STRENGTHENING CLIMATE RESILIENCE IN MOUNTAINOUS AREAS

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Abstract

Mountainous areas are at the forefront of climate change. This working paper presents approaches to strengthening the resilience of human and natural systems in mountainous areas against the impacts of climate change. Chapter 1 provides an overview of climate-related hazards to ecosystems and communities in mountainous areas, especially in developing countries, and their exposure and vulnerability to those hazards. The chapter then examines various ways governments and development co-operation providers can strengthen the climate resilience of mountain communities and ecosystems. Chapter 2 presents the case of the Indian state of Uttarakhand.

Foreword

This working paper is a joint product of the Development Co-operation Directorate (DCD) and the Environment Directorate (ENV) of the OECD. It was prepared under the leadership of Jorge Moreira da Silva, OECD Director of Development Co-operation.

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Abbreviations and acronyms

FAO	Food and Agriculture Organization of the United Nations
ICIMOD	International Centre for Integrated Mountain Development
ICTs	Information Communication Technologies
IPCC	Intergovernmental Panel on Climate Change
NMSHE	National Mission for Sustaining the Himalayan Ecosystem
PES	Payments for ecosystem services
SDC	Swiss Agency for Development and Cooperation
SDGs	Sustainable Development Goals
UAPCC	Uttarakhand Action Plan on Climate Change
UNCDF	United Nations Capital Development Fund
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
WEF	Water-energy-food

Executive summary

Mountain ecosystems, and the communities that depend on them, are extremely sensitive to weather and climate hazards. Mountains ecosystems are facing the risk of large-scale, non-linear, irreversible changes due to the rising impacts of climate change, also known as tipping points. Rugged terrains, steep slopes and stark seasonal contrasts in climatic conditions increase the exposure and vulnerability of mountain communities to climate-related hazards. Although people in the Indian Himalayan region have learnt to live and survive in a changing environment for decades, if not centuries, the present rate of change in the climate is perceived as too rapid for many of them to adapt. Besides, remoteness, along with economic and political marginalisation, hinders further the capacity of stakeholders in mountain communities to adapt to and cope with the diverse impacts of climate change.

Understanding the drivers of climate risks is the basis for plans and policies to build resilience in mountainous areas. A starting point is to identify and map areas, people, assets and ecosystems exposed to climate hazards. A good understanding of the causes of vulnerability is also critical. In Uttarakhand, persistent poverty, inequality, gender or caste/ethnicity-based discrimination exacerbate the vulnerability of mountain communities. These dynamics are also compounded by social conflict.

Multi-level stakeholder collaboration is central for building climate resilience in mountainous areas. For example, when developing a multipurpose hydropower project, various water users in upstream and downstream areas should discuss and agree from the outset on the benefits and potential trade-offs (e.g. electricity generation for urban areas and irrigation for agriculture in rural areas). Experiences from development co-operation also suggest that greater collaboration across the science-policy-practice interface can be beneficial. One example is the Regional Climate Awareness Forum in Nepal and India, which enabled researchers and government agencies to develop policies and strategies on climate resilience with mountain communities.

Governments and development co-operation have introduced various approaches to finance climate resilience initiatives in mountain areas. Mountainous areas often face greater challenges for attracting investment than lowlands. Bringing goods and services, with limited transport infrastructure, to remote, hilly areas tends to be more costly than plains. A sparse population also undermines potential returns on investments. Governments and their development co-operation partners have been aiming to improve risk-return profiles of climate resilience activities in mountainous areas through various ways. They include: integrating climate resilience considerations into budgeting processes at national and local levels; mainstreaming climate risk management in sectoral investment plans; mobilising private sector financing through public de-risking interventions; and facilitating access to climate finance and risk transfer mechanisms such as insurance. Payments for ecosystem services (PES) programmes have been introduced in several mountain countries.

Further investment in data and information is essential for assessing the vulnerability of biophysical and socio-economic systems to climate-related hazards. Decision-making processes in mountainous areas on climate resilience can greatly benefit from the combination of different kinds of information, e.g. on changes in the water cycle, dynamics of glacial lakes, loss of alpine biodiversity and the associated impacts on livelihoods. Nevertheless, geographical factors and limited financial resources keep hampering the installation and maintenance of meteorological stations and systematic observations, especially in remote and depopulated areas.

The monitoring and evaluation of climate-related projects is a resource policy-makers should make more of. For instance, in the East African Highlands, monitoring and evaluation processes helped the government identify high levels of deforestation and forest degradation. New measures were then taken to restore the forest cover on many mountain slopes, and improve forest and land productivity.

Governments and development co-operation providers should raise awareness and build capacity among local authorities and stakeholders in remote mountainous areas. In so doing, collaborating with civil society organisations and local governance bodies (e.g. at the village level) have proven to be effective for reaching out to remote mountain communities and developing their capacities. Such collaboration can also harness the communities' significant local and traditional knowledge of social and ecological contexts.

Governments, development co-operation providers and the private sector are increasingly promoting nature-based solutions for mountain communities, while at the same time making transitional infrastructure more climate resilient. Governments and development co-operation often provide support to "hard" (i.e. structural or physical) engineering solutions such as irrigation channels, flood control dams and water storage. Nature-based solutions have been increasingly promoted to support climate change adaptation and disaster risk reduction in mountain areas. The sustainable management of mountain forests, for example, helps stabilise soil and reduces risk of landslides.

Mountain communities are also increasingly using information communication technologies to strengthen their climate resilience. Thousands of farmers in Uttarakhand are already using mobile-based climate and market services. Effective geospatial technologies are also crucial for understanding temporal and spatial variabilities in the social, economic, geophysical and ecological contexts of mountain areas. Such technologies include geographic information systems, remote sensing and modelling of glacier dynamics.

Table 1 proposes practical action points on climate resilience, which are particularly relevant to mountain communities and ecosystems. The discussion and proposed list of actions are informed by a case study focused on approaches to strengthening climate resilience in the Indian state of Uttarakhand (Chapter 2) and practices by countries and development co-operation providers in various mountain regions across the world.

Table 1. Checklist for action on climate resilience in mountainous areas

ACTIONS	ACTOR(S)
Governance arrangements and policy cycles	
✓ Identify and map ecosystems, people and assets exposed and vulnerable to climate hazards in a given mountain landscape.	Gov't with support of dev-co
✓ Facilitate cross-agency and multi-level co-ordination to support the development of policies and programmes for climate resilience of communities and ecosystems across sectors and between highlands and lowlands.	Gov't
✓ Develop regulatory measures and economic instruments that manage trade-offs and facilitate benefit sharing across actors and sectors within the mountain landscape through, where relevant, regional co-operation among mountainous countries.	Gov't with support of dev-co
Financial management and instruments	
✓ Integrate considerations on mountain-specific challenges (e.g. remote and hilly terrain, sparse population, limited trade infrastructure) into decision criteria for public investment programming or development co-operation interventions.	Gov't and dev-co
✓ Increase access to financing and risk transfer solutions (e.g. mobile-based crop insurance, forecast-based financing) for remote and marginalised communities.	Gov't and dev-co
Monitoring, evaluation and learning	
✓ Develop monitoring and evaluation (M&E) systems and indicators that reflect the specific context of mountainous areas to track progress and evaluate results of policies and projects.	Gov't and dev-co
✓ Use M&E processes and their outcomes to facilitate stakeholder collaboration, strengthen the science-policy-practice interface and engage with marginalised mountain communities in policy dialogues on, for example, the use of natural resources among sectors within a given landscape.	Gov't with support of dev-co
Data and information	
✓ Invest further in the installation and maintenance of weather stations and observation systems, especially in remote and depopulated areas, and in the application of hydrometeorological models tailored to different mountainous areas.	Gov't and dev-co
✓ Promote the use of landscape-level climate risk assessment methodologies that can describe the interactions among different hazards, biophysical and socio-economic systems specific to a given mountainous area (e.g. integration of glacial lake assessments into local disaster risk management).	Gov't with support of dev-co
✓ Identify locally relevant measures for strengthening climate resilience in mountainous area by integrating traditional and local knowledge into scientific research on the hazards and management of the risks.	Gov't with support of dev-co
Awareness raising and capacity development	
✓ Enhance awareness and capacity among government officials and communities through local training programmes on, for example, disaster risk reduction, including those tailored to a given mountainous area.	Gov't
✓ Share results of research, policy interventions, good practices and lessons learnt through peer learning, relevant events and global, regional and national platforms on climate action in mountains.	Gov't and dev-co
Technologies	
✓ Provide technical and/or financial support to disseminate (e.g. engineering solutions, nature-based solutions at community and landscape levels in mountains, geospatial techniques, hardware/software for modelling mountain-specific climate risks), and manage them efficiently.	Gov't and dev-co
✓ Promote use of non-structural measures (e.g. training and education on the application of relevant technologies for mountain watershed/springshed management) to complement engineering solutions.	Gov't and dev-co

Note 1: **Gov't** refers to national and subnational governments of developing countries; **Dev-co** refers to providers of development co-operation. Some actions are led by governments but in many cases also supported by development co-operation providers (indicated as "**Gov't with support of dev-co"**).
Note 2: Actions in this list are indicative and some may not be relevant to all countries or development co-operation providers.

1 Strengthening climate resilience in mountainous areas

This chapter presents some of the main challenges facing mountain communities and ecosystems in light of a changing climate. It then applies the framework of the OECD Guidance on Strengthening Climate Resilience to the mountain context, discussing mechanisms and enablers that can contribute to strengthening climate resilience through planning and implementation at national and subnational levels in mountainous areas.

1.1. Context and objective

Mountains are diverse and characterised by their steep topography. They often feature cryosphere components, such as glaciers, snow cover and permafrost, due to their high elevation. These components are projected to undergo significant changes over the coming century regardless of the greenhouse gas emission scenario used. These changes include retreat of mountain glaciers, permafrost thaw, mass loss of ice sheets and decline in the depth, extent and duration of snow cover (IPCC, 2019[1]). These changes will affect both highlands (i.e. mountainous areas) and lowlands (i.e. zones below the mountains that are influenced by downslope physical processes and human activities).

Mountainous areas are at the forefront of climate change, experiencing above-average warming. They are areas in which tipping elements such as permafrost and alpine glaciers are at stake. Reaching these critical tipping points can result in large-scale, non-linear, irreversible changes in mountain ecosystems (IPCC, 2019[1]). Mountainous areas are home to 13% of the world's population (about 915 million people). Of these, close to 150 million people live at altitudes of 2 500 metres above sea level and 20-30 million people live above 3 000 metres (FAO, 2015[2]). Multiple factors shape the exposure and vulnerability of human and natural systems in mountains to the impact of climate change. These factors include changes in hydrology, vegetation and the ecological conditions of mountains, as well as socio-economic conditions, and close interactions between these factors (Alfthan et al., 2018[3]; IPCC, 2019[1]).

Recognising the complexity and interactions of the ecological and socio-economic factors is essential for building climate resilience in mountain communities and ecosystems upstream and downstream. As highlighted in OECD (2021[4]), based on IPCC (2018[5]), **climate resilience** refers to the capacity of human and natural systems to learn, adapt and transform in response to risks induced or exacerbated by climate variability and change. **Climate risks** are a function of the interaction between i) environmental hazards triggered by climate variability and change; ii) exposure of human, natural and infrastructure systems to those hazards; and iii) the systems' vulnerabilities (e.g. their sensitivity or susceptibility to hazards, and the constraints on capacity to adapt and cope) (IPCC, 2018[5]).

The geographical focus of this paper is **mountainous areas of developing countries**. These areas include the Andes, Central Asia, the Caucasus and the Hindu Kush Himalayan region, as well as other large mountain systems in Southeast Asia and the Middle East, the Atlas Mountains and the mountains in sub-Saharan Africa (Kohler and Maselli, 2009[6]). Examples from developed countries (e.g. the European Alps) have also informed the analysis. A map of the world's mountain regions can be found in Figure 1.1. There are many implications of climate variability and change for human societies and biodiversity in mountainous areas. An example is increasing cryospheric changes and associated stresses on economic activities such as agriculture, hydropower generation and tourism within a mountain region. Understanding such manifested and projected impacts of climate change in mountains can greatly benefit from effective co-operation in knowledge generation by, and exchange among, global, regional, national and local actors (Rasul et al., 2020[7]) (Rasul et al., 2019[8]).

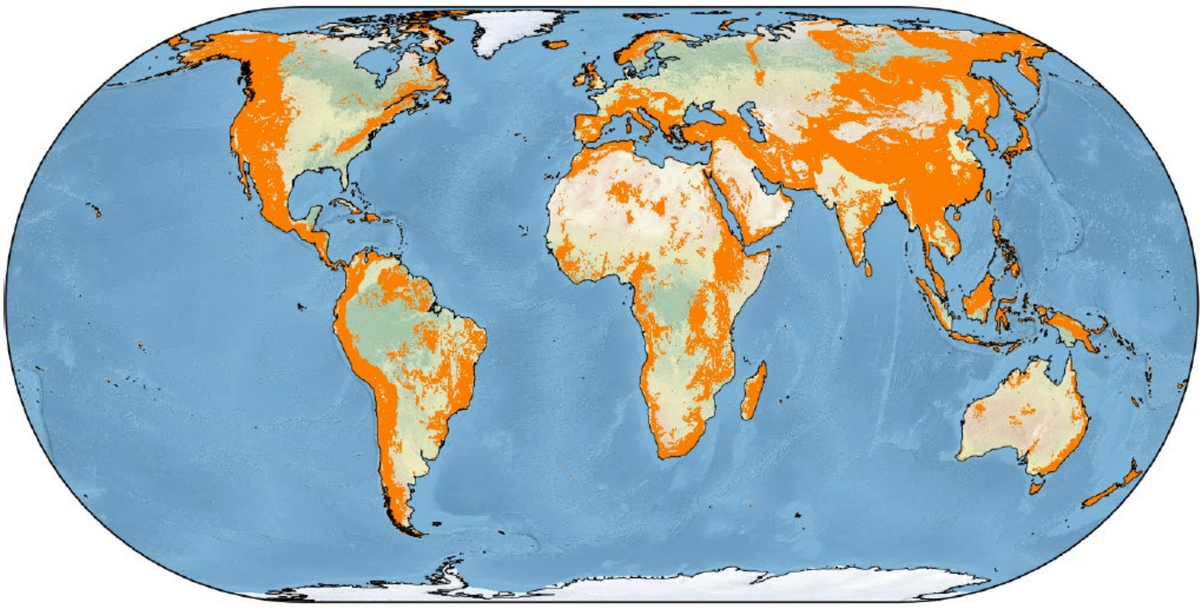
This paper aims to highlight the unique challenges faced by mountainous areas in strengthening climate resilience. It draws on good practices in different mountainous areas across the world. In so doing, it seeks to support relevant actors in integrating climate resilience considerations into their development policies, programmes and projects in mountainous areas.

The paper regards the following points as key specificities of mountainous areas. These points are provided so that governments and development co-operation practitioners can keep them in mind when planning and implementing action on climate resilience in mountainous areas:

- **Geographical characteristics** such as: rugged terrain, steep slopes, economic and ecological interdependency between highlands and lowlands, low-temperature climate regime, extreme sensitivity to climate change, and risks of sudden-onset events such as glacial lake outburst floods.
- **Socio-economic factors** such as institutional and spatial remoteness, lower levels of economic opportunities, high out-migration rates and challenges related to water, energy and food security due to disadvantaged access to these resources.

The primary audience of this paper is government officials and development co-operation practitioners working to strengthen climate resilience of human and natural systems in mountainous areas. It can also support other stakeholders, including the private sector, academia and civil society organisations (CSOs) who are working on climate resilience in mountainous areas. Ultimately, it is intended to benefit people and ecosystems of mountain regions, including those of their watersheds.[1]

Figure 1.1. Map of the world's mountainous areas



Source: Serafin et al. (2020[9]), Multi-scale transport and exchange processes in the atmosphere over mountains, https://doi.org/10.15203/99106-003-1, based on Global Mountain Explorer (https://rmgsc.cr.usgs.gov/gme/gme.shtml).

[1] A watershed is a hydrological unit from which runoff drains and is collected through a common outlet.

1.2. Understanding climate risks in mountains

This section summarises risks arising from climate change in mountainous areas. It highlights characteristics of climate-related hazards, the vulnerability and exposure of human and natural systems in mountains to such hazards, and their interactions.

1.2.1. Climate-related hazards in mountainous areas

Mountain regions face multiple natural hazards, including those related to climate change. Some hazards only occur in mountainous areas, or hit the areas harder and more frequently than in plains. These hazards are geophysical (e.g. rock falls), hydrological (e.g. landslides and avalanches) and climatological (e.g. glacial lake outburst floods), among others. Mountains and lowland areas also have other hazards in common such as floods and other meteorological (e.g. storms, extreme temperature) and climatological (e.g. droughts, wildfires) hazards (Wymann von Dach et al., 2017[10]).

Mountains are experiencing both slow-onset changes (e.g. changes in precipitation and temperature, and glacier retreat) and sudden-onset events (e.g. flash floods). Mountainous areas have already experienced severe socio-economic impacts from major hydrometeorological hazards. In the Hindu Kush Himalayan region, for instance, such hydro-meteorological hazards between 1985 and 2014 resulted in economic losses of around USD 45 million [(Wymann von Dach et al., 2017[10]), see also Table 1.1 for examples from other regions]. With climate change, the negative impacts in many cases are projected to be more severe in mountainous areas than the global average (IPCC, 2019[1]). Table 1.2 compares observed and projected impacts of climate change between mountainous areas and global average estimates; Box 1.1 summarises regional climate projections for some of the mountain regions.

The scale and intensity of hazards and their interconnectedness, combined with mountains' topography, can lead to risks of cascading hazards. They occur when a hazard triggers one or several other hazards, whether they happen over a short or long period. For example, landslides lead to the formation of a landslide dam (i.e. a natural damming of a river by debris). This can contribute to subsequent outburst floods, as observed in Nepal in 2014, in Pakistan in 2010 and in the People's Republic of China (hereafter "China") in 2008 (Vaidya et al., 2019[11]). In the case of northern Pakistan in January 2010, a large-scale slope failure above Atta Abad triggered a landslide that blocked 2 kilometres of the Hunza River valley. This resulted in the formation of an artificial lake that over the following months began to drown surrounding villages (one, Ainabad was entirely submerged). This example illustrates cascading multidimensional and highland-lowland effects with disastrous socio-economic impacts (Cook and Butz, 2013[12]).

Table 1.1. Mountain hydrometeorological hazards and impacts between 1985 and 2014

Mountain region	Number of disasters	Economic losses (in million USD)	Number of people killed	Number of people affected	Mountain population (2012)
Hindu Kush Himalaya	323	44 690.4	26 991	165 694 879	286 019 683
Eastern & North Africa	163	1 246.8	4 881	76 127 779	146 108 040
Andes	150	3 138.4	6 664	13 006 871	73 090 954
Central Asia	39	257.4	700	3 518 763	4 012 359
European Alps	38	7 245.0	607	33 011	22 814 551

Note: Major hydrometeorological hazards (mass movements such as avalanches, landslides and debris flows, as well as floods, storms, extreme temperatures, droughts and wildfires) and their impacts between 1985 and 2014 based on EM-DAT.
Source: IPCC (2019[1]), "High mountain areas", in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, www.ipcc.ch/srocc/; Wymann von Dach et al. (2017[10]), *Safer Lives and Livelihoods in Mountains: Making the Sendai Framework for Disaster Risk Reduction Work for Sustainable Mountain Development*, https://doi.org/10.7892/boris.99068.

Table 1.2. Observed and projected impacts of climate change in mountains and across the globe

Variables and impacts	Change in mountain regions	Change at the global level
Temperature change	Surface air temperature has become warmer over recent decades at an average rate of 0.3°C per decade, with a likely range of ± 0.2°C. While some regional evidence exists for higher frequencies of unusually warm days and lower frequencies of unusually cold days, no conclusive evidence exists for mountains globally.	The global warming rate for the last decades has been 0.2 ± 0.1 °C per decade. Other impacts include decrease (virtually certain) in frequency and magnitude of unusually cold days and nights; increase (virtually certain) in frequency and magnitude of unusually warm days and nights.
Precipitation	While mountainous areas do not show clear annual precipitation trends over the past decades (medium confidence), snowfall has decreased, especially at lower elevation (high confidence). Annual precipitation is likely to increase by 5-20% over this century in many mountainous areas, and decreases in the Mediterranean and the Southern Andes (medium confidence). Changes in frequency and intensity of extreme precipitation events vary according to season and region. Snowfall is likely to decrease at lower elevation both in near term (2031-50) and end of century (2081-2100) projections (very high confidence). At higher elevation, total winter precipitation increases can lead to increased snowfall (medium confidence).	Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (medium confidence before and high confidence after 1951). For other latitudes, area-averaged long-term positive or negative trends have low confidence. Increase (likely) in frequency and intensity of heavy precipitation events over many areas of the world.
Droughts	Warmer summers with greater incidence of droughts are expected in many regions, especially in Africa, the Caucasus and the Eastern Himalaya (high confidence).	Frequency and intensity of droughts have increased in some regions (e.g. the Mediterranean, west and northeastern Asia, South America, Africa) (medium confidence). The duration, frequency and intensity of droughts are projected to increase, particularly in the Mediterranean and Africa (medium confidence).
Floods	Glacier-related floods are documented for most glaciered mountains and are among the most far-reaching glacier hazards. New glacial lakes are likely to develop closer to steep and potentially unstable mountain walls where lake outbursts can be more easily triggered by the impact of landslides (high confidence). Floods originating from the combination of rapidly melting snow and intense rainfall (i.e. rain-on-snow events) have become more frequent over the past decades (medium confidence) and caused severe damages in mountainous areas. The frequency of such events is projected to increase and occur earlier in spring and later in autumn (high confidence).	There is low confidence in global projections of changes in flood magnitude and frequency because of insufficient evidence. Projected increases in heavy precipitation will contribute to rain-generated local flooding in some catchments or regions (medium confidence).
Landslides	Over recent decades, permafrost thaw and degradation increased the frequency and scale of landslides from frozen sediments, as well as the frequency of rock falls and rock avalanches. Expected increases in permafrost thaw (very high confidence) will lead to higher slope instability and more frequent landslides (high confidence). Increase in landslides in the Himalaya, European Alps and Pyrenees. Increase in avalanche in Himalaya and Caucasus.	There is low confidence in observed global trends in large landslides in some regions. Nevertheless, future changes in heavy precipitation will affect landslides in some regions (high confidence).

Source: Based on IPCC (2019[1]), "High mountain areas", in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* www.ipcc.ch/srocc/.

Box 1.1. Regional climate projections: Examples from the Andes and the Hindu Kush Himalayas

The Andes mountains

Annual precipitation is likely to decrease in the southern Andes, with relative changes being the greatest from June to August. For the rest of the Andes, future precipitation changes will depend largely on changes in El Niño patterns. Glaciers in many parts of the Tropical Andes may disappear over the next few decades. As in low mountainous areas, summer runoffs are likely to decline over the century in many basins due to lower snowfall and decreases in glacier melt after peak water.

Hindu Kush Himalaya mountains

In the Hindu Kush Himalaya region, warming is predicted to be well above the global average but occur to varying extents among its sub-regions. For example, it is projected that during the summers, relatively higher warming will occur over the hilly regions of the northwestern Himalaya than in the central and southeastern Himalaya. Projections of annual precipitation indicate increases on the order of 5-20% over the century. Moreover, frequency and intensity of extreme rainfall events are projected to increase, particularly during the summer monsoon periods. This suggests a transition towards more episodic and intense monsoonal precipitation, especially in the eastern-most part of the Himalayan chain. Projections indicate a continued increase in winter runoff in many snow- or glacier-fed rivers due to increased winter snowmelt, more precipitation falling as rain – in addition to increases in precipitation in some basins.

Sources: IPCC (2019[1]), "High mountain areas", in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*; Kohler and Maselli (2009[6]), *Mountains and Climate Change – From Understanding to Action*; Krishnan et al. (2019[13]), "Unravelling climate change in the Hindu Kush Himalaya: Rapid warming in the mountains and increasing extremes", in Wester et al. (eds.), *The Hindu Kush Himalaya Assessment*, International Centre for Integrated Mountain Development, Lalitpur.

1.2.2. Exposure and vulnerability of mountainous areas

The exposure of people, assets and ecosystems to climate-related hazards in mountainous areas has increased over recent decades, and this trend is expected to continue (IPCC, 2019[1]). Negative impacts of climate change on mountain ecosystems can have dire consequences for biodiversity at global, regional and local levels. Mountains are repositories of biodiversity, water and ecosystem services, home to more than 85% of the world's species of amphibians, birds and mammals. Many of these species are found only in mountainous areas (Rahbek, 2019[14]; 2019[15]), and are highly exposed to climate-related hazards (IPCC, 2019[1]; Wymann von Dach et al., 2017[10]).

Topographical features of mountains also contribute to greater levels of exposure and vulnerability of people and their livelihoods to climate-related hazards. In terms of exposure, land suitable for human use is more limited in mountains than in plains, and often concentrated in the valleys. This contributes to competition between different land uses, such as settlements, transport routes, tourism, critical infrastructure, and productive agricultural activities (Huber et al., 2013[16]; Patru-Stupariu et al., 2020[17]). Growing population and socio-economic development (e.g. agriculture, tourism and energy) have in recent decades contributed to increased pressure on the land in hilly areas. This has pushed critical infrastructure and vulnerable people into unsafe areas, exposing them and their assets to a greater level of natural hazards. For instance, nearly two-thirds of the hydropower projects in the Himalayas are in the path of potential glacier floods (Schwanghart et al., 2016[18]).

Mountain communities of developing countries also tend to be more vulnerable to climate-related hazards than those in plains, due to various socio-economic contexts and capacity constraints (Alfthan et al., 2018[3]). These mountain communities are often marginalised geographically, politically and economically, leading to isolation from markets, services and policy-making processes. Their limited institutional, financial or technological capacity also leave the communities less able to adapt to or cope with negative impacts of climate change (McDowell, Stephenson and Ford, 2014[19]; IPCC, 2019[1]). Limited access of mountain communities to education and health-care systems also exacerbates such capacity deficits. Poverty rates are higher in the mountains than in the lowlands in the Hindu Kush Himalayan region (Wymann von Dach et al., 2017[10]), while two-thirds of people live in poverty in the Andes. Limited availability and accessibility of weather and climate data and information specific to remote areas also constrain both short-term early warning for imminent disasters, and long-term planning for reducing climate and disaster risks. When disasters strike, the remoteness and difficulty of access (e.g. poor road infrastructure) hinder relief and recovery efforts from reaching to those who need them (Wymann von Dach et al., 2017[10]; 2016[20]).

Women are often among vulnerable groups of mountain communities to the impacts of climate change due to multiple factors, such as social structures and norms, as well as economic opportunities (Bhadwal et al., 2019[21]; Gämperli Krauer, Wymann von Dach and Bieri, 2017[22]; Goodrich, 2019[23]; Ogra and Badola, 2015[24]; Resurrección et al., 2019[25]). More women than men are likely to die when disasters strike, including in mountainous areas (Mehta, 2007[26]; Rye, 2016[27]). Among other reasons, this occurs because women have limited access to information, mobility and decision-making power, as well as to financial resources and training.

Gender-based social and cultural norms, including for the division of labour, can also negatively influence women's adaptive capacity. Increasing out-migration of working-age men from the mountains often results in increased workloads and responsibilities for women and children (Bachmann et al., 2019[28]; Goodrich, 2019[23]). This, in turn, often results in higher dropout rates of girls from formal education. This can further constrain the potential to improve their adaptive capacity (e.g. better understanding of hazards and exposure, greater access to technical solutions) in the long run (Vaidya et al., 2019[11]). Out-migration also increases the burden on the elderly, who are left to care for the land in the challenging mountain topography. In Batken and Osh oblasts in southern Kyrgyzstan, for instance, the working-age population migrates from the mountain villages, while children and elderly people stay in the regions more prone to disasters (FIDH, 2018[29]).

At the same time, remittances sent by migrants help their family members secure their livelihoods and improve living conditions, contributing to the families' financial resilience to climate risks. Out-migration can also reduce the pressure on natural resources and biodiversity in mountainous areas, and in turn the vulnerabilities of mountain ecosystems. Migration has been used as a response to past environmental changes and to the risk of future changes (Bachmann et al., 2019[28]). Increasingly, climate change and natural hazards add distress to the often-precarious situation of small-scale mountain farmers. Nevertheless, compared to economic opportunities found outside the mountainous areas, climate change impacts are often not the primary or only drivers of migration in mountainous areas (Dinshaw et al., 2019[30]; Schoolmeester et al., 2016[31]; Alberton, 2017[32]).

Mountain ecosystems, especially those that have been well adapted to long periods of very cold temperatures, are extremely vulnerable to warmer temperatures. For instance, a decline in snow cover can mean direct loss of physical habitat, and permafrost degradation can alter soil moisture content and soil nutrient availability, and influence species composition (Rasul et al., 2019[8]). Permafrost is also an important storage of carbon (Jin et al., 2009[33]; Shen et al., 2018[34]; Yang et al., 2010[35]). Upslope migration of species is also already being observed, leading to both increases in species richness at higher altitudes and declines in the abundance of cold-adapted endemic species. The latter increases the risk of local extinctions, particularly for species that live in cold freshwater (e.g. trout and salmon). Permafrost degradation also increases the risk of desertification. Changes in the thickness and duration of snow cover are modifying the growth conditions of plants and the food chain for animals (Rasul et al., 2019[8]).

Climate change can worsen water scarcity through changes in the water cycle, especially when combined with increasing demand. Populations in mountains closer to the glaciers are particularly vulnerable, especially during dry months and drought periods, because they depend largely on snow, ice and glacier meltwater (IPCC, 2019[1]). Given their function to store and provide water to sustain environmental and human water demands downstream, mountains are also known as "water towers". (see Box 1.2).

Box 1.2. Water towers and their vulnerability to the impact of climate change

Water towers are characterised by their water-supplying role (supply) and the dependence on this water of downstream ecosystems and societies for irrigation, energy, manufacturing and domestic purposes (demand). Immerzeel et al. (2020[36]) quantitatively assess different water towers across the world in terms of their supply and demand levels. The study also analyses the climate vulnerability of those water towers. The vulnerability is affected not only by current water scarcity but also by other factors such as water governance, political circumstances and future impacts of climate change, economic growth and population changes.

The study shows the Sir Darya and Amu Darya (in Central Asia) and Indus and Ganges-Brahmaputra (in South Asia) are among the most vulnerable water towers. These water towers are transborder, densely populated and heavily irrigated, while also seeing high economic growth rates and challenges in regional water governance among the basin countries. Some water towers in South America are also vulnerable, including northern Chile's Pacific coast (due to baseline water scarcity and decreasing precipitation) and the la Puma region in the Andes (due to population and economic growth).

See Immerzeel et al. (2020[36]) for further analysis of the role of water towers in supplying water, the downstream dependence on the water towers, and their vulnerability related to climate change, water stress and other socio-economic changes.

Source: Immerzeel et al. (2020[36]), "Importance and vulnerability of the world's water towers", https://doi.org/10.1038/s41586-019-1822-y.

1.2.3. Climate risks on socio-economic and environmental systems in mountainous areas

Climate-related hazards, exposure and vulnerability can affect various aspects of society and ecosystems in mountains, and impacts of climate change on them are projected to evolve over time. Table 1.3 summarises a range of adverse impacts of climate change on different socio-economic and environmental systems in mountainous areas that need to be considered when developing and implementing action on climate resilience.

Various economic sectors in mountainous areas face their own sector-specific climate risks. These sectors include traditional agriculture, livestock grazing and forestry, mining and extractive industry, hydropower generation and tourism (Fort, 2015[37]). In the **agriculture sector**, for instance, snow-dominated and glacier-fed river basins are already experiencing changes in the amount and seasonality of water runoff (Wester et al., 2019[38]). The average winter snowmelt runoff is projected to increase, and spring peaks are set to occur earlier in the year (IPCC, 2019[1]). Such runoff changes are expected to affect water management, related hazards and ecosystems. Altogether, declining runoff (following peak water) in snow-dominated and glacier-fed river basins is expected to reduce the productivity of irrigated agriculture. In the **energy sector**, melting glacier and change in water temperatures can affect hydropower generation, particularly from small hydro. This hinders efforts for energy security and action on mitigation of greenhouse gas emissions. In the **tourism** sector, seasons for snow-based winter activities are likely to be shorter due to decreasing snowfall and availability, especially at lower elevations. Changes in hiking seasons in the Himalayas and, to a lesser extent in the Andes and African mountains, have already been observed (Reynard, 2020[39]; Sharma, 2012[40]); (see also Box 1.3).

Climate change may also undermine the well-being of populations in mountainous areas. For instance, a decline in glacier and snow cover can impact cultural services of mountain landscape, including cultural identity, spiritual, intrinsic and aesthetic values, as well as contributions from glacier archaeology (Milan, 2016[41]; SDC, 2016[42]). Indigenous communities in the Andes, for instance, regard high mountain peaks and glaciers as life-giving spirits and the home of deities. Retreating glaciers therefore have triggered anxieties and emotional distress among these communities (Tschakert et al., 2019[43]). People's health can also be affected by worsened water quantity and quality (e.g. persistent organic pollutants released in water due to cryosphere changes). Some responses to climate-related hazards in mountainous areas may lead to trauma and psychological problems, including a decision to displace populations after glacier lake outburst floods (IPCC, 2019[1]).

Characteristics of climate hazards to people and ecosystems, as well as economic, social and environmental contexts, will continuously evolve. Thus, they vary across different points in time (e.g. daily, yearly and decadal changes). This dynamic of climate risk hold true for many landscape types, but in some mountainous areas, the evolution of climate risks may be even more drastic (Alfthan et al., 2018[3]; Mishra et al., 2019[44]). For instance, cryospheric changes (e.g. snowmelt, glacier retreat) initially contribute to an increase in water availability up to a certain point, after which the release of water starts to diminish (Figure 1.2). This turning point, called "water peak", is expected to occur at different times in different mountain regions. It is estimated that a water peak has already been reached in 82-95% of the glacier areas in the Tropical Andes, and in over half of glacier areas in Central Europe and the Caucasus (IPCC, 2019[1]). Many glaciers of the Hindu Kush Himalayan region are expected to reach their water peak by the middle of the 21st century (Rasul et al., 2019[8]).

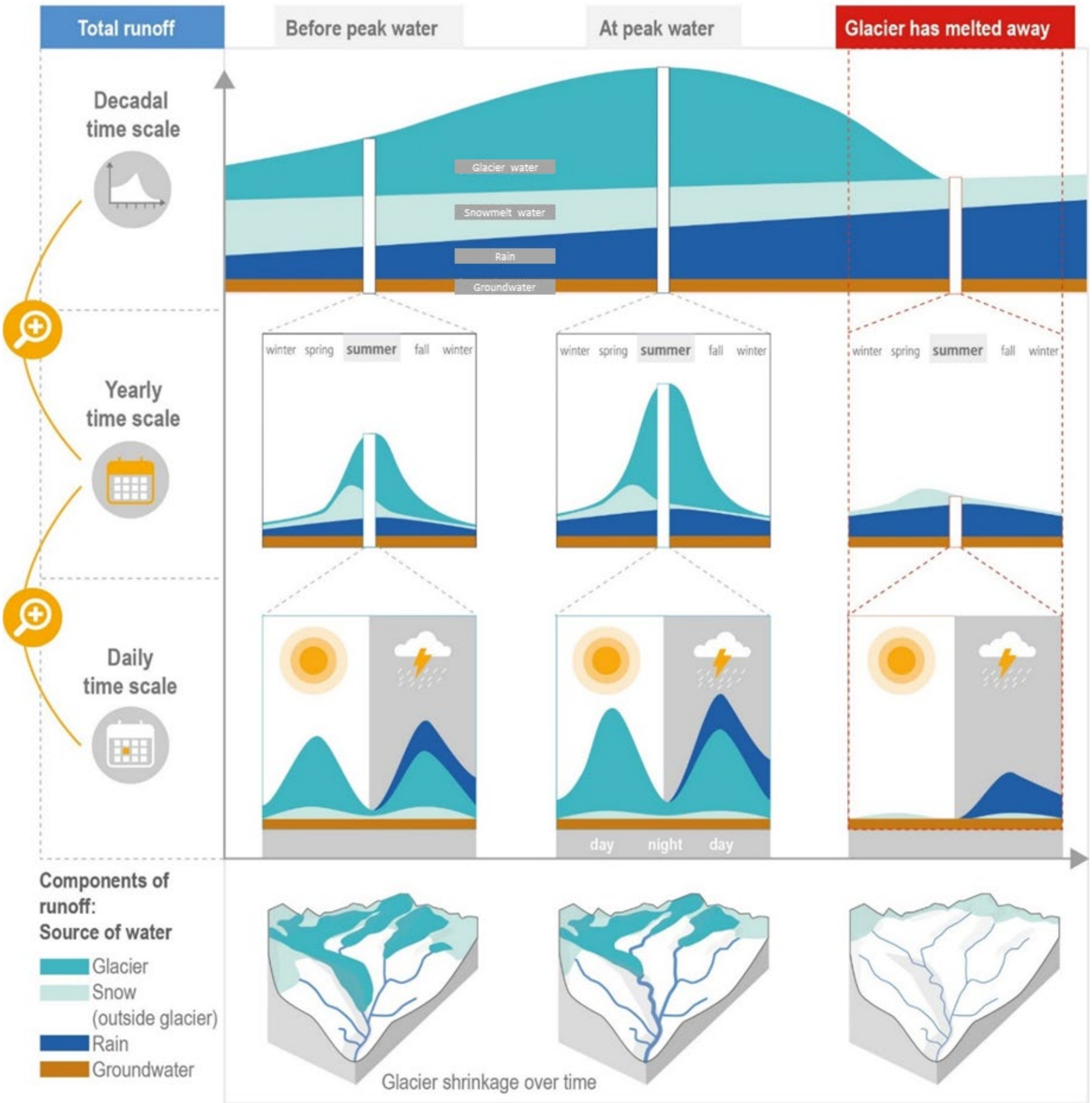
Table 1.3. Climate change and impacts in mountainous areas

System	Area of relevance	Impacts in mountainous areas, including cryosphere changes	Example of risk
NATURAL	Ecosystems	Changes in species composition/abundance; negative impact on reproductive fitness of some snow-dependent plant and animal species; new habitats open for establishment of species; decline in abundance of cold-adapted species in terrestrial and freshwater communities; upslope migration of terrestrial species	Livelihoods
	Water quantity	Change in precipitation and river runoff (seasonality and peak); reduced snow cover; glacier retreat; snowmelt; permafrost degradation	Livelihoods, and energy and water security
	Water quality	Release and shifts in downstream nutrients (dissolved organic carbon, nitrogen, phosphorus) and increases in heavy metals (mercury and other legacy contaminants) from glacier decline	Livelihoods, people, assets at risk, downstream ecosystems
ASSETS	Mining/energy	Glacier shrinkage and retreat; change in water supply	Change in mining activities (e.g. accessibility for extractive industries), generation of energy (hydropower production) and operational security (power plants cooling)
	Roads and buildings	Permafrost degradation	Infrastructural destabilisation (e.g. mountain stations, avalanche defence structures) and deformation (e.g. roads, power transmission infrastructure)
PEOPLE	Cultural	Glacier retreat and permafrost thawing	Disruption of cultural practices and beliefs; enhanced understanding of human history
	Health	Reduced water quality from glacier decline; change in disease vectors	Labour migration, displacement associated with extreme events
LIVELIHOODS	Economic activity (demand)	Uncertainty about future demand and change in consumption and trade patterns; risk of flooding to residential property, disruption to import/export flows	Investment, consumption and trade
	Economic activity (supply)	Decrease in productivity (e.g. agriculture); diversion of resources; productivity loss (heatwaves, natural disasters); food and other input shortages; damage to infrastructure	Labour migration, energy inputs, capital stock, technology
	Food	Shift in growing season; change in productivity following change in water availability for irrigation; drying of soils due to reduced snow cover; increase in crop evapotranspiration due to raising temperatures; upslope movement of cropping zones	Loss of income due to reduced yields, possibility to plant new crops
	Tourism	Access to tourism site limited due to floods and landslides	Loss of income

Note: Hazards include slow (temperature and precipitation change) and sudden (glacial lake outburst floods, wildfires, floods and flash floods, landslides, avalanches) events.

Sources: IPCC (2019[1]), "High mountain areas", in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, www.ipcc.ch/srocc/ and Batten (2018[45]), Climate change and the macro-economy: a critical review, https://www.bankofengland.co.uk/research

Figure 1.2. Changes in runoff from a river basin with large glacier cover as the glaciers shrink



Note: A simplified overview of changes in runoff from a river basin with large (e.g. >50%) glacier cover as the glaciers shrink, showing the relative amounts of water from different sources – glaciers, snow (outside the glacier), rain and groundwater. Three different time scales are shown: annual runoff from the entire basin (upper panel); runoff variations over one year (middle panel) and variations during a sunny day then a rainy summer day (lower panel). Seasonal and daily runoff variations are different before, during and after peak flow. The glacier's initial negative annual mass budget becomes more negative over time until eventually the glacier has melted away. This is a simplified figure so permafrost is not addressed specifically and the exact partitioning between the different sources of water will vary between river basins.

Source: (IPCC, 2019[1]), "High mountain areas", in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* www.ipcc.ch/srocc/.

Box 1.3. Impacts of climate change across sectors and regions

Rural livelihoods and insecurity in Uttarakhand

Erratic rainfall and rising temperatures have led to floods and landslides causing widespread loss of human life, livestock and infrastructure in mountainous areas of the state. Forests cover over 70% of Uttarakhand's land area. These forests are home to diverse fauna and flora, are an important carbon sink and supply a vast array of ecosystem services. These functions have important links to agriculture, animal husbandry, water and energy in the state. However, various types of climate and non-climate stressors threaten the livelihoods of the local communities that depend on several forest resources, e.g. for fuel and fodder (Ojha, 2019[46]; Dinshaw et al., 2019[30]).

Water quality, availability and energy in the Carpathians

The Carpathian Mountains span seven countries and are home to 18 million people in Central and Eastern Europe. Increased temperatures and less precipitation are expected to lead to runoff reduction, threatening electricity generation capacities. Nutrient leaching (i.e. the downward movement of dissolved nutrients in the soil) from agriculture, wastewater from households, and industry and heavy metals from mining activities deteriorate water quality. Foreseen periods of low precipitation and high temperatures may aggravate water contamination through, for instance, increased concentration of pollutants and eutrophication. The over-exploitation of surface water and groundwater resources has led to water shortages. These changes are expected to create irreversible damage to riparian ecosystems, agriculture and industry. Finally, surface runoff and increased risk of erosion produced by intensifying extreme precipitation lead to greater risk of desertification, landslides, floods and wildfires (Alberton, 2017[32]).

Agriculture in the Bolivian Andes

In Bolivia, agriculture represents 13% of gross domestic product and 32% of employment. Climate change will have both positive and negative effects on the sector. Rising temperatures in the mountains will enable crops suited to warmer environments, such as maize or rice, to grow at higher altitudes. However, crops adapted to higher elevations will be negatively affected due to natural constraints to upward migration. Potato and oca (a traditional tuber in the Andes) are examples of crops threatened by climate change. Many farmers in the high Andes are forced to move their crops upwards to keep up with favourable temperatures. Reduced frost in the high Altiplano also threatens the production of Chuño (freeze-dried potatoes), which has been a source of food security in the region for centuries. Climate change also threatens high mountain grasslands, important to pastoral communities in the high Andes (Schoolmeester et al., 2016[31]).

1.3. Mechanisms for strengthening climate resilience in mountainous areas

This section discusses mechanisms to support governments and development co-operation providers in managing climate risks, namely through: i) multi-level governance and policy cycles; ii) financial management and instruments; and iii) monitoring, evaluation and learning. Chapter 3 of *Strengthening Climate Resilience: Guidance for Governments and Development Co-operation* (OECD, 2021[4]) highlights a wider range of information on these mechanisms. It also refers to available tools and knowledge products, which are relevant to both mountain regions and other geographic contexts more generally. The following section primarily aims to examine approaches specific to mountains, while also touching on some generic issues on climate resilience.

1.3.1. Multi-level governance arrangements and policies for climate resilience in mountains

Institutional arrangements for multi-level policy co-ordination

Co-ordination of climate action across sectors and levels of government is important in any given geographic context (Dazé, Price-Kelly and Rass, 2016[47]; OECD, 2021[4]). However, it is particularly relevant to mountains due to their geographic and socio-economic characteristics (e.g. dissected topography, scattered settlement, lower population density than in lowlands) (Charlery de la Masselière et al., 2017[48]). Central governments remain in charge of developing relevant strategies and plans (e.g. national adaptation plans, national disaster risk reduction strategies, national biodiversity strategies and action plans), and monitoring progress where feasible. Local governments, indigenous groups, farmer associations, research institutes and traditional community institutions often lead, to a varying extent, development and implementation of locally specific policies and programmes on climate resilience in mountainous areas. Traditional institutions such as the *Dzumsa system* and the *Na Zong Nyo*[2] in the Indian state of Sikkim may sometimes govern natural resource management in mountain regions (Mishra et al., 2019[44]).

A policy measure applied in upstream areas within a mountain landscape may cause significant consequences for the exposure and vulnerability of those living in downstream areas hundreds of kilometres away. This is illustrated in the case of Uttarakhand and in other mountain regions, where economic activities in both highlands and lowlands are intertwined with the vulnerable ecosystems of the mountains. Action on climate resilience without landscape-level co-ordination may cause certain areas devastating damages due to activities that occur outside the administrative boundaries of an area (e.g. land-use and waste management in an upstream district or village); (see also Chapter 2).

Governments, with support from development co-operation where relevant, can establish or enhance institutional arrangements that facilitate such landscape-level, cross-sectoral and cross-jurisdictional co-ordination (Dhakal et al., 2019[49]). In the central Colombian Andes, strong leadership by the government with a clear mandate, competence and adequate resources was considered effective for strategic co-ordination for cross-sectoral approaches to disaster risk management in the mountain areas (Mishra et al., 2019[44]; Ojha, 2019[46]). Experience from the Hindu Kush Himalayan region suggests ways to strengthen climate resilience. Examples of such approaches include inclusion of marginalised mountain communities and social groups in decision making; greater co-ordination within and between organisations responsible for planning and implementing climate actions in various sectors; and better communication between central and local governments and non-state actors in mountainous areas, among others

[2] The Dzumsa in Sikkim (India) is an institution based on the traditions of chiefdom. It regulates agro-pastoralist migration in the area and governs other aspects like benefit sharing from different livelihood activities, social conduct and cultural practices. Na Zong Nyo is also a form of traditional natural resource management systems conducted among the Indigenous Lepchas communities of Sikkim.

(Dinshaw et al., 2019[30]). Challenges, however, remain to seizing such opportunities. In the Himalayas, the geographical, economic and political remoteness of mountain communities, including their distance from decision-making bodies, has constrained co-ordination between different kinds of institutions. Stakeholder analysis can help identify actors that need to be involved in developing and implementing measures (Box 1.4).

Box 1.4. Identifying relevant actors using stakeholder analysis

Stakeholder analysis examines relevant actors' capacity to influence the measures and their susceptibility to them. An approach called social network analysis complements stakeholder analysis to understand and visualise stakeholders and knowledge networks, and leverage such knowledge (UNDP, 2012[50]).

These approaches have been applied in mountain contexts, for instance, in the Swiss and French Alps. Social network analysis enabled the recognition of marginalised groups, bearing in mind the stakeholders' greater isolation and slower information flows compared to the lowlands. It also helps identify actors who can help co-ordinate and distribute information, and bridge the gap between different groups (e.g. across sectors, mountain valleys or administrative scales). Given how mountain terrain limits the access of government line agencies, local organisations can act as a bridge across natural resource-based communities, government departments, elected officials, civil society organisations and local universities (Mishra et al., 2019[44]).

Policy coherence for greater climate resilience in mountains

International momentum has been increasing to better address the challenge of climate resilience in mountains. The 2019 UN General Assembly Resolution on sustainable mountain development encouraged states to adopt a long-term vision. It acknowledges the importance of incorporating mountain-specific policies into national strategies for sustainable development (UNGA, 2020[51]). It also reaffirmed objectives of the Paris Agreement and of the Sendai Framework for Disaster Risk Reduction that refer to the challenges of building resilience among mountain communities (UNFCCC, 2015[52]; UNISDR, 2015[53]). Further, SDG 15 on Life on Land highlights the importance of conserving mountain ecosystems, including their biodiversity, given their important role in sustainable development.

Diverse efforts have been made to translate these international climate resilience objectives into regional, national and subnational action in mountainous countries. For instance, the Mountain Partnership, established in 2002, is a voluntary alliance to promote sustainable development of mountains and mountainous communities across the world (FAO, n.d.[54]). The partnership is hosted by the Food and Agriculture Organization of the United Nations and supported by Italy and Switzerland. Sixty governments are members along with numerous subnational authorities, intergovernmental organisations, CSOs and private sector actors. The partnership regularly publishes and disseminates evidence-based information for policy on mountains worldwide [see for instance, (Romeo et al., 2020[55]; FAO, n.d.[54])].

Furthermore, the Adaptation at Altitude programme, supported by Switzerland, UN Environment and other partners, is facilitating dialogues between policy makers, parliamentarians and science communities in different mountain regions, including the Andes, East Africa, the Hindu Kush Himalaya and South Caucasus (Adaptation at Altitude, 2020[56]). At the regional level, eight countries of the Hindu Kush Himalayan region recently adopted a declaration to strengthen regional co-operation for greater resilience in the region to climate and disaster risks (ICIMOD, 2020[57]).

At the national level, India has adopted the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) as a key policy objective. It aims to address climate-related issues concerning Himalayan glaciers, as well as development of scientific and traditional knowledge. In Georgia, the updated Nationally Determined Contribution (NDC) explicitly envisages further analysis of the impact of climate change on glaciers, mountain ecosystems and economic situation of the mountainous areas within the country in order to enhance its climate change adaptation (Government of Georgia, 2021[58]).

Illustrating local-level action, the Local Climate Adaptive Living Facility (LoCAL) in Bhutan has been run by the UN Capital Development Fund since 2011. It supports climate-resilient communities in mountainous areas through a robust mechanism to channel climate finance to local authorities. The project has enhanced local governments' and communities' capabilities to adapt to climate change. At the same time, it mainstreams cross-cutting policies such as on gender, environment, disaster and poverty in local development (UNCDF, 2021[59]).

A focus on potential synergies between different policy objectives while minimising trade-offs can also guide efforts to enhance the climate resilience of mountainous areas. Such synergies can also be linked to benefit sharing between actors who make efforts to safeguard ecosystem functions (often in the highlands and rural areas) and those who use ecosystem services (often in lowlands and urban areas). The "water-energy-food nexus" can be effective for shaping coherent policies to ensure water, energy and food security; enhancing the diversity and depth of mountain communities' livelihood options; and protecting mountain ecosystems (Wymann von Dach and Fleine, 2019[60]). The nexus approach also considers complex interactions between various challenges facing mountain communities (e.g. economic and political marginalisation and upstream-downstream conflicts over water resources) (Wymann von Dach and Fleine, 2019[60]).

Numerous models and tools have been developed to assist decision making based on the water-energy-food nexus approach (Albrecht, Crootof and Scott, 2018[61]). However, its application to actual policy making in the mountain context remains limited (Dargin, Daher and Mohtar, 2019[62]). The complexity of integrated modelling and extensive data needs could make its development and application both difficult and costly. Enhanced investment by governments and development co-operation in climate services can help address some of the challenges. Greater co-ordination between the stakeholders relevant to data collection could also mitigate resource intensity and deepen discussion on a range of policy objectives related to climate resilience in mountain regions (Dargin, Daher and Mohtar, 2019[62]).

Policy instruments to incentivise action on climate resilience in mountain regions

National and subnational governments in mountainous countries have applied a range of policy instruments for building resilience, including information-based instruments, economic incentives and regulatory measures. Examples include land-use planning regulations to limit construction of tourism sites and critical infrastructure in risk-prone areas (FAO, 2011[63]). Forest conservation policies such as nature reserves, national parks, biotope protection and protected landscape areas have also been widely introduced in mountainous areas (Sverdrup-Thygeson et al., 2014[64]). They can also be a basis for nature-based solutions against landslides and for avalanche protection, which contribute to limiting and managing damage from natural hazards (Dinshaw et al., 2019[30]). Measures to support farmers with proper access to lands, as well as tenure and resource use security, can also incentivise them to conserve agricultural soils and avoid forest encroachment – see examples from mountainous areas in Uganda, the Philippines and Lao People's Democratic Republic in the Global Land Tool Network (GLTN, n.d.[65]).

When properly applied and enforced, building codes promote resilient and sustainable design standards for the built environment and protect against disasters (Rasul, 2014[66]). These regulatory measures can be particularly effective in mountainous areas exposed to hazards such as landslides and floods. They are equally valuable for buildings like hospitals and schools where a failure to manage damages would be catastrophic. Building regulations need to be implemented in local spatial planning and land development processes to be effective (Wymann von Dach, 2016[20]). Governments in mountain regions often face a general challenge to enforce policies within their own jurisdictions and beyond. The limits to the effective monitoring, patrolling and use of sanctions in remote mountainous areas especially complicate enforcement of policies and monitoring of compliance.

Economic instruments, such as biodiversity-relevant taxes, fees and charges, subsidies, tradable permits and payments for ecosystem services (PES), can encourage stakeholders to act in support of climate resilience. PES[3] programmes, for instance, compensate conservation by individuals, communities, businesses and government bodies. Payments are made for measures by those living in mountains to conserve ecosystems and use natural resources rationally to provide environmental goods and services to lowland areas (World Bank, 2019[67]).

Ecuador's Socio Bosque programme, introduced in 2009 to protect the tropical mountain ecosystem and water resources, is an example of PES. The programme has been delivering vital economic benefits to mountain communities. However, some studies suggest it has potentially negative impacts on equality, indigenous communities' well-being and their traditional resource management practices in certain areas (Krause and Loft, 2013[68]; Mcburney, 2021[69]). Another example is the Inter-American Development Bank's support of the Trifinio Water Fund in Guatemala, Honduras and El Salvador. The fund involves water users such as households, agriculture (irrigation and fishery), energy (hydropower) and industry. It aims to direct payments for water (tariffs and permits) to sustainably manage the shared water and forest ecosystems in the region (UNECE, 2021[70]).

1.3.2. Financial mechanisms and instruments for climate resilience in mountain regions

Challenges to scaling up investment in climate resilience in mountain regions

It is often more challenging to attract investments to mountainous areas than to lowlands. For instance, it is more costly to bring resources such as construction material, equipment and services into remote, rugged mountainous areas. This lowers expected returns on investment. Sparse population and limited trade infrastructure may offer smaller local market sizes, which can make it more difficult to gain political support for public investments (Wymann von Dach, 2016[20]). Out-migration triggered by limited economic opportunities also undermines the prospect of potential cost-benefit profiles of investment projects due to the shrinking market size. Underinvestment in the resilience of mountain communities and ecosystems, and in sustainable natural resource management leads to disproportionate damage from disasters and climate change.

Estimates suggest that building climate resilience of the Hindu Kush Himalayan region alone could cost around USD 5.5-7.8 billion annually by 2050 (Mishra et al., 2019[44]). Efforts to narrow the financial gap benefit from various financing mechanisms and instruments, as well as improved enabling environments for mobilising finance. These include integrating climate resilience considerations into budgeting processes at national and local levels, mainstreaming climate risk management in sectoral investment plans, mobilising private sector financing through public interventions and facilitating access to climate finance from external sources.

Governments' investment decision making on climate-resilient infrastructure in mountainous areas is often influenced by a range of policy objectives, and their perceived synergies and trade-offs between upstream and downstream areas. Development co-operation often collaborates with governments in supporting such complex priority setting for investments. For instance, the World Bank analysed an investment opportunity affecting multiple sectors in the Zambezi River basin in Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe. The project analysed 29 scenarios to increase agricultural yields, hydropower outputs and economic opportunities. The analysis led to a more granular understanding of the

[3] Payments for ecosystem services are agreements whereby a user or beneficiary of an ecosystem service provides payments to individuals or communities whose management decisions influence the provision of ecosystem services.

relative strengths and weaknesses of different combinations of investment concepts for hydropower, irrigation and floodplain restoration in the river basin (IUCN, 2019[71]).

Financial mechanisms and instruments for supporting climate resilience in mountain regions

For many subnational governments, including those in mountain regions, main sources of public finance include budget transfers from the national government and local tax revenues. In some countries, local governments must allot certain amounts to earmarked funds for disaster preparedness (including climate change adaptation) and responses to calamities [see an example from the mountainous Panay region in the Philippines in Dariagan, Atando and Asis (2021[72])]. For post-disaster financing beyond budget reallocations, national governments often prepare a contingency reserve and contingent credit lines. These are intended to help subnational governments respond to disasters and recovery measures. National development banks and funds also often serve as intermediaries to channel public finance for investments in climate resilience in mountain areas, and to mobilise finance from the private sector. See Chapter 2 for concrete examples of these public financial management mechanisms and instruments in the Indian state of Uttarakhand.

Some countries have established funds aimed at addressing climate change or disaster risk reduction in mountains (Mishra et al., 2019[44]). India has set up the National Adaptation Fund on Climate Change (NAFCC) to support adaptation to climate change. While not limited to mountain areas, the NAFCC has supported many projects targeting the adaptive capacity of rural, small and marginal farmers in the Himalayan states (Government of Himachal Pradesh, 2021[73]). Bhutan has created the Bhutan Trust Fund for Environmental Conservation, focusing on environment and biodiversity conservation, capitalised by the Bhutan government, the Global Environment Facility and several donor countries (RAA, 2021[74]).

Development co-operation can support these national processes through financial and technical assistance, complementing national and subnational budgets. For instance, development co-operation providers can invest in structural measures, including climate-resilient infrastructure and nature-based solutions for landslide slope stabilisation [e.g. (ADB, 2016[75])], or the rehabilitation of hydropower plants to make them more resilient against climate-related disasters [e.g. (Bennett, 2019[76])]. Capacity development at national and local levels includes support to develop climate risk management tools for the challenges faced by mountainous areas and the mainstreaming of these tools in local development policies (Dinshaw et al., 2019[30]; ADA, n.d.[77]). Development co-operation can also support the development of disaster risk transfer instruments such as Pakistan's sovereign disaster risk insurance mechanisms (Mishra, 2014[78]). Denmark and Switzerland supported the development of micro-insurance schemes piloted in Bolivian mountain communities to protect against climate impacts (Wymann von Dach et al., 2017[10]).

A growing number of private-sector initiatives invest in climate resilience of mountainous areas. These include piloting business models for climate and market services based on information communication technology (ICT), introducing weather index-based crop insurance and creating disaster risk insurance funds (Mishra et al., 2019[44]; Wymann von Dach, 2016[20]; Bachmann et al., 2019[28]). The private sector also helps train farmers to strengthen agricultural value chains in mountainous areas (FAO, 2011[63]; Kohler, 2014[79]). Private-sector investment can have a positive impact on employment, income generation and well-being in mountains. This is especially the case when it involves local enterprises, promotes innovation, builds local capacity and creates employment particularly for younger people, while respecting to environmental and social safeguards (Hurlbert et al., 2019[80]; Karpouzoglou, Dewulf and Buytaert, 9 November 2016[81]).

Agricultural insurance arrangements, often taking the form of public-private partnerships, have been tested and deployed in many developing countries, including for protecting livelihoods in mountainous communities. For instance, the government of Nepal and private non-life insurance companies have been working to provide crop (rice, vegetables, fruits and potato) and livestock insurance. The government sets premium rates for the insurance products and subsidises the premiums (Praseed and Anju, 2018[82]). In India, weather-indexed insurance for ginger, potato, tomato and pea crops has recently been introduced in Himachal Pradesh state, while the private sector led a pilot project for such insurance in Uttarakhand and Assam states (Gioli et al., 2019[83]).

The adoption of insurance by mountain farmers in developing countries, nevertheless, faces persistent challenges. Some challenges are mountain specific, while others are more general for insurance dissemination in many developing countries. The reasons identified across mountain regions, include a lack of insurance culture, limited risk awareness due to constrained access to information on climate-related hazards, and limited ability to pay the insurance premium (Vaidya et al., 2019[11]; García Romero and Molina, 2015[84]). These are common challenges in developing countries. Yet remoteness, marginalisation and higher levels of poverty in mountain villages than in lowlands may exacerbate the challenges (Ghimire and Kumar, 2014[85]). Examples include higher administrative costs to deal with policy holders who are scattered geographically, lack of sales distribution networks for insurance and greater constraints on data and information (e.g. about animal mortality and crop production losses in remote mountainous areas) (Ghimire and Kumar, 2014[85]).

As mentioned in section 1.2, many mountainous areas see a high rate of out-migration for better economic opportunities in lowlands. Studies in the Gandaki, Indus, Upper Ganga and Teesta river basins in South Asia show that remittances from migrants can help household invest in certain measures for climate resilience in, for instance, the agriculture sector (Maharjan et al., 2021[86]). Out-migration also influences the resilience of farmers indirectly through livelihood diversification and access to climate-related information provided by external stakeholders. In some cases, out-migration is driven by an urgent necessity to cope with food shortages following a severe disaster. Remittances from such disaster-driven out-migration may be enough for the migrants' families to escape livelihood deprivation. Yet these remittances may not increase the families' savings sufficiently to invest in long-term, on-farm measures for climate resilience (Maharjan et al., 2021[86]).

A number of financial instruments for climate change adaptation and disaster risk reduction can also apply to mountain contexts. Further information can be found in, for instance, (IUCN, 2019[71]; World Bank, 2014[87]) and in *Strengthening Climate Resilience: Guidance for Governments and Development Co-operation* (OECD, 2021[4]).

1.3.3. Monitoring, evaluation and learning for climate resilience in mountain regions

Monitoring and evaluating progress on climate action in mountain regions

Projections of climate change, the socio-economic context in both upstream and downstream areas, and approaches for managing the risks, are all uncertain. This requires governments to regularly review and adjust climate-related policies and interventions, as well as the associated institutional arrangements (Hurlbert et al., 2019[80]; Karpouzoglou, Dewulf and Buytaert, 9 November 2016[81]). Such iterative management of climate risks greatly benefits from effective monitoring, evaluation and learning mechanisms, both in mountainous areas and in society more broadly (Noltze et al., 2021[88]). For instance, monitoring helps policy makers assess whether natural resources from mountainous areas are being used sustainably, and how policies to protect them can be further improved over time. Results of monitoring and evaluation could also provide a basis for discussing fairer benefit-sharing arrangements from the use of natural resources between mountains and lowlands, such as water resources for hydropower and agriculture (Jurek et al., 2016[89]).

The quality of monitoring and evaluation mechanisms, and the use of their results for learning, vary across mountain countries and regions. A study focused on the Tropical Andes identified several obstacles to monitoring progress in implementing climate resilience policies. These include a lack of both data and information to establish benchmarks, and of performance indicators for monitoring and evaluation (Schoolmeester et al., 2016[31]). Collecting information about the implementation status, outcomes and bottlenecks of policies on climate resilience is also challenging, especially in remote mountain communities (Schoolmeester et al., 2016[31]). For example, despite a multitude of studies on forestry and agriculture in the hilly areas of Nepal, there has been little monitoring and evaluation of the impact of different community-based resource management initiatives in these areas (Ojha, 2019[46]).

Some encouraging practices are emerging, however. The Hindu Kush Himalayan Monitoring and Assessment Programme has implemented participatory approaches to monitor progress on policies for sustainable mountain development in the region. The information obtained through the process informed expert judgement to identify key challenges and define objectives for strengthening resilience of mountain communities (Kulonen et al., 2019[90]). Monitoring and evaluation that informs learning through broad stakeholder engagement and consultation can also be important for replicating effective practices to improve the resilience of other marginalised mountainous areas (Adler et al., 2018[91]).

There are many lessons in common emerging between monitoring and evaluation systems for climate resilience and those in place to track progress on the Sustainable Development Goals (SDGs) and targets under the Sendai Framework in mountainous areas. Recent studies highlighted, for instance, the need for disaggregated data for SDG targets and indicators at subnational levels, as well as for (proxy) data standardisation (Bracher, 2018[92]; Gratzer, 2017[93]; Mishra et al., 2019[44]; Wymann von Dach, 2018[94]; Kulonen et al., 2019[90]). In contrast, despite technical guidance to assess mountain (glacier and permafrost) hazards (GAPHAZ, 2017[95]), monitoring of progress on targets from the Sendai Framework in mountainous areas remains limited (Wymann von Dach et al., 2017[10]). Box 1.5 outlines some indicators to track progress on climate change adaptation in the Hindu Kush Himalayan region and to support evidence-based decision-making.

Box 1.5. Indicators to guide climate change adaptation in the Hindu Kush Himalaya

Mishra et al. (2019[44]) propose ten indicators for tracking progress on climate change adaptation to guide policy makers in implementing the Sustainable Development Goals framework in the Hindu Kush Himalayan region:

- number of deaths, missing persons and persons affected by climate hazards per 100 000 people (disaggregated by gender)
- economic loss (e.g. as a percentage of national gross domestic product) averted by climate-proofing critical infrastructure and basic services
- percentage of population with access to improved weather and climate data and information
- percentage of population with improved access to technologies in support of climate resilience
- proportion of local governments that formulate and implement local plans aimed at climate resilience for vulnerable population groups
- number of cities or urban settlements with access to safe, climate-resilient infrastructure and service delivery systems
- percentage of rural population drawing a major part of their household income from climate-resilient livelihood systems (e.g. climate-smart agriculture, resilient livestock management)
- amount of climate financing directed to locally-led climate action (e.g. percentage of the national budget allocated to mountain districts)
- amount of climate finance committed/provided by bilateral and multilateral development finance sources and international climate funds
- number of knowledge institutions actively engaged in knowledge generation, communication, pilots and scale-up relevant to climate resilience in the mountain context.

Learning for adaptive approaches to strengthen climate resilience

Learning, based on results from monitoring and evaluation, can help policy makers and development practitioners adjust policies and governance in response to anticipated situations related to climate change. Factors that affect policies on climate resilience such as social norms and values, shifts in development priorities and available technological solutions can also evolve over time (O'Brien, 2012[96]).

In the East African Highlands, for example, results of monitoring and evaluation enabled learning to identify high levels of deforestation and forest degradation. This learning process triggered efforts to restore the forest cover on many mountain slopes, leading to substantial improvements in forest and land productivity in the region. Results of pilot projects on water resource management in the Uttarakhand state of India have provided insights into policy reforms for climate resilience in other Himalayan states (Agarwal, 2013[97]). Regular reviews and information sharing in the contexts of, for example, natural resource management and ecosystem-based adaptation in mountains have also proven valuable in multiple mountain contexts [see for instance (UNESCO, 2017[98]; Bizikova, 2014[99])]. Development co-operation providers may also facilitate learning across different regional scales to harness relevant opportunities, expertise and experiences, and identify common visions and priorities to manage mountain-specific climate risks (Ojha, 2019[46]).

Additionally, platforms that enable exchange of outcomes of both natural science and socio-economic research across mountainous areas could reduce duplication of research, policy efforts and other interventions (Schoolmeester et al., 2016[31]). The Mountain Partnership, the International Centre for Integrated Mountain Development (ICIMOD) and the Mountain Research Institute provide various benefits such as:

- allowing mountainous countries to learn from each other's experiences (Ojha, 2019[46]; Siddiqui, 2019[100])
- fostering learning for central government institutions from local (often informal) decision-making bodies (e.g. on water resource management) (Scott, 2019[101])
- enabling subnational governments to share sectoral knowledge on mainstreaming of climate resilience in broader development agendas (Dinshaw et al., 2019[30])
- facilitating learning across the science-policy-practice interface (Ojha, 2019[46]).

Forecasting can also complement learning processes based on results of monitoring and evaluation. For example, forecasting can be based on modelled projections of climate and socio-economic change, and participatory scenario analysis. Participatory and multidisciplinary learning based on historical information and forecasting can inform processes of decision making that are adaptive to future changes in the climate and socio-economic contexts of mountainous areas (Hermans, 2017[102]; Zandvoort, 2017[103]; Bloemen, 2018[104]). In the Eastern African mountains, the participatory analysis of potential adaptation pathways allowed for the integration of local knowledge about past disasters into quantitative projections of climate scenarios. This, in turn, enhanced participants' sense of ownership and the relevance of outputs to the local contexts (Capitani et al., 2019[105]). Such learning exercises have helped local stakeholders develop capacities in ecosystem management that contribute to climate resilience (Capitani et al., 2019[105]). Participatory disaster planning and emergency training has also proven successful in remote settlements in Tajikistan by helping communities learn how to prevent and respond to disasters, while integrating local knowledge (Wymann von Dach et al., 2017[10]).

Monitoring, evaluation and learning require, among others, credible weather and climate data and information. This is a significant barrier for such frameworks for climate resilience more broadly, as well as for assessing climate risk and vulnerability. The lack of measurements and the complex topography of mountainous areas necessitate increased investments in climate and weather data and information and the underlying infrastructure that supports them (e.g. installation and maintenance of hydrometeorological measurement stations and maintaining existing stations) (OECD, 2021[4]). The next section highlights key challenges and approaches to improve climate and weather data and information in mountain contexts.

1.4. Enablers for action to strengthen climate resilience in mountain regions

This section discusses enablers for implementing and scaling up action to manage climate risks in mountainous areas, namely: i) data and information; ii) awareness raising and capacity development; and iii) technologies. Chapter 4 of *Strengthening Climate Resilience: Guidance for Governments and Development Co-operation* (OECD, 2021[4]) highlights a wider range of information on these enablers and includes references to available tools and knowledge products. These products are relevant to both mountainous areas and other geographic contexts more generally. As in the previous section, the following section aims primarily at examining approaches specific to mountains, while also touching on generic issues related to climate resilience.

1.4.1. Data and information for supporting climate resilience in mountain regions

Weather and climate data and information

Weather and climate data and information underpin decision making for building climate resilience in mountainous areas. This necessitates, for instance, production of, and access to, long-term observations and accurate local climate projections in mountainous areas. Socioeconomic and environmental information such as on cultural, political, social, economic, ecological and technological aspects also complements such weather and climate data and information (McDowell et al., 2019[106]; Hodbod and Adger, 2014[107]) (Hodbod and Adger, 2014[107]; McDowell et al., 2019[106]). [See some examples from the Carpathian Mountains in Alberton (2017[32])]. For responses to disasters, the availability and management of information on humanitarian issues is also crucial. This includes issues such as displaced and vulnerable populations; damages to housing, infrastructure and services; influx of humanitarian supplies; and support by many domestic and international agencies (UN OCHA, n.d.[108]).

Governments of mountainous countries and their development co-operation providers have already invested in strengthening national climate services. These include construction of meteorological stations and production of weather and climate data, and development and application of hydrological and meteorological models at the local, regional and watershed scales. They have also compiled relevant climate- and weather-related information to make it more accessible to a broad range of stakeholders in mountain communities for their action on climate resilience (see Table 1.4 for examples of initiatives).

Indigenous knowledge can also complement data and information on climate and weather, and on humanitarian issues (IPCC, 2019[1]). For instance, local knowledge on water resource management and irrigation has historically provided an essential basis to address the uneven and irregular water supply for food production in remote high mountain regions such as Western Pamirs in Tajikistan (Dörre, 2018[109]). The Pan American Health Organization and the World Health Organization have been working to address challenges faced by Indigenous peoples in Latin and Central American countries. These peoples often live on steep mountain slopes, low coastal areas and other lands at high risk of natural hazards (PAHO/WHO, 2015[110]). These organisations recommend securing the input of indigenous peoples and their cultural and environmental knowledge for development and implementation of government disaster risk reduction plans and humanitarian aid (PAHO/WHO, 2015[110]).

Nevertheless geography and limited financial resources still constrain the installation, operation and maintenance of meteorological stations, especially in remote and depopulated areas (Yu et al., 2020[111]). For instance, a regional study of the Tropical Andes identifies two main constraints for establishing and maintaining observation networks: remoteness; and lack of stakeholder recognition by stakeholders of the importance of mountain ecosystems as water providers, among others (Schoolmeester et al., 2016[31]).

The 2019 Mountain Summit, organised by the World Meteorological Organization, recognised significant gaps in Earth system observations for mountains. It called for strengthened remote-sensing observations of the mountain cryosphere and data platforms of operational and research activities (WMO, 2019[112]).

Long-term monitoring stations must be expanded to create dense data collection networks. This should be coupled with community-level capacity development and awareness raising with regard to production and use of such data and information (Wymann von Dach et al., 2017[10]; Schoolmeester et al., 2016[31]; Bolch et al., 2019[113]). Monitoring and modelling for early flood warning, for instance, will require end-to-end information flows throughout river basins (Vaidya et al., 2019[11]). Equipping schools with meteorological stations to gather weather data can also help create awareness (Wymann von Dach et al., 2017[10]).

Table 1.4. Examples of climate and weather data and information platforms

Type of resource	Portal	Description
Information hubs	Mountain Research and Development	Scientific journal on research and development approaches in the world's mountain systems, including an edition on climate change adaptation and sustainable mountain development.
	HimalDoc	ICIMOD's central document repository that works as a one-stop portal for publications, journal articles, reports and other information resources related to the Hindu Kush Himalaya.
	Mountain Adaptation Outlook Series	Series of outlooks, created by GRID-Arendal and UN Environment, covering the Hindu Kush Himalaya, Carpathian Mountains, Western Balkans, South Caucasus, Central Asia, East Africa and the Tropical Andes.
Maps, graphs, datasets	Mountain Research Initiative – Datasets	Compilation of links to useful mountain-related datasets, databases and projects, including mountain observations, qualified bio-geophysical products, ecosystem data, etc.
	Mountain Geoportal	Geo-information resources of the Hindu Kush Himalayan region, created by ICIMOD. It provides access to science applications (e.g. decision support system for flood management, maps of potentially dangerous glacial lakes) and datasets, and disseminates information.
	Indigenous Peoples and Local Communities living in Mountainous areas Map	Geospatial information and database, presented in an interactive map, on Indigenous and local communities living in mountainous areas at global scale.
	Global Mountain Explorer	Interactive map of the global distribution of mountains.

Note: ICIMOD = International Centre for Integrated Mountain Development.
Source: Authors' elaboration.

Assessing climate risks in mountainous areas

As discussed in section 1.2, impacts of climate change on mountain communities and ecosystems are characterised by a complex set of factors (e.g. changes in the water cycle, loss of alpine biodiversity, damages to indigenous livelihoods, negative health impacts). Risk assessment methodologies must be able to describe the complex interactions among multiple hazards, and exposure and vulnerability of biophysical and socio-economic systems. A body of academic work has suggested approaches such as agent-based models, system dynamics models, Bayesian networks, event and fault trees, and hybrid models (Terzi et al., 2019[114]).[4] They argue that examining individual risks separately will not lead to a comprehensive representation of cumulative effects caused by different hazards in a given mountainous area (Terzi et al., 2019[114]) (see also an example illustrated in Box 1.6). Table 1.5 presents four index-based vulnerability assessment methodologies with a focus on livelihoods, which may be relevant to climate risk assessment in mountain contexts. The methods may also be suitable for comparative analysis across temporal and spatial scales in mountainous areas.

[4] See Table 1 in Terzi et al. (2019[114]) (Terzi et al., 2019[114])for more information about these modelling approaches for climate change adaptation in mountain regions.

Approaches to glacial lake assessments integrating climate risks are particularly relevant to high mountain regions. Such assessments have been conducted in, for instance, Peru and Nepal, to identify potentially dangerous glacial lakes. They also help address possible future impacts of glacier lake outburst floods (Byers, Cuellar and McKinney, 2015[115]). Those assessments can be conducted against several characteristics of a glacier lake, such as overhanging ice, size, volume and moraine stability (Byers, Cuellar and McKinney, 2015[115]).

Participatory vulnerability assessments can facilitate more place-based evaluation of the root causes of exposure and vulnerability driven by climate and other social changes. This is particularly important since policy and financial decision-making on climate resilience needs to consider how resilience interventions influence, and are influenced by, broader economic, social and political circumstances surrounding the mountainous areas in question (McDowell et al., 2019[106]). Experience and traditional practices by indigenous and local communities in mountainous areas can also complement scientific assessments. Specifically, they can provide insights into possible approaches to reduce vulnerability and exposure of communities and ecosystems (Wymann von Dach et al., 2017[10]). Longitudinal surveys[5] at regional and national levels can help gather data for tracking poverty and vulnerability in mountain livelihoods (Gioli et al., 2019[83]; Sharma, 2018[116]).

Table 1.5. Index-based vulnerability assessment methods with a focus on livelihoods

Method	Purpose	Description
Climate vulnerability index	Assessing a community's overall level of vulnerability to climate change. It can be used for monitoring vulnerability changes under stress conditions or for assessing proposed programmes or policy interventions by modifying variables and comparing the output to a baseline.	It incorporates the IPCC's dimensions of vulnerability – exposure, sensitivity and adaptive capacity – at the household level. Exposure includes natural hazard and climate variability measurements; sensitivity considers health, food and water variables; and adaptive capability encompasses socio-demographics, livelihood strategies and social networks.
Vulnerability and capacities index	Comparative analysis between households within a community, or between communities within a region or an urban area.	It includes three broad categories of material, institutional and attitudinal vulnerability. It focuses on livelihood diversification, infrastructure and social capital, among other indicators, as factors that reduce vulnerability and, to a lesser extent, on physical exposure as a driver of vulnerability. It was designed with the regional context in mind.
Analysis of socio-ecological patterns of vulnerability	Comparing the vulnerability of similar livelihoods (through consideration of livelihood type-specific attributes).	The method recognises that different livelihoods are subject to different vulnerabilities. The analysis focuses on socio-ecological systems (e.g. drylands) to understand spatial patterns of vulnerability at various levels (e.g. regional or household levels).
Multidimensional livelihood vulnerability index	Identifying vulnerable people at different levels (e.g. district, sub-basin), as well as areas of intervention. If conducted over regular intervals, it can be used to monitor the success of adaptive policies.	It covers the three dimensions of vulnerability: exposure, sensitivity and adaptive capacity. It can be adapted to local realities by adding or removing indicators. Final results can be heavily influenced by weights assigned based on normative decisions. By identifying the dominant determinants of vulnerability, the assessment can help suggest targeted policy responses.

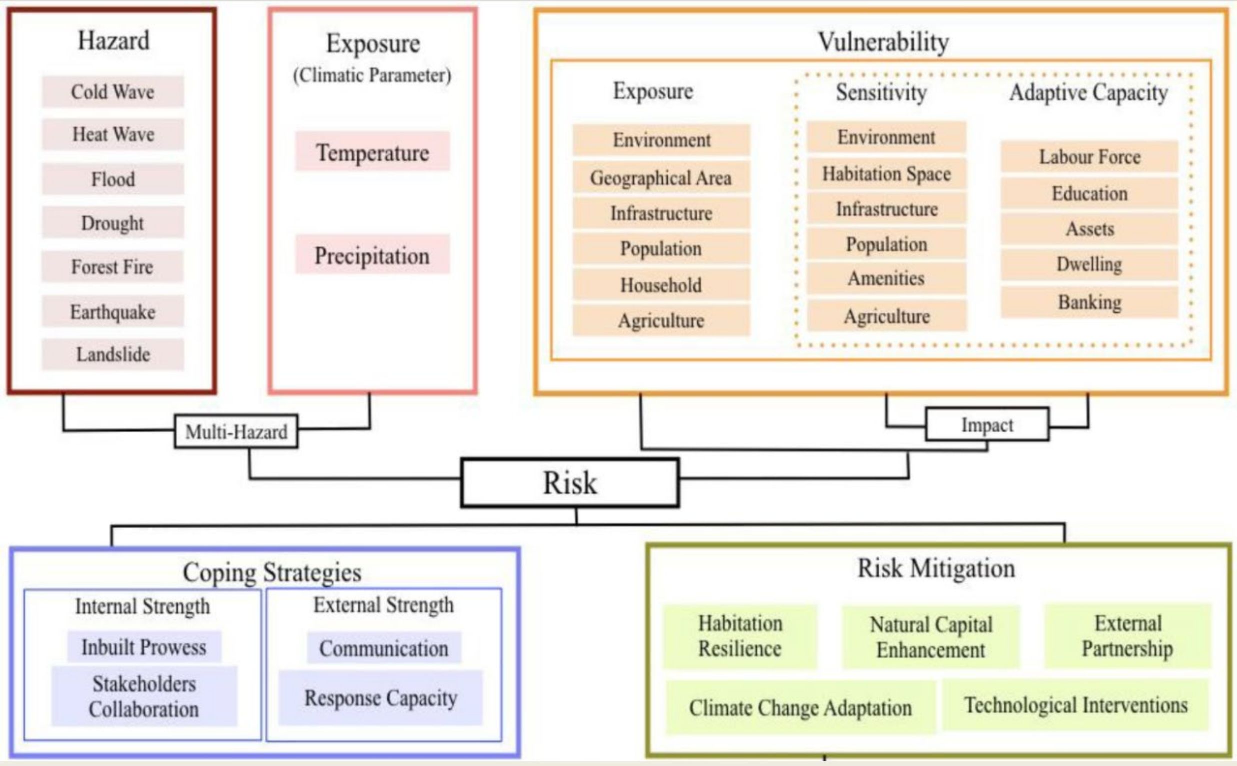
Source: Authors based on (Gerlitz et al., 2017[117]; Kok et al., 2016[118]; Mustafa et al., 2011[119]; Pandey and Jha, 2012[120]; Gioli et al., 2019[83]).

[5] A longitudinal survey is a methodology based on data from multiple subjects over short or long periods of time, and in a spatially explicit way.

Box 1.6. An example of a mountain-specific climate risk management framework

Multi-hazard risk assessments have been proposed as a way of evaluating the risk associated with possible interactions among a set of concurrent, primary and secondary hazards specific to a location. This approach can be applied to mountain contexts, as Figure 1.3 illustrates. This framework considers multiple types of hazards relevant to climate risks to biophysical and socio-economic systems in mountainous areas, and their inter-dependencies. In so doing, it helps identify measures to limit impacts of climate risks by enhancing capacities of people and ecosystems to manage such risks and cope with the impacts of disasters.

Figure 1.3. A framework for mountain-specific multi-hazard risk assessment



Source: Adopted from Sekhri et al. (2020[121]), "Mountain-specific multi-hazard risk management framework (MSMRMF): Assessment and mitigation of multi-hazard and climate change risk in the Indian Himalayan Region", https://doi.org/10.1016/j.ecolind.2020.106700.

1.4.2. Awareness raising and capacity development needed for climate action in mountain regions

Awareness across local communities, private companies and governments about the nature of climate change is an important enabler for efforts to strengthen climate resilience (FAO, 2011[63]; Rasul et al., 2019[8]). Public authorities and stakeholders in remote mountainous areas are often among those most constrained for resources and for capacities to understand and manage climate risks, despite their high exposure to certain types of risks. [See, for example, (Schoolmeester et al., 2016[31]; Wymann von Dach, 2016[20]; Wester et al., 2019[38]; Jurek et al., 2016[89]; Alfthan et al., 2018[3]; Meenawat and Sovacool, 2011[122]).]

Different actors have different needs for capacity development. Their needs can vary across stages of the policy cycle from risk identification to evaluation of implemented measures (see examples in Table 1.6). Examples of good practice and lessons learnt in approaches to strengthening climate resilience across different mountain regions can also usefully inform awareness raising and capacity development efforts (Schoolmeester et al., 2016[31]) (see Box 1.7).

Technical and financial support from development co-operation providers can play an important role to enhance capacities of local institutions (Ojha, 2019[46]). These include institutions responsible for land-use planning, agricultural extension, natural resource management or disaster risk management. Support for locally-owned and -led mechanisms and fora can promote exchange of climate data and information, discussion on key climate risks and locally specific constraints, and technologies available and suited for stakeholders in mountainous areas. Such policy dialogues have proven effective in enhancing regional co-operation and driving the development of strategic mountain agendas in the Andes, East Africa and Central Asia (World Bank, 2012[123]).

Table 1.6. Awareness and capacity building activities for climate resilience action in mountain regions (by stage, type of activity and target group)

Stage	Type of activity	Target group	Information specific to mountains
Understanding of risks	Awareness raising	Local communities (including vulnerable groups), public authorities	Hazards to mountain ecosystems, fragility and associated challenges; climate risks; costs of both structural protection and post-disaster reconstruction; natural resource use and management
	Capacity building	Research community	Training on socio-economic, climate and natural hazard risks in mountains to support risk assessments
Planning and development of policies and programmes	Awareness raising	All stakeholders	Importance of Indigenous knowledge and practices of mountain communities for the sustainable use of mountain ecosystems; and the role that Indigenous communities play in (along with formal governance structures) sustainable management of mountain landscapes
	Capacity building	Public authorities (national to local)	Disaster preparedness; development of climate-sensitive policy and planning; adaptation planning and prioritise investments, including financial and economic analysis
		Local communities; research community	Co-production of knowledge or research at the science-policy-practice interface for integration of policy into adaptation decision making
Implementation of policies and programmes	Awareness raising	Public authorities (including disaster management committees/ authorities)	Implementing climate resilience measures, such as the design of early warning systems for glacial lake outburst floods and long-term plans for lowering lake levels; support effective integrated disaster risk management; national hydrometeorological services of developing countries can support regional and community-level flood information systems
	Capacity building	Local communities (including water resource managers, hydropower producers, farmers)	Effective emergency response and rescue; improved water management and related technologies; training for farmers in alpine pastures to adapt their pasture management
Monitoring and evaluation	Capacity building	Public authorities, land managers, local communities	Training on monitoring of natural resources and ecosystems, as well as socio-economic and hazard impacts, vulnerabilities and risks
Other	Awareness raising and capacity building	Local communities, especially women	Financial literacy and skills to support financial safety and resilience to future risks; benefits of gender equality, and promotion of women's and girls' education to reducing their vulnerability to climate change

Source: Authors based on Bizikova (2014[99]); Byers, Cuellar and McKinney (2015[115]); Dinshaw (2019[30]); FAO (2011[63]); Holub and Fuchs (2009[124]); Jurek et al. (2016[89]); Meenawat and Sovacool (2011[122]); Rasul et al. (2019[8]).; Schoolmeester et al. (2016[31]); SDC (2020[125]); Wymann von Dach (2016[20]; 2017[10]).

Training initiatives, as well as integration of climate resilience into school curricula, are also a practical way to raise awareness and develop capacities (Byers, Cuellar and McKinney, 2015[115]). Involving local residents in data collection can also help increase their hazard risk awareness, as shown in remote mountains in Tajikistan and Nepal (Wymann von Dach et al., 2017[10]). In Nepal, local radio broadcasts on emergency response and disaster-proof construction were combined with training courses in masonry, carpentry and plumbing for disadvantaged and young people. This approach was considered effective in post-disaster reconstruction (Wymann von Dach et al., 2017[10]). In the Austrian Alps, specialised information on disaster prevention covered construction and maintenance costs of local structural measures, and average reconstruction costs from natural hazard damages in private households (Holub and Fuchs, 2009[124]). The information also provides options for prevention of damages and structural protection for homeowners, land-use planners and architects.

Broad consultations with local communities can also help mainstream in local development plans climate resilience considerations and technical options for managing climate risks (Byers, Cuellar and McKinney, 2015[115]). Participatory processes have also proven useful for enhancing understanding of relatively new methodologies and strengthening capacities of local actors to use them (Byers, Cuellar and McKinney, 2015[115]; Jurek et al., 2016[89]). For instance, the United Nations Economic Commission for Europe developed a methodology that combines expert analysis with stakeholder consultation processes. This approach, in turn, informs dialogues on water, food and energy security across sectors and countries in the Syr Darya basin (i.e. Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan) (Wymann von Dach and Fleine, 2019[60]). In the Indian Himalayas, media workshops on climate risks and climate resilience were organised for journalists. Local workshops can also provide sector-focused training for local communities and land managers regarding climate impacts, possible activities on climate resilience and how to implement them (Dinshaw et al., 2019[30]).

Box 1.7. Build capacity for climate resilience through "learning-by-doing": An example from the Indian Himalayas

A project to strengthen climate resilience in water, disaster risk reduction and forestry in the Indian Himalayas successfully applied a "learning-by-doing" approach to capacity building in state governments (SDC, 2020[125]). The approach included:

- developing hazard, vulnerability and risk assessments to mitigate climate-induced disaster risks in three towns in Sikkim state
- conducting sectoral vulnerability assessments for the five most vulnerable districts of Uttarakhand state to mainstream climate change in district-level planning
- fostering efforts to access and leverage financial resources from the National Adaptation Fund of the Indian government to reduce climate change vulnerability of the water sector in drought-prone areas.

Science briefs accessible to decision makers, as well as training workshops for officials of state governments, have also been offered to strengthen their capacities in considering climate science in their local planning for strengthening climate resilience in the Indian Himalayan region (SDC, 2020[125]).

The Regional Climate Awareness Forum also proved to be valuable as a policy advocacy platform across India and Nepal (Byers, Cuellar and McKinney, 2015[115]). The forum enabled collaboration between researchers and government agencies to develop climate-aware strategies with mountain communities. Organising sessions and sharing results on research and policy activities at regional events (e.g. ICIMOD's annual events) and global platforms (e.g. UNFCCC events) have also proven valuable in building awareness and support informed dialogues at national to global levels (Jurek et al., 2016[89]; SDC, 2020[125]).

1.4.3. Technologies in support of climate resilience in mountain regions

Residents of remote mountainous areas often face limited opportunities to access appropriate technologies to support their effort for sustainable development, including climate and disaster risk reduction and natural resource management. These technologies, such as early warning systems, water efficient irrigation systems and glacier dynamics modelling techniques, enable people to prepare for relevant climate-related hazards (IPCC, 2019[1]). ICT also has great potential to mitigate disadvantages caused by the geographical and social remoteness of mountain communities. Technologies can also enable people to better access education, health care and humanitarian support in case of emergencies (Wang et al., 2019[126]).

Different types of technologies that support climate resilience are already used to manage disaster risks, some of which are specific to the climatic and topographical features of mountains (see Table 1.7). Governments and development co-operation actors often support "hard" (i.e. structural or physical) engineering solutions, such as irrigation channels, flood control dams and water storage. For example, Peru, China, Nepal and Bhutan have used drainage techniques to mitigate the risk of glacial lake outburst floods [e.g. (Byers, Cuellar and McKinney, 2015[115])]. Operation technologies for storing and releasing water in reservoirs can also provide downstream areas with glacier-melted water as a buffer during the hot and dry seasons (IPCC, 2019[1]; Ehsani et al., 2017[127]). However, building physical infrastructure is capital intensive and requires regular maintenance. In some cases, development of large infrastructure may also cause unintended social, economic and environmental impacts to mountain ecosystems and populations (Rasul et al., 2019[8]). For instance, building a reservoir can increase flood risks in downstream areas and threaten biodiversity (see also Chapter 2).

Effective geospatial technologies such as geographic information systems and remote sensing are also important for understanding the large temporal and spatial variabilities in social, economic, geophysical and ecological contexts within a mountainous area. In the Hindu Kush Himalayan region, ICIMOD and its partners have developed such technologies over the past two decades (Vaidya et al., 2019[11]). These technologies contribute to the modelling of glacier dynamics, monitoring of forest fires and improvement of early warning systems for disaster preparedness (Wang et al., 2019[126]). Other examples for which such technologies provide important solutions include assessing land cover change; monitoring deforestation and forest degradation; and identifying corridors in cross-jurisdiction landscapes (Wang et al., 2019[126]).

Hard engineering solutions are often complemented, or in some cases substituted, by non-structural (or "soft") measures that encourage education and capacity building, practices and institutional reforms (e.g. to ensure that people do not live in hazard-prone areas) (see examples in Table 1.7). These tools are often low cost and flexible enough for adjustment to changing conditions and knowledge.

Nature-based solutions have been increasingly promoted to support climate change adaptation and disaster risk reduction in mountain areas. For instance, the 2019 UN Resolution on mountain development encourages countries to promote ecosystem-based adaptation (EbA). This could include agricultural biodiversity and resilient local crop varieties to reduce risk in extreme or variable climates. These measures are already used through local knowledge that is prevalent in mountainous areas. [See also Handbook for EbA in mountain ecosystems in Swiderska, King-Okumu and Islam (2018[128]) for further examples]. Such approaches can help improve water security downstream (The Mountain Institute, n.d.[129]). In Peru, for example, nature-based solutions helped restore ancient water management systems. In Nepal, the use of organic farming techniques increased resilience to pests and diseases, and restored ponds. These measures improved quality and provision of water, generating both ecological and social benefits (Jones, 2019[130]; GIZ, 2018[131]). Effective implementation of EbA should:

- be implemented at a landscape or an ecosystem level and led by collective community institutions
- ensure participatory processes at community and landscape levels, building on traditional knowledge, as well as science and multi-stakeholder engagement
- invest in participatory processes to build local capacity, institutions and ownership for effective EbA interventions and sustained impact beyond projects
- balance the needs of multiple resource user groups – from vulnerable communities to industry – and of different users within communities.

Table 1.7. Examples of technical options to strengthen resilience in mountain regions

	Protect	Retreat	Accommodate
Technical options	Build channels, drainage systems, nature-based solutions such as afforestation	Phasing out development in exposed areas; relocate exposed asset	New building codes; improved drainage; early warning and evacuation systems; hazard insurance; new agricultural practices, such as using salt-resistant crops
Related case studies	Constructing water gates and tunnel to reduce water level of glacial lake; generating hydroelectricity (Lake Paron, Peru).		Draining water to reduce pressure on moraine dam walls.
	Constructing channels to divert river discharge and retain debris in response to increased ablation of snow and ice (Coquimbo, Chile).		Installing and operating early warning system (Parvati valley, India; Tsho Rolpa and Imja glacial lakes, Nepal; Punakha-Wangdue and Chamkhar valleys, Bhutan).

Source: Rasul et al. (2019[8]), "Adaptation to mountain cryosphere change: Issues and challenges", *Climate and Development* 12, 297-309; Wester et al. (eds.), 2019, *The Hindu Kush Himalaya Assessment*, International Centre for Integrated Mountain Development, Lalitpur.

2 Approaches to strengthening climate resilience in the mountains of Uttarakhand

This chapter focuses on approaches of the Indian state of Uttarakhand and its development co-operation partners to strengthen climate resilience at the mountain landscape level. It explores ways in which these actors could further develop governance arrangements, policies and financial mechanisms intended to support action. The chapter also highlights the role of the state government of Uttarakhand and its development co-operation partners in enhancing awareness and capacities, as well as production and use of weather and climate data and information, to enable greater efforts to strengthen climate resilience.

2.1. Mountainous areas in Uttarakhand: An introduction

Among the major mountain ranges across the world, the Hindu Kush Himalayan region[6] constitutes the largest area of permanent ice cover outside of the poles. It is home to several global biodiversity hotspots whose ecosystem services sustain the livelihoods of close to a billion people living in the Ganges, Indus and Brahmaputra basins. The region is at risk from changes to its cryosphere with its glaciers' peak contribution to stream flow expected at the middle of this century. About 50% of the glaciers in the high mountains of Asia may disappear by the end of the 21st century. However, studies show climate variability and change may affect river runoffs differently (Thayyen and Gergan, 2010[132]; Huss et al., 2017[133]; Jeelani et al., 2012[134]; Bolch et al., 2019[113]).

With 93% of its surface covered by mountains, the Indian state of Uttarakhand, located in the Himalayan region, is at the forefront of these changes (IHCAP, 2019[135]) (see also Box 2.1). Uttarakhand has already experienced extreme weather events (floods and landslides). Devastating floods from heavy rains and the melting of the Chorabari glacier at a height of 3 800 metres in June 2013 resulted in more than 5 700 casualties. In February 2021, a portion of the Nanda Devi glacier broke off and led to more than 100 people missing (Floodlist, 2021[136]). With Uttarakhand highly prone to such disasters, the state government has strengthened institutional arrangements and policy frameworks, developing its capacity for disaster risk reduction over the past decade. The 2013 floods, for instance, subsequently led to various programmes and projects with a focus on disaster risk reduction and climate change adaptation. This case study draws on some of these experiences, offering lessons for, and insights into, future action to strengthen climate resilience in the state and other mountainous areas.

An increasing number of people in the Indian Himalayan region believe the rate of climate change has been accelerating (Jethi, Joshi and Chandra, 2016[137]; Chondol et al., 2020[138]; Shukla et al., 2019[139]). For thousands of years, people in the region have learnt to live with changes in the climate and the environment (Jethi, Joshi and Chandra, 2016[137]). Farmers, for instance, respond to changes in rainfall by shifting to less water-intensive crops. They will also delay sowing time in irrigated fields and shift to smaller livestock, thereby diversifying their sources of livelihood (Macchi, 2011[140]). Nevertheless, increasing number of disasters, especially of floods, over the past decade has further heightened the perception among local actors of the urgency to manage climate change impacts (Chondol et al., 2020[138]; Shukla et al., 2019[139]).

[6] The Hindu Kush Himalayan region spans areas across Afghanistan, Bangladesh, Bhutan, the People's Republic of China, India, Nepal, Myanmar and Pakistan.

Box 2.1. Uttarakhand in numbers

Uttarakhand is one of the 11 mountainous states of India. Located in the foothills of the Himalayan mountain ranges, it shares borders with the People's Republic of China and Nepal, as well as the Indian states of Himachal Pradesh and Uttar Pradesh. It is home to 10.1 million people who are mainly living in the mid hills and foothills; the elevation ranges from 210-7 817 metres (m). It has an average population density of 189 people per square kilometre. Uttarakhand has 13 districts grouped into two divisions: Kumaun and Garhwal. The state is predominantly rural with small and dispersed settlements. Its literacy rate of 79.63% is above the national average of 74.04%.

Gross state domestic product was INR 2.37 trillion (USD 32.87 billion, or USD 3 250 per capita) in the fiscal year 2018/19. Main economic activities include agro-based and food processing, information and communications technology, floriculture, horticulture, pharmaceutical and biotechnology, hydropower and tourism. Some of the highest mountains in the world are found in Uttarakhand (Nanda Devi with a peak at 7 817 m), Kamet (7 756 m) and Badrinath (7 138 m). Two of India's great rivers, the Ganges and the Yamuna, find their sources in the glaciers of Uttarakhand.

Table 2.1. Selected characteristics of districts of Uttarakhand

State level and districts	Typology	Average elevation (metres above sea level)	Share of population (%)	Sex ratio (females per 1 000 males)	Share of area covered by forest	Annual mean temperature trend in °C/100 years
UTTARAKHAND			100	963	45.8	
Almora	Middle hills	1 650	6.15	1 142	50.24	0.46
Bageshwar	Upper hills	935	6.15	1 093	61.49	0.52
Chamoli	Upper hills	800 - 8 000	3.87	1 021	33.56	0.54
Champawat	Middle hills	1610	2.56	981	66.87	
Dehradun	Plain		16.79	902	52.04	0.37
Haridwar	Plain		19.05	879	26.23	0.34
Nainital	Upper hills (some areas are middle hills)		9.44	933	72.69	0.44
Pauri			6.79	1 103	61.72	
Pithoragarh	Upper hills	1 514	4.80	1 021	29.53	0.58
Rudraprayag	Upper hills	690	2.34	1 120	56.7	0.53
Tehri	Middle hills		6.09	1 078	58.95	0.43
Udham Singh Nagar	Plain		16.29	919	21.48	0.42
Uttarakashi	Upper hills	1 158	3.26	959	39.23	0.51

Source: Based on (IBEF, 2019[141]) About Uttarakhand State: Tourism, Industries, Agriculture & Geography Information, https://www.ibef.org/states/Uttarakhand.aspx

2.2. Climate risks in mountainous areas in Uttarakhand

Stakeholders in the public and private sectors in Uttarakhand recognise climate change as a critical threat to sustainable development of their livelihood, food and energy security, and ecosystem conservation (Pandey et al., 2020[142]; Chondol et al., 2020[138]; Shukla et al., 2019[139]). This sub-section focuses on climate-related hazards, and exposure and vulnerability of the human and natural systems to the hazards in mountainous areas of Uttarakhand. In doing so, it also examines how climate risks are affecting development objectives of the state and why its mountainous areas require a tailored approach to strengthening their climate resilience.

2.2.1. Climate-related hazards in Uttarakhand

Climate-related hazards, both slow-onset changes and sudden-onset events, are different in mountainous areas compared to those on plains and other land forms. This difference is mainly due to steep slopes, elevation and stark seasonal contrasts in climatic conditions in those mountainous areas. Average ambient temperature in the mountains of the Hindu Kush Himalayan region, where Uttarakhand is located, is rising at a rate of 0.06°C per year – higher than the global average. Even if the global temperature increase is kept within 1.5 °C compared to the pre-industrial level, warming in the region will likely be at least 0.3°C higher. Rainfall is also expected to increase across seasons in the region (Wester et al., 2019[38]).

Slow-onset changes are already being observed: glaciers are retreating, albeit at different rates; the snowline is shifting upwards; winter snow cover is declining; perennial streams are drying up; and plants are flowering differently (Government of Uttarakhand, 2014[143]; IHCAP, 2019[135]; Wester et al., 2019[38]). The full impact of these changes may only become apparent in the long term, and hence it may not draw sufficient attention of policy makers and residents. The impacts, however, can gradually erode ecosystems and livelihoods in the region (Ritu, 2020[144]).

Climate change is also highly likely to increase the intensity and frequency of sudden-onset events such as erratic rainfall and flash floods (Wester et al., 2019[38]). Both observations and local residents' perceptions in the Indian Himalayan region indicate that landslides and flash floods are the most frequently occurring disasters (Chondol et al., 2020[138]; Baig et al., 2020[145]; Shukla et al., 2019[139]). While accelerated glacier melting may be a slow-onset change, it can increase the formation and expansion of glacial lakes. This, in turn, increases the likelihood of various water-induced natural hazards such as glacial lake outburst floods.

Climate and other environmental hazards are closely interlinked and must be considered jointly. Assessing climate and other types of hazards requires engagement with actors from multiple sectors in uphill and downhill areas within a given mountain landscape. For example, outburst floods from glacial lakes, or heavy rainfall, add glacial boulders, debris or sediments to rivers and this can obstruct them. This, in turn, can trigger the sudden increase in water levels, which may lead to secondary hazards such as flash floods, snow avalanches or landslides (Zimmerman, 2015[146]). This type of secondary hazard occurred in Uttarakhand in the 1970 flood in the Alaknanda River and in Kedarnath in 2013.

2.2.2. Climate-related vulnerabilities and exposure in Uttarakhand

Exposure of human and natural systems to climate hazards in mountainous areas has increased over recent decades, a trend expected to continue (IPCC, 2019[147]). Agriculture and livestock farming are the main sources of livelihoods in the mountainous areas of Uttarakhand. This means incomes and nutritional security can be highly susceptible to the impact of a changing climate. A study shows that crops in the hilly areas are less productive due to less fertile soil and more pest and disease infestations in recent years, partly caused by the temperature rise (Jethi, Joshi and Chandra, 2016[137]); (see also Box 2.2).

Box 2.2. Uttarakhand's main economic activities are vulnerable to climate change

People's livelihood largely depends on climate-sensitive activities such as agriculture and livestock farming. About three-fourths of Uttarakhand's population depend on **agriculture** in a landscape that consists of a mosaic of agricultural lands dispersed across the forest area. **Forestry and logging** are another key component of the economy. Farmers have faced deteriorating land productivity, varying and declining yields, increasing food insecurity and poverty, which are exacerbated by climate change (Shukla et al., 2019[148]; IHCAP, 2019[135]). The high dependence on monsoons, limited availability of irrigation facilities and small landholdings also contribute to the vulnerability of agricultural livelihoods (Shukla et al., 2019[148]).

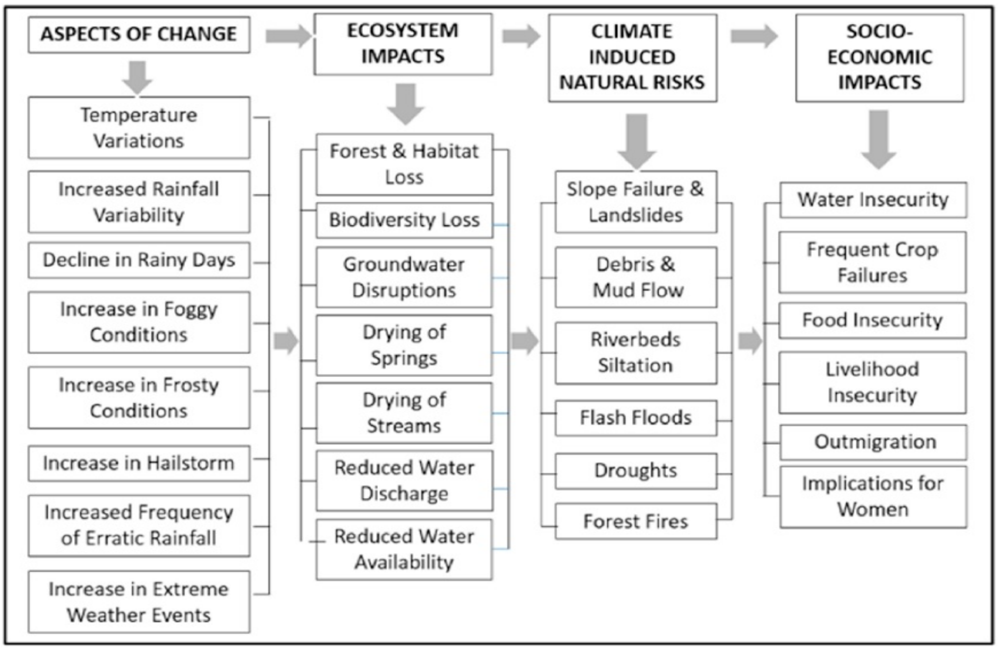
Tourism is another key contributor to the economy. The presence of several hill stations, wildlife parks, pilgrimage places and trekking routes makes Uttarakhand a popular tourist destination, visited by nearly 35 million domestic tourists in 2017 (IBEF, 2019[141]). At the same time, these geological and religious characteristics also lead to a high level of exposure to weather- and climate-related hazards, contributing to the vulnerability of people and ecosystems. The 2013 Kedarnath glacier flood disaster, for instance, took the lives of several thousand religious pilgrims.

Hydropower accounts for most of the state's electricity generation. It is a strategic priority to continue supporting its development and pursuing India's climate targets. The projected decline in water availability could affect future production of hydropower electricity, while flash floods have also damaged several elements of hydropower infrastructure. For instance, the Tapovan Vishnugad Hydro-Electric Project and the Rishi Ganga Hydro-Electric Project suffered extensive damage from the 2021 glacier lake outburst floods (Ramachandran, 2021[149]).

Multiple hazards interact, linked to the socio-economic contexts of the various mountainous areas of the state. This results in different characteristics and levels of impacts of climate change on individual actors (See Figure 2.1). For instance, poorer communities are more likely to live in hazard-exposed areas but are less able to invest in measures to reduce the risks (Maikhuri et al., 2017[150]). Steep slopes in mountainous areas of Uttarakhand have been identified as one of the most significant drivers for the state's climate vulnerability (IHCAP, 2019[135]). The steep hills make people and ecosystems highly susceptible to natural hazards such as floods, landslides and heavy rainfalls (IHCAP, 2019[135]). The state's steep topography also limits access of people to economic and social infrastructure such as transportation and health facilities. This, in turn, undermines their capacity to adapt to and cope with the negative impacts of climate change. Such infrastructure as electricity and road networks in the hill region districts of Uttarakhand is less developed than that of the plain areas; the hill region also has lower income levels (Government of Uttarakhand, 2014[143]).

Extreme weather events also negatively affect infrastructure and other assets of local businesses. Economic development, particularly that of the tourism sector, has led to an expansion of infrastructure. More roads, bus depots and trails are intended to accommodate more visitors in remote valleys and sites, but these sites are susceptible to climate risks (IPCC, 2019[147]).

Figure 2.1. Environmental and climate changes and their socio-economic impacts in rural areas of Ramgad (district of Nainital), Uttarakhand



Source: Heath et al. (2020[151]), "Building climate change resilience by using a versatile toolkit for local governments and communities in rural Himalaya", https://doi.org/10.1016/j.envres.2020.109636.

Persistent poverty and inequality in the Indian Himalayan region are also major determinants of vulnerability, compounded by gender gaps, caste/ethnicity-based discrimination and social conflicts (Gioli et al., 2019[83]). Mountain communities tend to be economically, politically and socially marginalised due to their remoteness and have less access to economic opportunities (Gioli et al., 2019[83]). Economic and gender inequities have had detrimental impacts on climate-related vulnerability in Uttarakhand (IHCAP, 2019[135]). Studies have shown that more women than men die when disasters strike. This difference is partly due to women's lack of access to information, mobility and decision-making power and disadvantaged access to resources and trainings. These are informed, in turn, by gender-based socio-cultural norms and conventional gender responsibilities (Wester et al., 2019[38]). Many men (approximately 100 000 over the last decade) have left rural areas for better job opportunities outside the state (Naudiyal, Arunachalam and Kumar, 2019[152]; Panda, Kumar Gupta and Kaur, 2020[153]). This means more women live in mountainous areas, and thus more exposed to natural hazards.

2.3. Mechanisms for enhancing climate resilience of Uttarakhand

The state government of Uttarakhand, often in collaboration with its development co-operation partners, has adopted various mechanisms to manage climate risk for people and their livelihoods in mountainous areas. This section examines such mechanisms, including institutional arrangements, policy frameworks, and financial management and instruments.

2.3.1. Multi-level governance for strengthening climate resilience in Uttarakhand

State-level governance arrangements for climate resilience

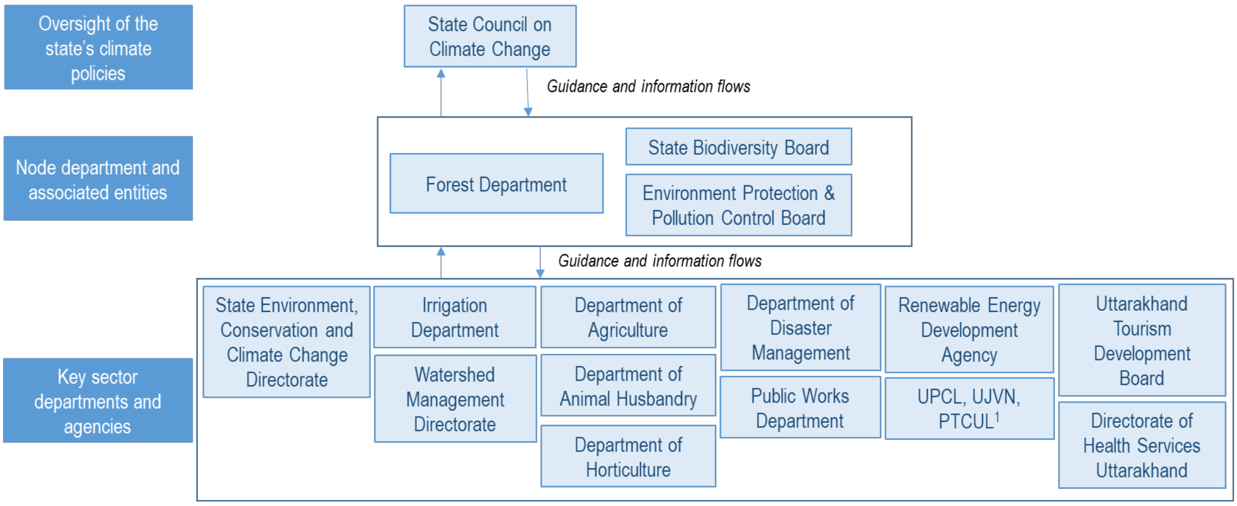
The Uttarakhand government, through its departments and agencies, is in charge of state-level policy decisions, resource allocation and mobilisation, as well as monitoring the implementation of policy measures on climate resilience. Along with institutions directly in charge of climate policies, the finance and planning departments, as well as other line departments and agencies, also play a key role in advancing action in support of climate-resilient development (Government of Uttarakhand, 2014[143]; Sharma, 2017[154]; SECCCD, 2020[155]). Following institutional restructuring in 2020[7], the relevant state government entities include the following:

- The State Council on Climate Change oversees development and implementation of climate-related policies at the state level.
- The State Forest Department, designated as the "node department", co-ordinates measures to achieve objectives of the Uttarakhand Action Plan on Climate Change (UAPCC).
- The State Environment, Conservation and Climate Change Directorate was set up in 2020 to plan, implement and monitor climate-related policies at the state level (SECCCD, 2020[155]).
- Several line departments (water, energy, disaster management, tourism, transport, agriculture, horticulture and public works) work on implementation of sectoral activities under the UAPCC with the State Forest Department. These departments have also agreed to establish climate change cells within their organisational structures to roll out sector-specific projects (see also Figure 2.2).

It is commendable the UAPCC has formally set respective mandates on climate action for these various departments and agencies. Nevertheless, experience suggests a potential for greater co-ordination across different government entities to facilitate cross-sectoral planning of measures to manage climate risks in mountainous areas of the state (Dinshaw et al., 2019[30]). For instance, the Swiss Agency for Development and Cooperation (SDC) and the United Nations Development Programme (UNDP) supported a pilot project to build climate resilience in forest-dependent communities in Uttarakhand. Identifying the responsible person for the project within each of the participating sectoral departments proved difficult and time consuming. This delayed implementation of certain activities under the project (Dinshaw et al., 2019[30]).

[7] The State Climate Change Centre (SCCC) of the Forest Department of Uttarakhand, established in 2016 to co-ordinate development of state climate policies, was disbanded. Other departments were restructured in 2020.

Figure 2.2. Uttarakhand-level institutional structure for climate policies



Note: UPCL = Uttarakhand Power Corporation Limited; UJVNL = Uttarakhand JalVidyut Nigam Limited; PTCUL = Power Transmission Corporation Limited.
Source: Authors' elaboration.

Inclusive governance for strengthening climate resilience in mountain regions

Social and economic inequality is a major driver for climate vulnerability of those marginalised or discriminated groups (OECD, 2021[4]). Consequently, decision-making processes within any governance arrangement for climate resilience also needs to be inclusive. For instance, a study on disaster risk management in the Kedarnath valley reiterates that poor, women and marginal communities living in disaster-prone rural areas are more vulnerable to climate risks than that of urban residents (Maikhuri et al., 2017[150]). The higher dependence of people in the rural areas on climate-sensitive sectors, and their limited technical and financial capacity to adapt or cope, has also augmented their susceptibility to climate hazards.

Social inclusion of vulnerable communities in policy making is also key to facilitating action to support climate resilience across different sectors within the mountain landscape (e.g. agriculture, tourism, hydropower) (Wester et al., 2019[38]). For instance, a multipurpose, run-of-the-river hydropower project should ensure that various water users consider and discuss its benefits and potential trade-offs in the development stage (e.g. electricity generation for urban areas and agriculture production in rural areas) (Buechler et al., 2016[156]). Improved benefit-sharing mechanisms of such projects can help address existing inequality among different actors in the mountain landscapes. In an encouraging development, micro hydropower development supported by policy initiatives has led to upstream-downstream co-operation among villages for equitable water allocation within the Hindu Kush Himalayan region (Wester et al., 2019[38]).

Policies on climate resilience, support programmes and legislative documents at the state level need to match local needs and capacities (Chondol et al., 2020[138]). Engagement with institutions and actors at district, block and village levels can foster understanding of such local needs. These can relate both to action on climate resilience and capacities to implement the action. For instance, local officials of line departments represent the state government at district and block levels. Most government programmes and arrangements are implemented at this level through District Development Plans. More than 15 000 villages exist in Uttarakhand. Their local institutions, such as village panchayats (councils), already play an important role in disaster risk management (e.g. conducting drills, preparing equipment for emergencies, etc.).

Actors at the sub-state level often have greater access to remote terrains in mountainous areas than state-level officials. Enhancing engagement with sub-state level actors and their capacities can therefore help the state government ensure its support reaches the needy in remote villages (Panda, Kumar Gupta and Kaur, 2020[153]; Maikhuri et al., 2017[150]). Various development co-operation providers help build capacity for local officials of the state departments. For instance, SDC has supported a District Development Plan with a focus on climate resilience. This programme highlighted the importance of the engagement and two-way interaction between the state government and sub-state actors (Government of Uttarakhand, 2014[143]).

Stakeholder engagement in knowledge creation and policy dialogues

Harnessing local and Indigenous experiences and knowledge can help tailor policies on climate resilience to the needs of the most vulnerable groups of society (Wester et al., 2019[38]). One example underlines the role of community participation in the conservation of natural resources. Hill communities have a long history of managing natural resources through village forest councils (panchayats). This experience in designing and implementing rules for sustainable forest management and related livelihood issues over the decades could provide useful insights into policy making on climate resilience in Kedarnath valley and other mountainous areas in the state (Maikhuri et al., 2017[150]).

Collecting and publishing information on the benefits of effective local-level interventions (e.g. introduction of resilient crops, ecotourism, agroforestry, etc.) could encourage a broader range of stakeholders to participate in policy dialogues, and the development of projects related to climate resilience. Such information could be disseminated through awareness-raising workshops, for instance, that provide a broader range of stakeholders with learning opportunities (Mishra et al., 2019[44]). Learning through such exchanges could help participants integrate risk reduction practices into their daily work and livelihoods, especially when the right regulatory frameworks are in place and implemented.

Integrating traditional knowledge and community-based natural resource management into environmental policies is also highlighted as a component of the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) (Wester et al., 2019[38]). In Uttarakhand, this approach could build on existing channels, such as farmer field schools (a group-based learning process among farmers), producer organisations and self-help groups to facilitate collection of such information and knowledge (Chunera et al., 2019[157]). Box 2.3 provides some examples of engagement between the state government, development co-operation providers and local actors.

Box 2.3. Encouraging stakeholder engagement: Examples from development co-operation providers

Some initiatives by the state government and its development partners focused explicitly on greater stakeholder engagement for building climate resilience in the mountainous areas of Uttarakhand. For example:

- Involvement of the village and forest panchayats (councils) at all stages of a forest recovery project by the Forestry Department has contributed to building institutional capacity and memory at the district level and supported effective implementation on the ground (Dinshaw et al., 2019[30]).
- Two workshops held in Uttarkashi (upstream Ganges, Uttarakhand) and Patna (downstream, Bihar) brought together researchers and stakeholders (e.g. farmers). They discussed the suitability of hydrological modelling data prepared for the agriculture sector and suitable adaptation options based on their combined knowledge and experience. Farmers suggested several suitable adaptation options, such as the implementation of small irrigation systems and improved access to credit (Winther, 2017[158]).
- Several rural enclave jurisdictions within the Ramgad watershed (Nainital, Uttarakhand) held multi-stakeholder dialogues for learning on climate risk impact assessment and adaptation options. Discussions led to 40 proposals on interventions for resilience of the enclave jurisdictions. The proposed measures were prioritised according to the stakeholders' technical, political, social and economic feasibility (Heath et al., 2020[151]).

Regional co-operation for climate resilience in mountain regions

Countries in the Hindu Kush Himalayan region have recognised the importance of cross-country co-operation to strengthening resilience of mountain landscapes to climate risks (ICIMOD, 2020[57]). This recognition is mainly driven by the strong upstream-downstream linkages between mountains and plains. Equally important are synergies and trade-offs among different policy objectives, including on water, food and energy security (Rasul, 2014[66]).

Despite political-level recognitions, however, there have been limited examples of cross-country projects. For instance, the Climate Summit for a Living Himalayas held in Bhutan in 2011 produced a regional framework of co-operation in, among others, food security, natural freshwater systems, biodiversity and energy security. However, there was little follow-up action with concrete outcomes as of 2019 (Wester et al., 2019[38]). The absence of institutions to link upstream and downstream areas and countries in mountain landscapes has also made the design and implementation of such cross-border co-operation challenging (Wester et al., 2019[38]). The remoteness of mountain communities from decision-making processes at the international level, as well as limits to effective monitoring and patrolling across borders, increases the challenge.

Nevertheless, there have been some encouraging developments in cross-border collaboration. A declaration to work together for the Hindu Kush Himalayan region, for example, was recently adopted (see also Box 2.4). Expanding co-operation on complex transboundary environmental and energy-related issues (e.g. water basin management and energy security) and establishing formal, mutually agreeable frameworks for co-operation can help address some challenges to cross-border collaboration. This, in turn, can promote approaches to enhancing the resilience of mountain landscapes (Wester et al., 2019[38]).

Box 2.4. Cross-border initiatives in the Hindu Kush Himalayan region

In October 2020, eight countries of the Hindu Kush Himalayan region adopted a declaration to strengthen regional co-operation for greater resilience in the region to climate and disaster risks (ICIMOD, 2020[57]). This declaration built on the extensive work of the International Centre for Integrated Mountain Development (ICIMOD) to provide the scientific evidence that human drivers and climate change pose immediate and long-term threats to the region's livelihoods, biodiversity and sustainable development [see (Wester et al., 2019[38])]. The declaration was signed to unify the voices of the Hindu Kush Himalaya at regional, global and United Nations platforms; enhance the uptake of scientific evidence for improving policies in the region, focusing on mountain environments and livelihoods; and assess the feasibility of establishing a regional institutional mechanism (ICIMOD, 2020[57]).

The Adaptation at Altitude programme, funded by the Swiss Agency for Development and Cooperation and implemented by UN Environment and partners, runs from 2020 to 2023. It seeks to increase the resilience and adaptive capacity of mountain communities and ecosystems to climate change. In addition, it facilitates science-policy dialogues in the Hindu Kush Himalayan region, the Andes, East Africa and South Caucasus, as well as supports inter-regional collaboration and sharing of experience (Adaptation at Altitude, 2020[56]).

2.3.2. Policy frameworks at the national and state levels

Various climate-related policies have been developed and implemented at national and state levels in India. The Indian government recognises climate change as a "risk multiplier" for vulnerable groups in the country, worsening existing social, economic and environmental stresses (Government of India, 2020[159]). India does not have a national adaptation plan at the time of writing. Instead, the country highlights climate resilience in its National Action Plan on Climate Change (NAPCC). This plan was adopted in 2008 to raise awareness among all Indian stakeholders about climate risks and take steps to address them (Government of India, 2008[160]). The core part of NAPCC consists of eight "National Missions"[8] that represent a long-term and integrated approach to achieving climate-related goals. Several focus on climate change adaptation in sectors such as agriculture, water and forestry (Government of India, 2015[161]), all of which are relevant to efforts to strengthen resilience of mountainous areas.

India's Nationally Determined Contribution (NDC) reiterates the priorities and objectives of climate change adaptation set out under the NAPCC. The NDC also clearly recognises the vulnerability of Himalayan ecosystems. It highlights the NMSHE as a key policy objective, which aims to address climate-related issues concerning Himalayan glaciers, as well as the importance of building scientific and traditional knowledge. NMSHE also underscores the importance of demonstrating replicable solutions to the issues in the Himalayan region (Government of India, 2015[161]). Multiple other missions mentioned in the previous paragraph are also referenced in the NDC, highlighting their relevance to the country's climate objectives (Government of India, 2015[161]).

At the state level, Uttarakhand's Vision 2030, released by the State Department of Planning of Uttarakhand in 2018, sets out the strategy for achieving the Sustainable Development Goals. One target under Vision 2030 is to "build the resilience of the poor and vulnerable to climate-related extreme events and environmental shocks and disasters" (Government of Uttarakhand, 2018[162]). Vision 2030 also highlights

[8] The eight National Missions are: National Solar Mission; National Mission for Enhanced Energy Efficiency; National Mission on Sustainable Habitat; National Water Mission; National Mission for Sustaining the Himalayan Ecosystem; National Mission for a Green India; National Mission for Sustainable Agriculture; and National Mission on Strategic Knowledge for Climate Change. See for further information (Government of India, 2008[160]).

the opportunities and challenges of being in a mountain region. The opportunities include economic diversification towards horticulture, aromatic and medicinal plants, animal husbandry, non-timber forestry products and tourism. The challenges relate to economic disparity between hills and plains, infrastructure gaps and environmental degradation, among others (Government of Uttarakhand, 2018[162]).

These challenges, opportunities and targets are in line with the Uttarakhand Action Plan on Climate Change (UAPCC) and the Disaster Management Action Plan. Table 2.2 shows key steps and actions outlined in the UAPCC to reduce climate-related risks and build resilience in key sectors. This includes climate risk assessments, the information and knowledge base, public awareness and capacity building. In addition, UAPCC also suggests developing district-, block- and village-level plans to strengthen climate resilience of respective communities, while being mindful of excessive administrative burdens. Further, building climate resilience in the mountains of Uttarakhand also requires integrating consideration of climate hazards and vulnerability in sector-specific policies, and ensuring coherence among them. These policies are related to watershed management, agriculture and forestry, tourism, energy, transport, disaster risk reduction and rural area development, among others (Tiwari, 2018[163]).

Table 2.2. Key actions and steps outlined in the UAPCC

Policy actions/steps	Role of sectoral departments and stakeholders
Sector policy reviews	Each sector to review sector policies and, where appropriate, articulate climate change risks and sectoral policy responses
Climate vulnerability and risk assessments	Sector-level climate vulnerability and risk assessments to be carried out Elements of sectoral programme elements to be reframed based on the findings of the assessments
Development of evidence base of sector climate change impacts	Each sector to collect and generate information on the impacts of climate change on the sector
Understanding public and community perceptions of climate change in each sector	Each sector to carry out periodic documentation of public/community perceptions on climate change and its impacts relevant to the sector
Periodic consultations with civil society and communities	Each sector to regularly consult with civil society and communities to gauge needs for action on climate resilience
Incorporation of poverty, equity, gender and livelihood concerns	Each sector to explicitly consider poverty, equity and livelihood concerns in the development of its sectoral policies, plans and budgetary processes The different schemes of various sectors to be examined in terms of gender concerns by the Women and Child Welfare Department
Monitoring and evaluation protocols.	Each sector to develop and deploy monitoring and evaluation processes and protocols to guide effective programme implementation in light of the overarching state level framework.

Source: Authors' based on (Government of Uttarakhand, 2014[143]), Uttarakhand Action Plan on Climate Change, www.forest.uk.gov.in.

2.3.3. Sectoral approaches to strengthening climate resilience in Uttarakhand

While managing climate risks coherently across multiple sectors within a mountain landscape is crucial, sector-specific approaches can also provide entry points to help integrate considerations about climate hazards and vulnerabilities into sector-level development policies. The rest of this sub-section focuses on some key sectors in the state, which are also vulnerable to the negative impacts of climate change. The sectors include water resources management, agriculture, forestry, tourism and energy. Addressing climate risks at the mountain landscape level (e.g. watersheds[9], forests, etc.) also requires policy coherence between different sectors to ensure that enhancing the resilience of one sector does not undermine that of another.

[9] A watershed is a hydrological unit from which runoff drains and is collected through a common outlet.

Water resource management

Water resources in the state, mainly used for agriculture, energy, tourism and forestry, are likely to change significantly over time due partly to climate change (IHCAP, 2019[135]; Wester et al., 2019[38]). Communities in the hilly areas, which are dependent on springs, are already feeling local impacts. Many such springs are likely to dry up due to lack of recharge during the summer months. Some of the state's rural water supply systems do not adequately meet community needs, while frequent landslides have damaged water pipes and other infrastructure for water supply (Acclimatise, 2016[164]; Lall and Misra, 2013[165]). Managing watersheds involves conserving soil and water for rain-fed agriculture, recharging underground water and capturing surface runoff into forms of water storage (Sutra Consulting, 2019[166]).

In 2019, the state government adopted a new water policy to promote integrated approaches to planning, management and use of water resources in Uttarakhand (PTI, 2019[167]). It aims to provide a water resource management framework that considers both environmental and development issues. It remains unclear whether and how the new water policy has been implemented to date (Bansal, 2019[168]). Other policy documents relevant to water resource management are summarised in Table 2.3.

Table 2.3. State-level policies and acts related to water resource management

Name	Objective
Uttarakhand Ground Water Act (2016)	Regulate and control the development and management of groundwater and matters connected to it
Uttarakhand Flood Plain Zoning Act (2012)	Regulate human activity in the flood plains of a river where the plains are created by overflow of water from the channels of rivers and streams
Uttarakhand Water Management and Regulatory Act (2013)	Facilitate and ensure judicious, equitable and sustainable management, allocation and optimal use of water resources
Uttarakhand State Perspective and Strategic Plan 2009-27	Increase the productivity and income of the rural inhabitants in the rain-fed micro-watersheds on priority basis area through sustainable management of the natural resources, recognising climate impacts

Source: (Government of Uttarakhand, 2012[169])Uttarakhand Flood Plain Zoning Act, 2012 ((Uttarakhand Act No. 07 of 2013), http://bareactslive.com/UTR/utr112.htm (Government of Uttarakhand, 2013[170]) Uttarakhand Water Management and Regulatory Act, 2013 (Uttarakhand Act No. 24 of 2013), www.bareactslive.com/UTR/utr121.htm and (WMD, 2009[171]) Uttarakhand State Perspective and Strategic Plan, 2009-2027, http://wmduk.gov.in/Perspective_Plan_2009-2027.pdf

The state government assessed vulnerability and risk of nine sectors in 2016, suggesting a range of climate resilience measures in water management and other sectors (Acclimatise, 2016[164]). Policy gaps nevertheless remain in pursuing water resource management in the mountain landscape in Uttarakhand. For example, although small springs provide 90% of the drinking water supply in the state, most water-related policies do not refer to springshed[10] management. They also do not adequately recognise the importance of combining scientific information on climate risks with community knowledge to explore locally appropriate measures for water management (Patil and Kulkarni, 2019[172]; Upreti and Panwar, 2018[173]).

Several studies have suggested measures which the state, possibly with support of development co-operation, can take, or reinforce, to adapt to seasonal changes in water availability and other water-related climate hazards such as floods and droughts (Patil and Kulkarni, 2019[172]; Upreti and Panwar, 2018[173]; Acclimatise, 2016[164]; Wester et al., 2019[38]). They include measures to:

- better integrate climate risks into policies and plans on water resources management by
    - mapping the availability, supply and demand of water resources at the basin level (based on the predicted impacts of climate change on precipitation patterns and glacier melting), using glacio-hydrology modelling, among others

[10] A springshed is a region that feeds multiple springs through a system of rock formations and can encompass single or multiple watersheds.

    - re-assessing the design of water infrastructure in light of the increasing probability of large magnitude flood events, including related technical criteria for new dams based on risks and vulnerability
    - preparing flood plain maps and hazard maps for flood-prone areas guided by the 2016 vulnerability and risk assessment, and assessing feasibility of structural and non-structural measures for flood management
    - adapting to changes in stream flows by using the findings of the above-mentioned assessment to guide investments in run-of-the-river hydropower, drinking water and irrigation projects.
- encourage sustainable use of water and engage with communities by
    - considering the various dimensions of water, such as the quality and quantity of surface and groundwater, seasonality and needs across sectors as a basis to promote integrated water resources management
    - promoting watershed and springshed management as well as water saving and re-use schemes
    - engaging communities to tap into their local and Indigenous knowledge to ensure small springs and groundwater are sustainable.

Agriculture and forestry

Uttarakhand's agriculture sector, which consumes about 75% of the state's water resources, is the main source of livelihood for over 70% of the population. Increasing stress on water resources, partly driven by increasing temperature and economic growth, is likely to affect irrigation needs, crop yields and risks from diseases and pests (Acclimatise, 2016[164]; Winther, 2017[158]). Agricultural productivity in Uttarakhand tends already to be low. This is due to small and scattered land holdings (14% of the total land area of the state is considered arable), steep terrain, high dependence on rain-fed agriculture, lack of access to improved inputs and poor trade conditions (Government of Uttarakhand, 2014[143]). Agricultural lands in the state are dispersed across forest areas, and farmers tend to depend highly on forests for inputs such as litter, which is used as fodder and manure.

In the absence of an overarching policy document to guide efforts to manage climate risks to the agriculture sector, the UAPCC provides a sectoral vision on the resilience of agriculture. The UAPCC recognises the importance of treatment of the catchment area and sustainable agriculture practices (Government of Uttarakhand, 2014[143]; Acclimatise, 2016[164]). While the UAPCC set out actions to address climate risks and vulnerability, it does not detail how to implement and monitor them (Government of Uttarakhand, 2014[143]). Nonetheless, it provides an important basis to promote climate-resilient agriculture and protect the watershed landscape in the mountains of Uttarakhand.

Several public- and private-sector initiatives aim to improve food supplies and availability (e.g. local grain banks to create buffer stocks against seasonal shortfalls) (Chunera et al., 2019[157]; Acclimatise, 2016[164]; Naudiyal, Arunachalam and Kumar, 2019[152]). Based on these initiatives and other analytical studies, several actions are possible to strengthen climate resilience of the agriculture sector in the mountains of Uttarakhand:

- enhance and disseminate the evidence base about expected impact of climate change on yield trends, including research by local institutions
- evaluate tolerance of hill crops to drought, heat and cold stress, and the cultivation of crop types that are more resilient to these hazards or require lower input
- promote crop diversification and use of traditional crops
- review state-level guidelines for irrigation management to consider findings of the climate risk and vulnerability assessment into the management of irrigation systems

- raise awareness of insurance schemes at farm level and explore weather-based index insurance by, for instance, the Agriculture Insurance Company of India
- support incubation of agro-based entrepreneurial ventures, land and labour consolidation to promote organic agriculture, and development of agriculture extension services
- enhance policies in support of agriculture extension services at block and village levels to help implement these activities.

Promoting livelihood diversification is another dimension to strengthen climate resilience of the rural economy. Non-farm livelihoods have been important income sources in many mountain villages in Uttarakhand. They are particularly valuable where and when challenges such as land degradation, population growth, scarcity of resources and technologies, and climate change have undermined the profitability of commercial farming (Naudiyal, Arunachalam and Kumar, 2019[152]). Policies that aim to develop other sectors such as tourism, sericulture, handloom and handicrafts, fisheries and livestock (e.g. yaks) can therefore support local livelihoods. These, in turn, can help the sectors become more resilient to natural hazards and other external shocks (Naudiyal, Arunachalam and Kumar, 2019[152]; Baig et al., 2020[145]). State departments and agencies responsible for relevant sectors would need to develop action plans to establish or upgrade value chains for alternative products and services, build individual capacity, explore financial resources to support pilot activities and upscale successful ones (Baig et al., 2020[145]).

Farmers in the Himalayan region have maintained close linkages between agriculture, forestry and animal husbandry, practising agroforestry to complement subsistence farming (Mahato et al., 2016[174]; Maikhuri et al., 2009[175]). Forest products are important income sources for those who live within or at the edge of forests (e.g. fuel wood, fodder and non-forest timber produce, specifically medicinal and aromatic plants) (Acclimatise, 2016[164]). Forest councils have often facilitated agroforestry activities within their communities. The Forest Department developed related policies such as the annual forest working plans, the Van Panchayat Rules (2005) and Van Panchayat micro-plans, and the ten-year management plan of the Forest Development Corporation. They could enhance integration of climate resilience into forestry with several possible actions (Dash and Punia, 2019[176]; Acclimatise, 2016[164]), including approaches to:

- make use of the result of the 2016 vulnerability and risk assessment to assess and prioritise forest conservation measures
- review and update the Uttarakhand Van Panchayat Rules in a way that considers climate risks to and vulnerability of local populations and ecosystems (building on the 2016 vulnerability and risk assessment)
- assess and improve mechanisms for better market access of non-timber forest produce
- conduct scientific and policy research on drivers of and prevention measures against forest fires
- increase focus on short rotation forestry to deal with uncertainty in biomass availability in forests
- research changes in specific floral species based on historical trends and areas where vegetation changes are projected
- raise awareness of benefit of livelihood diversification, such as cultivating medicinal plants to improve incomes.

Energy sector

Hydropower accounts for most of the state’s electricity generation. It is a strategic priority to continue supporting its development and meeting India’s climate targets (IBEF, 2019[141]; Dash and Punia, 2019[176]). Several major hydropower stations with a cumulative capacity of around 2 600 MW are operational in Uttarakhand. As of November 2019, 44 small hydropower plants with total capacity of 4.3 MW have been installed in the remote villages of Uttarakhand. Another 19 medium hydropower plants with total capacity of 2.3 MW are under development (Uttarakhand Renewable Energy Development Agency, 2019[177]).

Uttarakhand has also been setting up solar-based home lighting systems, especially in rural and remote areas.

The high reliance on hydropower can make the energy sector susceptible to the negative impacts of climate change, such as varying rainfall patterns and occurrence of extreme weather events. For instance, hydropower dams in Kedarnath, an upstream town of Uttarakhand, were severely damaged by the 2013 floods (Wester et al., 2019[38]). Similarly, the February 2021 floods destroyed the Rishiganga hydro-electric project and the larger Tapovan Vishnugad hydropower construction project (McSweeney and Tandon, 2021[178]). Furthermore, up to two-thirds of current and planned hydropower projects are in the path of potential glacier floods in the Himalayan region alone (Schwanghart et al., 2016[18]; IPCC, 2019[147]).

Development of hydropower projects has greatly contributed to the economic development of Uttarakhand, as well as to the energy security and the low-carbon transition of India. At the same time, some studies have highlighted social and environmental risks associated with hydropower plants, especially those with large dams (Mishra et al., 2020[179]; Buechler et al., 2016[156]; Dash and Punia, 2019[176]). The state's hydropower policy[11] focuses mainly on the ownership and tenure of hydropower projects. Multiple research suggests there is scope for more emphasis on environmental safeguards, the resilience of energy infrastructure to climate- and weather-related hazards, and resettlement and dam safety strategy (Dash and Punia, 2019[176]; iCED, 2014[180]; Chondol et al., 2020[138]; Buechler et al., 2016[156]; IRI, 2018[181]).

A well-functioning benefit-sharing scheme for hydropower projects could help reduce social inequality among different sectors within the state. Such a scheme could also address water stress in downstream communities and their vulnerability to climate change. Benefit-sharing arrangements could be used to balance increased revenues from hydropower electricity with the decreased availability of water for irrigation systems, riparian-corridor ecosystem services and other natural resource-based livelihoods (Buechler et al., 2016[156]). Several studies propose options to further develop the state's hydropower sector so that it supports climate resilience of the mountain region in Uttarakhand (Chondol et al., 2020[138]; Dash and Punia, 2019[176]; iCED, 2014[180]; Buechler et al., 2016[156]). Examples of these options are to:

- update the state hydropower policy by reinforcing the requirement and guidance for environmental impact assessment, securing environmental water flow for downstream ecosystems
- consider legal instruments for the state and central governments to facilitate more equitable benefit-sharing from hydropower projects between the community and hydropower developers
- promote springshed development through small hydropower projects that are built and operated by local populations, aiming to balance the management of water resources for energy, irrigation and household use within the rural community
- assess the accumulated negative impacts of run-of-the-river hydropower projects on the environment, even if these impacts are considered lower than those of large hydropower projects with dams.

Tourism

Uttarakhand's biodiversity, numerous peaks, mountains and pristine high-altitude lakes, and religious heritage sites are tourist attractions that contribute significantly to its economy. Some of the holiest Hindu shrines have attracted pilgrims for more than a thousand years (e.g. Gangotri, Yamnotri, Badrinath and Kedarnath). Tourist numbers increased from about 20 million in 2006 to 37 million in 2017 in the state whose population is about 10 million (Government of Uttarakhand, 2018[182]).

The geographical characteristics of tourism in the state's mountainous areas also make the sector vulnerable to the negative impacts of climate change. At the same time, tourism activities can also cause

[11] The Policy for Harnessing Renewable Energy Sources in Uttarakhand with Private Sector / Community Participation (adopted in 2008).

significant stresses to fragile Himalayan ecosystems, due to increased water consumption, excessive construction, heavy usage of fuel wood and improper waste disposal (Mishra et al., 2019[44]; Maikhuri et al., 2017[150]; Roy and Saxena, 2020[183]). Some regions in Uttarakhand have seen a decline in tourism due to environmental degradation, temperature rise and increased natural hazards (Government of Uttarakhand, 2014[143]; Jasrotia and Sharma, 2020[184]). These changes and hazards negatively affect, for instance, snow conditions, preservation of wildlife and biodiversity, and the quality and levels of water.

As of 2020, the Department of Tourism, with support of the UNDP, was drafting the Uttarakhand Ecotourism Policy 2020, building on the Uttarakhand Tourism Policy adopted in 2018 (Government of Uttarakhand, 2018[182]). The Ecotourism Policy aims to provide a guiding principle for balanced tourism development and biodiversity conservation (Aggarwal, 2020[185]). The draft[12] emphasises the urgent need for adequate environmental and social safeguards to reduce threats to biodiversity and promote socio-economic development particularly in hill districts. It also prioritises low-impact, responsible travel to culturally and ecologically sensitive tourist destinations. In addition, the draft document emphasises the involvement of local communities in decision-making processes for tourism sector development.

Studies of these opportunities, challenges and recent policy developments have identified several ways to promote tourism in support of climate resilience and environmental and social sustainability for mountain communities in Uttarakhand (Aggarwal, 2020[185]; Dash and Punia, 2019[176]; Maikhuri et al., 2017[150]). Based on these practices and studies, examples of potential ways forward could be to:

- assess the direct and indirect, and short- and long-term, impacts of tourism activities on biodiversity, the environment and the quality and quantity of water resources, while considering possible negative impacts of climate change
- provide clear guidance and by-laws to ensure safe distance for construction near riversides, to be better prepared for climate- and weather-related hazards
- provide clear guidance (possibly in the proposed Ecotourism Policy) on how permissions to open the forest areas for ecotourism will be granted and how environmental integrity will be ensured and monitored to avoid excessive disturbance to the movements of wildlife
- assess benefits and challenges of an environmental tax for tourism to direct the generated revenue into measures to protect the environment and local cultures, and strengthen the resilience of tourism and local infrastructure
- put in place a process of transparent and inclusive consultation with communities that may be affected by the tourism development, supported by the right information on climate, environmental and social risks, and vulnerabilities.

2.3.4. Financing for climate resilience in mountainous areas of Uttarakhand

State- and central-government budgets and incentives

Uttarakhand's public budget mainly comes from the national government (with an increasing dependence on it) and from the state's own tax revenues (Government of Uttarakhand, 2018[162]). The government of Uttarakhand had announced in 2016 an objective to allocate 1% of all departments' budgets to measures related to climate change. It is not clear whether and how such earmarked funding has actually been secured or disbursed (Sharma, 2017[186]). The state analysis of the government budget for 2016-19 is available but has not provided specific information on climate-related expenditures (Government of Uttarakhand, 2019[187]).

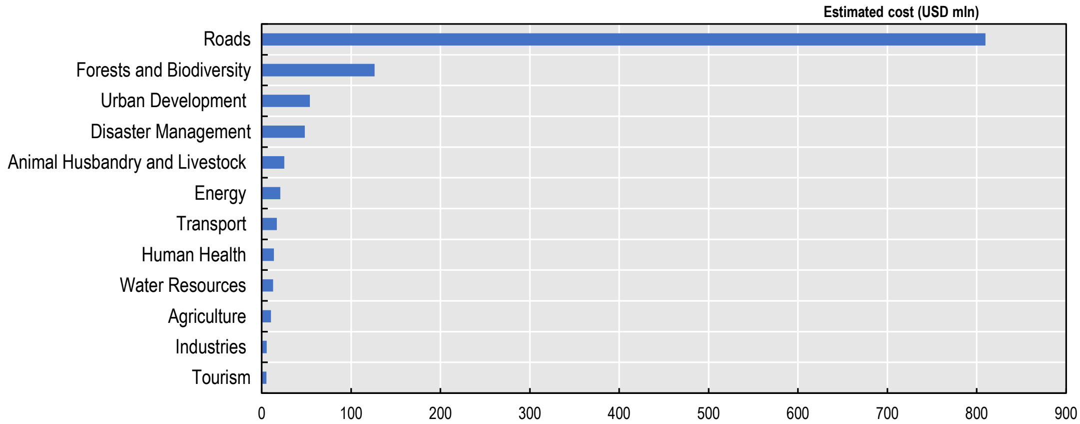
The state estimated the cost of implementing the UAPCC to be USD 1.2 billion (INR 88.3 billion) over five years, based on individual sector-level strategies (Government of Uttarakhand, 2014[143]). As shown in

[12] The version as of July 2020.

Figure 2.3, the estimated costs included both climate mitigation and adaptation activities such as road construction (USD 810 million), purchase of new buses (USD 15.6 million), and renewable energy and energy efficiency measures (USD 29.6 million). Among sectors that are more relevant to climate resilience, relatively large cost levels are estimated for sustainable management of forests and biodiversity conservation, as well as disaster risk management. On the other hand, the estimated costs of water resource management, agriculture and tourism are relatively small. There seems to be no publicly available information on monitoring or evaluation of public expenditures for activities determined and costed under the UAPCC.

These circumstances suggest the state government is well aware of the importance of mainstreaming climate resilience considerations in its development plans. It could be valuable to measure climate-related public expenditures at the state level by building on, for instance, periodical analyses of the state government budget by the Department of Planning. Information from such exercises could be used to evaluate the effectiveness of public expenditure for climate resilience under the UAPCC.

Figure 2.3. Estimated cost of implementation of UAPCC, 2014-2019



Note: Estimated based on the exchange rate: INR 1 = USD 0.013
Source: Authors based on Government of Uttarakhand (2014[143]), *Uttarakhand Action Plan on Climate Change*, www.forest.uk.gov.in/files/USAPCC/Uttarakhand_SAPCC.pdf.

Activities set out under UAPCC are to be implemented through relevant sectoral budgets. Funding is complemented by programmes funded by the central government's budget transfer (Government of Uttarakhand, 2014[143]). Sectoral departments often do not have adequate funding dedicated to climate resilience. Nor do they always understand how their sector development plans and programmes can integrate climate aspects (Dinshaw et al., 2019[30]). Many state departments have often used funding available through support schemes run by the central government in support of the National Missions under the NAPCC (Dinshaw et al., 2019[30]). This funding is not sufficient to cover the needs of all Indian states. India set up the National Adaptation Fund on Climate Change (NAFCC) to support adaptation to climate change, implemented by the National Bank for Agriculture and Rural Development. According to the NAFCC's website, INR 8.5 billion (USD 110.2 million) has been committed or disbursed, of which about half has targeted climate resilience in the Indian Himalayan region. To date, the database on the NAFCC website indicates no project supported in Uttarakhand (NABARD, n.d.[188]). This may have been due to a lack of project proposals by the state with sufficient quality to meet the selection criteria.

Both the state government and its development co-operation providers have been working on disaster risk financing to enhance the state's financial resilience to the negative impacts of disaster risks. Uttarakhand has a dedicated budget line to "Relief on calamities" that aims to provide flood relief, drought relief and relief work on other disasters (Government of Uttarakhand, 2019[187]). The State Disaster Response Fund (SDRF), constituted under India's Disaster Management Act (2005), is the primary fund available for state governments to respond to impacts of disasters. The central government contributes 90% of SDRF allocation for Uttarakhand and a few other special category states. SDRF aims to enable the provision of immediate relief to victims in the wake of disasters. These include climate-related disasters, such as cyclones, droughts, forest fires, avalanches and floods including glacial lake outburst floods (Government of India, 2020[189]). In addition, the National Disaster Response Fund supplements SDRF in case of "a disaster of severe nature", provided that financial need for the response exceeds the funding available within SDRF (Government of India, 2020[189]).

Several arrangements aim to ensure PES in the Hindu Kush Himalayan region. For instance, the Green India Mission provides funds at national level to encourage communities to participate in ecosystem restoration or afforestation of indigenous plants such as sea-buckthorn (Dutt Bhatta, 2018[190]; Government of India, 2014[191]). Such programmes aim to channel financial and non-financial benefits to the communities supporting various ecosystem services. There is also potential to develop or enhance a PES programme in Uttarakhand. This could offer financial support to local communities in the upstream water sources, compensating for ecological restoration in mountain ecosystems (Dutt Bhatta, 2018[190]).

National development banks and commercial financial institutions

National development banks, such as the National Bank for Agriculture and Rural Development, provide tailored financing to businesses, including small farmers. These development banks also collaborate with commercial banks and microfinance organisations to provide credits to farmers in hill villages. Some of the offered lending programmes target farmers who want to, for instance, commercialise, modernise and diversify their agricultural practices in response to changing market demands and the impacts of climate change (NABARD, n.d.[188])

Most farmers in mountainous areas of Uttarakhand, who have low risk tolerance, produce food grains that depend largely on rain and are sufficient only for three to six months of their family requirements (Rawat et al., 2020[192]). Accessing agriculture credits to enhance the productivity can therefore support their financial resilience to climate and disaster risks. Access of farmers to formal credits, however, remains a challenge. Research shows that many farmers in Uttarakhand do not come forward to borrow from financial institutions. Even when farmers do take loans, they are in many cases not in adequate volume, at the right time or at reasonable cost (Rawat et al., 2020[192]).

Farmers have received weather-based crop insurance for apple, litchi, mango, malt, peach, tomato, potato, pea, chilli and ginger (Government of Uttarakhand, 2020[193]). A private insurer has also implemented a pilot project on weather index-based insurance in Uttarakhand and Assam states (Wester et al., 2019[38]). However, recent studies in Uttarakhand show the number of insurance companies providing such crop insurance remains limited (Kandpal, 2020[194]).

While many households are interested in insurance and other formal financial services (e.g. credits), those which have actually bought such services remain limited to the ones living close to the market and roads. This is due, for instance, to geographical constraints faced by farmers in mountain villages and their limited awareness of related government support (Kandpal, 2020[194]). The state's ongoing effort for financial inclusion and financial education [under the Uttarakhand State Rural Livelihoods Mission (Government of Uttarakhand, 2020[195])] has great potential to improve vulnerable populations' access to finance and insurance. This could, in turn, contribute to their financial resilience to the impacts of climate change.

Bilateral and multilateral providers of development finance

Bilateral and multilateral providers of development co-operation have been supporting the state government and non-state actors to enable their action on climate resilience. Their financial support, technical assistance and advisory services play an important role in supporting implementation of the UAPCC (see also Table 2.4). Development co-operation providers also bring in international good practices, support knowledge management and networking, and foster inter-state and regional dialogues on climate change in the Himalayan region (Government of Uttarakhand, 2014[143]).

Building on the state-level vulnerability and risk assessment in 2016, development co-operation providers could help the state government to further reduce exposure and vulnerability of people and ecosystems to long-term climate hazards, in addition to imminent natural hazards.

Development co-operation has been supporting the state government in enhancing climate data and information in mountainous areas of Uttarakhand (See Box 2.5). Greater collaboration between the state government and development co-operation partners could facilitate further investment in enablers for long-term climate risk management. This could include financing for weather stations and other data-related infrastructure, capacity development activities at the sectoral level and implementation of policies that encourage disaster risk reduction.

Table 2.4. Examples of relevant activities supported by bilateral and multilateral development co-operation from 2010 to 2020

	Climate risk reduction activities	Policy and administrative management	Education, training and awareness on climate change	Climate scenarios and impact research
Cross-cutting (multi-sector)		Switzerland: Himalaya Climate Adaptation (mainstreaming and implementing national climate change adaptation policies)		Canada/UK: Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium
Agriculture, fisheries, forestry	Switzerland: Interventions on enhancing water use efficiency, and nutrition in mountains	Adaptation Fund: Climate-smart actions and strategies in northwestern Himalayan region	Switzerland: Climate Resilience of Forest-Dependent Communities in Uttarakhand	UK: Drought Assessment and Adaptive Resource Management
Disaster prevention and preparedness	GFDRR/World Bank: Uttarakhand Disaster Recovery Project (focus on early warning systems, post-disaster recovery plans) Switzerland: Development of a landslide early warning system	JICA/World Bank: Project on building codes	JICA: The Project for Natural Disaster Management in Forest Areas in Uttarakhand	UNDP project with State Disaster Management & Mitigation Centre
Water and sanitation	World Bank: Uttarakhand Water Supply Program for Peri Urban Areas Switzerland: Spring revival and management		Sweden: Water Rain-Him: Changes in Water resources and adaptation options in the Indian-Himalayan basins	Australia: Climate Change Adaptation Toolkit to help improve community resilience to climate change (rural watershed)
Health	World Bank Uttarakhand Health Systems Development Project			

Note 1: GFDRR = The Global Facility for Disaster Reduction and Recovery; JICA = Japan International Cooperation Agency; UK = United Kingdom; UNDP = United Nations Development Programme.
Note 2: Using the structure of Table 6 in Lamhauge, Lanzi and Agrawala (2012), "Monitoring and Evaluation for Adaptation: Lessons from Development Co-operation Agencies", *OECD Environment Working Papers*, No. 38, OECD Publishing, Paris, https://doi.org/10.1787/5kg20mj6c2bw-en.
Source: Authors' elaboration.

Box 2.5. Development co-operation role in enhancing climate data and information in mountainous areas of Uttarakhand

The Indian Himalayas Climate Adaptation Programme (IHCAP), supported by the Swiss Agency for Development and Cooperation, aims to enhance and connect the knowledge and capacities of research institutions, communities and decision makers to strengthen the resilience of vulnerable communities in the Indian Himalayan region. Its activities contribute to advancing knowledge about climate science, as well as to make it more accessible to the general public.

IHCAP has conducted extensive analytical work, including:

- *Climate Vulnerability Assessment for the Indian Himalayan Region using a Common Framework*
- *Comprehensive Report on Springs in the Indian Himalayan Region*
- *Manual on Adaptation to Climate Change in the Indian Himalayan Region.*

The manual provides comprehensive guidance for government to assess climate risk and facilitate integration of climate resilience aspects into the overall development process in Himalayan states, as well as their sector-specific policies (e.g. agriculture, water, forestry, health, urban, etc.).

As another example, the **Partnership for Resilience and Preparedness** platform by the World Resources Institute is a map-based, open-data online platform with climatic, physical and socio-economic data for climate resilience planning. As part of its global coverage, the platform has also been piloted in Uttarakhand. It provides map-based data on past and future annual precipitation change, flood hazard, water resource vulnerability and river drainage, among others topics (PREP, n.d.[196]).

2.4. Enablers for action on climate resilience in Uttarakhand

2.4.1. Data and information for enhanced climate resilience in Uttarakhand

Data and observations are an essential input to weather and climate information, as well as related scientific research. In 2011, the Indian Network for Climate Change Assessment conducted a regional assessment of the Indian Himalayan region. The UAPCC refers to the results of the assessment, such as past and projected increase in temperature and precipitation in the region (Government of Uttarakhand, 2014[143]; INCCA, 2010[197]). The State Department of Disaster Management monitors some climate parameters (e.g. meteorological information from weather stations, data on mass balance of glaciers), while the Uttarakhand Space Application Centre works on remote sensing (IHCAP, 2018[198]). The state's Disaster Mitigation and Management Centre assesses vulnerability and risk, as well as post-disaster needs. An observational network to monitor the health of the Himalayan ecosystem was created at the national level under the National Mission on Sustaining the Himalayan Ecosystem (Government of Uttarakhand, 2014[143]).

Several initiatives have been launched to improve the quality and availability of climate- and weather-related data and information in Uttarakhand and other Himalayan states. The **Himalayas Climate Change Portal**[13], for instance, provides a repository of data and information. It was established by the Department of Science and Technology, the Swiss Agency for Development and Cooperation, and a private company called the Development Alternatives Group, under the auspice of the National

[13] The portal can be accessed here: www.knowledgeportal-nmshe.in/.

Mission on Sustaining the Himalayan Ecosystem. The portal promotes interactions among research institutes, community-level organisations and other stakeholders (Government of India, n.d.[199]). The **Inter-University Consortium of Cryosphere and Climate Change** (IUCCCC) also co-ordinates research by Indian universities and provides capacity building and training to over 5 000 people (Government of India, 2020[159]). IUCCCC also aims to collect and exchange field-level data on climate and cryosphere changes, and to evaluate societal needs for and capabilities in adapting and responding to such changes (IUCCCC, n.d.[200]).

Several challenges remain to producing and communicating legitimate, granular and up-to-date data and information. For instance, the Himalayas Climate Change Portal has not been updated since 2015, while the latest reports on the IUCCCC website date to 2014. The UAPCC also points out broader challenges related to climate data and information. They include insufficient numbers of automatic weather stations and gauges to capture local variations in weather patterns; and lack of data for modelling. Underdeveloped skills of state government officials in using data for vulnerability assessments and to apply tools such as geographic information systems and remote sensing are also a challenge (Government of Uttarakhand, 2014[143]).

In addition to the state level, district- and village-level assessments of hazards, exposure and vulnerabilities will also be valuable for developing more context-specific actions. For instance, state government assistance after disasters may take days to arrive in remote regions of Uttarakhand. For districts and villages to respond quickly to disasters, they need to understand the risks locally, identify the riskiest areas and vulnerable communities, and prioritise and plan specific measures to prepare for disasters and long-term climate change.

Assessment of some types of hazards, such as risks of glacial lake outburst floods, cannot rely on historical data, or else tend to involve a greater level of uncertainty than other types. Under the National Mission on Himalayas Studies Programme, the Indian government commissioned a study on the hazards of glacial lake outburst floods and potential downstream impacts for four Himalayan states (Dubey and Goyal, 2020[201]). The study aims to enhance understanding of the locations of glacial lakes and risks of glacial lake outburst floods. It also examines types of events (e.g. avalanches, fallen rocks, extreme weather events and earthquakes) that could trigger a glacial lake outburst flood. Yet, there remains significant uncertainty concerning how these triggers are interlinked. Himachal Pradesh, another state in the Western Himalayas, conducted a state-wide large-scale assessment of hazards of glacial lake outburst floods. Its landscape-level modelling exercise quantified the potential likelihood of an outburst (hazard frequency) and potential downstream affected area (hazard magnitude) for each watershed, with results aggregated to the sub-district administrative unit (Allen et al., 2018[202]).

Combining scientific information with local and Indigenous knowledge in mountainous areas could inform climate risk assessments and help prioritise options to manage identified risks (Chunera et al., 2019[157]). Communities often have extensive knowledge about past disasters and emerging impacts of climate change, as well as their experience in coping with those shocks. One study examined 54 mountain villages in Uttarakhand from 2014 to 2016 to understand Indigenous knowledge, people’s perceptions on climate change and adaptation approaches (Maikhuri and Dhyani, n.d.[203]). Combined with such knowledge, a greater understanding of local resource endowments and household characteristics could provide valuable input to policy makers and practitioners for identifying social groups that require urgent support for building the resilience to climate and disaster risks, and who can spread good practices (Shukla et al., 2019[139]).

Selecting suitable measures to strengthen climate risks needs good understanding of climate risks and local vulnerabilities. This warrants continuous and greater efforts by the state government towards the generation and communication of such information (Mishra et al., 2019[44]). The state government and development co-operation partners should continue to collaborate effectively. The state government is also in a good position to further scale up such collaborative efforts. Based on studies, some examples of potential approaches could be the following (Mishra et al., 2019[44]; Ran et al., 2015[204]; Maikhuri and Dhyani, n.d.[203]):

- Enhance collaboration between the state government and relevant networks (e.g. the Indian Network for Climate Change Assessment, the IUCCCC, etc.) to extend training for officials of relevant state departments and local stakeholders in data collection, climate risk and vulnerability assessments and post-disaster needs assessment, among others.
- Develop and implement early warning systems for context-specific climatic hazards to enlarge the scope from response and recovery to preparedness for the impacts of disasters.
- Consider developing a portal where stakeholders can access state-level climate and weather-related data and information, or reinforce an existing knowledge platform, such as the Himalayas Climate Change Portal.
- Work with development co-operation partners to support relevant state agencies (e.g. the Forestry Department, the State Council for Science and Technology) and the private sector to scale up investment in data and information infrastructure and its operation and maintenance (e.g. rain gauges, automatic weather stations, early warning systems, modelling software, etc.) through financial and technical support.

2.4.2. Awareness and capacity enhancement on climate action in Uttarakhand

An assessment of capacity building needs in Uttarakhand has revealed the difficulties the state government and other stakeholders face in using weather- and climate-related information in policy making across sectors (water, disaster management, energy and forest) (IHCAP, 2018[198]; Wester et al., 2019[38]). The state government and development co-operation providers have supported various initiatives in support of capacity development and awareness raising related to climate resilience. For instance, the SDC and UNDP have provided support to strengthen capacities in the state for effective policy planning, implementation and monitoring under the UAPCC. Activities under this programme included interventions to mobilise relevant technical expertise, build capacity of resource persons and institutions, facilitate implementation of strategies, and share knowledge (IHCAP, 2018[198]).

Compounded by capacity gaps, the remoteness of mountain communities is another factor hindering access to information. Effective use of ICT can help bridge these gaps. Thousands of farmers in Uttarakhand, for instance, are already using a mobile-based climate and market services (Papnai, Prakash Upadhyay and Sunetha, 2015[205]). However, limited mobile connectivity and Internet literacy, as well as insufficient handholding support (e.g. customisation of systems for farmers), make it challenging to scale up these services (Wester et al., 2019[38]).

Organising extensive awareness-raising campaigns at district and village levels would be one way to improve awareness of and capacity for climate resilience. Such efforts could consider greater incorporation of issues on climate change and disaster risks into the educational curriculum, and active engagement of the media. Guidance documents, such as those of National Disaster Management Authorities on glacial lake outburst floods, contribute to awareness raising among state government officials and other stakeholders (NDMA, 2020[206]). Collecting information about people’s perceptions on climate risks and Indigenous knowledge about past weather events, and integrating such knowledge into available scientific and statistical information about climate risks, could also be effective.

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