CHAPTER 1

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Water, ice, society, and ecosystems in the Hindu Kush Himalaya: An introduction

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1.1. Introduction

The Hindu Kush Himalayan (HKH) region, covering more than 4.2 million km^2, encompasses the highest mountain ranges in the world and contains the largest volume of ice on Earth outside of the polar regions, as well as large expanses of snow. Hence, it is also known as the "Third Pole". Spanning some 3,500 km in length from Afghanistan in the west to Myanmar in the east, and covering parts or all of Pakistan, India, China, Nepal, Bhutan, and Bangladesh, the HKH is home to unique cultures, highly diverse landscapes, and all of the world's peaks above 7,000 meters. The region hosts all or parts of four global biodiversity hotspots supporting diverse flora and fauna – the Himalaya, the Indo-Burma, the Mountains of Central Asia, and the Mountains of Southwest China. The glacier- and snow-covered mountains of the HKH are an important source of water for 12 river basins, including 10 major (transboundary) rivers – the Amu Darya, Brahmaputra (Yarlung Tsangpo), Ganges, Indus, Irrawaddy, Mekong (Lancang), Salween (Nu), Tarim, Yangtse (Jinsha), and Yellow (Huang He) – that flow through 16 countries and provide freshwater services to 240 million people living in the HKH region and 1.65 billion downstream (Sharma et al., 2019).

Based on an assessment of the literature, this report shows that the HKH cryosphere is undergoing unprecedented and largely irreversible changes over human timescales, primarily driven by climate change. The impacts are becoming increasingly clear, with increased warming at higher elevations, the accelerated melting of glaciers, increasing permafrost thaw, declining snow cover, and more erratic snowfall patterns. Projected changes are deeply concerning, showing a loss of at least one-third of the region's glacier volume by 2100 if global warming is restricted to 1.5°C and much higher losses of up to two-thirds of glacier volume by 2100 under current emission rates and committed climate policy (Bolch et al., 2019). The water towers of the HKH, critical for downstream regions, are some of the most vulnerable to these changes in the world.

Mountain communities are already living with the impacts of the accelerated melting of glaciers, changing snowfall patterns, growing variability in water availability, and increasing incidences of cryosphere-related hazards. These changes have a direct impact on their lives and livelihoods. Cryospheric change also poses threats to downstream infrastructure, human settlements, livelihoods, and broader economies. In the coming decades, floods and landslides are projected to increase, and the timing, availability, and seasonal distribution of mountain water resources for large lowland populations will become more uncertain, especially affecting irrigated agriculture. These knock-on effects threaten not only the security of water, food, energy, ecosystems, and their services, but also the livelihood security of millions of people in Asia, and hence will have far-reaching consequences. For societies living at high elevations in the HKH, cryospheric change will also increase the risk of intangible cultural losses, such as loss of identity, rituals and traditions, place attachment, and cultural values (Adler et al., 2022). These losses are very difficult to quantify, but are arguably the most existential, comparable to the loss and extinction of species and ecosystems.

While the impact of climate change on glaciers, snow, and water resources is clear and supported by robust science focusing on high mountain areas (Hock et al., 2019; Adler et al., 2022), the observed and projected impacts of cryospheric change on mountain societies and ecosystems have received less attention. Although the evidence base is growing, key questions arise, including:

- How will the hydrology of water systems at higher elevations change and how will this impact downstream water availability?
- How will cryospheric changes affect the magnitudes of and trends in underlying hazards and disasters at higher elevations and downstream?
- What are the implications of cryospheric change for ecosystems, species, livelihoods, and societies at high elevations?
- What kinds of actions and policies are needed for societies to respond in the short and long run?

The *HKH assessment* report, published in 2019, included chapters focusing specifically on climate change, cryosphere, water, and biodiversity (Wester et al., 2019). However, the ecological and social aspects of cryospheric change and the linkages with water resources, society, and ecosystems were not systematically assessed. In addition, the report only assessed literature published up to late 2017. With the rapid advances in cryospheric sciences and emerging evidence on the linkages between cryospheric change, water, ecosystems, and society, there is a need for an updated assessment specifically focusing on cryosphere–hydrosphere–biosphere–society linkages in the HKH.

This *Water, ice, society, and ecosystems in the HKH* (HI-WISE) assessment report aims to meet this need by informing the people of the HKH, decision makers, practitioners, and the global community of the rapidly changing cryosphere in the HKH and its impacts on water, biodiversity, and societies, based on the latest science. The report explores the impact of climate change on cryospheric change, water resources, disasters, and subsequent impacts on people and ecosystems in the region. It focuses specifically on high-elevation ecosystems and the people living there, roughly defined as areas above 2,000 metres, while also giving attention to downstream linkages and the wider implications of climatic, cryospheric, ecological, and socioeconomic changes in the HKH.

1.2. Assessment scope

This assessment covers the high mountain areas of the Hindu Kush, Karakoram, Himalaya, and Tibetan Plateau, contained in the eight countries of the HKH region (see Figure 1.1). The Tibetan Plateau lies at the region's centre. To the east lie the Qilian and Hengduan Shan and to the north the Kunlun Shan. The Himalayan arc, which lies along the southern flank, stretches from Namche Barwa (7,756 metres) in the east to Nanga Parbat (8,125 metres) in the west, bounded by the Karakoram and the Hindu Kush mountains in the northwest. As well as being the source of 10 major (transboundary) rivers, the HKH region includes two additional river basins, namely the Interior Tibetan Plateau endorheic basin and the Helmand River, which originates in Afghanistan. The HKH boundary (see Figure 1.1) was developed by ICIMOD based on the K1 delineation of mountain areas (Kapos et al., 2000). All districts or similar lowest-level administrative units in the eight HKH countries that encompass land lying at elevations of 300 metres or above have been included in the HKH region in their entirety. The region, therefore, also includes areas lying below elevations of 300 metres. It covers mountains, hills, and plains and is characterised by immense topographic and climatic heterogeneity. While the primary focus of this assessment is on areas above 2,000 metres, it also pays attention to downstream linkages where relevant.

The HKH region is part of the High Mountain Asia (HMA) region, which also includes the Pamirs and the Tien Shan mountains to the west and north of the Tibetan Plateau (see Figure 1.2). The HMA region is generally understood to cover areas above 2,000 meters in elevation, and cryospheric modelling frequently focuses on the full HMA region, based on the 22 subregions shown in Figure 1.2. This delineation was used in the Cryosphere chapter of the *HKH assessment* report (Bolch et al., 2019) and is also used in this assessment with a focus on the HKH subregions (8–22).

FIGURE 1.1 **THE HINDU KUSH HIMALAYAN REGION**

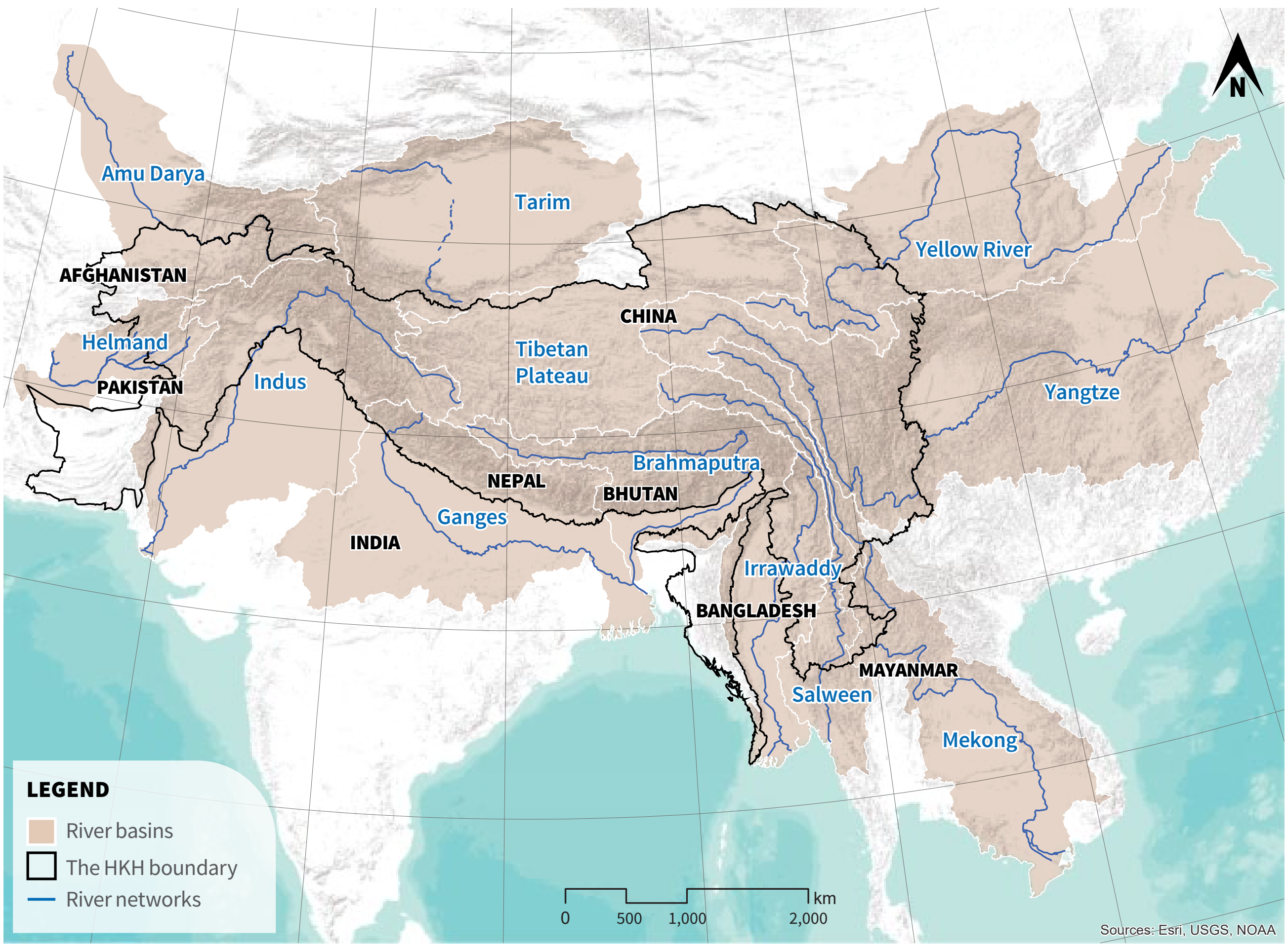
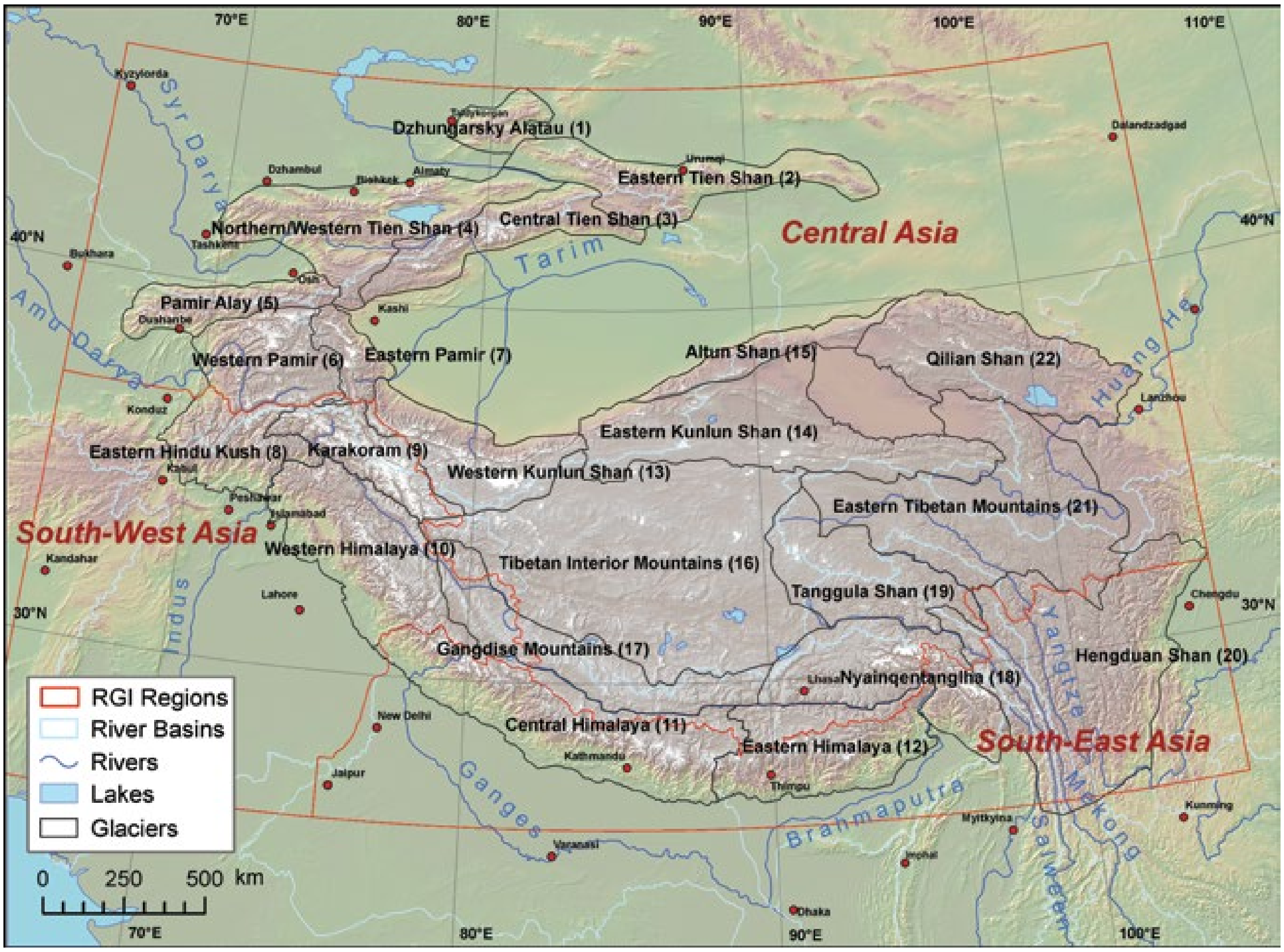


FIGURE 1.2 **HIGH MOUNTAIN ASIA SHOWING CRYOSPHERIC SUB-REGIONS (1-22), AND THE RANDOLPH GLACIER INVENTORY (RGI) REGIONS**



Source: Bolch et al. (2019)

The assessment approach consisted of carefully reviewing the relevant chapters of the *HKH assessment* report, rigorous review of both peer-reviewed and grey literature, and analyses of updated climatic and cryospheric datasets. The IPCC approach was used to indicate the level of confidence in key findings (Ara Begum et al., 2022). The chapter overviews use three confidence levels – *medium, high,* and *very high confidenc*e. These are italicised and in parentheses, and the attribution is based on an evaluation of the robustness of evidence and the degree of agreement for each statement. Each content chapter ends with an identification of key knowledge gaps. These were arrived at by revisiting the knowledge gaps identified in the *HKH assessment* report where relevant and evaluating progress made in addressing them. New knowledge gaps based on the assessment underlying this report were also identified.

1.3. Linkages between a changing cryosphere and water, society, and ecosystems

1.3.1. Key concepts

CRYOSPHERE AND HYDROSPHERE

The term cryosphere refers to the part of the Earth's surface covered by water in its solid form – including glaciers and ice caps, snow, frozen ground (including permafrost), and lake and river ice as well as cryospheric elements that are not present in the HKH, such as ice sheets and sea ice. Hence, the cryosphere has a significant overlap with the hydrosphere. As water can change its aggregate state at various temporal scales, the separation between the two domains is not always distinct. A lake can freeze over and thaw within a single day, snow changes from a liquid in the atmosphere to solid on the ground and back to liquid within days to months, while the same process for glaciers can take a hundred to a thousand years.

Lakes that form as ice retreats or dams a river, or as meltwater fills a depression are generally also investigated under the cryosphere, although they are not necessarily frozen. So are landforms created as ice advances or retreats, or as permafrost thaws. Snow can appear in many forms while still in the atmosphere and on the ground. Snow that lands on the accumulation area of glaciers transitions into ice that is then transported through a glacier body into the ablation area, where it will eventually turn into meltwater – over months, years, or even centuries. When water stored in the ground freezes, it is referred to as frozen ground or permafrost. The most common definition for permafrost is ground that remains below 0°C on average for at least two consecutive years. As water freezes and thaws within the soil over different time scales, it forms a direct link to the part of the hydrosphere referred to as the vadose zone, which encompasses soil moisture and associated processes of recharge and drainage of soils. As such, the cryosphere is a component of the hydrosphere, which includes all forms of water in its liquid and vapour forms.

HAZARDS AND RISKS

Mountain hazards and the ensuing risks to societies appear to be increasing due to climatic and cryospheric changes. Floods, flash floods, debris flows, glacial lake outburst floods (GLOFs), landslides, and avalanches are the most common mountain hazards, affecting the highest number of people in mountain regions globally (Adler et al., 2022). This report uses the updated IPCC definition of risk, which is "the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system." (Ara Begum et al., 2022: 132).

Compound hazards, the cumulative interactions between multiple hazards and/or hazard drivers, are increasingly occurring in high mountain environments. These range from rainfall during the peak melting season to unstable slopes from seismic shocks and increasing soil moisture. At the same time, and often as a result of compound drivers, hazards are becoming more cascading in nature (the domino effect), whereby a sequence of secondary events results in an impact significantly larger than the sum of individual or initial impacts. The term "multi-hazard" further helps to acknowledge the increasing occurrence of concurrent hazards that may interact (and hence become a compound event) or occur in parallel, resulting in a bigger impact than the sum of individual hazard impacts.

BIOSPHERE, BIODIVERSITY, AND ECOSYSTEMS

The biosphere refers to that part of the Earth where living things exist, or where life is sustained. It encompasses all the ecosystems on Earth, extending from the deep root systems of trees to the deepest parts of the oceans, from rainforests up to the highest peaks. This is where the diversity of life, i.e. "biodiversity", exists.

Biodiversity, as defined in Article 2 of the Convention on Biological Diversity (CBD), is "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems." (CBD, 1992). Similarly, CBD defines "ecosystem" as a dynamic complex of plant, animal, and micro-organism communities and their non-material environment interacting as a functional unit (CBD, 2006).

This assessment focuses on biodiversity in high-elevation areas encompassing all ecosystems spatially connected to and directly benefitting from components of the cryosphere. In the HKH region, mountain biodiversity is a complex mosaic of ecosystems hosting and supporting diverse communities of plants, animals, and microorganisms and their intricate interactions with mountain-specific environments (Hudson et al., 2016; Pandit et al., 2014; Allan et al. 2019). The major ecosystems are high-elevation grasslands, forests, shrublands, agricultural land, barren land, rocky outcrops, human settlements, and water bodies (Xu et al., 2019). Above 3,000 metres, the dominant vegetation zones are the cool temperate zone, which supports coniferous forests; the sub-alpine zone, which supports riverine, temperate hardwood and dry forests; and the alpine zone, which supports alpine meadows and cold scrubs, while the western part of the HKH region is mostly covered with arid and semi-arid vegetation (Chettri et al., 2010; Xu et al., 2019). These create a unique mountain biosphere, which supports rich biodiversity at the genetic, species, and ecosystem levels, often with high endemism (Mittermeier et al., 2011).

SOCIETIES AND MOUNTAIN SPECIFICITIES

A society is defined as "a population marked by relative separation from surrounding populations and a distinctive culture" (Keesing, 1981, p. 518). In this report, HKH societies refers to the population in the HKH basins (in both mountain and downstream areas) and their activities as a whole, while mountain societies refers only to the population in the mountain areas and their activities. Similarly, a community is defined as "a place-oriented process of interrelated actions through which members of a local population express a shared sense of identity, while engaging in the common concerns of life" (Theodori, 2005, p. 662). Livelihood comprises the capabilities, assets (including both material and social resources), and activities required for a means of living. A livelihood is said to be sustainable when it can withstand stress, recover from shocks, and maintain or enhance its capabilities and assets both now and in the future without depleting the natural resource base (Chambers & Conway, 1991).

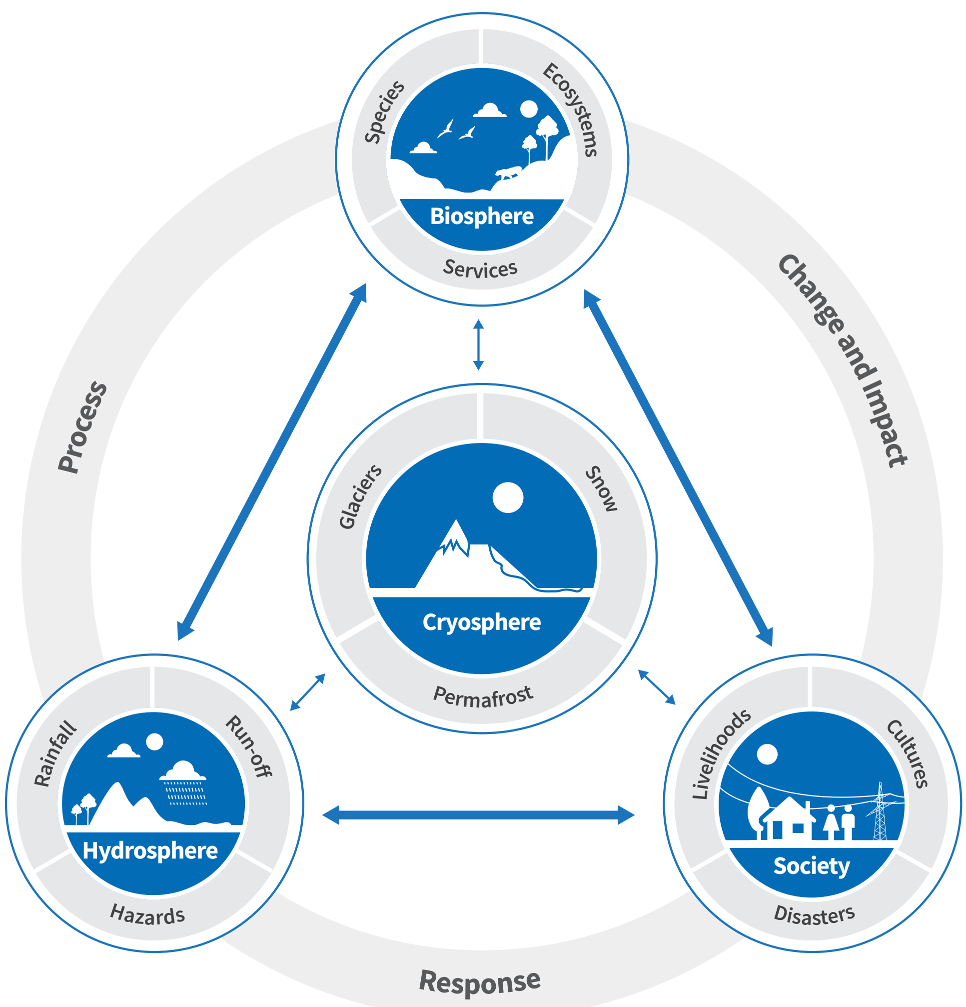
While the above definitions are generic, of particular importance for mountain societies and livelihoods is the concept of mountain specificities, or specific characteristics of mountain areas, which was developed to capture the unique challenges that people in the mountains face (Jodha, 1992). The four main mountain characteristics that have been identified are limited accessibility, fragility, marginality, and diversity (Jodha, 1992). These are classified as either constraining features, such as accessibility, marginality, and fragility; or enabling features such as diversity, niche, and human adaptative capacity. The term accessibility not only captures the elements of distance and mobility, but also the lower availability of risk management options. Marginality refers to the relative endowments of mountain societies in terms of low resource productivity, reinforced by a lack of social and political capital. Fragility can best be understood as the susceptibility of a social or ecological system to stresses or shocks. Diversity, niche, and adaptative capacity capture different coping abilities and strategies that emerge from natural resources management, livelihood endowments, and cultural practices.

1.3.2. Linkages between the cryosphere, hydrosphere, biosphere, and society: A framework

Drawing from the earth system science understanding of the "Earth" as an integrated, symbiotic, and self-regulating complex system, this report aims to understand the complex interactions and feedbacks between different spheres – cryosphere, hydrosphere, biosphere, and society (CHBS). Rather than investigate the individual domains as closed entities, the CHBS framework views the four domains and their linkages through a more holistic lens. It provides a deeper, more integrated understanding of the dynamic interactions and processes within and between the spheres of the Earth system. This is particularly important as the cryosphere interacts with all the spheres: through the provision of water (in solid and liquid forms) to the hydrosphere, by sustaining biodiversity through ecosystem services, and through linkages between the cryosphere and society – economies, livelihoods, cultures, and institutions. Cryospheric change and its impacts cannot be understood in isolation without consideration of the other CHBS domains as direct and indirect drivers of change, such as climate change and globalisation, which intersect across the four domains. Without holistic systems thinking, it is not possible to understand the interconnections and feedbacks between the different domains. Nor is it possible to effectively address associated issues and challenges or plan actions to strengthen people's adaptive capacities and meet their sustainable development aspirations.

Figure 1.3 presents a framework showcasing the linkages between cryosphere, hydrosphere, biosphere, and society. Linkages focus on processes within and between the spheres, observed changes and impacts, and responses to these changes. Insights into the interconnections and interactions between cryosphere, water, ecosystems, and society help unravel the linkages. These interconnections are particularly important to consider in the context of climate and non-climate changes, as changes in one domain can have ripple effects throughout the CHBS spheres and can exacerbate feedback that may lead to further changes.

FIGURE 1.3 **LINKAGES BETWEEN THE CRYOSPHERE, HYDROSPHERE, BIOSPHERE, AND SOCIETY**



Beyond the biosphere that directly inhabits the cryosphere, links between the two spheres through water are obvious. As ice and snow melt or permafrost thaws, water flows into adjacent habitats and is used by its plant and animal species. As the water flows further downstream, plants and animals located along its course continue to use it. Glaciers and glacier beds are also host to unique and diverse communities of microorganisms. Because of specific micro-climatic conditions at high elevations, the cryosphere also supports high endemism in both plants and animals, and specific ecosystems such as peatlands.

As ice and snow retreat and frozen ground thaws, new spaces for vegetation growth appear. Increased net primary productivity is further supported by an increase in air temperatures at high elevations, which may also lead to species richness. However, the changing cryosphere can also be a threat to the biosphere. Mass wasting events due to receding ice, unstable slopes from thawing permafrost, and increased snowmelt can have detrimental effects on existing or developing ecosystems. Habitats may degrade or contract rapidly, and many species, especially native and endemic species, may disappear due to an increase in invasive species. Thus, this may contribute to a reduced quality, quantity, and diversity of ecosystem services, including a lower diversity of pollinators and their services.

More severe extreme events such as GLOFs, avalanches, or debris flows may coincide or combine and impact ecosystems significantly. Permafrost thaw can negatively impact plant and animal species diversity and populations, accelerating shifts in community structures, compositions, and processes. Future lack of snowmelt in areas where a negative trend is already apparent would sever a crucial water supply source. Additionally, algal growth on ice and dust deposition from surrounding dry areas can decrease surface albedo, accelerating melt. The presence or lack of shrubs and trees also both affect snowpack development.

Changes in the cryosphere can affect livelihoods and society either directly or through changes in ecosystems. Almost all livelihood sources in high mountain communities are linked to cryospheric services through water and ecosystems. Any changes in the cryosphere will have direct implications for mountain livelihoods dependent on those services. For instance, agriculture is directly impacted by the availability of irrigation water and livestock by the availability of fodder. Both irrigation water and fodder availability are dependent on snow and meltwater. Similarly, cryosphere-related hazards can cause loss of life and livelihoods in mountain societies. The cultural, spiritual, and religious belief systems of mountain people are directly associated with cryospheric components such as snow cover, glaciers, and glacial lakes. The intangible losses in cultural heritage and belief systems – as mountains change colour or form permanently – is more difficult to assess and quantify. There are, however, direct effects as well, such as avalanches or high intensity snowfall affecting settlements and heritage sites.

Any change in the biosphere can directly affect livelihoods – either due to a change in sustenance; changes in the phenology of plants, including medicinal and aromatic plants; conflicts with wildlife; or changes in the landscapes people live in. The changing biosphere affects the water cycle by changes in evapotranspiration and may make soils less stable with higher risks of occurrence of hazards such as landslides and debris flow.

To understand how these linkages develop and how they can be affected by changes in the future, there is a need to understand what drives these changes. In principle, drivers of change can be differentiated as having either a climate change (CC) or a non-climate change (non-CC) related origin. This is not to be confused with the differentiation between anthropogenic and non-anthropogenic drivers. The rapid recession of glacier ice is driven by a rise in temperatures, a CC impact driver. Seismic shocks or the construction of a road, on the other hand, are clearly non-CC related drivers, the former non-anthropogenic and the latter anthropogenic. The attribution of what causes a certain effect is, however, more complex. For example, landslides have significantly increased in the central Himalaya in recent years. The 2015 Gorkha earthquake has been identified as an initial trigger for more unstable slopes (non-CC driver). However, the increased occurrence of landslides afterwards can possibly also be attributed to more intense rainfall (CC driver). Similarly, erosion in high mountain environments can often be attributed to a changing permafrost landscape (CC driver), which is exacerbated where road construction has been intense (non-CC driver).

How societies experience and respond to both CC and non-CC drivers of change varies depending on their pre-existing socioeconomic vulnerabilities and adaptive capacities. In the HKH region, mountain specificities are a major bottleneck when it comes to eradicating multi-dimensional poverty, which, in turn, limits the capacities of societies to respond adequately to changes. Besides the monitored and lived experiences of cryospheric changes, it is crucial to recognise the rapidly changing socioeconomic realities of mountain societies to better comprehend their adaptation capacities and needs.

1.4. Report outline

The four content chapters of this report weave a narrative of increasing connectedness focusing on the linkages between cryospheric change, water, ecosystems, and society. Chapter 2 starts with an overview of the changing climate in the HKH and the observed and projected impacts on the HKH cryosphere. Based on major recent advances in science, glacier mass changes between the 1970s and 2019 in the HKH have now been quantified with increased accuracy. The rate of glacier mass loss has increased significantly with an average of –0.17 m w.e. (metres water equivalent) per year for the period 2000–2009 to –0.28 m w.e. per year for 2010–2019 across the region. Importantly, the Karakoram range, known for balanced regional mass balances, showed slight wastage of –0.09 ± 0.04 m w.e. per year in 2010–2019, suggesting the 'Karakoram Anomaly' no longer holds. Projections for the future remain bleak, with the HKH glaciers losing 30–50% of their volume by 2100 if global warming remains below 2°C. For higher global warming levels, the loss of glacier volume will range from 55–80% by 2100.

With a few exceptions, snow cover has declined in most of the HKH region since the early 21st century. There has been a significant decrease in seasonal snow cover during the summer and winter months as well as a decline from mid-spring through mid-fall, indicating a seasonal shift. Snow cover days have generally declined at an average rate of five snow cover days per decade with most of the changes at lower elevation. At the same time, heavy snowfall events have increased in recent years with frequent snowstorms observed over the Tibetan Plateau and the Himalaya. These events are predicted to continue to become more frequent and intense in the future. Overall, snow cover is likely to experience an accelerated loss under different global warming levels in the HKH. The contribution of snowmelt to streamflow is expected to decrease in the future and the onset of snow melting is expected to occur earlier.

Chapter 3 focuses on the consequences of cryospheric change on water resources and hazards in the HKH. Both snowmelt and glacier melt contribute substantially to river flows in the HKH, although their relative contribution decreases from West to East, from as high as 79% in the Amu Darya to a mere 5% in the Irrawaddy rivers. The contribution of melt run-off is high in the western HKH due to the westerlies, with winter snowfall playing an important role. In contrast, the Indian summer monsoon plays an important role in the eastern Himalaya, which is reflected in the 50–79% rainfall run-off contribution to rivers such as the Ganges, Brahmaputra, Irrawaddy, and Yellow. While glacier melt receives most of the attention, it is notable that snowmelt accounts for most of the cryospheric contribution to streamflow in all HKH river basins (between 5.1% in the Irrawaddy to 77.5% in the Helmand, while glacier melt ranges from 0% in the Irrawaddy to a high of only 5.1% in the Indus). With the projected decrease in snow fall and snowmelt in the coming century and the increase in glacier melt, 'peak water' will be reached around mid-century in most HKH river basins, while water availability overall is expected to decrease by the end of the century. However, the variability from basin to basin is large, and due to the large uncertainty in projections of future precipitation, confidence in estimates of future run-off remains low.

With a changing climate and increased exposure of livelihoods and infrastructure, the mountain hazard landscape has become more hazardous. A number of different slow- (e.g. sedimentation and erosion) and fast-onset hazards (e.g. flash floods) are occurring in the same watersheds and, in many cases, concurrently and often also in a cascading manner. While there is no clear evidence yet of an increasing trend of such hazards, it is clear that many events have been made possible due to a change in climate resulting in more meltwater, larger and more potentially dangerous lakes, unstable slopes from thawing permafrost, and increasing sediment loads in rivers. Future frequency and intensity estimates exist for only a limited number of hazards, particularly for events associated with increasing heavy precipitation, indicating an increasing trend although the evidence base is limited.

Chapter 4 focuses on high-elevation biodiversity and its linkages with the cryosphere, an important source of water for maintaining ecosystem health, enriching biological diversity, and providing ecosystem services. Biodiversity in the HKH is highly sensitive to climate change, which is leading to visible range shift of species to higher elevations, ecosystem degradation and changes, and invasion by alien species. Future projections of the impacts of climate change and cryospheric change on biodiversity show an increase in ecosystem vulnerability and a reduction in the flow of ecosystem services, with cascading effects of cryosphere loss on species composition, degradation of ecosystems, and an increasing imbalance in ecosystem functions, all resulting in more acute vulnerability to society.

Chapter 5 pulls together all these strands to analyse the linkages between cryospheric change and society, with a focus on high elevation areas. Both climatic and non-climatic drivers of change are strongly impacting the lives and livelihoods of mountain people as well as their capacity to respond or adapt to these changes. While the lives of mountain people have generally improved with increased accessibility and economic development, their marginal and vulnerable status has hardly changed, having probably worsened due to cryospheric change. As mountain societies strongly depend on agriculture, livestock, and the collection and trading of medicinal and aromatic plants, they are particularly vulnerable to the adverse impacts of cryospheric change. More broadly, future cryospheric change will add more pressure on societies, particularly those living in transboundary glaciated river basins, where reliance on high mountain freshwater is high.

Meanwhile, both soft and hard limits to adaptation make mountain societies highly vulnerable to the changing cryosphere. To date, adaptation measures to address the impacts of cryospheric change have been mostly reactive, autonomous, and incremental in nature, and primarily limited to the household and community levels. Noticeably, there are large gaps between the adaptation needs of communities and their access to or the provision of necessary adaptation support and funds, which needs to be urgently addressed considering the increasing impacts of cryospheric change. Overall, adaptation constraints and limits and insufficient understanding of the interactions between cryospheric and non-climatic drivers and their impacts on mountain societies are hindering achievement of the Sustainable Development Goals.

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