 2020). There have also been efforts to conserve and propagate high-altitude MAPs such as *Hedychium spicatum,* the habitats of which have been destroyed as a result of climatic and anthropogenic factors (Koul et al., 2005).

5.4.2. Adaptation to ensure water security

Adaptation efforts in the water sector are more widespread as well as more diverse than in the other sectors (Table 5.6). For example, while community members are still the most active in leading adaptations, local, regional, and national government-affiliated entities as well as non-governmental organisations are also active in leading adaptations in irrigation and water supply. In a similar vein, while autonomous responses are more numerous, formal policies and adaptation plans are also more commonly observed here than in the other sectors.

Technical measures were commonly adopted to maintain water availability for irrigation and water supply. For irrigation, innovative water infrastructure such as artificial glaciers, ice stupas, and snow barrier bands have been devised through a collaborative approach between engineers and local communities (Clouse, 2016; Nüsser et al., 2019a). Such innovative approaches were also in evidence many decades ago, as recalled by the elders in Ladakh, India, when ice cultivation was practiced by spreading charcoal over the glacier to decrease the melting process (Gagné, 2016). Rainwater harvesting and installation of water tanks are other common measures adopted at the household and village levels (McDowell et al., 2013; Nüsser and Schmidt, 2017; Spies, 2016).

5.4.3. Adaptation to impacts on cultural heritage

The literature on cultural adaptations to cryospheric change in the HKH region is limited. Some efforts have been made to preserve structures constituting tangible cultural heritage, such as monasteries, against the impacts of cryospheric disasters (Table 5.7). For example, in the Limi valley, gabion walls have been constructed along the riverbank to protect the Rinchenling Monastery. Similarly, in the state of Uttarakhand in India, after the devastating floods

TABLE 5.6 ADAPTATION IN WATER SUPPLY

Form	Scale	Measures
Behavioural	Household	Water rationing, fetching water from distance sources, and hiring assistants to collect water (McDowell et al., 2013)
Technological	Household	Installing rooftop water collection systems (McDowell et al., 2013), and installing water efficient irrigation systems (Kelkar et al., 2008)
	Single community	Constructing ice stupas, snow barrier bands, and artificial glaciers for irrigation and water conservation purposes (Clouse, 2016)
Institutional	Single community	Adjusting and regulating irrigation timing (Clouse, 2016; Kelkar et al., 2008)
Informational	Single community	Community outreach activities to design artificial glaciers (Clouse, 2016; Nüsser et al., 2018)
Infrastructure	Household	Installing water storage tanks (Kelkar et al., 2008; McDowell et al., 2013)
	Multiple communities	Constructing, repairing, and rehabilitating irrigation canals (Parveen et al., 2015; Spies, 2016)

TABLE 5.7 ADAPTATION TO IMPACTS ON CULTURAL HERITAGE

Form	Scale	Measures
Technological	Single community	Construction of gabion walls (Kropacek et al., 2015)

of 2013, the government constructed double flood retaining walls to minimise the impacts of future flooding on culturally important infrastructure to protect the cultural heritage (Bharaj, 2018).

5.4.4. Adaptation to cryosphere-related disaster risks

Adaptations to cryosphere-related disaster risks aim to (1) prevent hazard occurrence, (2) reduce exposure, and (3) minimise vulnerability (Table 5.8). A wide range of stakeholders have been engaged in designing and implementing adaptation measures to address and minimise cryosphere-related disaster risks. Similarly, various types of adaptation measures, ranging from behavioural, technological, and institutional to infrastructural changes, have also been adopted in the region. Among measures taken are collaborations between governmental, non-governmental, and community-based institutions to drain out water from the glacial lakes, install early warning systems, build gabions, and monitor glacier lakes to minimise cryosphere-related disaster risk (Cuellar & Mckinney, 2017; Meenawat & Sovacool, 2011; Orlove, 2009; Schimdt et al., 2020; Somos-Valenzuela et al., 2015). Hydrological models, scenarios, and maps, too, have been developed to forecast cryosphere-related disaster risks such as GLOFs and debris flow (Maskey et al., 2020) in order to support better disaster risk preparedness. But many of these technological measures are confined to a few sites.

Considering the threat of disaster-related risks, some local communities have voluntarily abandoned their agricultural lands and settlements (Kreutzmann, 2011; Maikhuri et al., 2017); government agencies have provided support for resettlement at other safer sites. For example, this was the case with communities from Kumik village in Jammu and Kashmir, India (Grossman, 2015), and the Nagchu Prefecture in Tibet, China (Deimberger et al., 2015).

Cryosphere-related disasters are projected to increase in the future and will therefore require additional investments to secure the safety of mountain societies. For instance, the cost of digging a canal into the Tsho Rolpa glacier in Nepal to lower the glacial lake in 2002 was USD 3 million (Bajracharya, 2010). A similar disaster mitigation measure was implemented in 2016 in the Imja Tsho glacial lake, Nepal, which needed over USD 5 million (CFGORRP, 2017). And costs can be much greater when communities need to be relocated to safer locations.

TABLE 5.8 ADAPTATION TO CRYOSPHERE-RELATED DISASTER RISKS

Form	Scale	Measures
Behavioural	Single community	Relocation of settlements (Maikhuri et al., 2017)
Technological	Single region	Draining of water from the glacial lakes and installation of early warning systems (Meenawat & Sovacool, 2011)
Institutional	Single region	Formulation of disaster management plans and policies at sub-national and national levels (Kaul & Thornton, 2014; Meenawat & Sovacool, 2011; P. Y. Sherpa, 2015)
Infrastructure	Single community	Construction of gabion walls (Kropacek et al., 2015)

5.5. Adaptation to cryospheric change and links to sustainable development

The adaptation responses of communities to cryospheric change illustrated in section 5.4 are mostly reactive and autonomous – the use of available skills, resources, and opportunities to address experienced adverse conditions – and carried out at household/community scale. They are also primarily incremental, maintaining the essence of relevant systems or processes without driving fundamental changes in existing practices (A. Pandey, 2019; Adler et al., 2022). The autonomous nature of adaptations can be indicative of resilient mountain communities who are able to act without the need or desire for external support (Ingty, 2017; McDowell et al., 2014). However, such responses may arise from either the lack of, or lack of access to, relevant social safety nets (Gentle & Maraseni, 2012). Insofar as this is the case, there appears to be a significant gap between the adaptation needs of mountain communities and access to necessary adaptation support (McDowell et al., 2019).

Even when the adaptation actions are planned, they remain inadequate to address the negative consequences. For example, the increase in the number and extent of glacier lakes in the region (see Chapter 2, section 2.4) is endangering the lives and livelihoods of the populations living within the vicinity of the lakes and downstream when GLOFs occur (Bajracharya et al., 2020; Dimri et al., 2021). Early warning systems are often considered an important adaptation measure against GLOFs. Although such systems can save lives, both livelihoods as well as the ability to regenerate effective economic and sociocultural outcomes are still massively impacted, leading directly to an increase in poverty and hunger, which carry other broader social and economic implications. The lack of scope and depth in the adaptation response to address systematically the fundamental issues related to the exposure, sensitivity, and vulnerability of mountain societies to GLOFs poses a barrier to long-term sustainable development.

Adaptation deficit also persists for many high mountain livelihoods. For instance, the local communities dependent on medicinal products like the caterpillar fungus, have witnessed decline in their harvest under warming climate conditions compounded by unsustainable harvesting (Hopping et al., 2018), but lack any adaptation measures. Deficits in adaptation are also evident in the responses to the decline in rearing of mountain-suited livestock like yak (Joshi et al., 2020) as well as agrobiodiversity (Rasul et al., 2022; Hussain & Qamar, 2020). Such instances constitute barriers to advancing sustainable development.

Furthermore, a high number of reactive responses is concerning in the context of trajectories of climate change and, especially, non-linear processes of change such as peak water (Huss & Hock, 2018; McDowell et al., 2021b). Such dynamics call attention to the need for anticipatory responses that are attentive to novel climate futures in mountain areas. In addition, formal evaluations of adaptation in the HKH region are very rare, making it difficult to determine how, where, under what conditions, and for whom/what adaptations are (or are not) effective and equitable. Consequently, this makes it difficult to determine the extent to which adaptations are contributing to the advancement of SMD. However, even without formal evaluation, there are several bright spots reported in the literature which are presented here.

While autonomous approaches to adaptations appear to be common, it should be stressed that there are at present a wide variety of adaptation support programmes that are of relevance to advancing adaptation efforts in mountain communities, including those of the United Nations, multi- and bi-lateral aid organisations, government programmes, NGOs, and the private sector (McDowell et al., 2021a). However, ensuring that HKH communities benefit from such resources depends on addressing the underlying socioeconomic and political conditions as well as marginalisation that make it difficult for mountain communities to identify, apply for, and secure adaptation support (McDowell et al., 2020). This also requires overcoming biases on the part of supporting institutions and agencies regarding mountain specificities that result in the under-allocation of state support and resources to highland areas compared to lowland regions (Debarbieux & Rudaz, 2015; Romeo et al., 2020). In addition, ensuring that mountain communities can utilise the available adaptation support requires understanding the ways in which specific globalised discourses relating to climate change may conflict with the material and symbolic ways in which mountain communities understand climate-related changes (Gagné et al., 2014; Jurt et al., 2015; Mills-Novoa et al., 2017; McDowell et al., 2020). Here, bringing traditional and local knowledges into conversation with the approaches and findings of climate researchers and adaptation planners on equal grounds is crucial although this has proved to be very difficult in practice to date (Ericksen et al., 2021; Haag et al., 2021; Nightingale, 2017; Ojha et al., 2016).

Ultimately, adaptation aims to reduce risks by minimising exposure and vulnerability of societies when facing future changes (Y. Wang et al., 2019). Securing a desirable adaptation future across the HKH hinges on addressing soft limits to adaptation such as financial, institutional, governance, and policy constraints that impede sufficient adaptation action. For example, it will also be necessary to move towards deeply collaborative approaches to adaptation that are rooted in local needs, aspirations, and knowledges while being supported by external adaptation support (McDowell et al., 2020; Muccione et al., 2019).

In addition to addressing the limits, the success of adaptation measures also depends on depth, scope, and speed. Sustainable development would be able to build adaptive capacity (Munasinghe & Swart, 2005; R. P. Shrestha et al., 2019). It is therefore important to bring adaptation in line with sustainable development (Robinson & Herbert, 2001). Effective adaptation is key to meeting SDGs and to reducing the economic gap between mountain societies and those living in less marginalised geographies. In fact, as indicated above, there are three SDG targets that are explicitly related to the mountain region. However, a much broader development plan has to be implemented to address the social, economic, and environmental challenges in countries of the HKH region. Although each country has its own priorities in sustainable development, they share in common their desire to eradicate poverty (SDG1) and hunger (SDG2), to improve public health and well-being (SDG3), to provide decent work and economic growth (SDG8), and to develop partnerships for the goals (SDG17). In addition, the HKH Assessment Report (Wester et al., 2019) has identified and linked the SDGs that are relevant to the HKH through nine mountain priorities (ICIMOD, 2020; Jodha, 2007).

Changes in the cryosphere also have important direct and indirect implications for meeting the SDG 2030 targets in the region (Table 5.9). Cryospheric services are central to achieving the mountain priorities and specific targets and will enhance the adaptation capabilities of mountain communities. Cryospheric services (see also Chapter 4) benefit the mountain communities mainly through the provisioning, regulating, cultural, and supporting services (X. Wang et al., 2019; Zhang et al., 2022). The provisioning services with regard to the cryosphere include freshwater supply, clean energy, and snow and ice materials; the regulating services are run-off, climate, environment, and hydrothermal regulations; the cultural services are aesthetic, recreational, research and educational, and religious and spiritual; and supporting services are habitation and infrastructure, and engineering.

More specifically, provisioning service in terms of the freshwater supply and the regulating service in terms of run-off and climate play important roles in the eradication of poverty (SDG1), especially extreme poverty, for all people everywhere. They reduce the number of people living under the poverty line (Target 1.1, 1.2) through opportunities for land ownership (Target 1.4) and ensures food security by increasing agriculture production (Target 2.3), which also assists in ending hunger (SDG2). This combination of services also contributes to SDG15 (Targets 1, 2, 3, and 4), which includes two targets (Targets 15.1 and

TABLE 5.9 LINKAGES OF CRYOSPHERIC SERVICES WITH SUSTAINABLE DEVELOPMENT GOALS

Cryospheric services	Components	Linkages with the four dimensions	SDGs
Provisioning services	Freshwater supply, clean energy, snow/ice material	Livelihoods, water supply, culture	1, 2, 3, 5, 6, 7, 12, 13, 14, 16
Regulating services	Climate, run-off, environment, and hydrothermal regulations	Livelihoods, water supply, disasters	1, 2, 3, 13, 15
Cultural services	Aesthetics, recreation, religious and spiritual, research and education	Livelihoods, culture	1, 2, 3, 4, 5, 16
Supporting services	Habitation, infrastructure, and engineering	Livelihoods, disaster	1, 2, 3, 4, 7, 8, 9, 11

15.4) that are directly associated with mountains, their primary aims being the conservation of terrestrial ecosystems and sustainable use of natural resources. Run-off, climate, and hydrothermal regulation as well as habitation supporting services enhance the resilience of disadvantaged communities (Targets 1.5 and 13.1), agricultural practices, and ecosystems (Target 2.4) so as to minimise disaster displacement (Target 10.7). Similarly, the freshwater provisioning service together with the run-off and hydrothermal regulation service and habitation support service contributes to the goal of access to affordable, reliable, sustainable, and modern energy for all (SDG7). This would eventually help in decoupling economic growth from environmental degradation (Target 8.4). In the meantime, economic growth (Target 8.1) and good health and well-being (SDG 3) benefit from cultural services, which are likely supported by an enhanced tourism industry and spiritual/religious belief systems. Such linkages between cryospheric services and the SDGs suggests that adaptation must be highly sensitive to, and supportive of, broader socio-cryospheric dynamics that support the well-being of mountain societies. Similarly, advances in sustainable development should be seen as having the co-benefit of enhancing adaptive capacity amongst mountain communities (Munasinghe & Swart, 2005).

5.6. Conclusions, key messages, and knowledge gaps

The HKH is undergoing changes in multiple aspects of the society-cryosphere interface, but the region lags behind in terms of generating attention in global forums concerned with climate change. One of the reasons is the lack of research on the various drivers at play, particularly the human dimensions. This is highly consequential, as changes in the cryosphere directly impact the lives and livelihoods of some 240 million people living within the mountains of the HKH, while indirectly affecting approximately 1.65 billion people living on the floodplains of the rivers stemming from mountain watersheds. Such impacts include the destruction of traditional irrigation channels, crop losses and failures, rangeland degradation, land use changes, and an overall decline in crop and livestock production. In some instances, these changes have resulted in the abandonment of farming and livestock herding in subsistence farming villages and resettlement of entire villages.

In this chapter, four key dimensions of the society-cryosphere interface were assessed in relation to the interactions and interdependencies between CrIDs and nCIDs: livelihoods, water security, culture, and disaster risk. The review of the intersections between the CrIDs and nCIDS yielded valuable insights into the mosaic of lived experiences of cryospheric change impacts in the HKH region. Mountain societies in the HKH are highly dependent on the provisioning, regulating, cultural, and supporting services associated with mountain ecosystems. However, given the large number of people living both upstream and downstream of the HKH, their high dependence on natural resources from the mountain areas, and shortcomings in accessing basic services and support for adaptation, climate-related changes are manifesting themselves in largely negative ways for those who call the region home.

Despite these challenges and adversities, mountain people are displaying agency and adapting in diverse ways across the HKH region, drawing on their rich traditional knowledge and practices. Adaptation responses to date have been mostly autonomous, and have taken behavioural, technological, financial, regulatory, institutional, and infrastructural forms. However, these autonomous measures may prove to be insufficient in the long run with the rapid CrID and nCID changes taking place in the region. This exacerbates fears about the safety of the local inhabitants and the habitability of their locations. This realisation is complicating efforts at meeting SDG targets by 2030 and is raising concerns about possible transboundary water conflicts.

The mosaic of lived experiences of climate-change-induced cryospheric change in the HKH documented in this chapter will help to clarify the state of knowledge regarding the CrIDs, nCIDs, and their interactions in the region. But it has also brought to light significant knowledge gaps, which must be addressed to secure more sustainable and equitable futures for those living in the HKH. The chapter points to several key messages:

KEY MESSAGES

- Life in mountains of the HKH is generally improving, but this progress is being jeopardised by cryospheric change and the increasing pressures that these place upon mountain communities.
- Cryospheric change have mostly adverse implications for mountain societies as major mountain livelihoods such as agriculture, livestock, MAPs, and tourism are directly and indirectly dependent on cryospheric services.
- Risk perception within mountain societies – whether they underestimate or overestimate potential cryospheric hazards and disaster risks – plays a significant role in identifying and prioritising responses to cryospheric change and the associated adverse consequences.
- Mountain societies have been resorting to adaptations that are mostly autonomous and incremental in nature and largely limited to household and community scales. But limits to adaptation make mountain livelihoods highly precarious in the changing cryosphere.
- Effective adaptation is key to advancing SMD, while SMD can mobilise the capacity of mountain societies to achieve more effective adaptation.
- Cryospheric change has significant implications for societies in areas that rely on high mountain freshwater. Thus, collaborative efforts through mutual agreements are required among the relevant countries to share water resources, mitigate disaster risks, and explore options to counteract common threats to derive co-benefits. Regional and global cooperation would be needed for technical and financial assistance to facilitate adaptation and mitigation and to advocate on matters of common interest.

KNOWLEDGE GAPS AND POTENTIAL RESPONSES

Despite advances in the extent of understanding about the societal impacts of cryospheric change, existing adaptation efforts, and associated implications for sustainable development in the HKH, critical knowledge and action gaps remain. This section summarises several of these gaps and provides insights into potential pathways forward.

Gap 1

There is poor understanding about the interactions between cryospheric and non-climatic drivers of socio-ecological change and their respective influence on the lives and livelihoods of mountain societies. This knowledge gap hampers informed responses that are essential for minimising vulnerability and enhancing the capacity of mountain societies for effective and sustainable adaptation to a rapidly changing and complex mountain system.

Response

Increasing the number of case studies examining interactions between cryospheric and non-climatic drivers of change, the impact of the nexus of multiple drivers of change on mountain societies, and the responses of the communities to the interlinked challenges and opportunities. It will also require greater involvement with the local and traditional communities (including greater respect for diverse knowledge systems). Such studies should identify the context-specific as well as generalisable aspects of community-level experiences of the interlinked processes of change. The findings thus elicited should inform policies on adaptation that attend to the myriad pressures faced by mountain societies.

Gap 2

There is little understanding of the cascading consequences of cryospheric change as well as the extent of actual or potential maladaptation and responses that shift the burden of addressing cryospheric change to other places (downstream), systems (ecosystems), or times (future). Without greater understanding of such system-level dynamics, it would be difficult to anticipate and avoid undesirable regime shifts in socio-cryospheric systems across the HKH.

Response

Undertaking interdisciplinary observations and studies to explore the nexus of the spheres (cryosphere–hydrosphere–biosphere–society) that lead to mountain cryospheric change and its influences on the livelihoods and economy, which will help in addressing this knowledge gap. An in-depth study is a prerequisite to generate holistic knowledge and understanding about the multiple facets of the nexus involving upstream–downstream natural linkages, hazards and disasters, ecosystem services, livelihoods, and social behaviour pertinent to cultural and spiritual beliefs in order to represent the various interactions at different scales.

Gap 3
There is little knowledge on the impact of cryospheric change on the intangible cultural heritage such as spiritual practices and belief systems that generate societal well-being. Cultural/spiritual tourism is a growing livelihood opportunity in the region and that, too, is likely to be impacted by cryospheric change.

Response
Increasing the number of studies exploring the nexus of cryospheric change, intangible cultural heritage, and tourism, and identifying the contextually appropriate opportunities for protecting the cultural and spiritual practices and belief systems that are critical for the people's well-being as well as for cultural tourism.

Gap 4
The effectiveness and inclusiveness of adaptation remain poorly understood.

Response
Increasing efforts to monitor the effectiveness of adaptation activities bearing in mind that the criteria for 'effectiveness' should be informed by tenets of social and environmental justice and sustainable development more broadly. Such efforts can increase understanding of who is vulnerable (or adaptable) to which stresses, how, and with what implications. This is knowledge that is essential for generating durable responses to cryospheric change.

Gap 5
Too little is known about the transboundary implications of adaptation actions in glaciated river basins. Cultivating cooperation in knowledge generation, exchange, and sharing among global, regional, national, and local actors in the common interest and for co-benefits is urgently required.

Response
Undertaking studies exploring the transboundary implications of cryospheric change with the collaboration of research teams from the respective countries will not only help in filling the knowledge gap but also facilitate cooperation with regard to data/information sharing, cross-learning, and scaling of adaptation options from one country to another.

Gap 6
Disasters are complex socio-environmental events, often with upstream–downstream linkages as well as transboundary impacts. There is not enough understanding about the complex nature of hazards and their potential for loss and damage as well as appropriate management measures at different scales to mitigate risks and enhance resilience.

Response
Increasing the number of studies exploring the cascading and compounding hazards, their processes, and exposure to such hazards and vulnerability of mountain societies as well as infrastructure will help in better understanding this new phenomenon. It will also help policy makers and communities to better prepare for such emerging complex disasters in the HKH countries, with a more regional approach to finding and establishing effective solutions.

Gap 7
At present, adaptation is mostly autonomous and incremental in nature with investment in adaptation efforts low in mountain areas. This raises concerns about what warming beyond 1.5°C means for socio-cryospheric systems in the HKH, including the relationship between limits to adaptation and warming that exceeds 1.5°C.

Response
Increasing social scientific work that examines the nature, extent, and implications of the hard limits to adaptation associated with warming beyond 1.5°C, with the aim of shaping anticipatory responses to potentially transformative changes in the cryosphere of the HKH.

Despite existing knowledge gaps, this chapter demonstrates that, currently, there is sufficient understanding to address the many timely issues related to the societal impacts of cryospheric change in the HKH. Attending to the gaps listed above will enhance efforts to secure sustainable and desirable futures for the people living in (and beyond) the HKH.

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About ICIMOD

The International Centre for Integrated Mountain Development (ICIMOD), based in Kathmandu, Nepal, is the leading institute for the study of the Hindu Kush Himalaya (HKH). An intergovernmental knowledge and development organisation with a focus on climate and environmental risks, green economies, and sustainable collective action, we have worked in our eight regional member countries – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – since our foundation.

Entering our 40th year, ICIMOD is perfectly positioned to support the transformative action required for the HKH to face the challenges of the escalating effects of climate change, pollution, water insecurity, increased disaster risk, biodiversity loss, and widespread socioeconomic changes. We seek to raise our ambition to support the required transformative action to step up our engagement through to 2030.

REGIONAL MEMBER COUNTRIES

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