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Review Article

Glacial melting in Himalaya: Local Impacts of Climate Change on Mountain Ecosystems and Livelihoods

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Abstract: Mountains are amongst the most flimsy environments on Earth. They are prosperous repositories of biodiversity, water and providers of ecosystem goods and services on which downstream communities, both regional and global, rely. The transport of atmospheric pollutants and climate-altering substances can significantly impact high mountain areas, which are generally considered "clean" regions. The snow glaciers of the Himalayas, considered the "third pole", one of the largest stores of water on the planet and accelerated melting could have far-reaching effects, such as flooding in the short-term and water shortages in the long-term as the glaciers shrink. The data available on temperature in Himalayas indicate that warming during last 3-4 decades has been more than the global average over the last century. Some of the values indicate that the Himalayas are warming 5-6 times more than the global average. Mountain systems are seen globally as the prime sufferers from climate change. There is a severe gap in the knowledge of the short and long-term implications of the impact of climate change on water and hazards in the Himalayas, and their downstream river basins. Most studies have excluded the Himalayan region because of its extreme and complex topography and the lack of adequate rain gauge data. There is an urgent need to close the knowledge gap by establishing monitoring schemes for snow, ice and water; downscaling climate models; applying hydrological models to predict water availability; and developing basin wide scenarios, which also take water demand and socioeconomic development into account. Climate change induced hazards such as floods, landslides and droughts will impose considerable stresses on the livelihoods of mountain people and downstream populations. Enhancing resilience and promoting adaptation in mountain areas have thus become among the most important priorities of this decade. It is important to strengthen local knowledge, innovations and practices within social and ecological systems as well as strengthen the functioning of institutions relevant for adaptation. A common understanding of climate change needs to be developed through regional and local-scale research so that mitigation and adaptation strategies can be identified and implemented.

Keywords: Adaptation strategies, Biodiversity, Climate change, Himalayas, Livelihoods, Mitigation, Third Pole.

1. Introduction

The Himalayan region covers the mountain area from the Pamir region adjoining the Karakoram-Hindu Kush-Zaskar ranges in the West-Northwest, the Tibetan plateau at the centre bordered by the Kunlun Shan in the North and the Heng-Tuan Shan in the East and by the great Himalayan range in the South (Bahadur, 1993). The Hindu Kush-Himalayan-Tibetan (HKHT) region – which is also called as the "Third Pole" – extends 3,500 km from Afghanistan to Burma/Myanmar including western China, northern India, and the entirety of Bhutan and Nepal. Mountains are considered home for the world's most vulnerable and endemic species, plus to the poor people, who rely on their biological resources (Kollmair *et al.*, 2005).

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Keeping this view in mind, the Convention on Biological Diversity (CBD) exclusively developed a Program of Work on Mountain Biodiversity in 2004 aimed at reducing the loss of mountain biological diversity at global, regional and national levels by 2010. Despite these activities, mountains are still facing huge pressure of climate change (Nogues-Bravo *et al*., 2007; Eriksson *et al.*, 2009). The Himalaya along with adjacent mountain ranges in the northeastern region within Indian Territory (jointly known as Indian Himalaya Region or IHR) represents highly fragile and vulnerable mountain ecosystems in the country (Planning Commission, 2006). The Himalayas are having cold arid to wet tropical conditions with seasonal alterations of dry and moist conditions in a wide range of altitudes.

According to the recent researches, the temperature increase in the Himalayan region has been superior to the global average of 0.74°C over the last 100 years (IPCC, 2007; Du *et al*., 2004; Eriksson *et al*., 2008). This ongoing rapid warming may have an intense effect on the Himalayan environment, which may be most visible in the form of rapid retreat of Himalayan glaciers and diminishing snowfields (Dyurgerov and Meier, 2005). The permafrost layer in the Himalayas is also getting affected by this change in temperature. The decline of the permafrost layer can have impacts on slope stability, erosion processes, hydrology and the ecology, with major implications for people depending on these areas for their livelihoods. It is also expected that increased precipitation will result largely in a higher frequency and magnitude of "high intense" rainfall events, having a potential to cause flash floods, landslides and debris flows. In the eastern and central Himalayas, glacial retreat has led to the formation of glacial lakes behind terminal moraines, which is an unavoidable problem as we have seen during Kedarnath calamity in June 2013. Many of these high altitude lakes are potentially dangerous. These moraine dams can lead to unexpected catastrophic damage leading to discharge of huge volumes of water and debris (Ballantyne and Benn, 1994; Dadson and Church, 2005; Eriksson *et al*., 2009). The consequential glacial lake outburst flood (GLOF) can cause damage to life, property, forests, farms and infrastructure. In Nepal alone, 25 GLOF events have been recorded during the last 70 years (Eriksson *et al*., 2008). GLOFs have threatened the lives and livelihoods of millions of people in the region and these events are becoming more frequent during the past few years. In the longer-term, the loss of these glaciers will lead to a corresponding reduction in water availability. Climate change is currently exceeding with an unprecedented rate and will potentially have profound and widespread effects on the availability of, and access to, water resources (Eriksson *et al.,* 2009). Direct drivers of environmental changes include climate change, changes in land use and land cover, and introduction or removal of species whereas indirect drivers are demographic, economic and sociopolitical changes. Such changes have negative impacts on biodiversity conservation, ecosystem services, and the well-being of people living in the mountains. Land-use, land cover and climate change have already led to a contraction in the species' range as well as extinctions. Anthropogenic climate change is expected to threaten the existence of some species. People's ability to cope with the changes in mountain areas will also be threatened, with ramifications downstream and beyond.

2. Climatic discrimination in Himalayan region

The Himalayas are having great climatic differences. The mountains act as a barrier to atmospheric circulation for both the summer monsoon and the winter westerlies. The summer monsoon takes time of eight months (March – October) in the Eastern Himalayas, four months (June – September) in the Central Himalayas, and two months (July – August) in the Western Himalayas (Chalise and Khanal, 2001; Eriksson *et al.*, 2009). Due to different weather conditions, this variation happens, causing the monsoon to weaken from east to west (Hofer and Messerli, 2006; Rees and Collins, 2006; Eriksson *et al.,* 2009). Glaciated areas in the greater Himalayan region cover an area of more than 112,000 km^2 (Table 1) (Dyurgerov *et al.,* 2005). The Himalayan Range alone (a subregion) has a total area of 33,050 km^2 of glaciers or 17% of the mountain area (as compared to 2.2% in the Swiss Alps) with a total ice volume of 3,421 km^3 (Table 2), which provides important short and long-term water storage facilities (Qin, 1999). Continuing climate change is predicted to lead to major changes in the strength and timing of the Asian monsoon, inner Asian high pressure systems, and winter westerlies – the main systems affecting the climate of the Himalayan region.

Table 1. Glaciated areas in the greater Himalayan region.

Mountain range	Area (km^2)
Tien Shan	15,417
Pamir	12,260
Qilian Shan	1,930
Kunlun Shan	12,260
Karakoram	16,600
Qiantang Plateau	3,360
Tanggula	2,210
Gandishi	620
Nianqingtangla	7,540
Hengduan	1,620
Himalayas	33,050
Hindu Kush	3,200
Hinduradsh	2,700
Total	**112,767**

Source: Dyurgerov and Meier (2005).

Table 2. Glaciated areas in the Himalayan range.

Drainage Basin	No. of Glaciers	Total area (km^2)	Total ice reserves (km^3)
Ganges River	6,694	16,677	1971
Brahmaputra River	4,366	6,579	600
Indus River	5,057	8,926	850
Total	16,117	32,182	3,421

Source: Qin (1999).

3. Himalayan warming and glacial retreat

The Himalayan region has shown consistent trends in overall warming during the past 100 years (Yao *et al*., 2006). The rate of retreat for the Gangotri Glacier over the last three decades was more than three times the rate during the preceding 200 years. Recent studies have shown that permafrost shrinkage is increasing, and this has distorted the whole hydrological cycle (Lawrence and Slater, 2005; Xu *et al*., 2007). Climate change has been resulting in changes in the frequency and magnitude of extreme weather events. It is now globally accepted that global warming is associated with the most severe fluctuations, particularly in combination with intensified monsoon circulations (Xu *et al.*, 2007). Large fluctuations in the melting of snow and ice can result in excessive or insufficient water supplies: heavy snowfalls can block roads or overload structures. The action of frost and melting of permafrost can pose ecological and technological dangers. The most destructive hazards are mostly those, which are direct consequences of changes in the Cryosphere (Xu *et al.*, 2007).

4. Observed and projected effects on Himalayas because of climate change

Fourth Assessment Report of IPCC says that (IPCC, 2007; Eriksson *et al.*, 2009), there is more than a 90% chance that the observed warming since the 1950s is due to the emission of greenhouse gases from human activity. There is a significant hastening of warming in the 21st century over that observed in the 20th Century (Ruosteenoja *et al*., 2003; Eriksson *et al.*, 2009). Remarkable warming is observed in arid regions of Asia and the Himalayan highlands (Gao *et al*., 2003; Yao *et al*., 2006; Eriksson *et al.*, 2009). Himalayan glaciers are thinning faster today than the world average (Dyurgerov and Meier, 2005; Eriksson *et al.*, 2009). "Precipitation decrease in combination with temperature increase" can be the major reason of this glacial retreat. The glacier shrinkage will go up if the climatic warming and drying continue at the same pace" (Ren *et al*., 2003; Eriksson *et al*., 2009). During the last few decades, the Greater Himalayas have experienced fluctuating precipitation trends (Shrestha *et al*., 2000; Z. Xu *et al*., 2007; Ma *et al.*, 2009; Xu *et al*., 2009). The global warming might severely affect the river connection between the Himalayas and Gangetic Plains and climate regime of the entire region. Most of the talk on climate change in the Himalayas is centered on glaciers melting. However, the impact on natural ecosystems and agriculture is hardly considered.

Issues associated with modernization like GHG emission, air pollution, land use conversions, fragmentation, deforestation and land degradation have badly affected the Himalayan region. The landscapes and communities in the Himalayan region are being simultaneously affected by rapid environmental and socioeconomic changes. Identification and understanding of key ecological and socioeconomic parameters of the mountain ecosystems, including their sensitivities and vulnerabilities to climate changes, have become crucial for planning and policy making for environmental management and sustainable development of the mountain regions as well as the downstream areas (Schild, 2008).

5. Consequences for livelihoods and the environment

The Himalayan ecosystem is not only a home for mountain goods and services but also for biodiversity, community diversity and cultural diversity. Studies say that this change in climate is affecting grassland productivity, ecosystems and the distribution and composition of plant communities (Wilkes, 2008). Mountain ecosystems are sensitive to global warming and are gradually showing the signs of fragmentation and degradation (Xu and Wilkes, 2004; Körner, 2004; Eriksson *et al.*, 2009). The impact of climate change on health conditions can be broadly divided into three major classes:

(i) Direct impacts like drought, heat waves, and flash floods,
(ii) Indirect effects due to climate-induced economic dislocation, decline, conflict, crop failure, and associated malnutrition and hunger, and
(iii) Indirect effects due to the spread and provoked intensity of infectious diseases due to changing environmental conditions (WHO, 2005; Eriksson *et al.*, 2009).

Valuable infrastructure, as hydropower plants, roads, bridges and communication systems, would be at risk from climate change. Entire hydropower generation systems established on many rivers will get impaired if landslides and flash floods increase and hydropower generation will be affected if there is a decrease in the already low flows during the dry season. Engineers will have to consider how to respond to these challenges (OECD, 2003; Eriksson *et al.*, 2009). The Himalayan ecosystem is becoming highly vulnerable because of increased pressure of population, exploitation of natural resources and other related challenges. This would not only jeopardize the sustainability of the indigenous communities in the uplands but also the life of downstream dwellers across the country and beyond. Hence, there is an urgent need for giving special attention to the present conditions of the Himalayan Ecosystem (Asian Development Bank, 2010). Climate change has made the future of mountain indigenous people and their livelihoods more vulnerable and uncertain. According to present scientific evidence, climate change will place significant stress on the rural livelihoods of mountain people. Efforts to reduce vulnerability and enhance the adaptive capacity of at-risk groups need to take a practical approach that addresses the social processes leading to vulnerability and the structural inequalities that are often at the root of social-environmental vulnerabilities. It is noteworthy that poor and marginalized people have already faced all of the difficulties that are usually associated with climate change. They are already facing poor health, susceptibility to floods and landslides and a lack of adequate shelter, food and water. While they do need climate change adaptation, they need poverty alleviation even more (Eriksson *et al.*, 2009). Within these populations and communities, the impacts of climate change are not evenly distributed, either in intensity within the region, or among different sectors of society. There is seen earlier and greater impact of climate change on the fragile ecosystem and poorer and more marginalized people (Xu *et al*., 2007).

6. Health Impacts

The health of local people will get impaired due to changes in the frequency and intensity of thermal extremes and extreme weather events (i.e. Floods and droughts). These impacts may be indirect as changes in the range and intensity of infectious diseases and food- and waterborne diseases and changes in the prevalence of diseases associated with air pollutants and aeroallergens (Eriksson *et al.*, 2009). The harmful impacts on river flows, groundwater recharge, natural hazards and the ecosystem, as well as on people and their livelihoods, could be dramatic, but the rate, intensity, or direction of this impact would be different in all parts of the region. A risk assessment process is indispensable for the current state of knowledge about that particular area when we know that the determination of the diversity of impacts is a challenge for researchers (Eriksson *et al.*, 2009).

7. Biological Impacts

With the shifting of vegetation to higher elevations can result in a rapid reduction of alpine plants growing at high altitudes. The continuous increase in temperatures, change in vegetation, rapid deforestation and scarcity of drinking water, habitat destruction and corridor fragmentation may lead to being a great threat to extinction of wild flora and fauna (Xu *et al.*, 2007). Agriculture is facing climate change consequence every year by decreased crop yield and food supply. The weather is also affecting soil and plant growth; and animal growth and development. Most of the Himalayan people rely heavily on Horticulture as an important source of income. Irregularity in rainfall and snowfall; change in climatic condition; and rising temperatures can also affect fruit production which can result in economic downfall for local people. According to a research, the quality and quantity of tea production are also getting affected by irregular rainfall (Xu *et al.*, 2009; Barnett *et al*., 2005). These conditions are also getting converted into social stresses which are harmful for the welfare of the society (Ives and Messerli, 1989), causing uncertainty (Thompson and Warburton, 1985), and leading to contradictory perceptions (Ives, 2004). In case of forests, there are some clashing views. Some studies have shown a positive impact like shifts in forest boundaries by latitude and upward movement of tree lines to higher elevations; changes in species composition and vegetation types; and an increase in net primary productivity (NPP) (Ramakrishna *et al*., 2003; Xu *et al.*, 2007). However, shown a negative impact of climate change on the forest ecosystems (Siddiqui *et al*., 1999; Xu *et al*., 2007).

8. Adaptation measures

With the increasing rate of climate change and other global change stressors, the need for planned adaptation is becoming more acute. All the important adaptation and mitigation strategies depend on the availability of adequate information on the status of biodiversity, trends in environmental change including climate change, and its potential impacts on biodiversity, human resources, expertise, institutional capacity, political commitments and the financial resources. Therefore, we need a proper information regarding climatic parameters, physical and biological conditions, and socio-cultural and livelihoods situations in the Himalayas for generating consistent representative data. The information generated that could be used for sustainable development and for responding to climate change (Xu *et al*., 2007; Eriksson *et al.*, 2009).

9. Conclusion

The Himalayas cover one of the most dynamic and complex mountain ranges in the world due to tectonic activity, but they are also vulnerable to global warming and increasing human activities. Because of this uncertainty in science and research in the Himalayas, policies should be clear and easily adapted by local people. There is also indecision about the rates and proper direction of these changes because so little is known about the dynamics of Himalayan climates and hydrological processes and their response to changing climatic conditions. Mountain people have lived with and survived great hazards such as flash floods, avalanches, and droughts for millennia. There is a strong need to build capacity to adapt and strengthen the social-ecological system in this changing climate scenario. The degradation of the environment and ecology of the Himalayan States and its huge impact on the lives and livelihoods of the people of the region and the country as a whole has become a vital need to focus attention on preserving and enhancing the Himalayan ecosystem.

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