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Integrated Land and Water Management under Changing Climatic Conditions in the Ecologically Fragile Mountain Region of North India

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India is home to almost 1.2 billion people and population growth is still high (1.6 % in 2008, estimated in CIA World Factbook, Version May 16, 2008). The population density of 349 inhabitants per km² (2008) is among the highest in the world, although the distribution is very uneven. Even though the ecologically fragile mountain region of North India is less populated, population and economic growth of the country will put a high pressure on land and water resources also in this region. Particularly the demand for energy and high-value food products will significantly increase. Above all, effects of climate change will have a strong impact on the environment and land use.

The Himalayan region of North India with the states of Jammu and Kashmir, Himachal Pradesh, and Uttarakhand are highly diverse in natural landscapes and culture. The states cover a wide range of altitudinal and climatic zones from the subtropical foothills and valleys to the Himalayan peaks and glaciers. The unique region includes various vegetation types, such as alpine meadows, alpine to subtropical forests, and subtropical grassland. These ecosystems are habitats of many rare and endangered species. Some of them, such as the snow leopard and the Bengal tiger, are icons of wildlife conservation. For this reason, large areas are protected as national parks and other conservation units. This applies particularly for the state of Himachal Pradesh, where forests cover about two thirds of the territory, of which 90 % are under protection. Altogether 11 national parks with a total area of about 14,300 km² are located in the three states. The Nanda Devi and Flowers National Park in Uttarakhand is listed as a UNESCO world heritage site.

While the alpine regions are sparsely inhabited, settlements and agricultural activities are concentrated along the fertile valleys and on the plateaus. The main Kashmir valley for instance is about 100 km wide and covers about 15,500 km². Due to its favourable climatic conditions and fertile soils it is an important agricultural area and it is densely populated. The economies of all states highly depend on agriculture and tourism. Furthermore, hydropower became increasingly important, particularly in Uttarakhand.

The glaciers of the region are water sources for many important Indian rivers, such as the Ganges. Considering that these rivers supply water for domestic, industrial and agricultural use in densely populated economic areas of India, changes of the natural environment should be properly observed and analyzed.

Glacier retreat and permafrost thaw in the Himalaya have presently reached an alarming extent and speed and it is common understanding that the diminishing of these water resources must be attributed to climate change (ICIMOD, 2007). Studies reveal that it is likely that many glaciers will disappear completely with dramatic consequences for the natural and human environment. Some of the main effects discussed in literature are

- snow melt dynamics will shift with earlier peaks aggravating spring floods at the cost of the dry season base (Kääb et al., 2005), which in turn will affect rainfed and irrigation agriculture;

- glacier melt will increase melt water volumes in headwater rivers, however, when glaciers further retreat or even disappear this amount will significantly be reduced in the future;

- reduction in water supply from the glaciered headwater catchments will have negative impacts on the economy of the region by limiting the production of hydropower and thereby affecting the industrial productivity (World Bank, 2003);

- the role of ground ice in the hydrological cycle is largely unknown. Permafrost melt could for a limited time release additional water resources. On the long-term, however, adverse effects from permafrost thaw such as slope instability processes and changes in the sediment balance will likely predominate (Kääb et al., 2005);

- melt water trapped in glacial lakes generates destructive Glacier Lake Outburst Floods (GLOFs) (ICIMOD, 2007), which endanger livelihood and property, particularly of the highly vulnerable poor;

- rivers dammed by land slides are affected by flash floods (Subba, 2001);

- surface water deficit during the dry season will pose considerable stress to present water management in downstream forelands and floodplains in both, water quantity and quality (Hilhorst et al., 2004);

- increasing water stress will likely lead to enhancing of present water-related conflicts between different water users;

- higher temperatures and reduced precipitation in the dry season will put environmental systems such as wetlands and indigenous forest under further stress, thereby contributing to the reduction of biodiversity;

- the low quality of rural livelihood and human health will be reduced by water stress impacting especially women and children of more vulnerable families, which might force them to leave rural settlements and migrate towards the cities causing consequent numerous social, economic and cultural implications for both the rural and urban areas.

Considering the complex interactions between climate, the other geo- and biosystems and human activities, the author suggests integrated research approaches on the landscape level, including particularly the fields of hydrology, geomorphology, agricultural and soil sciences, biodiversity, and social sciences. The impacts of climate change can be assessed by downscaling of the global macro-scale resolution to a regional basin scale by Regional Climate Models (RCM). The results of the various areas should be integrated in a vulnerability model, which is an adequate instrument to develop adaptation and mitigation strategies.

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