Chapter–2

Climate Change over the Himalayan: Shrinking or Advancing the Glaciers!

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1. INTRODUCTION

Nature is our mother. People were worshiping the nature in ancient year. Climate is an integral part our nature. As due to some man-made activities by the name of civilization and the developmental process through the industrialization and urbanization, our climate is changing and our mother nature stands in a dangerous state. The causes of climate change are global warming and hugely deforestation. Climate change is a serious threat to the whole globe whiles the Himalayan region comprising the some parts of the states of Afghanistan, Bangladesh, Bhutan, Chaina, India, Myanmar, Nepal and Pakistan are project to be adversely affected by the global warming and climate change. The Himalayan is considered to be very young mountains, 30 million years old, compared to the age of the earth 4500 million years and the Indian peninsular shield 600 million years. The Himalayas covers of an area of 130,000 sq km with altitude ranges from 1500 to 3600 m. The numbers of countries namely Afghanistan, India, Nepal, and Pakistan constitutes the large mountains. Three states of India namely Uttarakhand, Jammu & Kashmir and Himachal Pradesh constitute the Western Himalayan Region of India. Several sectors like agriculture, forestry, hydrology, glaciology and water resources, *agro-ecosystems, socio-economic and animal and human health,* are highly vulnerable to the adverse effect of climate change.

2. IMPACT OF CLIMATE CHANGE

There would be drastic changes in the life style of several animals living in alpine areas. Negi et al. (2012) pointed out that research on climate change vis-à-vis its impact on ecosystems (e.g., forests, water, agricultural resources, etc.) is still in an infancy stage in the Himalayan Mountain. Research on assessing the climate change over Himalayan region is really a challenging task as meteorological data availability and the data quality is uncertain (Joshi and Negi 1995). It is to be mentioned that a paucity of long-term climate data in the region, and data recorded do not employ uniform instrumentation and methodology. Very limited studies are available which could demonstrate the impact of climate change on the mountain ecosystems. However, with the release of recent IPCC report on climate change also drew the global attention of the burning issues and its averse on effect on human civilization. Preliminary studies indicate that the Himalaya seems to be warming more than the global average rate (Liu & Chen 2000; Shrestha *et al*. 1999). Increase of winter and autumn temperature show greater amount than during the summer and other seasons and the increases are larger at higher altitudes (Liu & Chen 2000). The Indian Institute of Tropical Meteorology, Pune has reported a decrease in precipitation over 68 percent of India's area over the last century (Kumar *et al*. 2006). However, significant increase in rainfall was noticed in Jammu and Kashmir and some parts of Indian peninsula (Agarwal 2009). A study indicates that the mean annual temperature in the Alaknanda valley (western Himalaya) has increased by 0.15 ºC during the period 1960-2000 (Kumar *et al.* 2008). Satellite imagery suggests almost 67 % of the glaciers in the Himalaya have retreated (Ageta & Kadota 1992). For example, retreat of glacier in Hamalayan region in Nepal is as fast as 10 m per year (Ageta & Kadota 1992). The average temperature of Kashmir valley has gone up by 1.45 ºC over the last two decades (Sinha 2007). Impact of changing climate is also perceptible on vegetation. In some parts of the high altitude, The biodiversity is in the high altitude mountain is declining or endangered because of land degradation and the over use of resources, e.g., in 1995, about 10 % of the known species in the Himalaya were listed as `threatened' (IPCC 2002). However, impact of climate change on biodiversity and vegetation in the region is yet to be carefully studied to establish such a relationship. Exponential increase in green house gases (GHGs) like carbon dioxide,

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methane, nitrous oxide, water vapour, CFCs, etc., in the atmosphere has resulted in climate change change (World Climate News 2006). The concentration of CO_2, mainly responsible for global warming, has reached to 379 ppm in 2005 from its pre-industrial value (i.e., 280 ppm). The increase in GHGs between 1970 and 2004 was approximately 70 %. The mean temperature of the earth has increased by 0.74 ºC during 1901-2005. The sea level rose at the rate of 1.8 mm/ year during 1961 to 2003 globally, and recently it shows a faster (i.e., at the rate of 3.1 mm/year) during 1993 to 2003. Global average surface temperature could rise by 1.4 to 5.8 °C by the end of 21st century. Global mean sea level is projected to rise by 0.18 to 0.59 m by the end of the current century. Aerosols have been considered the primary cause for the increase of the Earth's atmospheric temperature. In Himachal Pradesh, aerosols optical depth (AOD), obtained through Multi-wavelength Radiometer (MWR) has shown highest ever AOD at 500 nm as 0.55 ± 0.03 in May 2009 which was 104 % more than mean AOD value from April 2006 to December 2009 (Kuniyal *et al.,* 2009). This value of AOD was found to be 0.056 ± 0.037 at Nainital (Pant *et al.* 2006), that is, far less to the values obtained at Kullu, indicating inter-regional variations in climate change within the Himalayan region. Temperature rise due to radiative forcing from aerosols in the atmosphere based on per unit AOD increase at Mohal-Kullu in Himachal Pradesh was reported as high as 0.95 kelvin (K) per day during summer (April-July) and as low as 0.51 K/ day during winter season (December, January-March) (Guleria*et al.* 2010). Climate change will have a wide range of health impacts across the Himalaya. For example, increase in malnutrition due to the failure of food supply, disease and injury due to extreme weather events (Epstein *et al.* 1995), increase in diarrhea diseases from deteriorating water quality, increase in infectious diseases and cardio-respiratory diseases from the build-up of high concentrations of air pollutants such as nitrogen dioxide (NO_2), lower tropospheric and ground-level ozone, and air-borne particles in large urban areas. Huge quantities of municipal waste produced in the western Himalayan region are further exaggerating the problem of emission, sanitation and associated health hazards (Kuniyal 2002).

3. GLACIAL AND CLIMATE OF HINDU KUSH HIMALAYAN (HKH) REGION

International Centre for Integrated Mountain Development (ICIMOD) for Asia Pacific Adaptation Network (APAN), published a summary report on the recent climate trends in the Hindu Kush Himalayan (HKH) region based on some review works over some specific locations. In general, mountains are highly sensitive to climate and sometimes referred to as a barometer of environmental changes. The IPCC (2007) has estimated that during the last century the global mean surface air temperature increased on average by 0.74°C but that increases varied from place to place. However, the temperatures in the world's mountains are increasing at higher rates compared to at plains. Knowledge of climatic patterns and changes in mountains are suffered by the constraint of temperatures and precipitation data which are scant. This is particularly true in the HKH region.

4. PROBLEM OVER HKH

The marked microclimatic variations with elevation and aspect in the HKH have been a constant constraint and challenge of collecting observational data over this vast mountainous terrain. A greater density of data sampling sites is needed to capture the details fine structure of local scale topographical features and local scale climate variability. Poor accessibility and low population density in the HKH resulted the less numbers of meteorological stations compared to other highly dense populated area. On the other hand, there is huge missing data records even from the stations that do exist. Analysing the trends is also challenging. There are a few hill stations in India that have archival data going back a century or more but, for the most part, these data are either lost or have not been analysed. Most archival meteorological data in the region extend back for only 50 years or less. The changes that have been reported in several studies are based on data records during the past half century. As for example, Dimri and Dash (2011) outlines key findings based on analysis of temperature data of winter (December–February) and precipitation data from 35 observation stations located between 2,192 masl and 3,250 masl in the western Himalayan region of the period from 1975 to 2006. Average temperatures increased over most of the region, as indicated by lower and higher percentiles of the daily maximum, minimum and average temperatures. Decadal trends indicate a rapid increase in the number of

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warm days (days with Tmax> 90th percentile) and warm nights (nights with Tmin> 90th percentile). The number of cold nights (percentage with Tmin< 10th percentile) has decreased. Precipitation is more erratic and difficult to predict its changing trends. The extremely complex topography makes it mandatory to survey a large number of meteorological stations in order to ascertain representative trends for the region. A distinct shift in precipitation from snow to rain was apparent. The longest number of consecutive dry days during winter increased and the longest period of consecutive wet days decreased. Temperature data collected from the mid-1970s from 49 stations in Nepal (Shrestha et al., 1999 and Shrestha and Aryal, 2011) indicate that the average temperature between 1977 and 1994 increased at a rate of 0.06°C per year. The rise in temperature was greater at the higher altitudes. In fact, the adjacent plains and foothill areas experienced only negligible warming. Increases in temperature were more pronounced during the cooler months (0.06–0.08°C per year from October–February in all of Nepal) than for the warmer months (0.02–0.05°C per year in March–September in all of Nepal). Using the relationship between glacial retreats and climate warming, scientists have found greater temperature rises in some glaciated areas in Nepal. For example, Kadota et al. (1997) estimated a 1.4°C temperature rise from 1989 to 1991 at the terminus of glacier AX010 in the Shorong Himal (at 4,958 masl) on the basis of rapid retreat of the glacier after 1989. Relatively smaller, but nevertheless considerable, temperature increases (average of 7 stations, 0.025°C per year) were recorded at the stations around the glaciers in the Dhaulagiri region during the last decades of the twenty-first century (Shrestha and Aryal, 2011). Few long-term data exist on climate change for the eastern Himalayas. The little data there are seem to indicate a moderate warming trend during the last decades of the twentieth century with the exception of one report which indicates a slight cooling (APN, 2003). Table 1 gives a summary of temperature and precipitation changes reported for the northeast Himalayas. In the Eastern Himalayas, the annual mean temperature (measured from 1975 to 2000) is increasing at a rate greater than 0.01°C per year or more; within this sub-region, the Yunnan Province of China, part of the Kachin State of Myanmar, and the northeastern states of India and Assam show a warming trend that is relatively less(≤ 0.02°C per year) and eastern Nepal and eastern Tibet show relatively greater warming trends (>0.02°C per year) (Shrestha and Devkota, 2010). The warming trend was more evident during the winter months (December– February), when it was about 0.015°C per year higher than the annual rate, and at higher altitudes.

Table 1: Changes in temperature and precipitation observed in the northeast Himalayas

Region or place	Changes in temperature	Precipitation	Source
Northeast Himalayas	+1.0 °C during winter and 1.1 °C during autumn over the last century	Small increase	Dash et al.. 2007
Southeast Himalayas	+0.008 to -0.06 °C per year from 1960 to1990		APN. 2003
Eastern Himalayas	Annual temperature changes from 1977 to 2000: +0.01 °C per year below 1,000 masl; +0.02 °C per year between 1,000 and 4,000 masl. +0.04 °C per year above		Shrestha and Devkota. 2010
Bhutan	+0.5 °C between 1985 and 2002 (non-monsoon period)	Uncertain	Tse-ring. 2003

Source: Singh et al., 2011

In the westernmost part of the HKH region, studies differ in their findings on temperature (Bhutiyani et al., 2009). Whereas Fowler and Archer (2006) reported that mean and minimum summer temperatures show a cooling trend beginning in 1961, Chaudhry and Rasul (2007) reported a non-significant increasing trend in the annual mean temperature in the mountainous areas of the Upper Indus Basin in Pakistan. In contrast, for the 47-year period from 1960 to 2007, Baluchistan reported a +1.15°C increase, Punjab reported a +0.56°C increase, and Sindh reported a +0.44°C increase. The seasonal trend in the Upper Indus Basin takes the form

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of rising summer and falling winter temperatures. Long-term data sets, from as far back as the late nineteenth century, showed significant trends in increasing annual temperatures in all three stations studied by Bhutiyani et al. (2009) in the northwest Himalayan region.

These areas have shown consistent trends of overall warming during the past several decades (Yao et al., 2006; Shrestha et al., 1999; Xu et al., 2007; Eriksson et al. 2009). Various studies suggest that warming in this part of the HKH region has been much greater than the global average of 0.74°C over the last 100 years (IPCC, 2007; Du et al., 2004). Data are scarce but one study in Nepal estimated that the average warming in Nepal was 0.6°C per decade between 1977 and 2000 (Shrestha et al., 1999).

Since the studies mentioned above are limited to isolated parts of the HKH region, they may not be representative of the region as a whole. Shrestha (2009) attempted to analyze the temperature trend for the last two decades of the twentieth century for the whole HKH region based on a reanalysis of data from the Climate Research Unit, University of East Anglia (New et al., 2002). This study showed that a major part of the region is undergoing warming at rates higher than 0.01°C per year. Lower rates but still considerable warming (0.01–0.03°C per year) is observed in the western Himalayas, Eastern Himalayas, and the plains of the Ganges basin. Greater warming rates (0.03–0.07°C per year) are observed in the central Himalayas and the whole of the Tibetan Plateau. There are some pockets of very marked warming in the northeastern Tibetan Plateau, southern Pakistan, and Afghanistan. The central part of the Himalayas shows a south–north gradient in warming rates. This is clearly demonstrated by the area averaged trends of three elevation zones (<1,000 masl, 1,000–4,000 masl and >4,000 masl) in the region. There were strong warming trends in all the three zones over the past one and a half decades, although the trend is greater at higher elevations (in the >4,000 masl zone) compared to the other two. The warming trend in all three zones is significantly greater than the global average. In fact, the HKH region is one of the world's hotspots in terms of warming trends. In the global record, the warmest year up to the year 2000 was 1998; in the HKH region 1999 was the warmest year and 1998 the second warmest year.

The HKH region stores freshwater in the form of glaciers and, for centuries, millions of people downstream have benefited from the glacial melt waters that feed the rivers downstream. In addition to providing freshwater, glaciers are repositories of information about climate change as they are sensitive to changes in temperature and precipitation. Bajracharya and Shrestha (2011) prepared an inventory of all glaciers larger than 0.01 km2 in the HKH region (except for China) based on Landsat7 ETM+ satellite images from 2005±3 and the SRTMZ DEM. (Data from China were integrated into the inventory through data exchange in collaboration with CARRERI/CAS). The results are summarised in Table 2 and show that the HKH region has over 45,000 glaciers with a total glacial area greater than 61,000 km^2 representing about 30% of the total glaciated mountain area of the world. This area is about double the previous estimate of 33,000–38,000 km^2 (Dyurgerov, 2005), and this is probably because earlier reports did not include the entire HKH region. The present analysis is still continuing and this number may be revised. The area of an average HKH glacier is just above 1 km^2. Over most of the region, glaciers were found to be predominantly the 'clean' type; debris-covered glaciers were mostly found in areas with a great deal of ruggedness.

Table 2: Estimated number and dimension of glaciers in the HKH region

Number of glaciers	**>54,000**
Total glaciated area	>61,000 km2
Ice reserves	6,000 km3
Percentage of the total glaciated area of the HKH	
Chinese Himalayan region (Qinghai-Tibetan Plateau)	48.9%
India	20.3%
Pakistan	18.2%
Nepal	7.0%
Afghanistan	4.4%

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Bhutan	1.1%
Myanmar	0.04%

Source: Bajracharya and Shrestha (2011)

Based on these huge storage of ice deposits, the HKH region is often referred to as the Third Pole because its vast stores of ice and snow are greater than in any other part of the world with the exception of the polar regions. Recent reports indicating the glaciers of the HKH region are shrinking, subsiding and retreating have focused the world's attention on the need to develop glacier inventories for the HKH region. A better understanding of the Himalayan cryosphere can give insights into the future of freshwater resources and can be an indicator of climate change that is taking place globally. Moreover, the loss of snow cover in the high mountains can be both an indicator and a cause of warming.

Since when snow cover is lost, the reduction in albedo can itself contribute to increasing temperatures. Gurung et al. (2011a, 2011b) have recently estimated the snow cover area in the HKH region for the period from 2000–2010 at 0.76 million km^2 and this accounts for approximately 18.2% of the total geographical area of the HKH region. The western HKH region has the most extensive snow-cover area on average because, in addition to having some of the highest elevations, it is at higher latitude and is also more subject to the influence of winter westerlies. In contrast to the noted reduction in the length of glaciers, the snow-cover area of the HKH region is estimated to have been more or less stable, or to have only decreased slightly during the decade of 2000–2010. Linear regression analysis of snow-cover area indicates a negative trend in inter-annual variation for the year 2002–2010 which is prominent in the central HKH region. The trend for 2001–2010 is positive in the western and eastern HKH region. A similar study showed a 16% decrease in snow-cover area in the Himalayas from 1990 to 2001 (Menon et al., 2010). During the decade of 2000–2010, snow-cover area and annual snowfall were significantly correlated, suggesting the influence of annual variation in circulation patterns. The snow-cover area during this period varied from both season to season and from area to area across the region. The snow-cover area in spring and summer time demonstrated a declining trend and in autumn an increasing trend. But the data are still insufficient to generate statistically significant results. Some studies predict that the snow cover of the Himalayan regions will decrease by 43–81% in 2100 if the annual mean temperatures at higher elevations in Asia increase by 1–6°C as predicted by the IPCC.

The data for glaciers which have been observed over a number of years are given in Table 3. Overall, a retreat of 15 m per year or less was recorded for about 70% of the glaciers studied. Most studies in the Indian Himalayas have been in the form of intermittent expeditions, and there is a lack of continuous long-term data. Much of the data on glaciers collected by the Geological Survey of India are still unavailable as they have been classified.

Table 3: Observed rates of glacial retreat in different parts of the Himalayas based on observations of glacier termini

Glaciers and Region	Rate of retreat (m/yr)
Kashmir and Himachal (India)	
Barashigri, Chandan Basin of Eastern Lahul	44
Tajiwas Nar, Sindh basin of Kashmir	5
Stock, Ladakh	6
Fanfstang, Bhara basin of western Lahul	12
Garhwal (India)	
Trisul, Nanda Devi sanctuary	10
Betharti, Nanda Devi sanctuary	8
East Kamet	5
Gangotri, Bhagirathi Basin	15
Santopanth – Bhagirathi glaciers complex, Alaknanda	12
Kumaun (India)	
Milam, Gouri Ganga basin	13.5
Poting, Gouri Ganga basin	5

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Shankalapa, Gouri Ganga basin	23
Sikkim (India)	
TistaKhangse, Tista Basin	8
Nepal	
Shorong region	2.7–2.3 (1978–1989)*
Khumbu region, 7 clean-type glaciers	30–60 (1998–2004)* 2.0–3.4 (1970s–1989)*
Exceptional rate in Nepal	71
Bhutan	
Luggyeglacier**	160
* mean for the period; **this glacier is in contact with a large glacial lake *Source*: Bajracharya et al. (2007); Fujita et al. (1998, 2001); Mukhopadhyay (2006); and Shrestha and Ayal (2011)	

Substantial decrease in the total area of glaciers and their accelerated fragmentation are noted in Bhutan and Nepal. Glacial depletion in Bhutan was 27% (measured in 2006–7) and 21% in Nepal (measured in 2008). Other investigators have reported a similar range of glacial retreat from various areas in the HKH region (e.g., Kulkarni et al., 2010; Nie et al., 2010). These regional estimates are mostly based on measurements of glacier termini and area.

In order to compare changes among glaciers, relative estimates are more useful than changes in absolute values which may be misleading. For example, a decrease in area at a rate of 50 m^2 per year in a 1 km^2 glacier is 2.5 times greater proportionally than a decrease of 200 m2 per year in a 10 km2 glacier. Reported area shrinkage has varied, on average, between 0.4 and 0.5% annually since the 1950s, while data on termini indicate rates of retreat that vary widely from 0.08% per year for large glaciers to 0.3% per year for smaller ones (Miller et al., 2011). Bajracharya et al. (2010a, 2010b) have analysed changes in glacial area from 1980 to 2010 in the Langtang Valley, Nepal, and in the Bhutan Himalayas from Landsat satellite images and have found decreases in area but not disappearance of glaciers. They also found that the perennial snow/ice on steep mountain slopes does disappear but not in the valleys.

Data and information on the glaciers in the Hindu Kush-Himalayan region are sparse and often lack consistency, multi-temporal recording, field validation, and peer review, particularly of the glaciers at higher elevations. A recent review by Armstrong (2010) gives an extensive literature survey and references, as well as a comparative analysis and analytical discussion. Miller et al. (2011) have compared recent studies on glaciers together with the relative confidence levels for the measurements. Their summary shows that across the HKH region there is an increase in data parse and in confidence in the quality of data which indicate that glaciers are shrinking than in data which indicate that glaciers are advancing. Interestingly, the data accepted with most confidence for the Karakoram indicate shrinkage, not growth. As an exception, about half of the glaciers in the Karakoram are thought to be either growing or stable (Hewitt, 2005), possibly in some cases as a result of surging, but these estimates are based on measurements of glacier termini rather than glacial mass. Further, it is possible that debris-covered glaciers might be losing mass at high altitudes (Kulkarni, 2007, 2011). The role of debris deposition in slowing down glacial melt is demonstrated by the fact that the 'clean' glaciers of the Tibetan Plateau are retreating at a faster rate than the debris-covered glaciers of the rugged central Himalayas (Immerzeel at al., 2011). From measurements of the mass balance of three benchmark glaciers, Fujita and Nuimura (2011) found multi-decadal oscillations, trends of thinning and retreat, and, in two cases, indications of accelerated thinning. The paper underlines the complexity of individual glacial responses. The problems of glacial response times are highlighted in the discussion by Kargel et al. (2011), as is the fact that a stable terminus position may still be accompanied by considerable mass loss from thinning.

Shifts in the altitudinal range of species and communities are a common impact of climate change; however, evidence based on research is scant. In a recent study on endemic species of the alpine belt in the Sikkim Himalayas (>4,000 masl), Telwala (2011) found that 87% of the 124 endemic plant species investigated demonstrated a pronounced upward shift over the past 150 years (from 1850 to 2007–10) with a mean species' shift in altitudinal range of 237.9±219.8 masl. During this period, the mean temperature increase was approximately 0.76 °C during the warmest months and approximately 3.65 °C during the coldest months. The upward shift in species' range was between 100 and 400 m in 70% of the species, but in extreme cases, the range shift was 600–800 m. About half of the endemic species showed an upward shift in both the upper and lower margins. A sizeable portion of endemic species, however, only showed an upward shift on the upper side of their range, leading to an altitudinal expansion of the range. The distributional ranges increased in more than 50% of the species. There were also a few species which showed an upward rise only at the lower end of their range and thus a reduction in range. Such species have poor tolerance to warming as their ability to migrate appears to be limited and they are particularly vulnerable to warming. Species at relatively lower altitudinal bands (4,000–4,500 masl) showed more of a shift than species at higher altitudes (> 4,500 masl). The species' richness maxima showed a shift of 200 masl and, in general, species' richness increased, possibly because of accumulation of species in higher areas due to migration from the lower areas.

In a mountain belt, a 1°C increase in mean annual temperature can cause an isotherm shift of 160 m. Since the lapse rate is relatively lower in the Himalayas (around 4.5°C per 1,000 m increase in altitude (Singh and Singh, 1992)), the altitudinal shift in isotherm should be greater. The upward shift in species range in Sikkim might be partly due to the low temperature lapse rate. Himalayan species have the highest timberline (4,700 masl) and highest altitudinal limit of vascular plant species (6,400 masl) and plant communities (5,960 masl) of all alpine areas; species' migration in the forest zone would be difficult because of extensive fragmentation (IIRS, 2003).

Based on a comparison of repeated photographs, Baker and Mosely (2007) estimated a 67 m rise in the tree line and a 45 m rise in the tree limit in northwest Yunnan. In another study, the tree line shift in the eastern Himalayas was estimated to be 110 m, with a considerable reduction in the area of Abiesgeorgei forest (Xu et al., 2009). A smaller tree line species shift was observed on the cooler North aspect than on the warmer South aspect in the western Himalayas (Dubey et al., 2003). Using the Holdridge life zone system, Xu et al. (2009) indicated a marked depletion of alpine vegetation and expansion of the tropical lowland forest in the Himalayas with a temperature rise of 5°C.

An assessment of the impact of projected climate change to 2085 on the forests of India indicates that between 68-77% of the forest grids will change in forest type (Ravindranath et al., 2006). Since the areas under Himalayan forests in India are projected to experience relatively greater increases in temperature, bigger changes in forest type are very likely. Widespread changes are expected for the khasi pine (Pinuskesiya) of the eastern Himalayas, the chir pine (Pinusroxburghii) of the western Himalayas, the fir (Abies spp.) and spruce forests (Picea spp.), the temperate broad leaved forests, the blue pine (Pinuswallichiana) forests, and the mixed conifer forests. The general forest dieback during the transient phase would be a serious problem. Clearly, the list includes almost all Indian forest types, particularly coniferous forests. Although the Himalayas are often associated with conifers, broadleaved evergreen forests are also significant in terms of ecological dominance. While almost all forest types are projected to experience marked increases in net primary productivity with the warming climate, Himalayan forests are expected to do so only at a relatively lower rate (<1.5 times the present values).

Dimri & Dash (2012) studied how the wintertime climatic trends in the western Himalayas vary from station to station. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) the global mean surface air temperature increased by 0.74°C while the global mean sea surface temperature (SST) rose by 0.67°C over the last century. In regional context, Kothawale and Rupa Kumar (2005) have shown diurnal asymmetry of temperature trends, indicating that the warming over the India was solely contributed by maximum temperature. In the backdrop of the above, it becomes imperative to examine the changing climate over the Western Himalayan Region (WHR). Not much attention has been given to the climatic change in the WHR although in the recent past more observations are available in the region. It is of vital importance for a number of reasons. First, this being a data sparse vast region it becomes necessary to obtain information concerning the effect of climate change. Second reason is the presence of glaciers in this

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part of the world, which happen to be a quick response indicator for climatic change. The two most important weather parameters which may represent the effect of global warming are surface temperature and recipitation.

Dimri & Dash (2012) illustrates the observational analysis in trends of temperature and precipitation over the WH in winter (DJF) during period 1975–2006. This is the only observational data series available in the WHR region. Analysis indicates that most of the WHR shows significant increasing trends in the lower and higher percentile of the daily maximum, minimum and average temperatures. There are more warm events compared to fewer cold temperature events. The changes in the daytime and nighttime temperatures are not symmetrical since warming is more pronounced in the daytime as opposed to the nighttime temperatures. The coldest nights are getting warmer and hence percentage number of cold nights is decreasing while percentage number of warm nights is increasing during winter (DJF).

5. THE GLACIAL AND CLIMATE OF HIDU-KUSH-HIMALAYAN-TIBEAT (HKHT) REGION

Global warming is having dramatic effects on the climate system in this region: temperatures increasing faster than the global average, a weakening monsoon system; and reduced precipitation in some areas, including over the HKHT mountains. As a result, the majority of the glaciers in the region are retreating, and the monsoonrains are becoming less predictable. The vast and heterogeneous HKHT region is broken down into two major sub regions:

- Western China, which includes the Tibetan Plateau (TP), the Qilian Mountains in the east, the Kunlun Shan,which forms the northern border of the TP, and the Tien Shan in the far north, along the China-Kazakhstan/China-Kyrgyzstan border.
- The Himalaya, which can be divided into the Western Himalaya/Karakoram range, where India, China, andPakistan meet; the Central Himalaya, which includes Nepal and northern India; and the Eastern Himalaya.The northernmost Himalaya spill onto the Tibetan plateau.

6. TEMPERATURES IN THE HKHT ARE INCREASING FASTER THAN GLOBALLY

Over the last 120 years, average temperature in the HKHT has increased by 1.2 °C, twice the global average. Overthe last 50 years, regional temperatures have increased by 0.16°C per decade, with winter temperatures increasing0.32 °C per decade. Warming over parts of the Tibetan Plateau have been in the range of 0.2 – 0.6 °C per decadebetween 1951 and 2000. Nepal in the Central Himalaya is warming even faster: 0.6 °C per decade between 1977 and2000.

Glaciers are retreating, although glacier behavior is not uniform across the region

The mass balance of a glacier is determined by the difference between accumulation (via precipitation) and ablation (loss of ice through melting, evaporation, wind scouring). Changes in mass balance control a glacier's long term behavior and are the most sensitive climate indicators on a glacier. High-altitude alpine glaciers generallyaccumulate more snow in the winter than they lose in the summer, leading to a positive mass balance.

However, some glaciers accumulate snow in the summer, such as those in the Central and Eastern Himalaya. When ablation exceeds accumulation, a glacier has a negative mass balance. If the negative balance is sustained over time, the glacier will retreat Chinese researchers estimate that more than 82% of the glaciers in Western China have retreated and glacial area hasdecreased by 4.5% in the last 50 years, with the greatest percentage of retreat occurring on the north slope of the Himalaya glaciers in the central and northwestern Tibetan Plateau (TP) are relatively stable, while those in themountains surrounding the TP have experienced extensive mass loss. Many Himalayan glaciers are retreating faster than world average and glacial retreat is accelerating across much of the region. Mass shrinkage of glaciers started toaccelerate in the late 1970s and again in the 1990s. Evidence from ice cores from Naimona'nyi Glacier (6050 masl) in the Tibetan Himalaya suggest there has been no net accumulation of mass (ice) since at least 1950. The Gangotri Glacier, located on the southwestern edge of the TP, has shrunk over 30 km, at a rate of 23 meters /year. Some Chinese researchers have concluded that “strong warming and reduced precipitation are likely key drivers for the extensive ice-cover reduction in the eastern and southern parts of the TP. Glacial behavior varies across the Himalaya. Glaciers in the Central and Eastern Himalaya, which are fed by precipitation from the summer

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monsoon, appear to be retreating. In the Western Himalaya and Karakoram Ranges, some glaciers may be advancing.

These glaciers are fed by inter precipitation brought by westerlies, and are not as sensitive to changes in the South Asian Monsoon.

The monsoon cycle is weakening

Local records show a significant decreasing trend in monsoon precipitation from 1866 – 2006 in the West Himalaya. Ice core data also suggest a decrease in monsoon strength in the Central and Eastern Himalaya over at least the last 80 years. Since the 1980s, rainfall over the heavily-populated Indo-Gangetic plain has decreased by approximately 20% and the number of rainy days for all India is decreasing, although the frequency of intense rainfall is increasing, leading to more frequent floods. Sea surface temperatures (SSTs) in the equatorial Indian Ocean have warmed since the 1950s by about 0.6–0.8 °C, but there has been very little warming or even a slight cooling trend over the northern Indian Ocean. Summertime weakening in the SST gradient between these two ocean areas weakens themonsoon circulation, resulting in less monsoon rainfall over India. Model simulations suggest that warming from black Carbon (BC) aerosols is a major contributor as the water table is being depleted at a growing rate.

Impacts of climate change on people

The HKHT glaciers are considered to be a 'climate tipping element', much like the loss of Arctic summer ice or theGreenland ice sheet. This is due to the positive feedback that results when ice melts revealing darker land whichleads to further warming and melting, as well as the Catastrophic cascade of social and ecological impacts that wouldoccur if such a large number of people were forced to look for resources elsewhere and sensitive ecosystems werepermanently disrupted.

Weakening Monsoon Means Less Water

Throughout the region, the water table is being depleted and aquifers are drying out due to rapid population growthand increased water usage for drinking and irrigation. The monsoon rains are needed to replenish them. The Indiansummer monsoon is the most significant source freshwater to the region: over 70% of the annual precipitation overIndia occurs during the summer monsoon (June – September). Reduction in rainfall is also of concern because, inSouth Asia, there is a strong positive correlation between the amount of precipitation and food production.

Melting Glaciers Pose Short-Term Hazards and Long-Term Problems

The melting of Himalayan glaciers poses hazards to people living downstream of the thousands of glacial meltwaterlakes that have formed over the past few decades. Glacial lake outburst floods (GLOFs) threaten the lives andlivelihoods of millions of people in the region and these events are becoming more frequent. In the longer-term, theloss of these glaciers will lead to corresponding reduction in water availability. Snow and ice melt contribute 70%of the summer flow of the main Ganges Indus and Kabul rivers in the 'shoulder seasons' before and after the summermonsoons and the contribution to inner Asian rivers is even greater. The Gangotri Glacier, which is shrinking at therate of 23 meters/year, is the main water source for the 500 million people living in the Ganges River Basin.

Causes of climate change at the third pole

While CO_2 is the primary culprit, recent studies suggest that black carbon (BC) may play as large a role in warmingthe HKHT region. Increasing amounts of soot in atmospheric brown clouds (ABCs) have been shown to causeatmospheric solar heating, surface dimming, and BC deposition to the HKHT glaciers and snow packs. Studiesconducted by Chinese researchers on the Tibetan Plateau demonstrate increased soot concentrations and their potential radioactive effects on accelerated snowmelt. There is a need for similar quantitative studies on the Indian sideof the Himalayas.

Atmospheric Black Carbon (Aerosols)

Black carbon, a component of soot, is a by-product of incomplete combustion. Unlike most aerosols, black carbonabsorbs solar radiation. Atmospheric BC alters radiative forcing in a number of complex ways. BC mixes with otheraerosols, some of which reflect solar radiation, such as sulfates, nitrates, and organic carbon (OC). Together, theseanthropogenic aerosols contribute to Atmospheric Brown Clouds (ABCs), large plumes of particles that can stretch over whole continents or ocean basins. Determining the effects of ABCs is challenging due to the cooling effects ofsulfate and other aerosols that are mixed with BC. Overall, ABCs intercept solar radiation by absorbing as well asreflecting it, leading to a warming of the lower atmosphere and simultaneous a reduction of sunlight at the Earth's surface (surface dimming).

The Tibetan Plateau is at the crossroads of influence between maritime air masses from the Indian Oceans (monsoons) and continental air masses from central Asia (westerlies). During the winter and pre-monsoon season (October to April), large-scale circulation patterns (predominantly westerlies) transport air masses to the Plateau.Westerlies do not bring large quantities of pollutants with them, as they travel a long way from populated areasbefore they reach the region. In the summer (June to September), low pressure over the plateau induces a supply ofmoist, warm air from the Indian Oceans to the continent (summer monsoon). These masses bring considerablepollution from South Asia, some as far away as the Indian plains. Atmospheric BC Concentrations Modern atmospheric aerosols over the central Himalayas are dominated by anthropogenic sources which haveincreased at a rapidly accelerating rate since 1930 with the increase in energy demand and fossil fuel use. Studies ofatmospheric aerosols have found that aerosol optical depths (AOD), which increase as the transparency of the airdecreases, were low in the summer and during the monsoon, then increased through the late winter to peak duringpre-monsoon season (May). This enhanced buildup of aerosols is dominated by dust transported by westerlies fromthe arid regions of India, the Middle East, and perhaps the Sahara Desert. During monsoon season, the aerosols areWashed out, and build up again during the following dry winter season. Some studies have found that the abundanceof carbonaceous aerosols or soot measured also exhibited a seasonal pattern: on Manora Peak in the outer Himalayas, carbonaceous aerosols were highest in the winter. On Mt. Qomolangma (Everest) the abundance of sootwas higher in the non-monsoon period (25%) than during the monsoon period (14%). Backward trajectories suggestthat northwestern India contributed to the atmospheric aerosols in these areas.

There are few modeling studies of the transport of BC to this region from China. Trajectory analysis suggests thatemissions from Xinjiang Province and Central Asia transported by westerlies could be the most important sourcesfor BC to the northern and western edges this region. However, up to 40% of these emissions could come fromwithin the region: e.g., the high concentrations measured close to Lhasa and the Qinghai-Tibet Highway couldreflect the influence of local anthropogenic activity. In the north, the highest BC concentrations were measured nearthe city of Urumqi in the Tienshan. In the central/southeast and southern TP (Himalayas), analysis indicated that BCconcentrations are influenced by emissions from the Indo-Gangetic basin transported by westerlies and monsoons.ABCs have been found to enhance lower atmosphere heating by about 50% over Asia and contribute as much tolower atmospheric warming trends as anthropogenic greenhouse gases. Unmanned aircraft flying through theseABCs over the Indian Ocean found that the zone atmosphere containing the clouds is warming by 0.25° C perdecade as compared to 0.10° C at ground level. The Himalayas are located at the same altitude as that where the ABCs have been measured; suggesting that atmospheric heating due to BC in these ABCs may be as important asCO_2 in the melting of the Himalayan glaciers. Surface dimming reduces the amount of solar radiation reaching thesurface. Modeling studies suggest that BC aerosols in ABCs play a role in both the recent increases in precipitationseen in the pre-monsoon season, as well as the reduction of precipitation during the monsoon itself.

Black Carbon on Snow

BC is removed from the atmosphere by snow, rainfall, and direct deposition onto surfaces. Clean snow is the mostreflective natural surface on earth, with an albedo of almost 90%. Snow albedo can be reduced by very smallamounts of impurities, like dust or black carbon. The atmosphere in the Himalayas has high levels of natural dust,resulting in the deposition of dust on Himalayan glaciers. However, BC is estimated to be fifty times more efficientthan dust in reducing snow albedo; experimental results show that parts-per-billion of

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black carbon (BC) on thesurface can reduce snow albedo by 1-2%.Modeling suggests that the total warming impact of black carbon per meter may be greatest in the mid-latitudes ofCentral and East Asia because of the BC-snow forcing. This model further suggests that the greatest forcing is overthe Tibetan Plateau, averaging 1.5 W m-2 over all land. During some spring months BC-snow forcing may exceed10 W m-2 over parts of eastern China and 20 W m-2 over the Tibetan Plateau. The forcing is greatest over thePlateau because lower latitudes are exposed to more solar radiation, have less vegetation cover, and are closer to thesources of black carbon than higher latitudes. Climate experiments suggest that fossil fuel and biofuel emissions ofblack carbon plus organic matter induce almost as much springtime snow cover loss over Eurasia as anthropogenicCO2 emissions. There are uncertainties associated with these models, due to the low resolution of the grid.

Significant work is needed to develop realistic simulations of the effects of BC on snow in this varied and highly complex terrain. Concentrations of BC in Snow Concentrations of BC in snow/ice have been reported from about 16 sites in Western China. Most of the work hasbeen done along the southern and eastern margins of the area; little has been done in the interior. One study analyzeddata from snow/ice core samples across the Tibetan Plateau. It includes samples along a north-south transect from the Tienshan mountains in Xinjiang Province, along the eastern margin of the Tibetan Plateau (TP), from the QilianMountains to Lhasa, to the Himalayas in the south. Other sites were samples along the western and southwesternedges. Other studies have sampled sites north of the TP in the Altay Mountains, the western edge of the TP in theKunlun Mountains, and along the eastern edge. The highest concentrations of BC (67 – 114 ng/g) were found at thenorthern (MEG2 and HXR48) and southeastern (DK, LN, ZD) edges. These sites are close to regional populationcenters: Xinjiang Autonomous Region in the north > 19 million people and Lhasa and the Qinghai-Tibet Highway inthe southeast. Sites along the eastern/central (LHG2, QY) and southwestern margin, and in the Himalayas (KW, ER,QIY) were low (18 – 35 ng/g) but still reflected significant anthropogenic influence. Even the lowest concentrations(4.3 and 6.6 ng/g) found in the remote eastern Qilian (J1) and western Himalayan Mountains (NM) exceeded theconcentrations measured in relatively pristine Antarctic snow by an order of magnitude. Ice core records of the past 50 years from Mt. Qomolangma (Everest) revealed an apparent trend of increasing BC concentrations that started inthe mid-1990's, with higher concentrations measured during the monsoon season.

Emissions and sources of Black Carbon

The HKHT region is bounded by two high BC-emitting neighbors: China and India. When determining BCemissions, there is a noticeable discrepancy between top-down studies that rely on measured ratios of BC to totalcarbon or other aerosol components, and bottom-up emissions inventories based upon fuel consumption andemissions factors. Measurements of elemental composition of ambient aerosols point at fossil fuels as the source of 50 – 90% of BC, whereas emission inventory models suggest biofuels as primary source of emissions, with fossilfuels responsible for only 10-30%.

China

A study of sites in the Central TP near Lhasa and the Qinghai-Tibet Highway (ZD and LN) reported that aerosolshad local biogenic sources, such as burning of dung for heating and cooking. On the western edge of the TP, analysisattributed the BC measured there to fossil fuels. A high-resolution emission inventory of BC from China in 2000,based upon fuel consumption data (fossil and biomass) and socio-economic statistics, estimated total BC emissions of 1499.4 Gg, per year, mainly due to burning of coal and biomass. This is higher than previous estimates becauseburning by rural industries and residences were found to be higher than previously assumed. There was a strongseasonal pattern to emissions, with peaks in January and December, and lower emissions in July and August, due tochanges in residential heating and open burning of crop residues.

India

The Atmospheric Brown Cloud BC Radiocarbon Campaign (ABC-BC14) used radiocarbon measurements of winter monsoon aerosols to determine that both fossil fuel and biomass burning contribute significantly to the

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ABC over South Asia. Fossil fuel was found to be responsible for up to and biomass for – ⅔ of the BC in the ABC.

Significant science gaps remain

There are significant gaps in all areas of the science on the effects and impacts of climate change in this region. TheThird Pole is grossly under-monitored relative to the Arctic and Antarctic. Only a handful of stations are conductingin situ observations in high mountain regions. A 2008 workshop in the region noted the scarcity of observationaldata, including few actual measurements of aerosol deposition onto snow and ice. Little is known about the chemicalcomposition, origin and transport pathways of aerosols arriving in Himalaya, air-to-snow transfer processes, and thefate of aerosols once they are deposited. Workshop participants noted the need for integrated field and modelingstudies of ABC characteristics and deposition rates, the energy and mass balance of glaciers, and hydrologic fluxesof streams receiving inputs from glacial melt and/or snowmelt. They also indicated a need for studies on selectbasins to estimate socioeconomic impacts of glaciers and snowpack melting.China and India recognize that the HKHT region is vulnerable to climate change, but view data from westernsources with suspicion. While research is being conducted in both countries, more is needed. The majority ofChinese research comes out of the Tibetan Plateau Research Institute, Chinese Academy of Sciences. Much ofIndia's research is conducted under the auspices of the Indian Network for Comprehensive Climate Assessment,which includes 127 research bodies, and the National Institute of Climate Institute. The Indian Space ResearchOrganization (ISRO) is also involved in Himalayan BC research. There is growing interest in establishing jointresearch initiatives, although historical tensions between the two countries make that a challenge.

7. CLIMATE CHANGE CHALLENGES IN THE MOUNTAINS: IMPLICATION TO ADAPTATION NEEDS OF THE HINDU KUSH HIMALAYAS

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8. NEW KNOWLEDGE FOR ADDRESSING IMPACTS OF CLIMATE CHANGE ON HKH RESOURCES

Inadequate knowledge hinders effective planning, and its implementation. Knowledge gap continues to pose a major challenge in the HKH region where data and information are scant, particularly those required for making concrete policy decisions. It is necessary for people to be knowledgeable in order to adapt and be resilient to change. At present, many adaptation measures are being devised without proper analysis and without a complete understanding of the sources of the problems. It is therefore the key agenda of the future actions to generate more knowledge and technologies applicable to achieve the dual objectives of development and climate change adaptation in an affordable cost and time.

9. TAPPING POTENTIAL OF INTERNATIONAL CLIMATE AND ENVIRONMENT POLICY FORUM

There are some concrete progresses on understanding significance of mountains and their specificities – fragility, marginality, inaccessibility and richness of niche ecosystem products and services. They are, however, far from adequate to have an impact on mainstreaming mountain agendas in the global policy fronts. The Rio+20 can be a unique opportunity to have a deeper, comprehensive and effective approach to sustainable mountain development taking into account the developments in the last two decades. The regional initiatives such as the one by the countries associated with SAARC (South Asian Association for Regional Co-operation) and national initiatives such as the international conference on mountain countries in April 2012 provide more opportunities to pave the way of greater co-operation on the mountain agendas. Clearly, there is a need to take up the issue of mountains in a holistic manner.

Future action

The Himalayan ecosystem is hampering by the climate change, but base on the previous study the researchers and policy planners will take some important action for future study viz. (i) Collection of meteorological data involving standard methodology and instrumentation,(ii) Understanding drought and flood cycles, climate variability and other extreme events, (iii) Plant taxa vulnerable to CC and survival strategies of plants, (iii) Global warming associated with upward migration of altitudinal boundaries and consequent change in snowline position and its biota, (iv) Habitat requirements and corridors for upward migration of plants and animal species, (v) Impact of CC (involving eco-physiological studies such as drought, elevated CO_2 and atmospheric temperature) on important food crops, timber spp., medicinal plants which may affect the food security and revenue generation for the region, (vi) Studies on air pollutants (AODs, GHGs) and temperature rise to observe the impact of aerosols, GHGs and other pollutants on the atmospheric temperature, (vii) Invasion of weeds, such as Lantana, that compete with the native flora for soil nutrients and (viii) Documentation of local traditional knowledge of climate variability and coping-up strategies can be useful in formulating strategies to adapt to the impact of climate change.