Mountains at risk

JOHANN STÖTTER & MATTHIAS MONREAL

"Mountains are highly vulnerable to human and natural ecological imbalance. Mountains are the areas most sensitive to all climatic changes in the atmosphere." (AGENDA 21)

Introduction

Mountains certainly are much more prone to risks than most other regions in the world. At a first glance, images of flooded valley bottoms, destroyed houses, eroded roads or cut off villages may come into mind. These risks related to natural hazard processes, e. g. rock fall, debris flows, avalanches or floods, have been part of the specific human-environment system in mountains regions ever since settlement and intensive utilization of land began. In this sense, they were perceived as part and parcel of the mountain environment (in the sense of a base disposition), infrequently topped by extreme events with the character of an existential threat (in the sense of a variable disposition). By learning to cope with these challenges throughout centuries, mountain societies have adapted to the specific natural hazard conditions of their local environments.

In addition to these locally or regionally controlled interrelationships, nowadays global driving forces impact on human-environment systems in general, i. e. (i) global climate change, (ii) globalization and (iii) scarcity of resources. While the regional variations of climate change processes alter natural process dynamics, globalization processes cause new demographic, cultural, social and economic structures. As a consequence, a trend of new forcings overrides both base and variable disposition, resulting in new dimensions of challenges to mountain societies never experienced before.

This story is more than a tale of minor relevance in a naturally extreme environment. A fifth of the terrestrial surface is classified as mountains and roughly 12% of the world population live in mountain areas. Moreover, these changing conditions affect nearly half of the inhabitants of the adjacent medium- and lower-watershed areas as they depend highly on mountain-bound resources in one way or another.

Ecosystem services, primarily water, hydropower, flood control and tourism, exceed the geographic limits of highlands through direct linkage with adjacent lowlands in catchments systems and the global demand for the extractive resources of mountains, such as timber and minerals (e. g. Viviroli & Weingartner 2004).

Traditional risk concept

In order to address the linkage between natural hazard impact and exposed human systems and the intrinsic uncertainty of all future developments, the idea of risk provides a conceptual framework with a high integration potential (e. g. Bohle & Glade 2008). In most risk concepts, the sensitivity of the reacting system to the external impulse is determined by vulnerability and capacity or resilience, which, as interacting and linking factors, govern the dimension of risk and as a consequence the adaptability of the human-environment system.

Originally expressing the sensitivity of organisms to external impact in ecological systems, vulnerability can go much further. In an (under)development context, vulnerability explains the degree to which an exposed social system is susceptible to harm from perturbation or stress as well as the ability or inability to cope, recover, or fundamentally adapt (see Chambers 1989). In the study of the interface between natural hazards and human systems (Wisner et al. 2004), many approaches deal with dimensioning vulnerability to specific process magnitudes (Hollenstein et al. 2002). In the context of global / regional warming, vulnerability may be understood as the degree to which a human-environment system is susceptible to, or unable to cope with, adverse effects of changing climatic conditions (see e. g. Füssel & Klein 2006). Like vulnerability, the general idea of resilience, the ability of a system to withstand a shock impact and to rebuild itself, has been adopted by different disciplines. Considerable insights have evolved since it was first brought into discussion by Holling (1973).

In natural systems, resilience stands for the capacity to tolerate disturbances without collapsing into a new

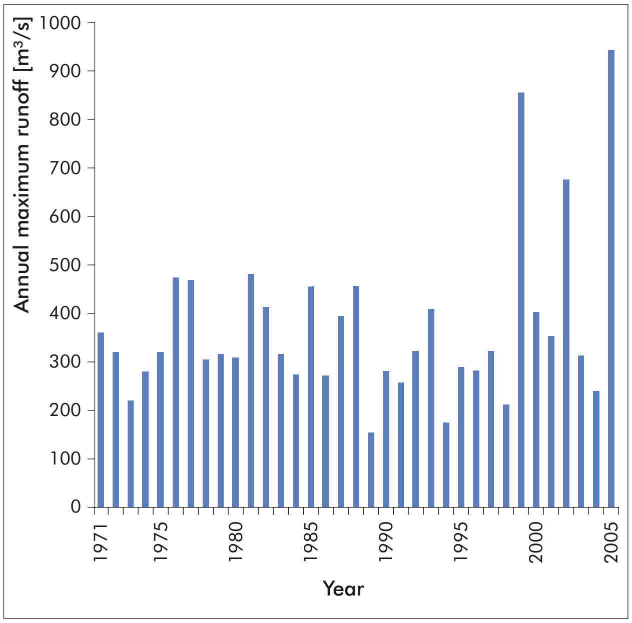

Fig. 1: Runoff record of the river Lech, indicating increased likelihood of extreme events. Source: Christian Dobler, © Institute of Geography, University of Innsbruck.

Fig. 2: Increasing damages due to both extreme runoff and high accumulation of values (Paznaun valley, summer 2005). Photograph by ASI Landeck, © Institute of Geography, University of Innsbruck.

state where the system is controlled by a different set of conditions (Diamond 2005). In the context of social systems, resilience lies predominantly in the added capacity of individuals to anticipate and to plan for the future (Watts & Bohle 1993). In modern interpretations, the concept of resilience is applied to social-ecological systems.

Both vulnerability and resilience have a dynamic character as they are subject to temporal and spatial changes within the relationships between forcing and reacting systems (see Bohle & Glade 2008) and are thus key prerequisites for understanding the adaptation attempts of human-environment systems.

Risks related to natural hazards

In Central Europe in general and in the Alps in particular, a surprising clustering of extreme runoff events with a recurrence probability of one in one hundred years and less is evidence that the frequency-magnitude relationship of natural hazard processes triggered by hydrometeorological drivers has undergone a marked change (first noted by Bader & Kunz 1998). The analysis of floods since the 1990s shows i) runoff maxima exceeding all measured records, and ii) a coupling of two or even three extreme flood events in independent river systems within a short period of time which is statistically highly unlikely (see Stötter et al. 2009). Most prominent examples are the floods of both Bregenzer Ache and Lech in the years 1999, 2002 and 2005 (Fig. 1). The statistical probability of such an accumulation of extremes of approximately 1 : 30 000 highlights how unlikely and thus how significant these events were.

These events may be seen as a clear indicator for a trend towards a more intensive precipitation-runoff relationship as a consequence of global / regional warming. Recent modelling of future scenarios supports the idea that seasonally differentiated warming with maxima from May to August and from November to February and a marked increase of mean precipitation in the winter season will cause new patterns of the frequency-magnitude relationships. This new trend is further supported by the fact that higher winter temperatures will cause a dramatic rise of the snow line, which means that a much higher portion of winter precipitation will fall as rain (see Beniston 2003).

As major consequences within in Alpine human-environment systems, this development of precipitation-runoff relationships means a major threat to the natural hazard management system. As this is based on the acceptance of defined protection limits (goals) and remaining risks, it does only provide measures against e.g. floods, which have so far been understood as 100 year events but may now and in future be expected to occur more frequently. The extreme socio-economic changes since the mid 20th century, resulting in population growth and rapidly increasing numbers of dwellings and other values further contribute to this new challenge (Fig 2).

Risks related to global climate change – global change

In the Fourth Assessment Report, the Intergovernmental Panel Climate Change (IPCC) stated that most of the observed global warming over the last 50 years has *very likely* (probability >90 to 99%) been caused by greenhouse gas forcing, while it is cited to be *very unlikely* (probability 1 to 10%) that it is due to known natural external causes alone (Solomon et al. 2007). These findings have fundamentally altered the perception of climate change and led to a worldwide acceptance that global warming and dependant changes of other climate elements as well as multiple effects on nature and society are no longer disputable – they have become a fact. Prior to the World Climate Conference held in Copenhagen in December 2009, a group of IPCC authors highlighted that in recent years multiple evidence has been produced for even more drastic warming in the 21st century (Copenhagen Diagnosis, see Allison et al. 2009).

Due to the complex topography as well as specific and spatially intensive variability of human-environmental subsystems, mountains tend to become regions disproportionally affected by global climate change (see e.g. Becker & Bugmann 2001). In some mountain areas, it can be shown that warming trends and anomalies are elevation dependent, where increasing temperature has a steeper positive gradient at higher altitudes (e.g. in the Alps, see Böhm 2009)

The impact of intensified climate change on the natural mountain environment has become especially apparent in the shrinking water storages of the cryosphere, i.e. snow and ice cover (see e.g. UNEP & WGMS 2008). As these are key components of the hydrological cycle, this development causes further radical changes in the seasonal character (regimes) and amount of runoff of mountains and adjacent lowlands (see e.g. Viviroli et al. 2007). In fact, mountains are the source for 50% of the world's rivers (Beniston 2003). The Hindu Kush Himalayas alone feed the Indus, Ganges, Brahmaputra, Irrawaddy, Salween, Mekong, Tarim, Yangtse and Yellow River, the Alps supply the Rhine, Po, Rhône and Danube tributaries. Mountains are i) water pumps, which extract moisture from the atmosphere through the orographic uplift of air masses and ii) water towers due to their water storage capacities in glaciers, permafrost, snow, soil and groundwater. Much of the inter- and intra-annual variation of discharge is compensated by discharges from mountains. In semi-arid areas, mountain discharge accounts for 50–90%, in extreme cases (e.g. Nile, Colorado, Rio Negro) for more than 95% of the total river discharge (Viviroli et al. 2007). Roughly 23% of China's 1.3 billion people depend on glacier discharge from the Himalayas (UNEP & WGMS 2008). The Alps supply a significant proportion of fresh water for the population of Europe (Braun et al. 2000) to be used as freshwater, irrigation and hydropower.

As much of the cryosphere stays at a temperature close to 0 °C, mountain regions are highly sensitive indicators of climate change. This is manifest from the loss of 7000 km² of mountain glaciers within the last four decades of the 20th century (Fig. 3). The surface area of European glaciers decreased by 30–40% during the 20th century (Haeberli & Beniston 1998) and a further 30–50% of glacier mass may be lost by 2100 (Maisch et al. 1999). These changes in the cryosphere will have significant repercussions in the hydrological cycle and alter the availability of water and the seasonality of run-off regimes (Ellenrieder et al. 2004). After a period of increased discharge due to melting, the compensatory discharge of meltwater will wane as glaciers disappear. Coupled with changing seasonality of precipitation, with less rainfall in summer and more liquid precipitation in winter, this may lead to severe water shortage as a result of exhausted water stores (Bates et al. 2008). The cryosphere and the related hydrological cycle in mountain regions are most severely affected by the impacts of a warmer climate and feedbacks are transferred to other resource areas, i. e. hydropower.

The extreme summer of 2003 (see Schär et al. 2004) may give us a glimpse of potential future consequences of regional warming for mountain water cycles. Under extremely dry conditions, meltwater runoff from Alpine glaciers could hardly compensate the water deficit in the foreland river systems, e. g. the upper Danube, where it caused the lowest recorded water levels for more than a century, with multiple economic losses due to very limited river trade or reduced production of electricity at hydropower plants along the Danube and its tributaries.

At the end of this century (2071–2100), about every second summer could be as warm and as dry as the summer of 2003 or even warmer and drier (Schär et al. 2004). Therefore, periods of minimum discharge like in 2003 are expected to become more frequent (see e. g. Mauser et al. 2008). As glacial and snow meltwaters will no longer compensate the missing precipitation, it is very likely that the consequences will be more serious than in 2003. Comparable warming trends with obvious repercussions for winter tourism can be expected even under the assumption of moderate emission scenarios (e. g. IPCC A1B), as illustrated in Figure 3.

Apart from this specific reaction to global climate change impacts, it is the unique spatial situation of mountain areas' natural, i. e. meteorological, hydrological, vegetation, geomorphological conditions that will change dramatically over relatively short distances. Consequently, boundaries between these systems will experience drastic shifts due to climate warming or changing precipitation. These extraordinary spatial variations of environmental resources mean a severe challenge to societies in mountain areas. The limited utilizable space there rather restricts the alternatives to the specialized economic situation.

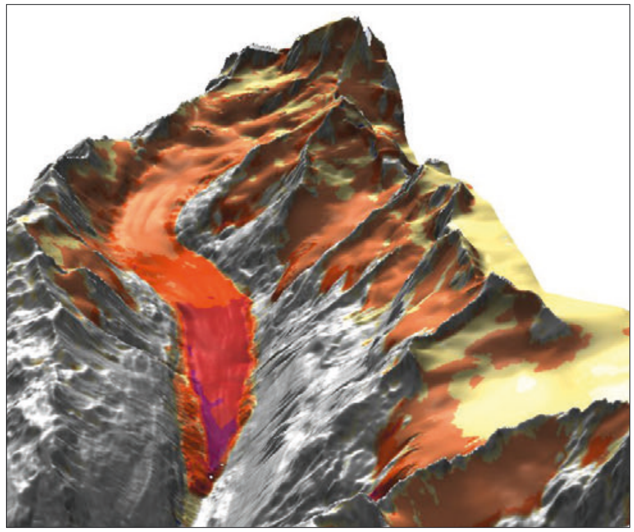

Fig. 3: Extreme losses (dark red) in mass during summer 2003 at Hintereisferner, Ötztal Alps. Source: Rudolf Sailer, © Institute of Geography, University of Innsbruck.

Although there is a common pattern of global climate change challenges to mountain areas worldwide (e. g. melting cryosphere, increase of natural hazards), it must be stressed that due to their positions in the global circulation system and the specific stages of development, vulnerability and resilience / coping capacities vary greatly from one mountain region to another.

Since the 19th century, mountain regions have become attractive destinations for tourism and recreation. Today, both play a key role in mountain economies. International tourism has increased 25-fold in the second half of the 20th century and mountain regions take an increasing share of possible destinations (Beniston 2003). In fact, with 336–370 million overnight stays, i. e. 11% worldwide, the Alps are the number one tourist destination in Europe (Bätzing 2003).

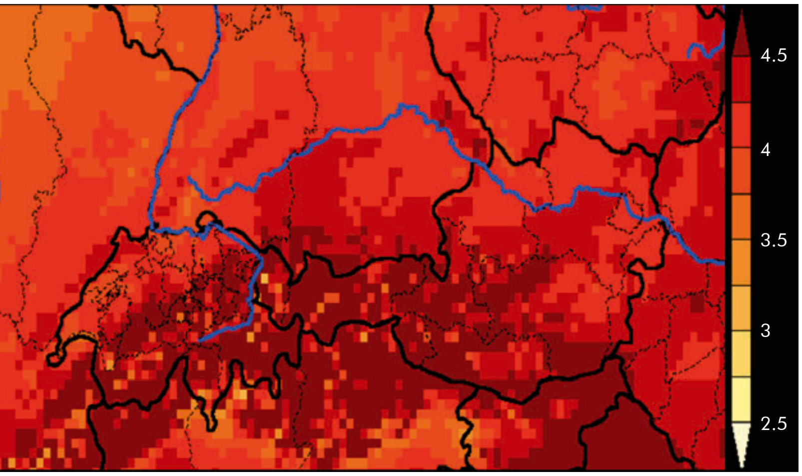

Fig. 4: Scenario (A1B) of winter temperature, comparison of the period 2071/2100 with 1961/1990 – note the alpine arc, clearly rendered by the extreme temperature changes expected for mountain regions (modified after Jacob 2008). White = small change; dark red = severe change.

Towards an open risk concept

Risk research provides the conceptual framework for investigating uncertain impacts of global climate change on environment and society on regional and local scales, regardless of whether they be negative or positive. As a consequence, risk has to be understood as an indicator for an open and uncertain future bearing options for both positive and negative outcomes. Thus, the often negatively connoted concept of risk is superseded by a neutral understanding allowing for both good risk, i. e. an opportunity to be grasped, and bad risk in the classical sense of a negative option to be avoided (Stötter & Coy 2008). Since risk analysis helps to understand the likelihood of occurrence as well as the magnitude of an anticipated impact, it constitutes the primary decision-making tool for development and deployment of adequate adaptation measures as highlighted in the research concept of the alpS – Centre for Climate Change Adaptation Technologies.

There may be many different attitudes towards risk, but common to all definitions are the core aspects of: i) future-orientation, and ii) uncertainty. In global change research, risk has to be understood as an open and uncertain future bearing options for both positive and negative outcomes, interpreted as good risk and bad risk (Stötter & Coy 2008).

All future climate change driven developments of human-environment systems in mountain regions may generally be understood as pointing in one of two directions, which mean either an improvement or a deterioration of the accustomed situation. Consequently, all adaptation activities have to aim in both directions, either to mitigate specific harm or to exploit beneficial opportunities, corresponding to the principle idea of minimizing bad risks and optimizing good risks.

Due to the spatially varying character of effects of climate change, all adaptation activities, no matter if they have anticipatory, autonomous or planned character, have to be especially designed to respond to climate change impacts by meeting the demands of sustainability objectives at local or regional level. In this sense, it must be a primary aim to develop solutions that make it possible to retain the present quality of life largely unchanged and / or to develop living conditions in areas with current development deficits further. Again, we must distinguish good from bad risks in order to be able to define needs and development goals that will meet the normative standards of sustainability.

“There is, however, a lack of knowledge of mountain ecosystems. The creation of a global mountain database is therefore vital for launching programmes that contribute to the sustainable development of mountain ecosystems.” (AGENDA 21)

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