Journal of Climate Change, Vol. 2, No. 2 (2016), pp. 71–82.
DOI 10.3233/JCC-160018

Response of Himalayan Eco-system to Anticipate Climate Change

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Received April 10, 2016; revised and accepted June 20, 2016

Abstract: The climate change is going to have far reaching consequences in the vulnerable Himalayan ecosystems. Although there are efforts to understand the eco-system response to climate variability, considering the vividness and extreme topographical configuration, there is no unique suggestion on the likely impacts of climate change in the Himalayan valleys. In fact each valley should be treated separately in terms of their responses. The present paper is an attempt towards this direction, which gives some insight into the terrain responses that exists in the region to global warming and what really is a way forward. Attempt has also been made to underline implications of these changes on the human communities, along with few success stories; the study gives some recommendations towards combating this threat in the region.

Keywords: Ecosystem, Himalaya, Climate, Monsoon, Westerly.

Background

The spectacular Himalayan orogen is an outcome of continental-continental collision that took place ~55 million years ago. The Himalaya is intimately associated with the climate of SE Asian countries and is the source of innumerable life giving river systems that nearly feed more than half of the population in the Indian subcontinent. Being the youngest and loftiest ranges in the world, the continued northward movement of Indian plate is known to make it restless at times, which is manifested in the form of infrequent high magnitude earthquakes. It is because of its dynamic nature, the topography of Himalaya is immature, thus makes it vulnerable to erosion and denudation. Superimposed on the sensitivity of the Himalayan eco-system, the threat posed by global warming suggests that human-induced climate changes, particularly increases in temperature is going to have cascading effect on the Himalayan eco-system because mountain eco-system respond too sensitively to slight change in temperature and precipitation condition (Whiteman, 2000).

Under the anticipated global warming scenarios, it is speculated that the earth surface processes are going to be different so much so that the conventional geological concept viz. the *present is the key to past* may not hold if one would like to reconstruct past earth surface processes using the sediment archives because the anthropogenic modification has significantly altered the natural processes. The IPCC (2007), report in its regional climate projection indicated that there would be an increase in warming (well above the global mean) over central Asia, the Tibetan Plateau and northern Asia. Similarly, precipitation in summer is likely to increase

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in northern Asia, East Asia, South Asia and most of Southeast Asia. The report further suggests that it is likely that heat waves/hot spells in summer will be of longer duration, more intense and more frequent in East Asia. Based on current temperature trends, it is inferred that the mean annual global surface temperature has risen by 0.74°C during the last 100 years and is projected to warm an additional 2–4°C during the 21st century (IPCC, 2007). The data from the Himalayan region indicate that warming during last 3-4 decades has been more than the global average of 0.75% over last century (Du et al., 2004). Temperature increases are more during winters and autumns than during summers, and they clearly increase with altitudinal rise (Liu and Chen, 2000). For example, decadal temperature rise remains up to 0.2°C up to 2000 m altitude, while above 2000 m it often exceeds 0.3°C.

Precipitation, River Discharge and Sediment Flux

The behaviour of precipitation patterns in Himalayan region has a direct impact on river discharge. The consequences of this change on human population are far reaching as approximately 12 billion people are directly dependent on the water resources of the Himalaya (Table 1). Considering that the precipitation is going to decrease ~68% in large part of the Indian sub-continent (Kumar et al., 2006), there is a threat posed on the sustenance of our river hydrology which largely depends on the Indian Summer Monsoon (ISM). However, there is an alternative model to suggest that in a warm earth scenario, there would be a changing precipitation pattern over the Indian sub-continent (Figure 1). In fact an alternate hypothesis speculates that if world warms up, the summer monsoon fed Himalayan glaciers would expand (Owen et al., 2002). The reason being landmass will squeeze in more moisture from the Arabian Sea and Bay of Bengal which in the higher Himalaya would precipitate as snow thus contributing to the growth of the glaciers. In this speculation there is an inherent assumption that the air temperature of higher Himalaya would remain constant.

The global warming might severely affect the river connection between the Himalayas and Gangetic Plains, and climate regime of the entire region. Most of the talk on climate change in the Himalayas is centred on glaciers melt. How natural ecosystems and agriculture are going to be affected is hardly considered. The high sediment flux from the Himalaya has become a grave concern for the hydropower and irrigation projects in the country. For example, the silt load in Ganga in Bangladesh is reported to be 15.7 t/yr, compared to 0.8 to 5.1 t/yr for the rivers of the trans-Himalaya region (Holeman, 1964). This increase in sediment flux can be ascribed to the increasing intervention in the terrain during last few decades and accelerated exploitation of the natural resources particularly the forests. Climate change not only alters the average annual precipitations of different regions but also cause drastic change in precipitation behaviour including increased frequency of extreme precipitation events (Cubasch et al., 2013).

Table 1: Principal river systems of the Himalayan region (After Jainchu et al., 2007)

	River		*River Basin*			
	Mean discharge (m^3/sec)	*Glacial melt in river flow (%)*	*Area (km^2)*	*Population (million)*	*Population density (No/km^2)*	*Water availability (m^3/person/yr)*
Yanrze	3430	18.5	1,722,193	368.5	214	2909
Ganges	18691	9.1	10,16,124	407.5	401	1,447
Brahmputra	19824	12.3	651,335	118.5	182	5,274
Irrawadi	13565	small	413,710	32.7	79	13,089
Mekong	11048	6.6	805,604	57.2	71	6,091
Indus	5533	44.8	1,081,718	178.5	165	978
Tarim	146	40.2	1,152,448	8.1	7	571

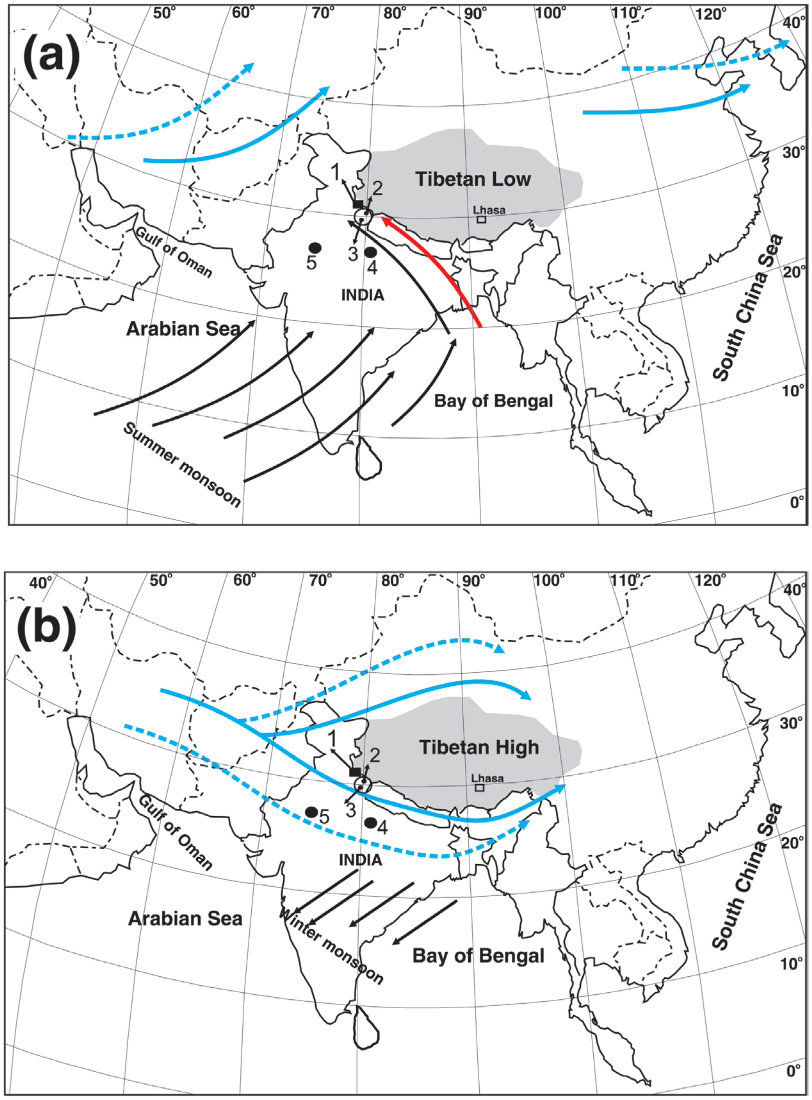


Figure 1: Schematic illustration of the position of westerlies (blue solid line) and the southwest monsoon (black solid line), (a) summer and (b) winter. During periods of enhanced monsoon (dotted blue line), westerlies moved north of the Tibetan Plateau and the moisture laden southwest monsoon winds penetrate the arid landscape of Trans-Himalaya (red solid line). (After Juyal et al., 2009).

Glacier Response

Mountain glaciers respond too sensitively to global warming. In the higher Himalayas (above 3000 m), snowfall builds up year after year to form glaciers that are long-term reservoirs of water. The higher Himalayas and inner Asian ranges together have the largest glaciated areas outside the Polar Regions (Dyurgerore and Meier, 2005) (Table 2). Glacial melt accounts for 6% to 45% of average river flow across the Himalayan rivers studied (Table 1). However glacial melt may account for up to 70% of the total river flow during summers.

The rising temperature may reshape vegetation, but such changes are visually subtle on landscape; compared to this, glacier retreats present stunning evidence of how climate shapes the face of the planet earth (Mote and Kaser, 2007). This is amply demonstrated in the valleys around mount Kailash, where significant valley glacier recession is observed in last few centuries (Figure 2). Most mountain glaciers and ice caps have been shrinking with the frontal retreat probably having started about 1850. It is further suggested that climate change will affect the magnitude of accumulation and ablation and the length of the mass balance seasons (IPCC, 2007). In such a scenario, the worst affected would be

Table 2: Glacial resources in Himalayas by drainage basins (Qin, 2002)

Drainage basin	*No. of glaciers*	*Total area (km^2)*	*Total ice volume(km^3)*
Ganges River	6,696	16,677	1971.5
Indus River	6,057	8,926	850.4
Brahmaputra River	4,366	6,579	600.4
Sutlej River	1,900	2,861	308.0
Mapam Yamco lake	48	67	4.4
Total	18,067	35,110	3,734.5

the small Himalayan glaciers (Figure 3) because small glaciers have virtually no response time lag between the climate variability and the glacier response (Kaser et al., 2003).

Overall, there is consensus that after the Little Ice age (LIA), glaciers began to recede and the significant recession seems to occur after 1950 (Table 3). Any reduction in glacier ice volume may have serious societal consequences particularly in China and parts of Asia, including India which houses 50-60% of the global population. Melting of glaciers in these regions provide a major source of water in the summer months as much as 70% of the summer flow in the Ganges and 50-60% of the flow in other major glacier fed rivers is contributed by the glacial melt (Barnett et al., 2005). The above concern is supported by the recent study that anthropogenic induced increase in greenhouse gases and aerosols may add to the accelerate melting of the Himalayan glaciers (Ramanathan et al., 2007; Das et al., 2010) (Figure 4).

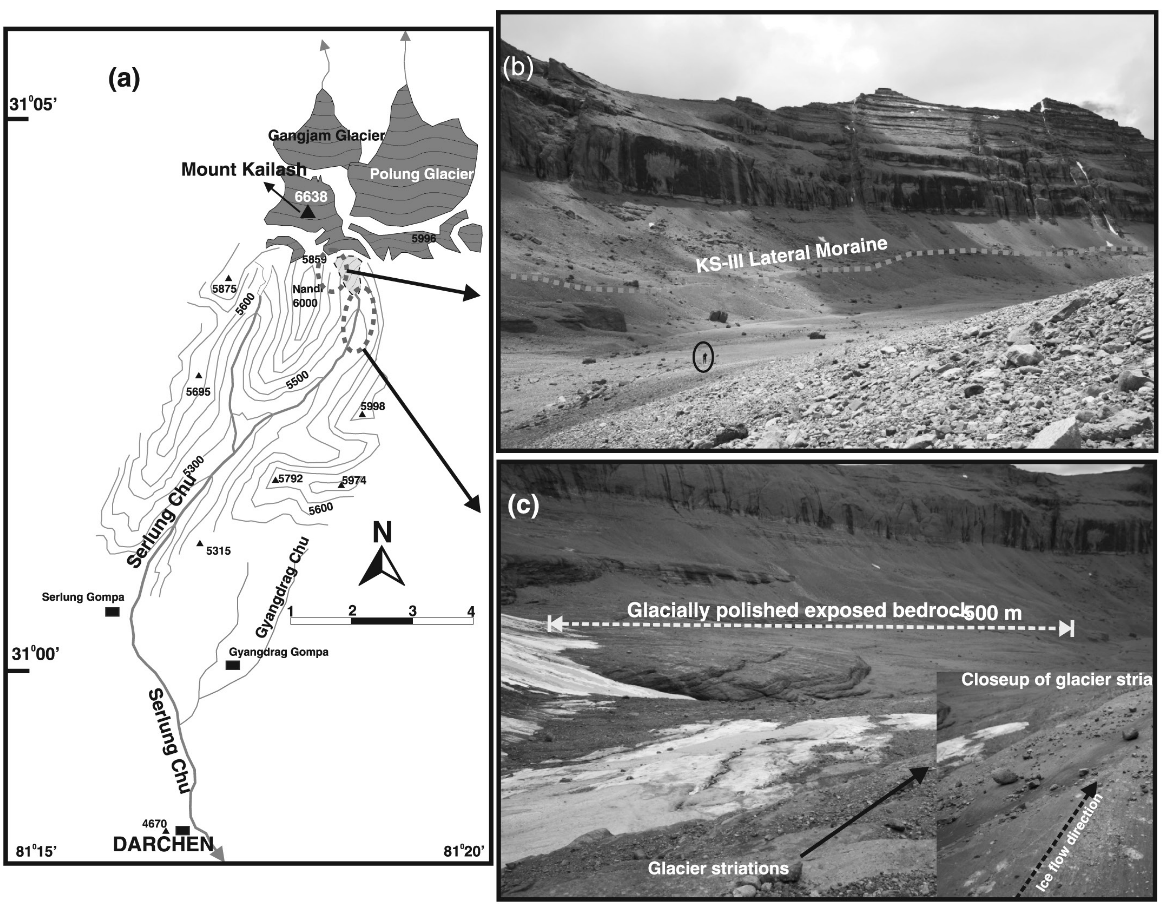
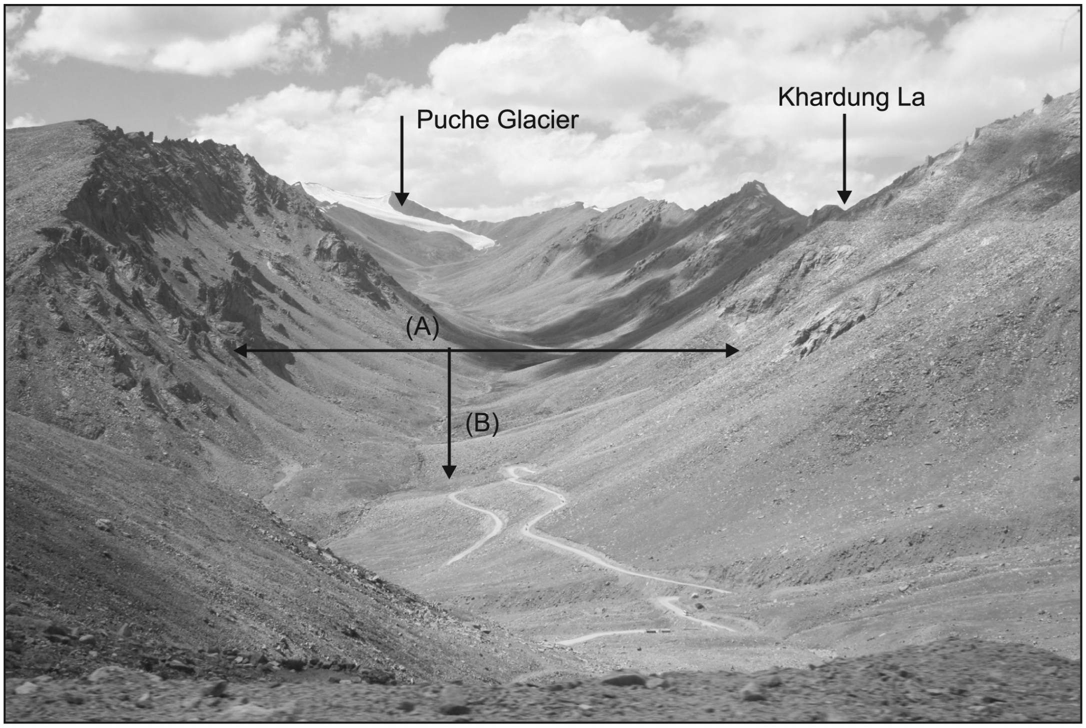


Figure 2: Geomorphic expression of frontal retreat is well preserved along the SE valley of Mount Kailash showing (around 500 m) exposed glacial bed rock. This retreat was attributed to post little Ice Age event (After Juyal et al., 2011).



(A) Horizontal arrow indicate approximate relict lateral extent of Puche glacier.
(B) Vertical arrow gives approximate relict glacier ice thickness.

Figure 3: Eloquent evidence of global warming caused disastrous effect on small (Puche) glacier; the glacier is on the verge of disappearance.

Table 3: Estimated loss in glacial area in the different river basins of Himalaya (Kulkarni and Karyakarte, 2014)

S. No.	*Basin*	*Period*	*Areal extent (sq. km)*	*Loss (sq. km)*	*No. of glaciers*
01	Janskar	1962-2001	1023	92	671
02	Warwan	1962-2001	847	178	253
03	Miyar	1962-2001	568	45	166
04	Chandra	1962-2001	696	139	116
05	Parvati	1998-2009	154.5 ± 0.39	8	51
06	Baspa	1998-2009	145.2 ± 0.27	19	19
07	Dokrani	1962-1995	8	1	1
08	Bhagirathi	1962-2001	1365	191	212
09	Alaknanda	1968-2006	324.7+_8.4	18	69

One of the most revered rivers viz. the Ganga originates from two major glacier systems that originate from a common Chaukhamba and associated group of peaks. Towards the east these ranges feed the Satopant and Bhagirathi Kharak (source of the Alaknanda river) and in the west is the great Gangotri glacier (source of the Bhagirathi river) which eventually converge at Devprayag to form the Ganga. There are studies to suggest that glaciers are retreating at different rates in Uttrakhand Himalaya. The largest Gangotri glacier in Uttrakhand was receded by around 76 m during 1996 to 1999 (Naithani et al., 2000). Similarly, a subsidiary Dokriani glacier located south of the Gangotri glacier shows an average recession rate of 15.6 m/yr (Dobhal and Mehta, 2010). The Satopant and Bhagirathi glaciers are retreating at 22.88 m/yr and 7.42 m/yr respectively (Nainwal et al., 2008).

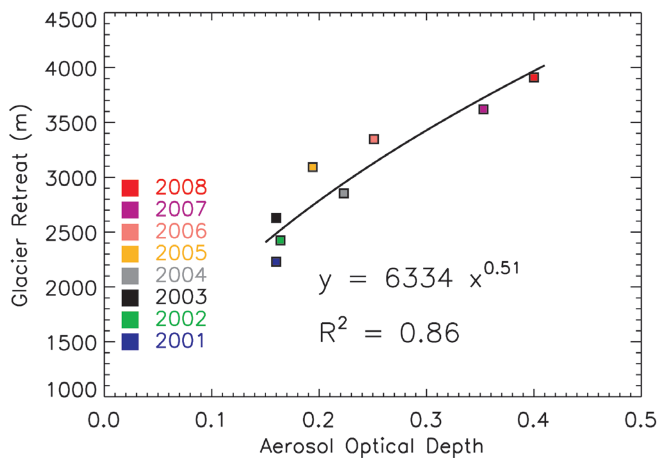


Figure 4: The curve showing a reasonable correlation between the Aerosol Optical Depth and the cumulative recession rate of Dokriani glacier between 2001 and 2008 (Das et al., 2010).

The linear recession rates, based on two or three time series data points, may be misleading as such interpolation explicitly assumes that a receding glacier did not re-advance in between. Whereas studies suggest that Himalayan glaciers did advance at least during little ice age (Sati et al., 2014). Further, the time series data on glacier mass balance is limited to few years only, therefore, attributing the growing temperature response of Himalayan glaciers may not be correct. We have to wait for decade or so when real time mass balance data would be available from Himalayan glaciers so that a much realistic picture can be drawn; till then the above data should be treated as suggestive and utmost care should be taken while interpreting them in terms of temperature change. Even if for the sake of argument we considered the above numbers to be true representation of climatically induced reduction in ice volume, we have no explanations to provide whether the reduction is due to the rise in winter temperature, increase summer rainfall, or decrease winter precipitation? In the past due to lack of Automatic Weather Stations (AWS), the meteorological data existed only for those months when the field party stayed at the glaciers. Hopefully in near future our scientists will not struggle for the real time data for better interpretation and future prediction of Himalayan Glacier (eco-system) response to global warming.

The increased melt water discharge and rainfall may trigger flow of debris available in tremendous quantity in form of moraines and can also cause flash floods in higher Himalayan regions in addition to formation of potentially dangerous lakes.

Biodiversity of the Himalaya and Climate Change

Climate is one of the major controlling factors for the biodiversity of any region. Studies suggest that different plant and animal communities belong to certain climatic regime (Thornthwaite, 1948; Walter, 1985). Besides the carbon sink, the rich biodiversity of the region serves in maintaining slope instability, regulating hydrological integrity and sustaining human livelihood. Stretched an area of more than four million sq km, the Hindukush Himalayan Region is endowed with rich variety of gene pools and species and ecosystems of global importance. The region hosts parts of four Global Biodiversity Hotspots, namely The Himalayan hotspot, The Indo-Berma hotspot, The Mountains of SE China Hotspot and the Mountains of Central Asia Hotspot (Mittermeier et al., 2004). As such there is a huge gap in research on climate change vis-a-vis its impact on biodiversity of the Himalayan region. There is quite inadequate availability of long-term climate data in the region (Joshi and Negi, 1995). The Himalayan region has varied landscapes and soil which facilitated in diversity in vegetation: flora and fauna and high level of endemism (Myers et al., 2000). The change in the behaviour of plant species due to climate change have an obvious effect on their life cycle and growth There are several other possible facets of impacts of climate change on the biodiversity of the region (Figure 5). Upward migration of the species, change in temporal and spatial distribution of biota, mass extinction, abnormal abundance of few species, change in physiological and behavioural characters and breeding pattern are only few possible impacts of the climate change in the Himalaya.

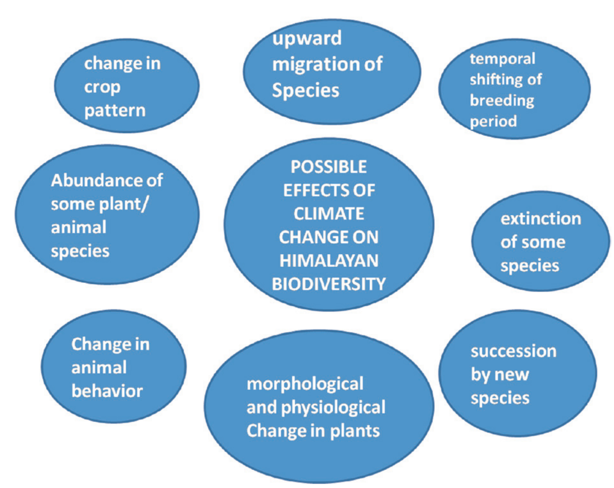


Figure 5: Schematic diagram showing possible effects of climate change on Himalayan biodiversity.

Societal Implications

The impact of glacier recession in particular and overall warming in general on the Hill society have not received much attention in India. Although there are some indications that suggest that the villages located in paraglacial zones (areas located within the margins of a former glacier) are witnessing unusual weather condition during the last couple of years. In Indian context, these zones lies in the rain shadow areas of Trans Himalayan (north of High Himalaya) such as Ladhak, Zanskar (Jammu and Kashmir) and Lahul–Spiti (Himachal Pradesh) and the Trans Himalayan villages in Uttrakhand viz. north of Malari in Dhauli Ganga, Malla Johar (Gori Ganga) and Darma valleys (Eastern Dhauli Ganga). It is feared that with the rise in global temperature, glaciers may lose their mass which may reduce the river flows and would negatively affect water supply in the villages that depends on the glacial melt for various domestic and agricultural activities. The direct impacts of climate change on livelihood of the Himalayan communities are in many ways (Figure 6). The worse part of the problem is that no serious efforts are being made by any government of the region.

We have been travelling across Himalaya and had opportunity to talk to the local people in Ladhak, Lahul-Spiti, and the Trans Himalayan villagers of Uttarakhand. They all are worried about the irregular rainfall spells, unusual snow, early turbidity in the rivers, temporal changes in the flowering seasons in Bugyals (alpine pastures), deserted and dry appearance of the higher Himalayan ranges, illusive Monals (Himalayan peacock) in the lower altitude (below 2000 m) during winters etc. Is it the ecological and geomorphological expression of recent warming trend? In order to arrive at a consensus, it probably would take longer time than we think. But the local people cannot wait till the final inferences are drawn about the factors responsible for changes which they have already started experiencing in the Himalaya.

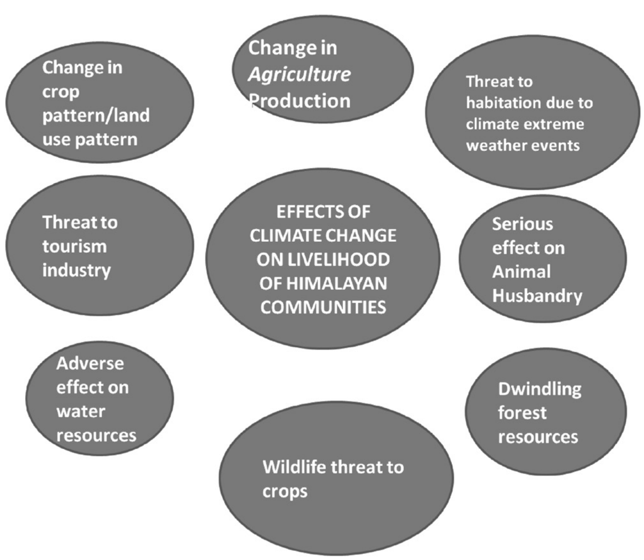


Figure 6: Schematic diagram showing possible effects of climate change on livelihood of Himalayan communities.

In the lower valley ignoring the consequence glacier recession a renewed intervention in the Himalaya has started with an aim to exploit the water resources for hydropower generation. These power projects have virtually swamped the entire Himalayan valleys including the higher Himalaya. A recent study suggests that at Rishikesh, the contribution from glacier melt during the summer monsoon is around 40% (Maurya et al., 2010). If there would be an accelerated pace of glacier ice volume reduction, one can very well imagine the fate of the hydropower projects in Himalaya which relies significantly on the glacial melt.

It also feared that if the rainfall seems to increase and become abnormal in the spatial variability, the paraglacial areas are likely to experience high magnitude debris flow/flash floods. Being in the rain shadow zone, such areas have no appreciable vegetation cover to protect the sediment (which is in plenty due to the recession of glacier in the geological past). The exposed glacial and fluvial sediments are susceptible to the onslaught of falling rain drops during abnormal rainfall events as was the case during August 2010 in Leh (Juyal, 2010). It has been observed that there were periods in the geological past when monsoon indeed penetrated into the Trans Himalaya (Bookhagen et al., 2005; Juyal et al., 2009) and cause large-scale sediment mobilization in the form of debris flow from the unprotected steep mountain slopes (Bookhagen et al., 2005). This would imply that if the summer precipitation is going to increase as suggested in IPCC 2007 report, the Trans Himalayan region is likely to experience increase in debris flow frequencies—events similar to what we witnessed recently in Leh. Figure 7 shows the recent devastation caused due to debris flow in Leh.

The threat due to extreme precipitation events is being observed in the Himalayan regions causing severe threat to life and property (Table 4). The temporal and spatial distribution pattern of these extreme events also showed abnormal behaviour. For example the high rainfall event caused disaster in Central Himalayan region occurred in the third week of September 2010, till this time otherwise the monsoon becomes inactive

Figure 7: Devastation caused due to debris flow in Leh in June 2010. An evidence of change in spatial distribution of SW Monsoon.

Table 4: Some extreme precipitation events which caused disasters in different Himalayan states

S. No	*Year*	*State*	*Loss(People killed)*
1.	1997	Shimla (Himachal Pradesh)	1500
2.	1998	Okhumath and Malpa (Uttarakhand)	107 and 250
3.	2003	Kullu (HP)	40
4.			
5.	2010	Ladakh (J&K), Manali (HP), Uttarkashi (Uttarakhand)	1000 Approx
6.	2011	Uttarkashi and Okhimath (Uttarakhand)	50 Approx
7.	2013	Kedarnath and whole Uttarakhand (Uttarakhand)	More than 10,000 Huge loss of infrastructure and property
8.	2014	Srinagar (J&K)	Tremendous loss of life and property

in this region (Sati et al., 2011), while that of Kedarnath mega-disaster event of 2013 occurred in mid June which is approximately two weeks early of reaching of monsoon in this region (Sati and Gahlaut, 2013). Likewise 2010 Flash flood disaster of Leh and 2014 Flash flood event of Kashmir Valley occurred in the region of least SW monsoon activity.

Extreme precipitation events cause tremendous loss of life and property in Himalayan region. Kedarnath tragedy of 2013 for example alone claimed more than 10,000 lives and a huge loss of property and is supposed to be one of the largest extreme rain caused disaster in the Himalaya. Increased frequency of these events in future is one of the biggest threats to communities residing not only in this region but also to approximately 50 million people of North India.

Intervention at Local level

Over the next twenty years the decisions that our societies make and the actions we take to address the

Table 5: Climate change and its conséquences in the Himalaya: Possible measures

Patterns of climate change	*General consequences*	*Possible remedial measures*	*Consequences on communities*	*Possible remedial measures*
a. Change in annual average temperature	Altitudinal shifting/Extinction of species threatened biodiversity Single vegetation and animal dominance/Change in water demand and availability	– Methods to apply for species control Water harvesting/proper drainage management system	Threatened agriculture/threatened livelihood practices/epidemics Water related troubles	Change in agriculture practices/ nursery to protect agriculture germplasms/change in livelihood practices/strengthened health system/safer settlements, water harvesting
b. Depleting ice cover/glaciers	Increased discharge in rivers/ increased sediment load in rivers/incresed incidences of GLOF	Smaller dams on rivers in higher Himalayan regions	Damage to hydropower projects/ Threats to settlements along river beds/flood plains	Avoiding big hydropower projects/discouraging settlements along river beds/flood plains
c. Increased average annual rainfall	Increased discharge in rivers/ increased sediment load in rivers	Efficient drainage management in Lesser Himalayan region	Damage to hydropower projects/ Threats to settlements along river beds, flood plains/increased landslide hazard/damage to villages, agriculture, forests/increased flood frequency in plains/infrastructure damage	Avoiding big hydropower projects/discouraging settlements along river beds/flood plains/ efficient drainage management
d. Increased frequency of extreme rainfall events	Damage to terrain/high flux of sediments in the rivers gigantic landslides/River damming/tremendous damage to hill environment, threat to biodiversity Flash floods	–	More and more hill population exposed to life and property threat/tremendous damage to infrastructure/flash flood caused damage to hill population/gigantic floods in plains	–
e. Increased frequency of extreme dry seasons/extreme hot summers	Forest fire/drying springs/ threat to biodiversity/rapid propagation of few species e.g. Pinus rox./parthynium etc	Efficient watershed management/forest fire control measures/controlling monoculture tendencies of some species	Acute drinking water shortage/ threat to traditional agriculture and horticulture practices/fertility loss of soil/threat to traditional livelihood practices	Adopting water harvesting techniques/change in farming pattern accordingly(?)/R7D for new livelihood practices(?)

crises of climate change and environmental degradation will be critical for determining the quality of life our descendants experience over the coming centuries. Human societies have three options for dealing with any crisis: mitigate, adapt, or suffer (Thompson, 2010). The problem with the communities which are going to be worst affected due to climate change in the Himalaya is that they have hardly any role to improve the worsening scenario. A solution that may be in the hands of them is to enhance the natural carbon sinks through expansion of forests. Table 5 gives a holistic picture of the societal impact of climate change in the Himalaya and few possible measures which can minimize the impact.

Some initiative has already been taken by the local people with support from outside. To name few, Bhutan is the first country which is gearing up to combat one of the severest threat posed by the fast receding glaciers i.e. the Glacial Lake Outburst Flood (GLOF). A scientific study carried out in the past indicated that rapidly melting Thorthormi glacier may create a lake which may eventually burst that would lead to a major catastrophe. This threat was passed on to the administration which has put its resources to deepen and widen the lake outlet so that water can drain faster and minimize the downstream catastrophe in Pho River (Nayar, 2009).

Chewang Norphel

One of the major regions in Himalaya that may face severe consequences of global warming is the Ladakh region. There are already indications that the hydrology of glaciers fed village streams are declining which is attributed to the reduction in glacier ice. The local irrigation systems were failing due to drying up of streams (Vince, 2009). In this region, the entire population depends on the melting of glaciers and snow because the average rainfall is <150 mm (Juyal, 2010 and reference therein). As a proactive measure to combat the warming induced glacier recession, *Chewang Norphel* a local resident came with a noble idea of creating artificial glaciers by arresting the stream flows in the artificial ponds so that in winter it freezes and forms miniature ice sheets. This sheet provides irrigation water to the villagers during the summer (Vince, 2009). The results of this experiment are quite encouraging.

To Summarize

Climate change is a reality; we may debate the magnitude of its impact on the Himalayan eco-system. Glacier recessions provide a first order approximation towards the growing threat posed by increase in temperature and changes in the rainfall pattern in Himalaya. The unusual rainfall event that covered nearly half of the Himalaya (Ladhak to Uttrakhand) was unprecedented. Considering the sensitivity of the Trans Himalayan region to climate change, this region should be studied and monitored for the geomorphic and ecological indicators of climate change. This would involve monitoring glaciers having different sizes and orientations, stream flow monitoring, cropping pattern, animal behaviours and most importantly, the biodiversity of the alpine pastures. More specifically we should:

(i) Generate base line data on the existing resource (glacier, tree line, alpine flora and fauna, water bodies, agricultural practices (land use), local dependency i.e. population).
(ii) Data thus generated can be compared with the available past record (~last 50 years) along with the meteorological data (where available) in order to assess the impact of climate changes on the ecosystem.

Once the above data base becomes available, it would set the stage for scientific interpretation and methodological development for combating the threat posed by global warming to the higher Himalayan ecosystem.

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