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Climate Change in Himalayas: Research Findings and Complexities

Surendra P. Singh[1]* and Surabhi Gumber[2]

[1]Central Himalayan Environment Association (CHEA), Nainital-263001, INDIA; [2]Kumaun University, Nainital-263001, INDIA

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Corresponding author:
Prof. Surendra P. Singh
Mob.: +91-9758765300
Email: spsecology@gmail.com,
surps@yahoo.com

Abstract

Himalayas are important for its influence on the climate of much of Asia, and ecosystem services, which serve some 1.3 billion people living in 10 river basins that originate from the region. The region is warming rapidly and is highly vulnerable to climate change. This review (i) sheds light on some fairly well established facts about climate change in Himalayas, (ii) makes an attempt to give an integrated picture of its impact on various components, and (iii) discusses complexities in generalizing the findings. Himalayas are warming at 2-3 time higher rates than global average rate, at least in some areas. The rate of warming is increasing in time and with elevation. As for rainfall, uncertainty is high, but generally predictions are for more violent events. According to an analysis based on 75 glaciers, 63 glaciers are showing shrinkage and 12 growth, however, their (growing ones) measurements are of low confidence level. The contribution of glacier and snow melt to total river discharge varies from 5-60% from west to east. Violent extreme events and glacier melt lakes are predicted to generate more disasters. The intensification of pre-monsoon drought is likely to be a critical climate change factor, affecting several ecological processes and social behaviour. Its examples are drying of water springs, suppression of treeline and desiccation of seeds of the species in which seeds remain lying on ground for a relatively longer period before conditions for germination become favourable, and spread of forest fires. The intensified water shortage is a threat even to tourism supporting capacity of the region. Apple cultivation in the state of Himachal Pradesh is getting adversely affected by the lack of sufficient winter-chilling. Some interventions are possible to undertake to address climate change impact. They include addressing data gaps, particularly with regard to changes in glacier ice mass, volumes and timing of river flows, frequency and duration of extreme events, transboundary cooperation, and development of translational ecology research in which scientists work in a close partnership with stakeholders and administrators. The Himalayan region is disproportionately affected by climate change induced disasters and miseries, though the region's per capita fossil fuel consumption is ridiculously low, raising a issue of climate change justice.

1. Introduction

Himalayas are high (with hundreds of peaks above 6000 m), huge, massive, and highly heterogeneous, easily one of the greatest geo-ecological features of the planet. With 2500 km wide arc from west-to-east, Himalayas along with Hindu Kush region are spread over about 35°longitude and 16°latitude. The rise of Himalayas and arrival of monsoon rainfall pattern coincided. Himalayas have influenced the climate of much of the sub-continent, intercepting moist winds rising from oceans during summer and not allowing cold winds from the north to penetrate. These mountain ranges are young and still rising, hence are vulnerable to landslides and landslips even without human presence. Their vulnerability is to further increase because they are warming at a much higher rate than global average rate (Singh *et al*., 2011). The slopes in the south of the main Himalayan ranges, exposed to the full thrust of monsoon often have annual rainfall in excess of 3000 mm, while in the north of the main ranges are some of the major rain shadow areas, with well below 500mm annual precipitation. While Himalayas are easily one of the largest wilderness regions in the world, to them are connected some of the most populated river basins of the world, with human density often exceeding, 1000 persons per km^2. The 10 river basins which originate from Hindu Kush Himalayas and adjoining mountain ranges have about 1.3 billion people (Schild, 2008).

The heterogeneity in Himalayas is not limited to physical features, the region is known for cultural diversity and numerous languages (>1000) and dialects (Turin, 2005). The western part is known for age-old pastoralism, with herders taking their sheep and goats to alpine meadows during summer months. In contrast, large scale grazing has been absent from the eastern part. These two Himalayan regions differ sharply in biodiversity and agricultural practices. Rich in biodiversity, the Eastern part is known for shifting cultivation, while settled agriculture on terraces carved out of mountain slopes is the characteristic feature of much of the remaining Himalayas. Nearly 1000 languages are spoken in the region, some by less than 400 people.

The Gangetic plains owe their astonishing population supporting capacities to the ecosystem services flowing from Himalayas. Evidences for it are as following: (i) Because of the flow of water and soil from Himalayas the plant water potential is higher in adjacent plains despite about 100 cm less rain fall and warmer temperatures (Fig. 1); (ii) Despite a history of over 10,000 years of agriculture in the Gangetic plains, soil erosion is not a major environmental issue because of continuous flow and spread of slit from mountains to plains; (iii) People scoop out soil and make bricks in plains for several years, then again start growing crops; (iv) Some of the most productive ecosystems of the world are in the first plains that surround Himalayas presumably because water, soil and nutrients that Himalayan forests generate move down and are trapped in them. Himalayas are globally important for its biodiversity, the region has about 10,000 plant species with 3,160 being endemic (Conservation International, 2015). Many of the species, including lichens, morels, medicinal and aromatic herbs, trees and shrubs are in trade.

Himalayas have more snow and ice (61,000 km^2 area under glaciers) than any other parts of the world outside the two poles (Singh *et al*., 2011). How climate change- induced glacier melt and snow depletion and construction of proposed dams are affecting ecosystem services is poorly known.

This paper (i) seeks to review and integrate some established features of climate change in Himalayas; (ii) summarises impact of climate change on various components by selecting some relevant examples, and (iii) discusses briefly complexities in generalizing research findings in the region. The main approach is to cover various aspects connected with global climate change in the region to give an over view. Needless to say, it has not allowed us to go for an in-depth analysis. We have particularly argued that pre-monsoon (March-May) warming and the resultant drought is likely to be a factor of critical importance in several spheres of Himalayan ecosystems and human life. It may even counter the positive effect of warming on plant growth in cold areas, by intensifying drought stress.

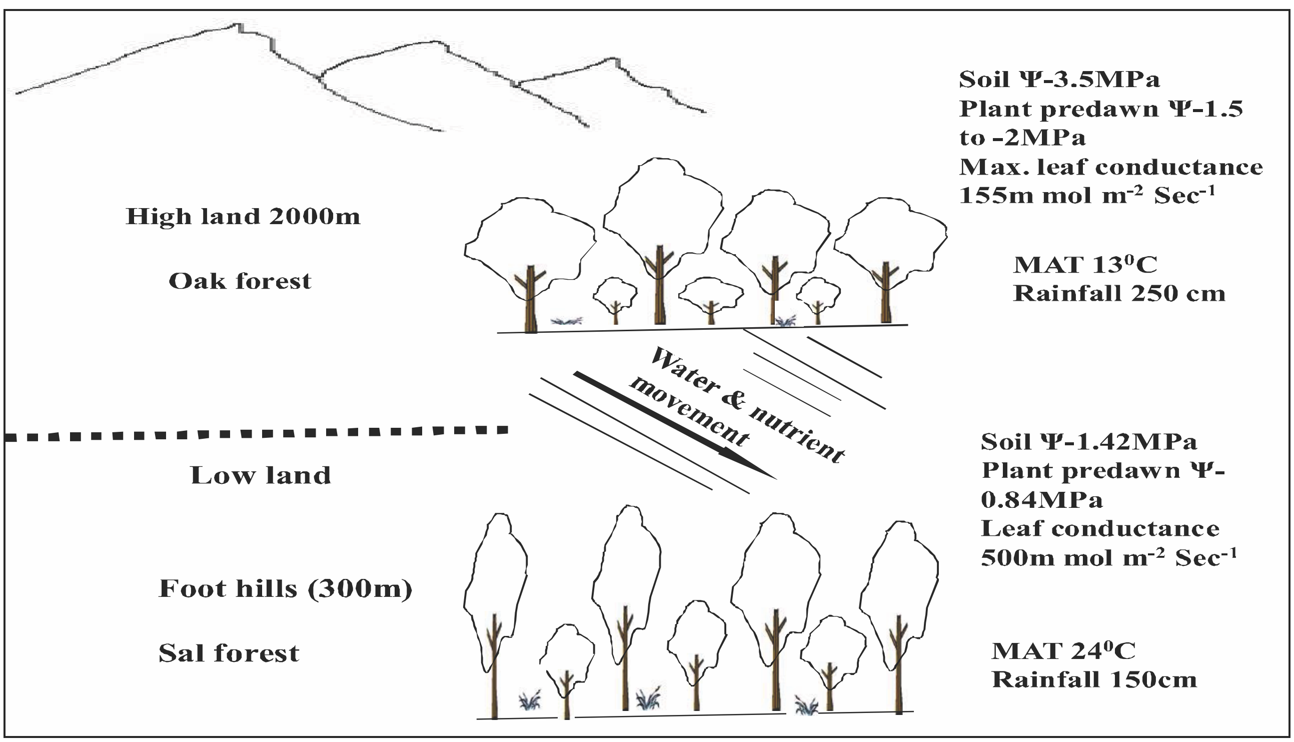

Fig. 1: A comparison of highland and lowland forest ecosystems in a central Himalayan region with regard to tree water status. The lowland sal (*Shorea robusta*) forest has markedly higher water status, despite lower precipitation and higher temperature than highland oak (*Quercus* spp.) forest, indicating flow of water and soil from mountains to the plains forest area. (MAT=Mean Annual

Table 1: Some recent trends of climatic change concerning warming and precipitation in Himalayas (plus Hindu Kush, HKH).

- Warming rate in the HKH is increasing more than global average; however, the rate varies considerably across the regions. For example, Tibetan Plateau (TP) is getting warmer more at rates 2-3 times global average rate (Ren *et al*., 2017).
- The rate of temperature rise has increased with time, e.g., in Tibet Plateau (TP), the mean temperature rise was 0.16°C/decade between 1955-1996 and 0.32°C/decade between 1961-2012; thus doubled the previous rate (Liu and Chen, 2000).
- Distinctly warmer events have increased and distinctly colder events declined during last several decades (Singh *et al*., 2011).
- Generally, temperature rise is more during winters and in nights (minimum), resulting in narrower seasonal diurnal temperature ranges.
- Recent data on Temperature Lapse Rate (TLR) with increase in elevation is lower (0.53°C per 100m increase in elevation) than generally estimated in past, so temperature of high mountain areas are greater than assumed. Elevation dependent amplification of temperature might be one of the major contributors to decrease in TLR.
- Western disturbances have strengthened, resulting in more expansion of snow and glacier in Karakoram and some other areas. Increase in winter precipitation in Karakoram but decrease in much of the Himalayas, particularly in Central Himalayas, are being observed (Singh *et al*., 2011).
- Monsoon rainfall is predicted to increase, but it has been declining since 1979 in Himalayas (Yao *et al*., 2012).
- The events of heavy rainfall have increased and those of light showers have decreased in many parts of the Himalayas (Deshpande *et al.*, 2012).
- Extreme events will become more violent.

2. Himalayas are Warming Rapidly

Himalayas are warming at rates two to three times more than global average rate (Table 1), and in Tibet Plateau the rate of warming is particularly high (Yao *et al*., 2012). At Mukteshwar, Uttarakhand state of India, the minimum and maximum temperatures have increased at a decadal rate of 0.65° and 0.25°C, respectively during last three decades or so (G.C.S. Negi, unpublished data).

The rate of temperature rise increases with altitude in most of mountains of the world (EDW Working Group, 2015) because of several reasons, and this trend is particularly evident in Tibetan region (EDW Working Group, 2015). The aerosols consisting of organics, minerals, dust, metals and inorganic pollutants having cooling effect, are in higher concentrations in low altitude areas than in high altitude remote areas (Kuniyal *et al*., 2005; Bonsoni *et al*., 2012). Decrease in snow cover in high mountainous areas due to the global warming results in a decrease in albedo and higher absorption of solar radiation, and consequently in a higher temperature rise (Fig. 2). This difference in the rate of temperature rise between lower and higher elevations can lead to lower temperature lapse rate (TLR) along the elevational gradients in Himalayas. The recent TLR estimates (under a coordinated Indian Himalayan Timberline Research Project, IHTRP[1]) based on observed temperature data are consistent with this. At Tungnath, Uttarakhand the winter TLR observed in above mentioned collaborative project of ours is 0.46° and 0.36°C/100m elevation for North-West and South-East aspect while values elsewhere in past are generally above 0.5°C (Rajesh Joshi and Co-workers, IHTRP, unpublished data). If EDW were to stay, TLR will become more milder and species and vegetation distribution along elevation greatly modified. These complex processes along the elevation gradients may combine to expand species elevation ranges, form novel associations, and shrink alpine meadows, where so many native/endemic medicinal and aromatic plants occur (Dhar, 2002).

3. Glacier Melt

In Indian Himalayan region alone the extent of glaciers is 23314 km^2 (Kulkarni and Buch, 1991). That is why how global warming is going to affect glaciers in the region is a matter of great interest and concern. In fact,

[1] This is a major research project on Indian Himalayan Timberline under National Mission on Himalayan Studies of the Ministry of Environment, Forests and Climate Change, Government of India.

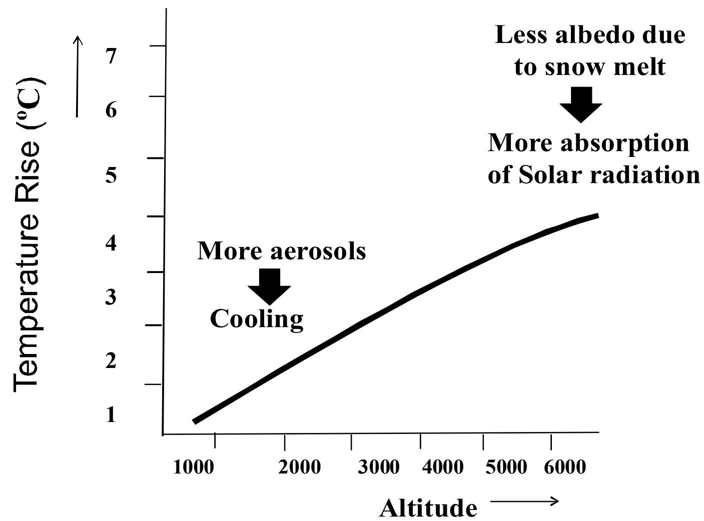

Fig. 2: Under the influence of climate change, temperature rise increases with elevation in mountains of the world; it applies to Himalayas. Though reasons for this elevation dependent temperature rise are still not well understood, change in albedo in high elevations and increase in aerosol concentration in atmosphere in low elevation are suggested to be partly account for it.

in recent years Himalayas are more in news because of glacier shrinkages and disasters, partly because even research journals tend to pay more attention to a alarmist view. Are glaciers going to disappear, and when they disappear what will happen to our rivers, and the springs which feed them and on which local people depend heavily for water? A very small fraction of glaciers of the region are being monitored. Remote sensing can be effective in measuring changes in glaciers, but without ground truthing the data generated are unreliable.

Data on glacier measurements generate controversies, first, because of the extent of reliability of methods, and the second, because the region is highly heterogeneous; data of one site are often not applicable to other sites. As for techniques, glacier tip based observations are easy to collect, but they are less

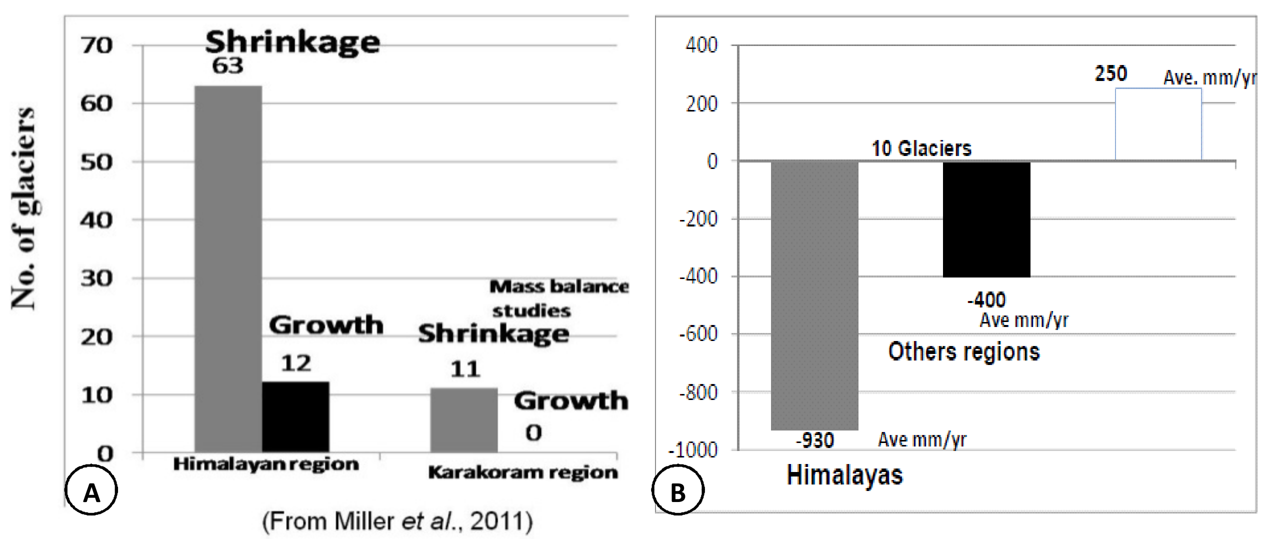

Fig. 3: Summary of change in glaciers. (A) Based on 75 glaciers from Hindu Kush Himalayas (from Miller *et al*., 2011); (B) From Third Pole study (Yao *et al*., 2012; Bajracharya, 2015; Kulkarni *et al*., 2013).

reliable indicator of change in glaciers. Mass balance method is reliable, but is far more time and energy consuming. Environmental conditions in Karakoram where glaciers were reported to be swelling (or not shrinking) are different from those of Himalayan regions where glaciers are mostly shrinking. In Karakoram and some other extreme western parts, moisture is largely driven by westerlies (wind blowing from the west), which have become stronger in recent decades, while monsoon which influences much of the Himalayas has weakened during last several decades (Yao *et al*., 2012). It seems that the role of moisture is also critical in relation to glaciers (Bajracharya *et al*., 2015).

In an analysis, based on 75 glaciers, Miller *et al*. (2011) showed that 63 glaciers were shrinking and 12 showing growth (Fig. 3A); all the 11 mass balance based measurements, which are most reliable, indicated glacier shrinkage; and none of data showing glacier swelling was based on mass balance measurement (Fig. 3B).

A third pole environmental programme study has shown that glaciers in Himalayas are depleting rapidly, on average at the rate of 930 mm/yr, than the glaciers of adjoining areas, at the average rate of about 400 mm/yr; and only one glacier, in Pamir, gained in mass, at the rate of 250 mm/yr (Yao *et al*., 2012). Another data set based on 7,090 glaciers of south-east Tibet, Central Himalaya and Western Himalayas indicates a loss of 1232.8 km^2 area from 1970s to 2000 (Yao *et al*., 2012).

By deciding to establish a glacier institute, Department of Science and Technology, Government of India has made a good beginning to address this problem. The glacier institute is unlikely to deal alone with the huge task of glacier monitoring and glacier and snow-melt hydrology. The institute should take a lead in organizing a network of researchers in the country to monitor glaciers, snow and permafrost. Communicating to lay persons about cryosphere is important, as glacier melt and glacier lakes which result from them often create controversies and doubts. High elevation springs and treeline communities and ecosystems need also to be studied by the institute.

4. How Glacier Melt is Affecting River Discharge?

The principal time of river discharge varies considerably from one region to other; it is spring in the snow-dominated Kabul, summer in glacier dominated Indus, and monsoon months in Ganga, Brahmaputra and Salween (Table 2). In the last group of rivers, snow-melt dominated during the first monsoon month (July) and rain during later monsoon months (August-September). These rivers, thus are being affected differently because of climate change (Bookhagen and Burbank, 2010). For example, in the case of Ganga and Brahmaputra rain may combine with snow melt water to cause floods during monsoon months. It is expected that for several more decades, river discharge due to glacier melt will not be affected, as the warming-induced increase in glacier melt water will be compensated by reduced glacier size, or reduction in glacier melt water may be compensated by increased precipitation such as in Indus basin.

Table 2: Contribution of glaciers and snow to the total discharge in some major river systems of Himalayas (Compiled from Alford and Armstrong, 2010; Bookhagen and Burbank, 2010; Immerzeel *et al*., 2012)

Ganga basin, from Nepal catchment 2-20%
Brahmaputra 21.1%
Indus 60% (34% from snow melt + 26% from glacier melt
*However, data suffer a lot from the lack of meteorological stations in higher reaches, and poor quality of glacier-hydrological modelling.

How these rivers are likely to be affected by the loss of glaciers and snow depends on their contributions to river discharge? The most severely affected river will be Indus, where glacier melt (26%) and snow melt (34%) together account for 60% of river discharge. In others, the river discharge is primarily monsoonal, so they are less likely to be affected by glacier and snow disappearance (Immerzeel *et al*., 2010). However, local people who depend on springs and streams to meet their water needs during summer months, may be greatly affected by the loss of snow.

5. Glacier Lakes Outburst Floods and other Climate Change Induced Disasters

In Himalayas climate change adaptation is largely a issue of managing flowing water- primarily to preventing damages that uncontrolled flowing water can cause during monsoon months, and retaining water for human use during the rest of 8 to 9 months where there is little rainfall. Glacier Lake Outburst Floods (GLOFs), cloud burst or excessive rainfall events, all can be highly destructive to infrastructures like roads, bridges and buildings. Glacier lakes are moraine-dammed lakes formed beside the lateral moraines and at the front of glacier tips. Glacier and snow melt water coupled with heavy rains can break the moraine dams, and release a huge amount of water and debris, called Glacial Lake Outburst Flood (GLOF), which can be very destructive. There are 1268 glacier lakes larger than 2500 m^2 area in Uttarakhand, located between 2900-

5850m (Bhambri *et al*., 2015). Yamuna basin has 7.6 km^2 area under glacier lakes, Alakhnanda basin 3.4 km^2 area, and Bhagirathi basin 1.6 km^2. The moraine dammed, lake, Chorabari contributed substantially to Kedarnath disaster of 2013.

As for precipitation, things are more uncertain. Earlier predictions were for increased precipitation, however, in last three decades precipitation generally decreased. Mukteshwar data indicate that the annual precipitation has not changed, but pre-monsoon period (March- May) has become drier (G.C.S. Negi, unpublished data).

Being young and rising, Himalayan mountains are unusually vulnerable to landslides and slope instability. Since the number of days with high intensity rainfall is predicted to increase, climate change is likely to increase frequency and intensity of landslides, overflow of rivers and floods (Table 3). Not all disasters might have climate change connection, but higher disaster frequency in recent years is consistent with climate change predictions.

Such destructions speed up out migration and affect tourism and other economic activities over long periods. The June 2013 Kedarnath disaster not only induced migration to plains from affected areas, but it also shifted settlements within mountains. Many capable people left mountains for plains (Sharma *et al*., 2014).

6. Intensification of Pre-monsoon Drought a Critical Factor

There are now several evidences to suggest that the intensification of pre-monsoon (March to May) drought is becoming a major climate change factor. Warmer temperatures without additional water affect plant growth adversely even in a cold region. Some of the observations which are related to warmer and drier pre-monsoon period are as following: (1) Spring drying and water scarcity, particularly during pre-monsoon period; (2) Unusually higher decline in water level in water bodies, such as Nainital lake; (3) Widespread fires in the years of drier pre-monsoon months (Singh *et al*., 2016); (4) Negative relationship of tree ring growth with temperature of pre-monsoon period and positive relationship with pre-monsoon rainfall (Dawadi *et al*., 2013; Gaire *et al*., 2014; Ghale *et al*., 2017); (5) Desiccation of banj oak (*Quercus leucotrichophora*) seeds to the extent that they fail to germinate by the time rains arrive (Ashish Tewari, unpublished data). Though not yet investigated, drying up of spring is likely to make a forest more inflammable. How fire affects a

Table 3: Six major disasters between 2010 and 2014: in Indian Himalayan Region (from Singh and Sharma, 2014; Disaster Data and Statistics, NDMA, 2017).

Type	Year	Affected town	Impact
Flash Flood after heavy downpour	2010 (August)	Leh	255 killed, Several missing. Estimated Damage Rs. 1.33 billion.
Flash Flood	2010 (September)	Almora & Nainital	Loss of property. Road blocked for several days.
Heavy rainfall and Landslide	2012 (August)	Shimla	Two evacuated houses collapsed in Totu area of Shimla following heavy rainfall.
Flood	2012 (August-September)	Uttarkashi, Rudraprayag and Bageshwar	52 killed
Thunderstorm accompanied by strong squall	2013 (May)	Aizawl	10 killed, few missing, Injured 16 People.
Flood	2013 (June)	Kedarnath, Srinagar & Several others areas	Thousands died as well as missing. Heavy loss of property and infrastructure, Rs.250 billion.
Flood	2014 (September)	Srinagar & Jammu	Still nothing is certain. Rescue operations are in place.
Cloud burst	2017 (August)	Malpa, Pithoragarh	28 killed, few missing; damage to roads and other constructions.
Heavy rainfall and flood	2017 (August)	Kotdwar	9 killed; damage to roads.

Table 4: Water sources based on a survey of 45 towns/cities (31 Uttarakhand 10 Himachal Pradesh, Meghalaya, 1 Sikkim, Arunachal, 1 Jammu & Kashmir) (from Singh and Sharma, 2014).

Category	Number of towns/cities	Examples
At least some dependence on water of springs and streams	45	All towns surveyed
Entire dependence on springs and streams	17	Shillong, Gangtok, Itanagar Mussori,
River water lifting from a distant place along with other sources	7	Manali, Almora, Ranikhet,
Water from river at the bank of which city is located, along with others	10	Bliaspur (HP), Srinagar (Garhwal) Bageshwar, Devprayag,
Stream, spring and ground water	9	Palampur, Solan, Berinag,
Lake	2	Srinagar (Kashmir), Nainital

spring is not investigated?

Spring drying is a major problem not only in rural areas, but also in cities, particularly in tourist towns like Shimla, Mussorie and Gangtok of India. It may be pointed out that climate change is simply one of the several factors that account for spring drying. A preliminary data compilation indicates that of the 45 cities/town for which information was collected, all depend on spring water to an extent, and 17 are entirely spring-dependent (Table 4).

The interesting point is not that springs are no more able to meet water demand of cities like Shimla and Mussorie, but that they have been supporting them for more than a century. Scientists are required to address several questions related to springs to develop a package of solutions. First, could springs be 'tamed' enough to get water in a regulated way? Second, what is the realistic assessment of spring as a source of water and to what extent water yield could be increased by treating spring-sheds? Third, what are co-benefits or co-ecosystem services of spring-shed restoration and, are they enough to justify watershed treatments for reviving and maintaining springs? To understand the functioning of springs we need to understand the related geological, biotic and soil components, apart from precipitation. It seems that the lean period spring water output could be raised by 20% or so at a large area basis (Negi and Joshi, 1996; Tambe *et al*., 2012). Then, what could be other water sources if springs can only partially meet people's needs of water? River water lifting is already in practice in Almora and recently Shimla has also gone that way. What is the scope of recycling water, water harvesting, and creating new cities keeping in view water sources? These questions need to be addressed.

In a way, springs' main role is to provide water after monsoon months, during dry periods. Forest degradation is one of the causes of spring extinction, and drying springs, in turn cause forests to degrade. Restoration of a degraded forest and treatment of slopes to retain water longer can improve spring water flow, and other ecosystem services, such as species richness, water interception by forest floor litter, carbon sequestration in increased forest biomass and others. The relationship between ecosystem services, such as spring water, and recreational service of lakes and forests and mountain urban sustainability should be made explicit in policies and practices (Table 5).

Table 5: Mountain springs: Policies and practices.

- Institutionalize ownership and management of springs.
- Map springs and monitor them with the help of local people by developing citizen science.
- Evaluate and promote co-ecosystem services of springsheds, such as increase in biodiversity, carbon sequestration, and recreation connect them with accounting systems.
- Explore the scope of springs and stream-and waterfall based tourism, and ensure sustainability.
- Orient human settlements in relation to spring water supply and spring shed conservation. Declare that mountain cities are more ecosystem services supported systems and manage them accordingly. Let spring water availability decide the location and size of human settlements, instead of allowing the growth of settlements to force to supply from any source at any cost.
- Time has come to decide whether tourism should be supported at any costs, including costs of deterioration in life of local people, and permanent damage to water sources.

Tourism activities in cities like Nainital and Mussorie or Shimla have considerable environmental costs, adversely affecting the life of local people and posing threat to sustainability. In Nainital, the lake water level declined by about 6 m during pre-monsoon months of 2016, which make the principal tourist season. It is largely because of (i) increased consumption of lake water; (ii) increased evapotranspiration loss due to climate warming; (iii) deterioration of Sukhatal, a valley fill, supplying a considerable amount of subsurface flow water to lake Nainital; (iv) drying of springs;(v) deterioration of slopes, which results in increased runoff (roof tops and roads are impervious surfaces to water infiltration), and (vi) some reduction in the amount of water returning to lake after domestic use.

The contribution of Sukhatal to lake Nainital hydrology was established by a research carried out by National Institute of Hydrology. The research findings were constantly communicated to different groups of decision makers by scientists and Centre for Ecology, Development and Research, Dehradun, and earlier by Central Himalayan Environment Association (CHEA), Nainital. But Sukhatal continued to deteriorate and lose its function of providing subsurface water to lake, like a kind of spring. Scientists are often asked about the usefulness of their research. Here, a useful research was not only carried out but was also communicated along with repeated appeals and applications from various stakeholders and sensitive groups, but little attention was paid by administrators.

Pre-monsoon is also the time of forest fires. Though the fire scale and intensity are driven by several factors, a decline in pre-monsoon precipitation and warmer temperature have increased both frequency and area affected. Fire incidents are fewer in the years with more pre-monsoon rains (Fig. 4).

How much drying of springs contributes to fires and how much fires contribute to the drying up of springs have not been investigated, but they are likely to be interconnected to an extent. Fire and smoke pollute air, and deteriorate living condition for local people and tourists. Wild animal mortality is partly related to the water shortage in forests during a fire incident.

7. Impact of Climate Change on some Biotic Features

The elevations of the uppermost trees in a mountain site make Alpine treelines (Fig. 5). Since tree growth stops in high mountains because of heat deficiency, climatic warming is expected to raise treeline elevation. Little research has been done on Himalayan treelines, though the highest treeline of the Northern Hemisphere occurs in Himalayas-*Juniperus tibetica* at 4900 m in Tibet (Miehe *et al*., 2007). The lack of facilities in remote high mountains is one of the major reasons of it (in Europe a treeline may occur even at 1000 m because of high latitudes). Himalayas have all form of treelines (Fig. 5), generally formed by species of *Abies* (fir), *Betula* (birch), *Juniperus* (juniper) and *Rhododendron*.

Studies on tree ring width chronology (Dawadi *et al*., 2013; Gaire *et al*., 2014) indicate that whether a treeline moves up a slope in a warming world, partly depends on pre-monsoon conditions. Warming alone

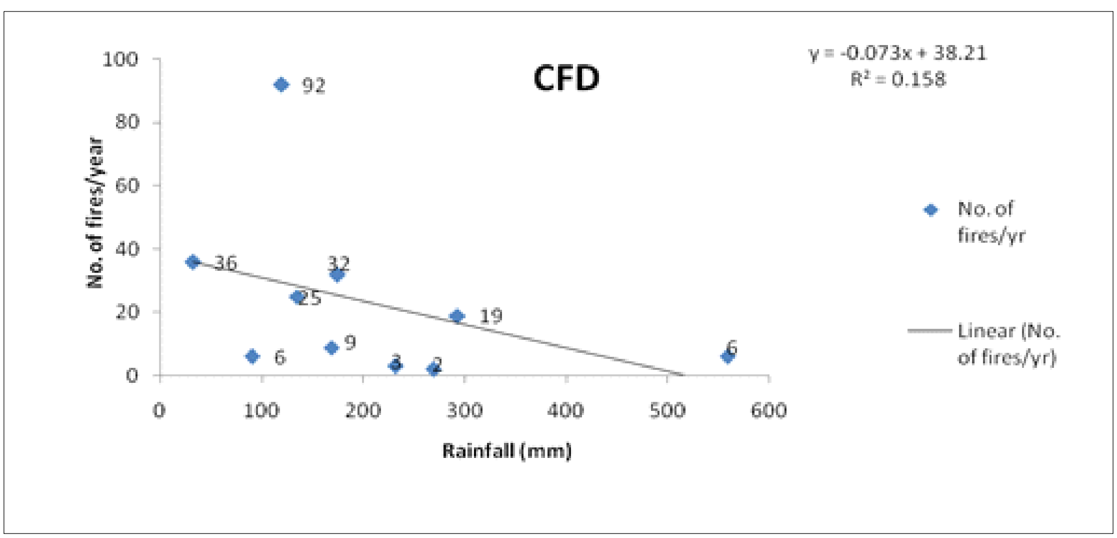

Fig. 4: Relationship between fire incidences and rainfall during pre-monsoon season (March to mid-June) across the years, from 2004-2013 in Chamoli Forest Division (CFD). (Source: Singh *et al*., 2016).

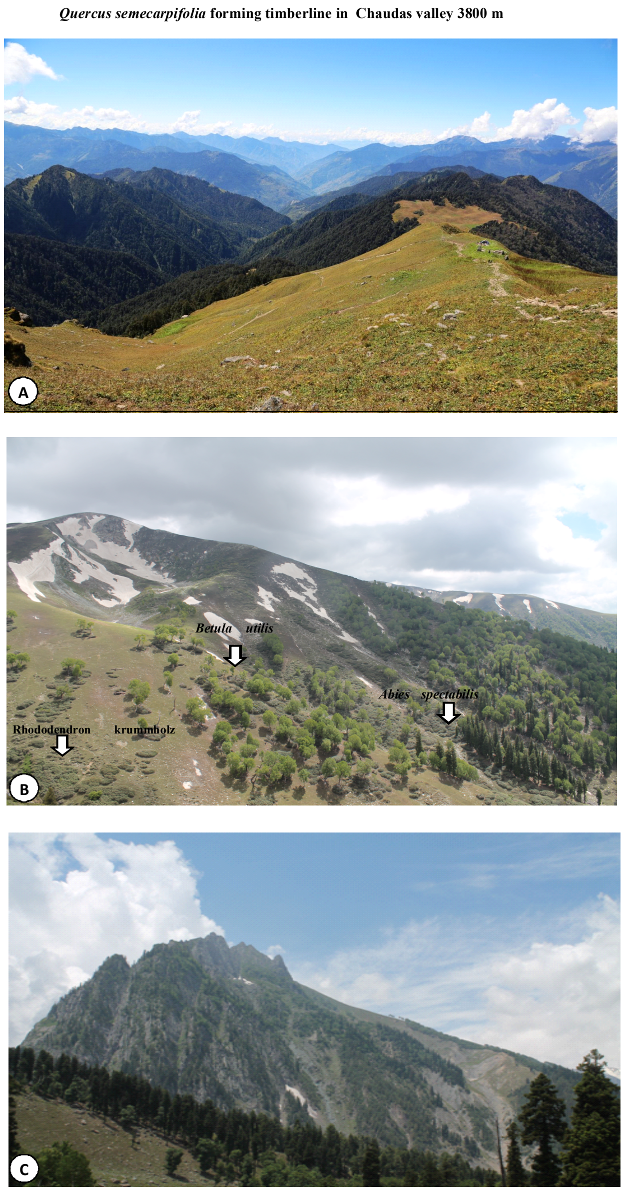

Fig. 5: Various forms of treeline: (A) Abrupt treeline (Picture courtesy: Dr Vikram Negi, GBPNIHESD); (B) Diffuse treeline (Picture courtesy: Dr. Subrat Sharma, GBPNIHESD); and (C) Finger like treeline (Picture courtesy: Dr. Subrat Sharma, GBPNIHESD).

may, suppress treelines by causing soil water deficiency. Treeline advancement, thus requires pre-monsoon rains. At several sites treelines have gone higher possibly because of reduced grazing. Grazing in Alpine meadows has kept treeline low as tree seedlings recruited in Alpine meadows are damaged by sheep and goats (Suwal *et al*., 2016). Research in treeline dynamics warrants long term, multi-site, multi partner research. Changes in treeline elevation would have consequences for herb species diversity, soil carbon and several vital ecosystem processes.

Studies on treeline landscapes call for an ecosystem approach; a treeline is not simply a landmark, treeline ecotone needs to be treated as an assemblage of physiognomically diverse communities. Within a few hundred meters, one can find fir (*Abies spectabilis*) forest stands with close canopies; open birch (*Betula utilis*) patches, scattered individual trees; stands of twisted, tilted and stunted trees, called krummholz, such as of *Rhododendron campanulatum*; juniper mats, and herbaceous communities of different forms and composition, such as tussock grass and forb communities.

Species growing in treeline and near summits can be in problem because of climatic warming if space above their occurrence is limited. *Quercus semecarpifolia*, a major evergreen oak of high elevation forest belt is one such species. It is distributed in island like fashion near summits with distances 30-70 km. Warming of another 1°C temperature from 2010 can halve its area in a longer run (Singh *et al*., 2011). This oak species has not been regenerating well because of growing pressure for quite some time. Climate warming and grazing together might drastically affect its distribution (Fig. 6).

Impact of pre-monsoon drying due to climatic warming is seen on banj oak regeneration. Banj oak seeds mature and fall during winter months, remain on forest floor for several months and germinate only when monsoon arrives or there are pre-monsoon rain showers. But because of global warming oak acorns get desiccated well before rains arrive. Forest floor litter removal makes conditions drier for oak acorns lying on ground. Banj oak being a foundation species needs to be given importance in management of forests in view of climate change. To what extent pre-monsoon drought can affect vegetation, and to what extent species affected by deficiency of heat in high mountains are going to be benefitted by warming in combination with increased droughts are some of the key points that will influence species dynamics in Himalayas. A severe drought, as observed in 1999 in Uttarakhand, can reduce tree water potential more than twice of the normal water potential. In a population of *Quercus floribunda* tree water potential declined to -5.5 MPa in summer, compared to normal year level of about-2 MPa, driving many young trees at the verge of mortality (Singh *et al*., 2000).

Because of high species richness and endemism in the eastern Himalayas, climate change could result in considerable biodiversity loss in that region, which intersects three global biodiversity hotspots and has 25

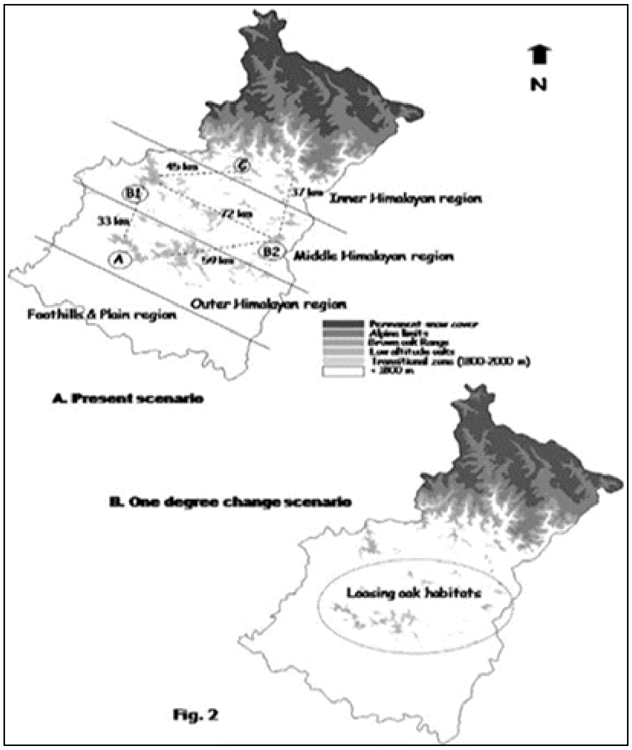

Fig. 6: Example of how warming temperatures can lead to the disappearance of certain species: The Kharsu oak (*Q. semecarpifolia*) which occurs in isolated islands separated by 30-72 km is predicted to be halved with a warming climate (Source: Singh and Sharma, 2014).

eco-regions (Chettri *et al.*, 2008). It is a home to several globally significant species of mammals (45 species), birds (50 species), reptiles (16 species), amphibians (12 species) and plants (36 species) (CEPF, 2005). Its alpine flora, particularly around mountain summits is highly endemic, and vulnerable to global warming (Sharma *et al.*, 2009). Evidences are there to indicate that many herb species are faced with the problem of the contraction of their elevational ranges under the influence of warming because they are poor dispersers (Telwala *et al.*, 2013). Telwala *et al.* (2013) emphasized that between 1849-1850 and 2007-2010, 87% of 124 endemic plant species studied in Sikkim showed upslope shifts in the range of 23-998 m due to the ongoing warming. These data suggest that species assemblages in high mountains of Himalayas are not the same as in earlier centuries. How these changes have affected ecosystem structure and functioning needs to be investigated.

8. Agriculture in Mountains

Agriculture in relation to climate change in mountains is a complex subject, and beyond the scope of this article which is about giving an overview. In general, agriculture abandonment because of non-viable land holding sizes and lack of irrigation is already quiet common (Singh *et al.*, 1994; Rao and Pant, 2001). Climatic uncertainties, by making things more difficult, may induce more abandonment of agriculture, at least in states like Uttarakhand.

Growth of apple cultivation in Himachal during the last decades of the 20th century is one of the major success stories; state-sponsored development it raised the living standard of a large number of families. There are indications that in Shimla and Kullu valleys, farmers are finding difficulties in sustaining apple cultivation because of warming temperatures and, uncertain and extreme weather events. Apple requires 1200-1500 hours of chilling, which is now available at 2700 m and above (Basannagari and Kala, 2013) because of global warming. There are evidences to suggest the shift of apple cultivation to higher valleys like Lahul-Spiti, in Himachal. This can be called a kind of adaptation at a regional level, however, increase in cultivation in Lahul-Spiti is unlikely to compensate for decrease in apple cultivation in Shimla and Kullu valleys. However, at individual level, shifting to other crops and other economic activities may be a preferred option. Relatively rich apple farmers in Shimla have begun to grow other fruit crops and take up other economic activities, resulting in fall in the contribution of apple to their earnings (Table 6). Shifting a complex infrastructure of apple cultivation and trade from one area to another has enormous costs and difficulties. Uttarakhand, Nepal and eastern Himalayan states might need to think about cultivating tropical crops like mangoes in valleys below 1000 m or so.

Cultivation of mangoes in these valleys may contribute to prolong the mango season in the country, as mangoes are likely to ripen up to September -October or so. The more important point is to think differently in view of the fact that geographical area of tropical fruit crops is to increase in Himalayan region.

The climate change impact on cash crops could be seen also in the eastern Himalayan state of Sikkim, where large cardamom production dropped sharply after 2004. Though several reason for the decline in production are given, the role of altered seasons, erratic rainfall, prolonged dry spells, temperature increase, soil moisture loss, and increasing instances of disease and pests were quiet prominent (Sharma *et al.*, 2016). Presumably, because of these climatic factors, the annual production of large cardamom at country level increased from 16.70 thousand tonnes in 2003 to 20.72 thousand tonnes in 2015 and in Sikkim it declined from

Table 6: Apple cultivation in three major valleys of Himachal Pradesh (Source: Rana *et al.*, 2008).

Valley	Mean annual temperature (°C)	Orchard area /household/yr		Income from fruit (% of total income	
		1995	2005	1995	2005
Kullu	17	0.55	0.45	69.9	39.6
Shimla	15.4	0.62	0.60	59.3	32.8
Lahul-Spiti	<14	0.48	1.09	17.2	29.1

5.10 thousand tonnes to 4.08 thousand tonnes during the same period. While at the country level, the area under large cardamom increased from 95.60 thousand ha in 2003 to 99.20 thousand ha in 2015, it decreased from 26.73 thousand ha to 23.41 thousand ha in Sikkim during that period (Agriculture Statistics at a Glance, 2014).

9. Climate Change Justice

Very low ratio of per capita CO_2 emission from fossil fuels to the burden of climate change impact is a common feature across the Himalayan region. Per capita fossil fuel CO_2 emission of India is among the lowest in the world, less than 2 t CO_2, compared to global average of ~ 4.7 t CO_2 or so. It is ridiculously low in Himalayan countries and states (0.4 t CO_2 for Nepal), substantial part of forests in Himalayas sequesters carbon, and the rivers of the region are tamed to generate hydropower used also by regions outside Himalayas which favourably contribute to their carbon budgets. It is quite possible that some Himalayan regions are net carbon sequesters, that is their fossil fuel CO_2 emissions are less than CO_2 saved by electricity generation plus forest carbon sequestration. However, people in Himalayas suffer most as a consequence of climate change. Cloud burst, GLOFs, avalanches, landslides, forest fires, road disruption and road blocks, water scarcity, and crop failures. The cost of infrastructure development in Himalayas is much higher than in plains, and often because of the shortage of finances their quality does not correspond to the requirements in a geologically fragile region. The extra finances required should be made available to mountain states to develop better roads, stable slopes, and climate change proofing. An example could be the construction of roads on high columns through forest areas to allow safe movements of wild animals, such as elephants and in mountain cities for pedestrians, as the roads meant for walking of people are now occupied by automobiles.

10. Conclusion

The Himalayan region was referred to as a 'white spot' in the context of climate change by Intergovernmental Panel for Climate Change (IPCC), emphasizing the lack of data. During last five years or so, however, data gaps have begun to be reduced. Recent data indicate that Himalayas are to warm at higher rates than global average rates, and temperature rise in some parts is predicted to be extraordinarily high. Glaciers are likely to continue to lose mass, and extreme events may become more violent, if not more frequent. Pre-monsoon drought may intensify, and affect such vital processes like spring flow, seed germination of important tree species, forest fires and tourism. Some interventions which directly improve the condition of local people could bring about positive change in forest carbon sequestration and biodiversity.

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