Daniel Viviroli, Bruno Messerli,
Bruno Schädler, Rolf Weingartner
Institute of Geography, University of Bern
Switzerland

# Water Towers in a Changing World

## Mountain waters, a key resource for development

Mountains are the water towers of the world. They provide freshwater to half of the world's population for irrigation, industry, domestic use and hydropower. But mountains are also among the regions most sensitive to climate change.

Lake Ladtjojaure, Sweden (D. Viviroli)

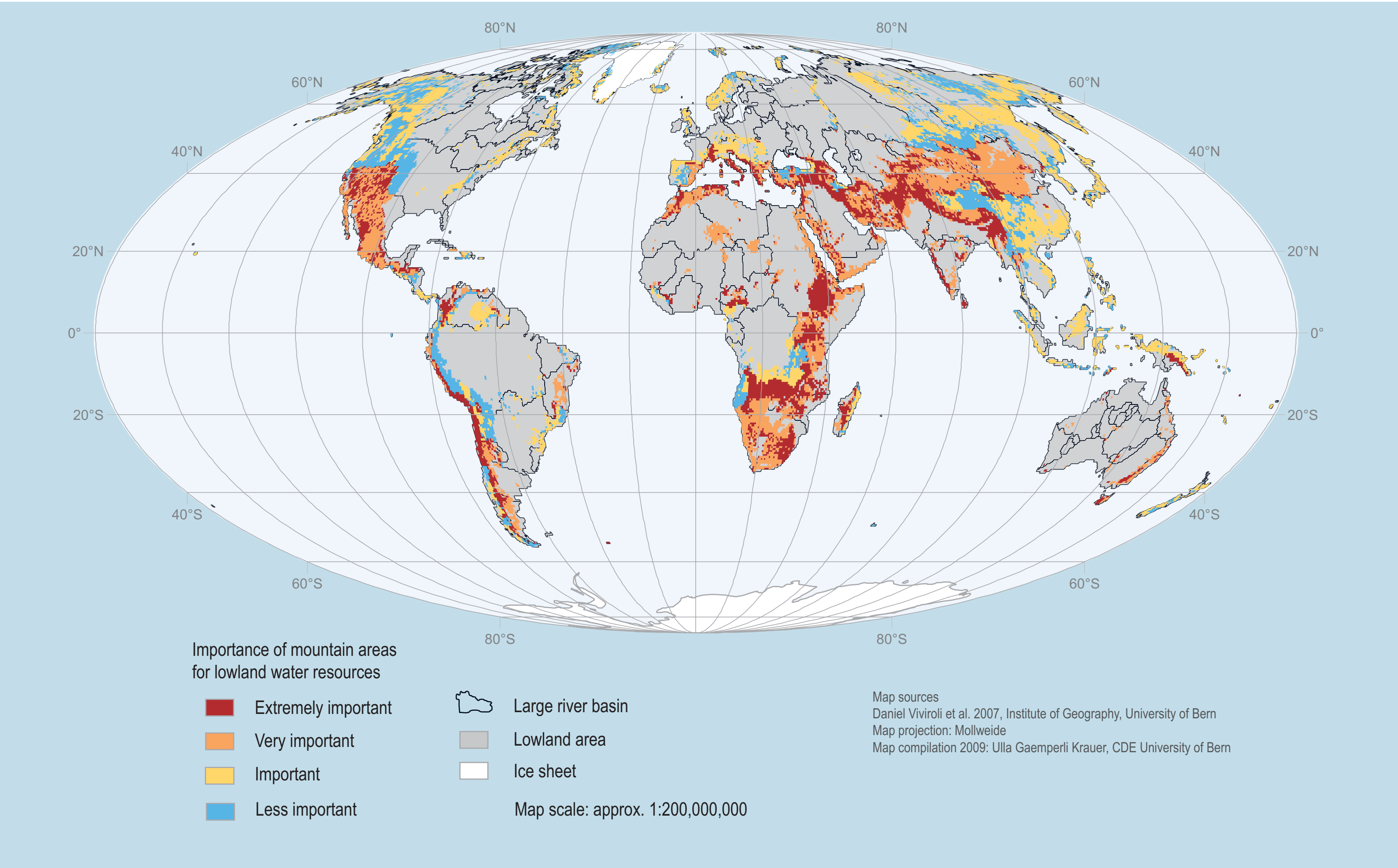
Global assessments of mountain water resources are challenging owing to the limited data available. An initial comprehensive global overview was recently created based on a set of global maps at a resolution of 50 × 50 km$^2$ (Figure 2.1; Viviroli et al 2007). Analysis of this overview shows that even in temperate climates, which are relatively water-abundant, mountains deliver about twice as much runoff per unit area as lowlands. In arid zones, mountains provide as much as 7 times more runoff than lowlands; in these dry water-scarce zones, mountains frequently contribute as much as 90% or more to the total runoff of a river basin (Figure 2.2, Viviroli et al 2003). The importance of mountains is particularly pronounced in subtropical regions with a high variability of precipitation, especially if they depend on a single rainy season. Cases in point are the countries of monsoon Asia, such as India and Pakistan, as well as Southeast Asia and southern China, where about 1.3 billion people or close to 20% of the global population depend on mountain waters from the Himalaya, Karakoram, and Tien Shan massifs and from Tibet. Other large mountain systems critically important for water supply are the Rocky Mountains, the Andes, the mountains of the Middle East, the Atlas Mountains, and the mountains of South Africa. In addition, a number of regional 'water towers' found on each continent play a key role. In East Africa, for example, Mount Kenya is the only source of freshwater for over 7 million people.

## Implications of climate change

Temperature and precipitation in the form of rainfall and snow largely determine the hydrological cycle, including runoff. Changes in these factors will thus impact freshwater supplies from mountain areas and have implications for water availability in the lowlands. Snow cover is particularly sensitive, as it reacts quickly to changes in temperature. In a warmer world, a smaller fraction of winter precipitation will fall as snow, and the melting of winter snow will occur earlier in spring. This will lead to a shift of the seasonal runoff maximum to winter and early spring. At present, the seasonal maximum occurs in summer and autumn, when demand in the surrounding lowlands is highest. Where no sufficient storage capacities are available, much of the winter runoff will flow directly to the oceans. Such changes in seasonal maxima, predicted by the IPCC with high confidence, have already been observed in some regions such as the Rocky Mountains and the European Alps. Their future impacts are likely to be severe, since more than one billion people, or one-sixth of the earth's population, rely on snow-melt dominated runoff for their water supply (Barnett et al 2005). To this the impact of shrinking glaciers will be added, which is more limited to mountain regions but has the potential to jeopardise large irrigation systems that rely on glacier melt runoff, such as those found in the mountains and forelands of the Andes. Regions where the water supply is dominated by snow and glacier melt, such as the Hindu Kush-Himalaya and the Rocky Mountains, will also be highly vulnerable, particularly where water systems are already over-allocated, as in the Western US (e.g. Columbia River) and Canada. Although adaptation of these systems appears to be possible by building up infrastructure such as dams, this will be expensive; moreover, it will have unknown impacts on societies and ecosystems downstream.

Changes in water availability due to climate change are taking place at a time when pressure on water resources for irrigation and food production, industrialisation and urbanisation is increasing. The effect will be the greatest in semi-arid regions and in the monsoon belts, especially during seasonal deficits which have been covered by water supply from mountains until now. These changes will give new impetus to the construction of dams and water transfer systems. India and China, for example, are planning or already implementing large interbasin schemes to transfer water to water-scarce regions, the effects of which are difficult to anticipate. If these two schemes are realised, more than two billion people will depend on water originating in the Hindu Kush-Himalaya.

Figure 2.1: Importance of mountains as "Water Towers" of the world (Viviroli et al 2007).



## The way forward

Projections of climate change and its impacts remain a challenge due to the highly non-linear interactions of the relevant factors. This is especially true for mountain regions with their marked topography, which is not well reflected in present climate models. Mountains can alter atmospheric circulation and hence rainfall patterns and snow cover beyond current predictions and over large areas, for example in the Hindu Kush-Himalaya region, where the interplay of the Indian summer monsoon and the winter westerlies over Tibet is little understood. In light of such knowledge gaps, global climate models and predictions of future freshwater supplies are subject to great uncertainty.

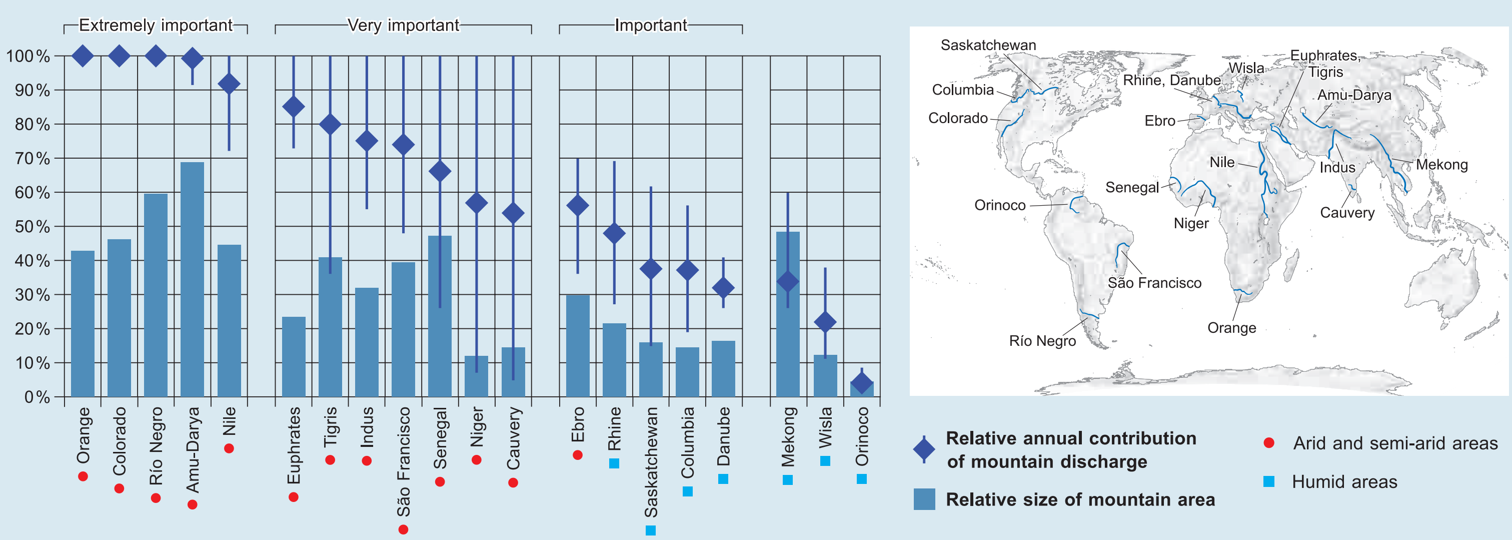
In a world of growing water scarcity, it is urgent that we improve our knowledge of present and future mountain water resources and freshwater supplies. This necessitates investment in long-term high-altitude observatories, especially in mountain areas in the developing world, where they are few and far between; the current trend of closing down monitoring networks due to high operating costs must thus be reversed. While monitoring is essential, it is not enough. Public access to data

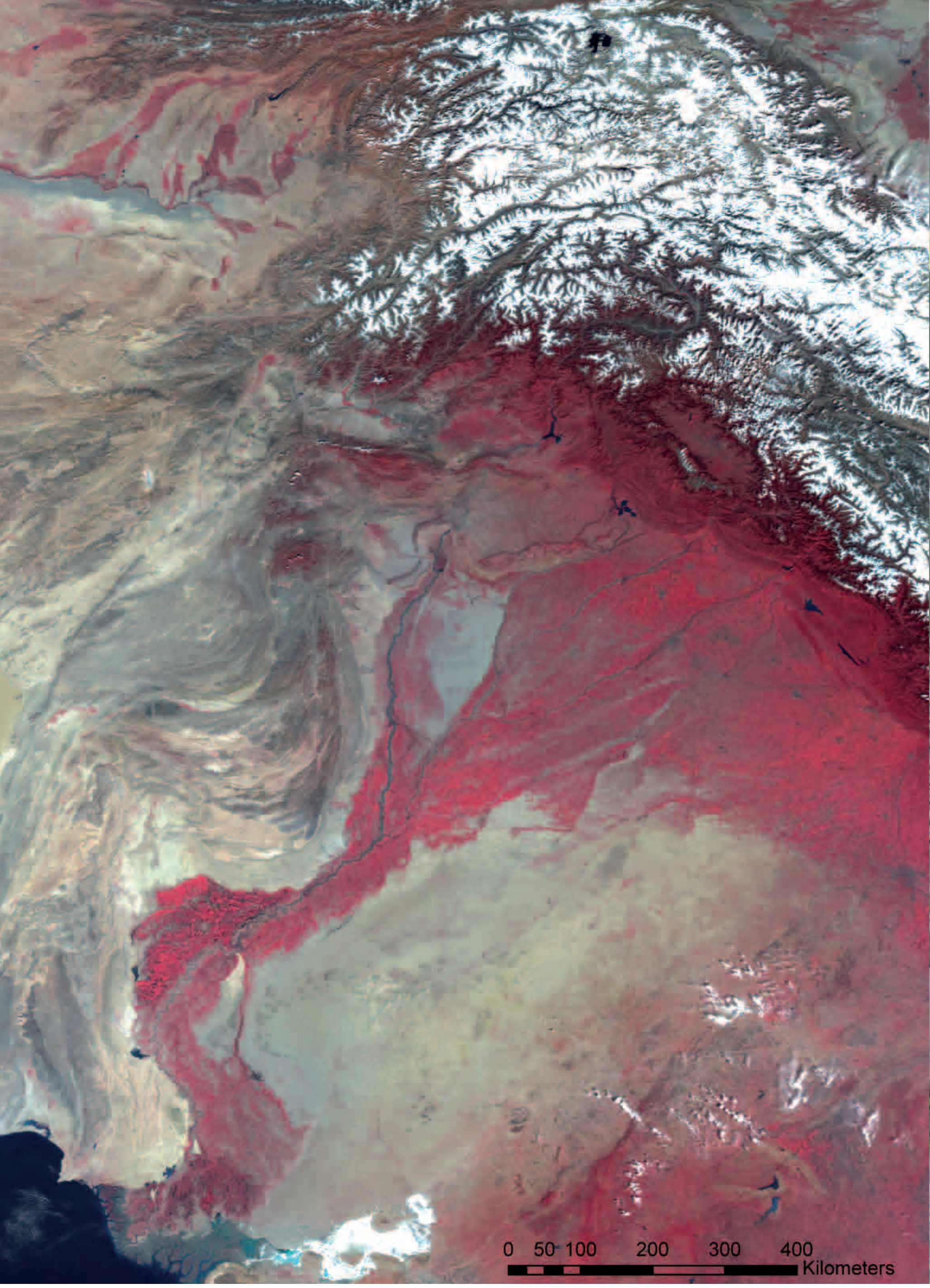
### Mountain waters on the global agenda

The importance of mountains in their role as headwaters and sources of water for the often densely populated surrounding lowlands has long been recognised by the scientific community. Since the 1992 Rio Earth Summit, this importance has increasingly become the focus of political attention, even more so during the International Year of Mountains in 2002 and the subsequent International Year of Freshwater in 2003. The Intergovernmental Panel on Climate Change (IPCC) stated in 2007 that mountain regions will be particularly affected by climate change, and that changes in the water cycle can already be observed in these regions.

In 2008, the UN General Assembly adopted Resolution 62/196 on Sustainable Mountain Development, stating that "The UN General Assembly notes with appreciation that a growing network of governments, organizations, major groups and individuals around the world recognize the importance of the sustainable development of mountain regions for poverty eradication, and recognizes the global importance of mountains as the source of most of the Earth's freshwater […]".

Figure 2.2: Contribution of mountain area to total discharge, and size of mountain area as compared to total basin area for selected rivers world-wide (Viviroli et al 2003).






In the Hindu Kush-Himalaya (H. Rueff)

Left: This false colour infrared satellite image shows the Indus Basin in Pakistan. The irrigated area (in red) is one of the largest in the world. It ensures the country's food supply and generates 23% of its GDP. 80% of the waters that feed the basin are provided by seasonal snow and ice melt in the Hindu Kush-Himalaya mountains (in white at the top of the image). Source: NASA/GSFC, MODIS rapid response/1.10.2002

on water resources, where they exist, must be improved and current restrictions imposed for strategic reasons must be removed. Investment in infrastructure, technology, and international collaboration, as well as a shift in water management from the supply side to the demand side, will be necessary in order to share future water supplies from mountain areas equitably and sustainably.

### Vulnerability of snowmelt-dominated regions to climate change

"Geographic areas where snowmelt hydrology dominates the water cycle are expected to be especially vulnerable to climate change because a warming climate, which is projected with high certainty for the twenty-first century, directly affects the seasonality of runoff, generally shifting runoff from the warm season to the cool season." Adam et al 2009.