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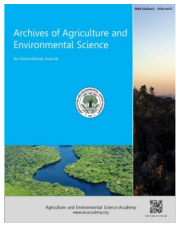

REVIEW ARTICLE

# Climatic fluctuations in Uttarakhand Himalayan region and resulting impacts: A review

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**ABSTRACT**

The Himalayan Mountains are the stock of precious biodiversity and water, and providers of ecosystem goods and services on which local communities depend. These "clean" regions are becoming victims of transport of atmospheric pollutants and climate-altering substances. Uttarakhand state has become victim of several catastrophic events such as Cloud bursts, landslides and Floods in past few years. The young Himalaya is facing worse calamities with every passing year. The devastation in Uttarakhand in June, 2013 showed that some of the effects of climate change are already upon us. Flash floods in Uttarakhand were inevitable, given the record rainfall. But their strength was multiplied by glacial lake outbursts. And the effects were worsened many times by ill-planned development. It ought to serve as a wake-up call to desist from a development model that upsets fragile ecosystems on a large scale and impoverishes people who are already highly vulnerable to a wide range of social and economic problems. The economy of the mountain communities of Uttarakhand is largely dependent on its natural resource base and climate-sensitive livelihoods like subsistence agriculture, and forestry. However, the impacts of climate change are visible in mid- and high- altitude regions in the shape of changes in ecosystems and changes in seasons. These changes have both positive and negative effects on resource-based livelihoods. There is a need to identify the changes that are currently visible in the mountain regions, analyze them and help the local communities to adapt to them.



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## INTRODUCTION

The Himalayas are known as the youngest mountains in the world, and with this, they are acutely fragile. Any change in the climate here affects the people ecologically, socially, economically and culturally, not just in the region, but beyond. Uttarakhand lies on the southern slopes of the central, western Himalaya. It extends latitude wise from $28^0$N to $31^0$N and Longitude wise from $77^0$E to $81^0$E. Its elevation ranges from 300 meters to 3,600 meters spanning the Great, Middle and Sub-Himalaya (Figure 1). The Great Himalaya comprises a stretch above the tree-line with snow-covered peaks and few or temporary habitations. The Middle Himalaya region, about 80 km. wide, is a complex mosaic of forest-covered ranges and fertile valleys. The Sub-Himalaya, the southernmost zone, is a large number of long, flat-bottomed valleys known as *duns,* which are usually spindle-shaped and filled with gravelly alluvium. South of the foothills are the Tarai and Duars plains, which are heavily farmed.

The Uttarakhand disaster which took place at the beginning of the 2013 monsoon season is an outcome of ignorance of the ecological systems that hold up the flimsy Himalayas, and greed to profit from the exploitation of the rich natural and cultural heritage of the region. Today the ecologically brittle Himalayas and our sacred rivers are being ruthlessly exploited. The disaster which has led to around 5,000 deaths on current estimates and the disappearance of nearly 1 lakh people is a wakeup call to stop the destruction of environment. Present paper reviews the literature on the potential biophysical and economic impacts of climate change in the Himalayas. The fragile landscapes of the Himalayan region are highly susceptible to natural hazards, leading to ongoing concern about current and future climate change impacts in the region.

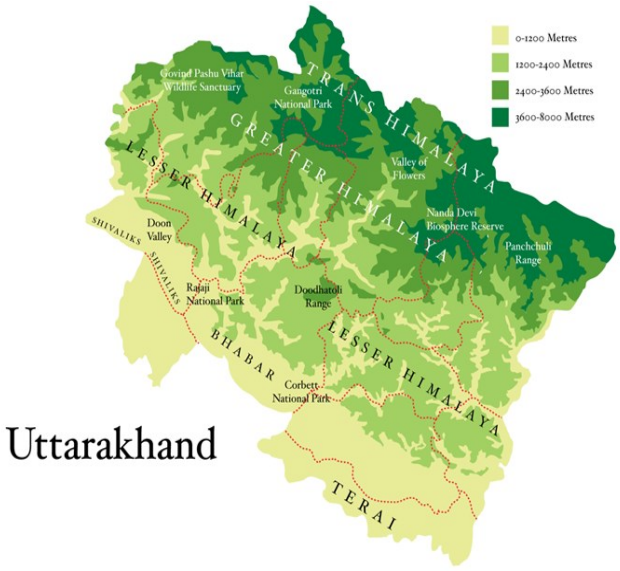


**Figure 1.** *Map of Uttarakhand Himalayan region.*

**Global climatic change:** Global climate change is one of the most important challenges which are being faced by the international community nowadays. Scientists have presented overwhelming evidence that climate change is certainly happening, that human action has contributed to the problem, and that it will have far-reaching implications for ecosystems, including human settlements (Salehyan, 2008). The human systems that are highly vulnerable to climate change are water resources, agriculture, forestry, fisheries, energy production, industry, insurance and other financial services, and human health (particularly a net increase in the geographic range of malaria and dengue). Much of Earth's surface may not be habitable by 2300 due to the limits to human tolerance of heat. Though it is normal for local temperature to fluctuate, but over the past 50 years the average global temperature has amplified at the fastest rate in recorded history. Carbon dioxide and other air pollutants that are accumulating in the atmosphere like a thickening blanket, trapping the sun's heat and causing the planet to warm up, generally called greenhouse effect.

**Climate change in Himalayan region:** The Himalayan region expresses a huge changeability of climates, hydrological and ecological systems, plus a diversity of cultures and communities. It is an essentiality to the ecological security of the Indian landmass, by providing evergreen forest cover, feeding recurrent rivers that are the source of potable water, irrigation, and hydropower, conserving biodiversity, providing a rich foundation for high value agriculture, and outstanding landscapes for supportable tourism in the Himalayan region. Increasing concentration of greenhouse gases in the troposphere and the consequential global warming is posing a great environmental menace to water and food security at widespread level. The alterations in the climate of the Himalayan region may affect exposures to air pollutants by affecting weather, anthropogenic emissions, and by changing the dispersal and types of airborne allergens. Therefore, this possible variability in climate will have a thoughtful impact on several ecosystem services, such as cleaning water and removing carbon from the atmosphere. A number of precious services of ecosystems viz., land and water resources, agriculture, biodiversity will experience a wide range of stresses together with pests and pathogens, invasive species, atmospheric pollution, acute events, wildfires and floods. Direct pressures posed due to climate change may get intensified by high temperatures, decreased water availability, and altered frequency of extreme events and severe storms. Climate change will potentially make a threat on the obtainability of, and access to, water resources (Tariyal *et al*., 2014; Tariyal, 2014, 2015).

**Retreating Himalayan glaciers:** The Himalayan region has the largest concentration of glaciers outside the polar caps. With glacier coverage of 33,000 sq km, the region is aptly called the "Water Tower of Asia", as it provides around 86,000,000 cubic meters of water annually. These Himalayan glaciers feed seven of Asia's greatest rivers; the Ganga, the Indus, the Brahmaputra, the Salween that passes through China and Myanmar, the Mekong, the Yangtze and the Huang Ho. They ensure a year-round water supply about 1 billion people. The changes in climate variability have led to a rapid retreat of mountain glacier systems, which are considered the lifeline of river basins and ecosystems. Scientific studies have shown that 67 percent of glaciers are retreating at a startling rate in the Himalayas as a result of various factors including climate change. Such changes in average global surface temperatures can have serious consequences on the stability of the glacial systems. The impact of global warming is perhaps already upon the Himalayas. The 30.2-km-long Gangotri glacier, the second largest among the 6,500-odd small and large glaciers in the Himalayas and which feeds the perennial Ganga, is receding at a rate that is worrying (Tariyal *et al.*, 2013; Tariyal and Bartwal, 2014).

The melting of the Gangotri Glacier in India is accelerating with an average rate of retreat of 30 meters annually. The immediate or short-term impact of a receding Gangotri (or any other large glacier) would be an increased risk of glacial hazards, such as incidents of landslips, changes in the courses of rivers and floods. The higher melt means more discharge into rivers and reservoirs. Already there is evidence to this effect, there have been instances of flooding in the Ganga basin during drought years and this is obviously because of increased melt. This increased flow can also lead to landslips downstream by triggering unstable flow along the area evacuated by the receding glacier because the soil, rocks and the vegetation on them are loose and can give way to surging water easily. The UN panel report warns that glaciers across the Himalayas are melting at an alarming rate and may disappear altogether by 2035. Such an event will not only have a severe impact on the Himalayan ecology and the people living in the region, but also cause a wide swath of misery downstream. This is because most of India's great northern rivers, like the Ganga and the Yamuna, are dependent on the glaciers for perennial water supply (Chengappa, 2007).

The Himalayan region has shown consistent trends in overall warming during the past 100 years (Yao *et al*., 2006;

Tariyal *et al*., 2013). 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 into 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; Tariyal *et al*., 2013). 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; Tariyal *et al*., 2013).

**Climate imposed impacts and common livelihood:** 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 (Tariyal *et al*., 2014). The Himalayan ecosystem is not only a home for mountain goods and services but also for biodiversity, community diversity and cultural diversity. Mountains are sensitive to global warming and are gradually showing the signs of fragmentation and degradation (Tariyal *et al*., 2014; Eriksson *et al*., 2009). The impact of climate change on health conditions can be divided into three major categories: (i) direct impacts from phenomena 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 (Eriksson *et al*., 2009). Valuable infrastructure, such as hydropower plants, roads, bridges, and communication systems, will be increasingly at risk from climate change. Entire hydropower generation systems established on many rivers will be jeopardized 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 (WHO, 2005). This would not only impact the sustainability of the indigenous communities in uplands but also the life of downstream dwellers across the country and beyond. Hence, there is an urgent need for giving special attention on the present conditions of the Himalayan Ecosystem (Tariyal *et al*., 2014). 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 (Eriksson *et al*., 2009). It is noteworthy that poor and marginalized people already face 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 fragile ecosystem and poorer and more marginalized people (Eriksson *et al*., 2009; Tariyal *et al*., 2014; Tariyal, 2015).

**Vanishing biodiversity due to climate crisis:** Human behaviour has already caused the destruction of over one third of the world's forest. The rapidly rising demand for natural resources is resulting genes, species and habitat to vanish at an unprecedented rate. Even at the global level, these forests are important in terms of combating greenhouse gases, soil erosion and climate change. In a due time, as a result of use and abuse of these forests and with wrong or inappropriate property rights and institutional arrangements, they are subjected to severe degradation and depletion resulting in loss of biodiversity. The core causes of habitat and biodiversity loss are largely institutional and socio-economic. A key challenge in addressing the threat to biodiversity for emerging economies is to balance conservation with the use of their natural resources for growth; and to find ways to protect vital natural resources, without causing suffering to vulnerable and poor citizens who depend on them for their daily subsistence needs (Tariyal *et al.*, 2013; Tariyal and and Bartwal, 2014). Impact of Climate Change on forest ecosystems is a subject of recent origin. In this context biophysical models in association with regional Climate Change scenarios need to be used to assess the impact of Climate Change on forest ecosystems at national and regional levels in terms of the (i) shifts in boundary of forest ecosystems and upward movement of tree lines, (ii) forest ecosystem change matrix, (iii) change in species mix and composition of vegetation types, and (iv) species vulnerability to identify vulnerable forest ecosystems, regions and hotspots. Implications of Climate Change on biodiversity, biomass production and net primary productivity also need to be kept in view in designing programmes of work (Tariyal, 2014). It is envisaged that the effects of Climate Change on the sub-alpine and alpine plant species that inhabit mountain ranges with restricted habitat availability, above the tree line, would experience severe fragmentation, habitat loss, or even local extinction

if they fail in moving to higher elevations (Singh *et al.,* 2010). Identification and management of corridors for facilitating effective movement of biota in the face of Climate Change have, therefore, gained global attention. There is imminent need at the regional level, to have reliable information to predict the most vulnerable forest types as well as regions. Likewise, research based evidences are required to project future scenarios of shifts in boundaries, and/or to highlight potential corridors for movement of forest species and wildlife under changing climate. These aspects and many more, require immediate attention of the planners, researchers, and forest managers with adequate sensitization of stakeholders.

**Uttarakhand disaster: Witness of the impact**: Recent climate changes have a significant impact on high mountain glacial environment. Due to continuous rising air temperatures, on regional and global scales, the precipitation pattern at higher altitude can change from snow to rain (Immerzeel *et al.,* 2010). This high altitude rain causes rapid melting of snow, ice and therefore formation and expansion of moraine dammed, supra glacial and cirque lakes, creating the potential danger in the downstream valley. Exceptional early monsoon rains between June 15 and 17, 2013 combined with melting of snow caused voluminous floods in the rivers of Uttarakhand (Bhagirathi, Alaknanda, Mandakini, Dhauliganga and Kali) and subsequently triggered widespread mud- and landslides. Thousands of pilgrims got stranded at various pilgrimage places and en route. However, the majority of casualties took place in the Kedarnath Valley and en route. Heavy downpour activated widespread landslides and flash floods in the region that caused irreparable damage to lives and property in the Mandakini valley including complete damage of 60% of the 14 km pedestrian route from Gaurikund to Shri Kedarnath town. The moraine-dammed Chorabari Lake, about 1.5 km upstream the town of Shri Kedarnath, breached and deposited loose unconsolidated moraine debris downstream. This was the main cause of the maximum devastation in the downstream of the Kedarnath valley. The Mandakini River completely washed off Rambara and partially washed off Gaurikund, Sonprayag and settlements near the river course. This flash flood event brought major changes to the landscape of Uttarakhand thus making the whole region more fragile and vulnerable (Dobhal *et al*., 2013). The Uttarakhand disaster that has been witnessed at the beginning of the 2013 monsoon season is a consequence of ignorance of the ecological systems that hold up the fragile Himalayas, and greed to profit from the exploitation of the rich natural and cultural heritage of the region. Today the ecologically fragile Himalayas and our sacred rivers are being ruthlessly exploited. The disaster which has led to around 5,000 deaths on current estimates and the disappearance of nearly 1 lakh people is a wakeup call to stop the destruction of environment (Deccan Herald, 2013; Tariyal, 2014, 2015; Tariyal *et al.*, 2014).

The flash flood together with landslides incurred heavy losses to the infrastructure, agricultural fields, human and animal lives, roads and widespread destruction of natural resources. Such a magnitude of disaster was perhaps not witnessed by the region at least over the last 100 years. Thus, this disaster can be considered as an Extreme Climatic Event of the century. The extent and intensity of the tragedy can easily be visualised by the fact that all the famous shrines of the Uttarakhand state, located in high mountainous, snow bound areas such as Badrinath, Kedarnath, Gangotri, Yamunotri, and Hemkund Shahib were badly affected by this extreme fury of the nature. The ancient Shri Kedarnath shrine was among the worst affected areas where maximum damage and casualties were reported. Active erosion of the loose soil and debris began due to this excessive flow in all the gulleys/streams causing excessive water and sediment accumulation in the rivers. The voluminous water with unconsolidated debris moved rapidly towards and smacked Shri Kedarnath town, washing away the peripheral part of the town as well as old iron bridge over the Mandakini River and damaging infrastructure including houses, hotels and shops, etc. This natural hazard turned into a major disaster due to the overcrowding of the town by the pilgrims and local population. As month of June is a peak time for the visit of pilgrims, the entire state of Uttarakhand was crowded with people from different places as they wanted to have sight of deities and worship in Holy Shrines before the monsoon sets in. The unusual timing of very heavy rainfall and its consequences made people helpless as it did not let them even realise to find ways to escape. If the same event was happened in the month of July-August the number of lives lost could have been very less as the movement of the people during these months is far less than in the month of June.

## Conclusions

Thus the human induced climate change will continue in the decades and centuries to come and actions to mitigate climate change may slow the rate of climate change, but will almost certainly not stop it. To prepare our societies better for the changes in climate ahead, and to identify possible critical thresholds in the climate system, considerable efforts have been made to project the likely regional and global climate consequences of the range of plausible socio-economic development pathways. Therefore, the world community must come up with an effective response in curbing global warming by evolving norms and taking strategic steps to mitigate climate change and achieve stabilization of greenhouse gas atmospheric concentrations through good laws and implementing machinery. Climate change is the biggest sustainable development challenge the international community has had to tackle to date. The process to address the climate change needs to be completely compatible with the international community's wider ambitions for economic growth and human advancement. It is a challenge that transcends borders and requires solutions not only at national levels but at the international level as well. The challenge is to translate and adapt the national level policy imperatives and equity considerations to sub-national level actions, and the State Governments have a key role to play in incorporating climate change concerns in everyday governance and adopting climate-friendly policies, and investment decisions.

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