

# 3 Mountain Systems and Climate Change

## Increasing Vulnerabilities

It is widely recognised that mountain regions include many of the world's most sensitive ecosystems. They are particularly vulnerable as a result of their high relief, steep slopes, shallow soils, adverse climatic conditions, and geological variability (Sonesson and Messerli 2002). Mountain ecosystems and people are subject to a variety of drivers of change including globalisation; economic policies; and increasing pressure on land and mountain resources due to economic growth and changes in population and lifestyle. Global climate change acts as an additional stressor which is expected to exacerbate the impacts of other drivers of change. Although we acknowledge the importance of these other drivers, and that their impacts on mountain social-ecological systems may currently be even more severe than those from climate change, it would go beyond the scope of this paper to analyse them in detail. In this context, we recognise further that the exact impacts of climate change on mountain systems, and the interlinkages with other drivers of change, are not yet well understood, and that there are large knowledge gaps which need to be addressed.

Regardless of the high degree of uncertainty, it is clear that the biophysical fragility of mountain ecosystems has direct consequences for the socioeconomic vulnerability of mountain people, estimated at 720 million or 12% of the world's total population. Nearly 90% of the mountain population – 663 million people – live in developing or transition countries (Huddleston and Ataman 2003); of these, half live in the Asia-Pacific region and one-third in China. Although 30% of all mountain people are urban, the vast majority live in rural settings (Hassan et al. 2005)<sup>1</sup>. Mountain areas are ethno-culturally very diverse, with a high diversity of languages and culture. The proportion of indigenous peoples is also high. These people often guard a vast body of traditional ecological knowledge on how to sustainably manage the land in a challenging mountain environment. Their traditional land management practices (e.g., trenching, terracing, and irrigation systems) are still crucial today for low-intensity production systems at high altitudes (UNEP-WCMC 2002).

Fragility and vulnerability to climate and other drivers of change, along with growing scarcity of freshwater and energy as a basis for economic growth, have created not only new challenges but also new opportunities and possibilities for mountain regions and mountain people. Examples for emerging opportunities include a growing demand for high-value mountain niche products, including tourism, in the lowlands; hydropower generation for local and possibly also regional use; payments for ecosystem services; and potential for carbon sequestration to name just a few.

## Biophysical Fragility

### Temperature

Mountain regions have experienced above-average warming in the 20th Century (IPCC 2007a,b), which has significant implications for mountain environments and environmental processes. In the Himalayas, for example, progressive warming at higher altitudes has been three times greater than the global average (Eriksson et al. 2009; Xu et al. 2009). Predictions for the 21st Century indicate that temperatures will continue to increase disproportionately in mountain areas. The greatest temperature rise under the four IPCC Special Reports on Emissions

<sup>1</sup> These numbers have been estimated using the UNEP-WCMC definition of mountains which categorises mountains into six classes, including areas starting from 300 m above sea level that exhibit steep slopes and have a wide range of elevation in a small area. All areas above 2,500 m are considered as mountains.

Scenarios (SRES) is expected in high- and medium-latitude mountains, including the high-latitude mountains of Asia, North America, and Europe and mid-latitude mountains of Asia. The high-latitude mountains of Asia are expected to experience the greatest changes in temperature, whereas tropical and mid-latitude mountains in Africa and South America are expected to warm less (Nogues-Bravo et al. 2006). The average warming projected in mountain areas across the globe by 2055 ranges from 2.1°C to 3.2°C, depending on the emissions scenario (Nogues-Bravo et al. 2006). This is two to three times greater than recorded during the 20th Century (Pepin and Seidl 2005).

## Cryosphere

The most noticeable impact of climate change in mountains is the recession of glaciers. According to a recent publication by United Nations Environment Programme (UNEP) and the World Glacier Monitoring Service (WGMS): “The ongoing trend of global and rapid, if not accelerating, glacier shrinkage on the century timescale is of non-periodic nature and may lead to the deglaciation of large parts of many mountain ranges in the coming decades” (UNEP WGMS 2008). In the European Alps, for example, the Alpine glacier cover is estimated to have diminished by about 35% between 1850 and the 1970s, and by a further 22% by 2000 (UNEP WGMS 2008). In the Canadian Rockies, glaciers lost at least 25% of their volume during the 20th Century (Luckman and Kavanagh 2000). In the Himalayas, glaciers appear to have receded relatively faster than the global average (Dyurgerov and Meier 2005). The rate of retreat for the Gangotri Glacier over the last three decades has been more than three times the rate during the preceding 200 years (Srivastava 2003). Most glaciers studied in Nepal are also undergoing rapid deglaciation (Seko et al. 1998; Kadota et al. 2000; Fujita et al. 2001; and others). In the last half century, 82.2% of the glaciers in western China have retreated (Liu et al. 2006; Kang et al. 2010). On the Tibetan Plateau, the glacial area has decreased by 4.5% over the last twenty years and by 7% over the last forty years (CNCCC 2007). One exception is the Karakorum, where some high altitude glaciers have been found to be advancing (Hewitt 2005). In South America, the Northern Patagonian Ice Field lost about 3.4% or 140 km<sup>2</sup> of its area between 1942 and 2001 and in Africa, 85% of the total ice volume of the plateau glaciers of Mount Kilimanjaro disappeared between 1912 and 2000 (Thompson et al. 2009). Other consistent trends are that the degradation of permafrost is accelerating, with the active layer becoming thicker due to surface warming, and that most snow and ice caps across the world are shrinking at increased rates. These alterations in the cryosphere are already leading to changes in land surface characteristics and drainage systems and are very likely to have significant repercussions on water availability for mountain and downstream communities (Stern et al. 2006).

## Hydrology

With global warming, it is likely that the hydrological cycle in mountain areas will intensify, changing the frequency and intensity of floods and droughts (Beniston 2005). The discharge regime may also change as a result of the expected shifts in the species composition of mountain ecosystems. Moreover, with continuing melting of glaciers and snow and ice cover, the supply of water to vast landmasses and billions of people may no longer be guaranteed, leading to severe water stress and potential conflicts. In Asia, for example, changes in perennial snow and glacial melt induced by climate change could affect half a billion people in the Himalayan region and a quarter of a billion people in China, who all depend to some extent on meltwater from the mountains for their water supply (Stern et al. 2006). Nevertheless, it should be recognised that as a result of the interlinkages between the climatic and non-climatic drivers influencing the world’s freshwater resources, as well as the high uncertainty regarding changes in precipitation patterns and other parameters influencing the hydrological cycle in mountains, it is extremely difficult to predict what changes will occur.

## Biodiversity

As a result of the steep terrain, the compression of climatic zones, and landscape fragmentation, mountain ecosystems are characterised by a high biological richness in terms of both species diversity and endemism (IPCC 2007a,b; Körner 2009). Mountain systems support about half of the world’s biological diversity and nearly half of

the world's biodiversity hotspots (Hassan et al. 2005). Of the world's total acreage of land-based protected areas, some 27.6% is situated in mountains (Kollmair et al. 2005). However, mountain species are very sensitive to climate warming because they are adapted to specific altitudinal zones and microclimatic conditions (Hassan et al. 2005, IPCC 2007a,b). With rising temperatures, upward shifts of vegetation belts to higher elevations and northward advances in the geographical ranges of species in the northern hemisphere are expected. Changes in the species composition of communities are also likely (Nogues-Bravo et al. 2006). These processes should not only be regarded as negative, however, they may also bring new opportunities. Because temperatures decrease with altitude, mountain species are in the privileged position of being able to migrate upwards into cooler areas, whereas lowland species usually have no other option than to adapt to higher temperatures which is much more difficult (Körner 2009). Thus, mountains can serve as refuges for species which can no longer be grown in the lowlands and which need to climb to cooler areas (Singh et al. 2010). However, some mountain species are likely to become losers. These include large territorial animals, late successional plant species, species with small, restricted populations, and species confined to summits (Körner 2009).

### Extreme events and natural hazards

Mountains are typically exposed to multiple hazards (Kohler and Maselli 2009). With climate change, it has been predicted that the frequency and magnitude of extreme events, including floods, windstorms, and droughts, will increase (IPCC 2007a,b). This is expected to have significant implications for fragile mountain ecosystems as well as for mountain livelihoods and infrastructure. For example, it is expected that the intensity of precipitation events will increase, especially in the tropics and at higher latitudes where an increase in overall precipitation is expected. More intensive precipitation events could trigger flash floods and landslides in mountainous terrain. Conversely, it has also been predicted that the risk of droughts in most subtropical and mid-latitude regions will be greater in the future. What is more, continuing glacier recession increases the danger of glacial lake outburst floods (GLOFs). In the Hindu Kush-Himalayan region, there are about 204 critical glacial lakes that have a potential for breaching (Ives et al. 2010).



Saptari district, Nepal





Kulekhani, Nepal



## Socioeconomic Vulnerability

### Determining factors of socioeconomic vulnerability to climate and other drivers of change

Mountain people and their livelihoods are particularly vulnerable to climate and other drivers of change (UNEP-WCMC 2002). The underlying causes of vulnerability include disproportionate poverty rates, high prevalence of food insecurity and poor health, high dependency on natural resources, marginalisation, and limited livelihood diversity. These factors, which are described in more detail below, are the driving forces of mountain people's vulnerability, and are expected to be further aggravated by climate change.

### Climate change and economic development

Experts believe that the impacts of climate change on economic development will be unevenly distributed around the globe (Sanderson and Islam 2009). The relationship between climate change and economic development depends on a particular region or country's extent of vulnerability to the impacts of climate change, as well as the opportunities the factors of change provide for policy actions towards alleviating climate change vulnerability, particularly through adaptation measures. Mountains, in general, are considered highly vulnerable, and knowledge about the impacts of climate change on economic development is lacking. However, to sustain and enable current economic development in the mountains, it will be crucial to address the issue of climate change and its relationship with economic development through adaptation measures. Climate change is threatening sustainable development, especially poverty alleviation, in the mountains since a single extreme event such as a flood can wipe out major livelihood resources such as standing crops, stored food and seeds, and fertile land. The mountain poor will face more serious impacts in future due to the likelihood of more and more frequent occurrences of extreme events, and their economic development prospects are increasingly facing risks.

### Poverty and marginalisation

In the developing world, mountain communities generally tend to suffer disproportionately from poverty and lower levels of development than those in lowland areas. The prevalence of poor and vulnerable people increases with elevation (Hassan et al. 2005, Huddleston and Ataman 2003). A recent study in Nepal has shown that poverty inequality between mountain communities and those living in other areas is currently increasing (ICIMOD 2010). Globalisation tends to further reinforce differences between highlands and lowlands (Royal Swedish Academy of Sciences 2002). Mountain poverty has to be understood in the light of several mountain-specific constraints which intensify the prevalence of poverty. These include fragility of ecosystems; remoteness; poor accessibility and marginalisation of mountain communities from the mainstream; lack of equity in terms of access to basic facilities such as health care, education, and physical infrastructure, as well as to markets, political power, and representation; lack of employment opportunities; and proneness to natural disasters (Jodha 1992; ICIMOD 2010). In this context, climate change acts as another stressor which may limit the capacity of mountain communities to cope or adapt to new and often more stringent environmental conditions. Climate change may thus further increase existing inequalities between highland and lowland communities.

### Nutrition and health

Mountain people are highly susceptible to food insecurity. Around 40% of mountain people living in developing and transition countries have been estimated to be vulnerable to food insecurity; of these, about half are likely to be chronically hungry<sup>2</sup> (Huddleston and Ataman 2003). Malnutrition is also prevalent among mountain people, who often lack a balanced diet providing sufficient micronutrients. Furthermore, respiratory infections exacerbated by harsh climate and exposure to smoke from heating and cooking are common among mountain people (Huddleston and Ataman 2003). Maternal and infant mortality rates are also above average for mountain populations due to limited access to

<sup>2</sup> For these estimates, two indicators have been used to measure vulnerability: one looking at the proportion of people living in areas where cereal production does not exceed 200 kg per person, and one focusing on low to medium bovine density.

primary health-care and sanitation facilities, as well as food deficiencies (FAO 2008). Food insecurity could grow more acute with climate change, and the health status of mountain people – especially those with low adaptive capacity such as the elderly, children, pregnant women, and the chronically sick – may worsen. Crop failure as a result of water shortages and more frequent natural disasters, and the spread of crop and livestock pests and vector-borne diseases to higher altitudes with rising temperatures may further challenge the wellbeing of mountain communities.

## Natural resource dependency

Overall, 78% of the land surface in the world's mountain areas has been classified by the FAO as not suitable or only marginally suitable for agriculture. Nevertheless, the vast majority of rural mountain people engage in some form of agricultural activity and are thus highly dependent on natural resources (Huddleston and Ataman 2003). Intensive mixed farming systems are the most common form of agriculture at lower altitudes in the highlands. However, due to environmental constraints such as unfavourable climatic conditions, poor-quality or shallow soils, and sloping terrain, productivity is generally low and harvest output is not competitive in the global market (Huddleston and Ataman 2003). At higher altitudes, where mountain environments are harsh and suitability for agriculture is restricted, pastoralism is the most common livelihood strategy. Pastoral systems, however, are becoming increasingly vulnerable due to population growth and the resulting increasing pressures on the land, the impacts of more frequent and severe droughts, and the breakdown of traditional trade routes and patterns of exchange (Huddleston and Ataman 2003). Climate change may further reduce the competitiveness of agriculture-based mountain livelihood systems, although it may also provide new opportunities such as longer growing seasons for certain crops or the possibility of growing crops at higher altitudes. This, however, may again result in increased pressure on already stressed fragile landscapes.

## Changing livelihood options

The livelihood options of mountain communities besides agriculture are often restricted, mainly due to the poor accessibility of the areas in which they live. However, there are new opportunities emerging which may gain in importance as alternative livelihood strategies in the future.

Tourism is a major livelihood strategy in mountain areas in both the developed and the developing world. Especially in the developing world, tourism is a major source of foreign exchange and is one of the few factors that stabilises mountain populations and deters people from migrating. Like agriculture, the tourism industry is highly sensitive to changes in environmental conditions. It depends on pristine landscapes, high biological diversity, and well-managed protected areas, which serve as important tourist destinations, and, in the case of winter tourism, on reliable snow cover. Temperature rises as a result of climate change, and the increase of extreme events, already challenge the tourism industry in developing and developed countries. Over the past years, winter resorts in the developed world have made heavy investments into adapting to higher temperatures, and it is expected that in the future particularly those situated at lower altitudes will no longer be competitive (IPCC 2007a,b). On the other hand, with rising temperatures, cool mountain resorts in the subtropics and tropics may increase in popularity and provide important new livelihood options as summer destinations for people who wish to escape the heat in the lowlands.

Out-migration, especially of young household members, has also become a vital livelihood strategy which reduces the dependence of mountain communities on natural resources. Migration provides important connections between upland and lowland areas, and financial as well as social remittances are becoming increasingly important for the development of mountain areas (Hoermann and Kollmair 2009). However, migration can place significant burdens on those left behind, especially women, children, and the elderly (Hoermann et al. 2010). With increasing environmental stress, the number of migrants may increase. Yet there is great uncertainty regarding the numbers of expected environmental migrants both from and to mountain regions (Guzman et al. 2010). The current phenomenon of migration of upland populations to lowland plains and urban centres is a manifestation of the existence of unequal economic opportunities and access to services between mountains and plains. Poor rural households always seek better livelihood opportunities. It can very well be argued that if we can create more economic opportunities in the mountains, the current migration pattern can be changed.

## Upstream-downstream Linkages: Mountains are Vital Providers of Resources and Services

Mountains support many different ecosystems and provide key resources and services for human activities well beyond their natural boundaries (Beniston 2005). Whereas most of the goods and services provided by mountains have their origin in the headwaters, the consumers of these goods and services are mostly in the lowlands. Highland and lowland systems are thus highly interdependent in terms of ecology and economy as well as in social and political terms. Mountain communities with their traditional ecological knowledge contribute significantly to the quality and the sustainable management of these goods and services. However, they are rarely compensated fairly for the services they provide to downstream communities. The goods and services provided by mountain ecosystems can be divided into three major groups: provisioning services; regulating and supporting services; and cultural services (Hassan et al. 2005; UNEP WCMC 2002).

### Provisioning services: Water as a key resource

Probably the most important good provided by mountains is water. Mountains are often referred to as ‘water towers’ for the world’s lowlands (Viviroli 2007; UNEP-WCMC 2002). Mountains store a vast amount of water in glaciers, snow, and ice; as well as in soil, groundwater, and lakes. Almost all the world’s major rivers, as well as many minor ones, originate in mountains (Messerli and Ives 1997) and, according to Viviroli et al. (2007), over 50% of the Earth’s mountain areas are vital for supplying water to adjacent lowlands for drinking and agriculture, to generate electricity, and for industry.

Besides water, mountains feature high biological and agricultural diversity including food, fibre, and medicinal plants. Many important crops (e.g., maize, potatoes, barley, sorghum, tomatoes, and apples) and domestic

mammals (e.g., sheep, goats, domestic yak, llama, and alpaca) originated in mountain areas (UNEP-WCMC 2002). High-value mountain products such as medicinal plants and nutraceuticals, precious fibres such as cashmere or alpaca wool, and mountain-specific crops are in great demand in downstream and global markets. Mountain forests provide timber, fuel, forage, and non-timber forest products for mountain and downstream economies. Thus the genetic diversity remaining in mountains represents an important resource in a changing world with a growing population.



### Regulating and supporting services

Apart from providing important resources to mountain and downstream communities, mountain ecosystems are of vital importance for maintaining and supporting a healthy and safe environment and climate. For example, they play a vital role in water purification and water retention in the form of groundwater, ice, and snow, as well as in lakes and streams. Mountain ranges are also responsible for atmospheric and climate regulation, modulating the climate well beyond their geographical boundaries. Mountain soils are important storage reservoirs for water and

carbon as well as nutrients for soil fertility. Mountain forests (28% of the world's forests are situated in mountains) are highly relevant for protection against natural hazards, ensuring slope stability and preventing or reducing erosion, landslides, and avalanches. Moreover, mountain forests, especially in the tropics, have high genetic diversity and serve as wildlife habitats. Together with highland wetlands, mountain forests play a significant role in biospheric carbon storage (IPCC 2007a,b).

## Cultural and recreational services

Mountain areas are home to a high diversity of cultures. Until now, many of these cultures have maintained a rich traditional agricultural knowledge that commonly promotes sustainable production systems. These lifestyles are severely threatened, however (Sonesson and Messerli 2002). For many of these cultures, mountains play an important spiritual role: they are living forces, sources of power, and symbols of the sacred (Bernbaum 1997). In addition, as mentioned above, mountains and many aspects of their people's cultures are attractive for tourism as well as for many recreational activities.

## Implications of Environmental Change for Mountain and Downstream Communities

As a result of the strong highland-lowland linkages, particularly the fact that mountain ecosystem provisioning services mainly benefit lowland populations (Hassan et al. 2005), the consequences of unsustainable management of mountain resources, and the impacts of climate change on mountain ecosystem goods and services, reach far beyond mountain areas. What is more, due to the high fragility of mountain systems, their ecosystems take longer to regenerate from environmental stress than lowland ecosystems and can more easily deteriorate irreversibly.

The weakening of mountain ecosystem services due to climate change and other drivers of change will affect the lives and livelihoods of hundreds of millions of people in mountains and a much higher number in downstream communities (Viviroli et al. 2003). This is particularly true in the case of water. It has been estimated that the reduction of water supplies during the dry season associated with increasing glacier retreat and loss of mountain snow will affect up to one-sixth of the world's population (over one billion people), predominantly in the Indian sub-continent, parts of China (over a quarter of a billion people), and the Andes (up to 50 million people) (Stern et al. 2006). In the Hindu Kush-Himalayan region, seven of Asia's largest rivers are fed by meltwater from mountain glaciers. The Ganges alone provides water to about 500 million people (Stern et al. 2006).

Decreasing flows of water from mountains will be inextricably linked to a decline in agricultural productivity, with serious implications for the food security of mountain and downstream communities. Increasing water stress could lead to conflicts, especially in arid and semi-arid areas which are highly dependent on mountain water. Furthermore, with increasing water shortages, water quality may decline and the risk of spread of water-borne diseases may increase. Similarly, increases in air temperature have been linked to the expansion of diseases such as malaria to higher altitudes in both Africa and Latin America.

## Mountain Systems as Global Early Warning Systems

Mountain systems, particularly the cryosphere, serve as important early warning systems for global climate change impacts. Because of their high sensitivity, environmental changes become visible earlier or are more pronounced in mountains than in the lowlands. Data on higher temperatures in mountains resulting from increasing concentrations of greenhouse gases and aerosols in the atmosphere – for example as a result of the impact of black carbon and the brown cloud over Asia on the Himalayas (Ramanathan et al. 2007) – could help in understanding changes in climate parameters and assessing the efficiency of global mitigation efforts. In terms of biodiversity, mountains offer an early biological indication of change (Körner 2009). Reducing the knowledge gaps with regard to changes of different climatic parameters in mountain systems will thus help the international community to understand better global climate change and the consequences of the associated changes.





Thimphu, Bhutan