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GLACIER RECEDING AND ECOLOGICAL THRESHOLDS FOR TIBETAN PLATEAU AND ASSOCIATED CRYOSPHERE

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ABSTRACT

Mountain hazards are environmentally created and their strength changed with rigorousness of climatic factors. High alpine areas are usually covered with glaciers where atmosphere, biosphere, hydrosphere, geosphere, and cryosphere including mankind interrelate. Climate change accelerations in 21st century and past assessments of the stressors how they affect ecosystems in the mountains of South Asia with observed and projected temperature and precipitations impacts and with a focus on plant ecology changes were examined. The ecological thresholds for biosphere is achieved when an alteration in the quality, singularity or features of an ecosystem produce large and persistence responses in an ecosystem. This review builds on an extensive scientific literature and IPCC recent calculations of the historical and potential impacts of glaciers receding with climate change affecting ecosystem thresholds. It identifies the rate of changes in plant communities and phenologies and processes observed in Tibet Plateau, Greater Himalayas and associated mountain ranges. The increased glacier melting water accounted for the increase in lake's volume. Similarly the water storage properties of glaciers and seasonal snow have been studied focusing on the impact of recent trends regarding glaciers and snow due to climate change. The findings conclude that by the end of twenty-first century, an ecosystem collapse could result from the sensitivity of glaciers towards the current warming scenario and climate change. This reviewed research will draw attention of the international research community towards this region leading to a more dynamic research to deal with the aforementioned crossing of ecological thresholds and anthropogenic problems.

Key Words: Tibet and Associated Cryosphere, Glacier Receding, GLOF, Ecosystem Thresholds

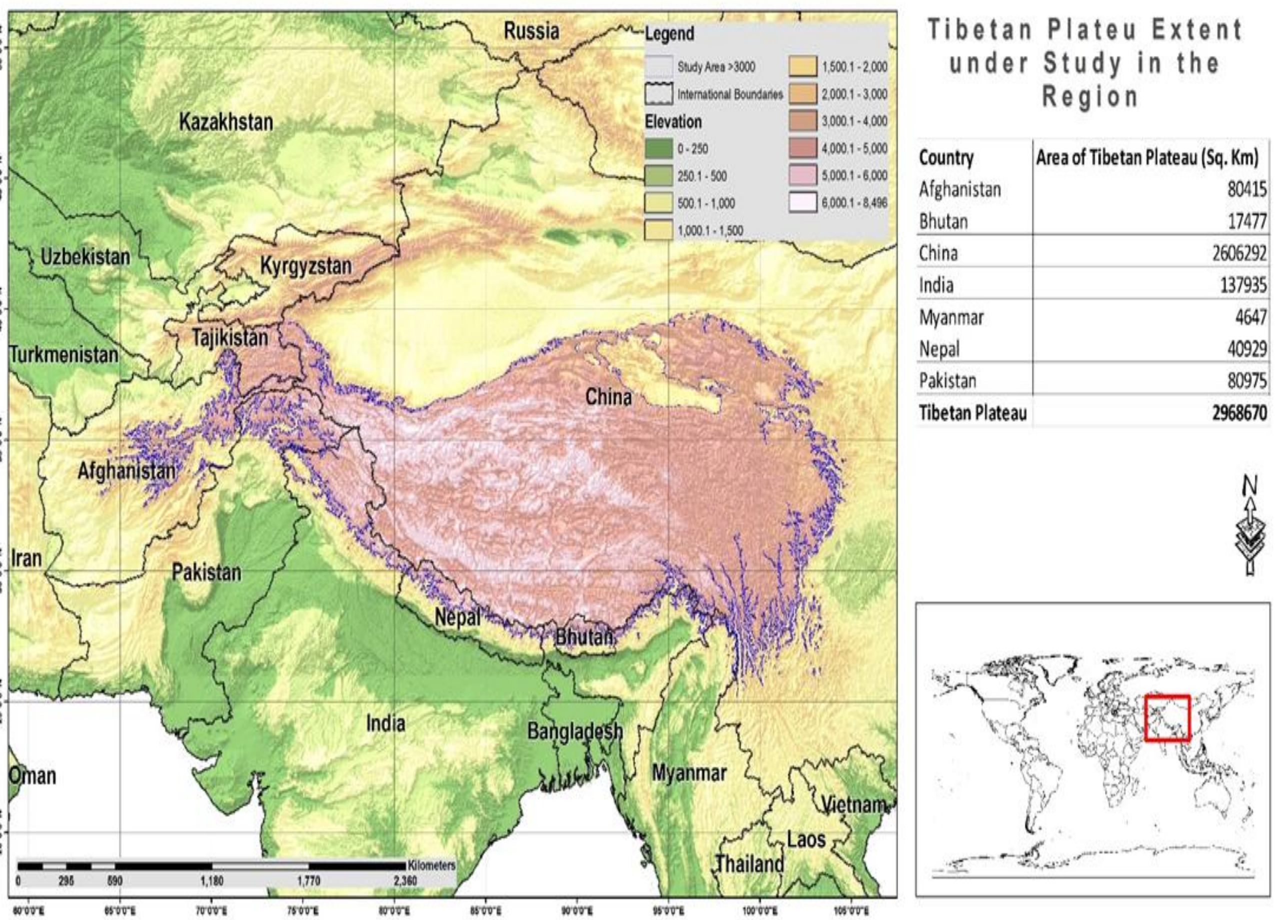
INTRODUCTION

Gradual successional changes never harm ecology of an area, however, unexpected change can accelerate species extinction at an amplified rate. Different environments vary in scale and complexity, comprising a series of interconnected components or subsystems ranging in scale from microscopic to continental. In the past, human environmental impact was mainly at subsystem level, but the growing scale of anthropogenic interference has caused the impact to extend to continental or even global scale (Kemp, 1994).

Climate change is affecting ecosystems continuously and disturbs the biological organization among as well as within species that is of concern to the scientific community for some time (IPCC 1990; Lovejoy and Hannah 2005). The variations in physical climate is an incessant process that may impact significantly on biodiversity so the scientific literature and community is focusing on observed and expected changes in future (IPCC 2001; IPCC 2007; Millennium Ecosystem Assessment (2005).

Worldwide mountain glaciers are retreating with increasing runoff as reported in many studies like Kaser *et al.,* 2003; Box and Cohen 2006) with changing hazard conditions (Haeberli and Burn, 2002). The mountain ranges in the world have different slopes and aspects with glaciers receding. The retreat of glaciers from prominent Little Ice Age moraines is resulting in formation of lakes which present a high potential for glacial lake outburst floods (GLOFs). Annual mass-balance data for the last 60 years from a total of 3480 measurements collected from 228 glaciers worldwide has been compiled by Zemp *et al.* 2009 for the World Glacier Monitoring Service and associated organizations. The data compilation was started since 1940's and the decadal regime shows that glaciers retreat was strong up to 1950's with a moderate loss until 1970's and a subsequent acceleration that persists until now. Fate of the glaciers is defined by weather parameters such as temperature, solar radiations, wind, precipitation etc. Air temperature predominately characterizes the ablation and recession of a glacier along with radiation balance, solid/liquid precipitation ration and turbulent heat exchange (Kuhn, 1981; Ohmura, 2001). Generally the climatic sensitivity of a glacier is dependent upon the inconsistency of the regional climate and the local topographic effects as well. As a result two adjacent glaciers can exhibit different specific mass-balance responses (Kuhn *et al.* 1985).

Glaciers are mosaic between renewable and exhausted resources that serve as buffer against climate variability. During dry season glaciers provide water to both humans and biodiversity. As a limited resource, freshwater is already under pressure in coming decades with increasing human population. Greatest source of snow outside the poles is under threat of global warming. The temporal and spatial variations among precipitation events have happened in last century, that influence the ecosystem thresholds leading to the lengthened growing season of vegetation, advanced plant phenology in spring, altered geographical distribution and composition of vegetation particularly in the ecotone and timber line vegetation, and also the net primary productivity linked with increase in vegetation cover and activity (Ni, 2011). Differences in local climates, aspects, size, steepness and the speed of individual glacier may explain the different behavior. In addition, the effect of a given climatic fluctuation on the glacier mass balance depends on the area-altitude distribution of the glacier. As a result, glaciers in the same area are likely to react differently, or at different rates to the same mass balance variation (Paterson, 1994). The WGMS findings have compiled data for frontal variation of 2115 glaciers from South Asian (Supplementary Table-1, 2014), of which 392 are detailed with the core assessment (Figure-1). Advance and retreat of the glaciers in WGMS collected data normally lag behind the climate forcing because the signals must be transferred from the accumulation area to the snout. The compilation of frontal variations indicates that glaciers appear to be shrinking with temperature rise in the region.



Country	Area of Tibetan Plateau (Sq. Km)
Afghanistan	80415
Bhutan	17477
China	2606292
India	137935
Myanmar	4647
Nepal	40929
Pakistan	80975
Tibetan Plateau	**2968670**

Figure 1: Tibet Plateau and associated cryosphere with 3000m elevation.

First decade of 21st century is feeling warmer as rise in temperature registered has been 2 times higher than expected. The records of first decade 2001-2010 states that it was warmest on earth with the yearly record 2010 (+0.53°C) followed by 2005 (+0.52°C) and 1998 (0.52°C). Similar observation has been observed in the Pakistan Mountains and in the region (Figure-2).

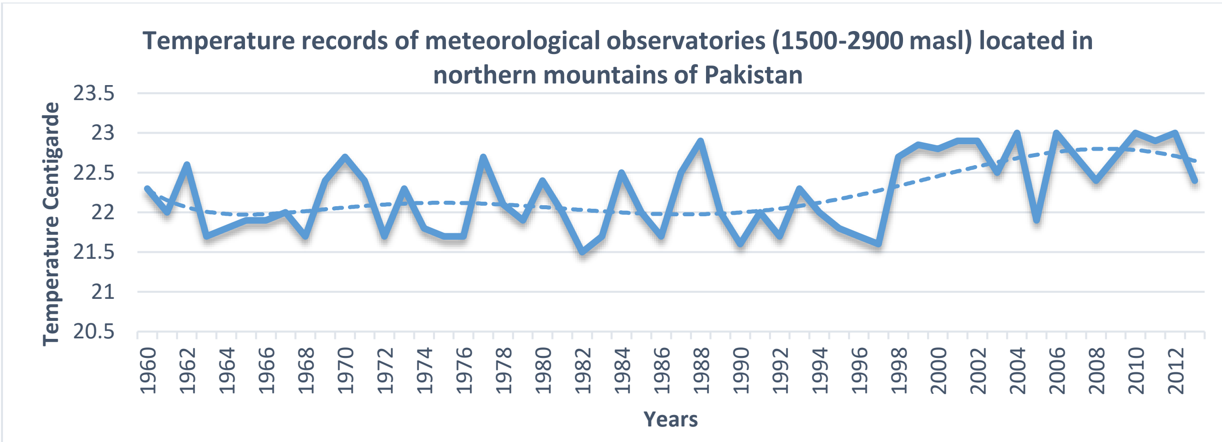
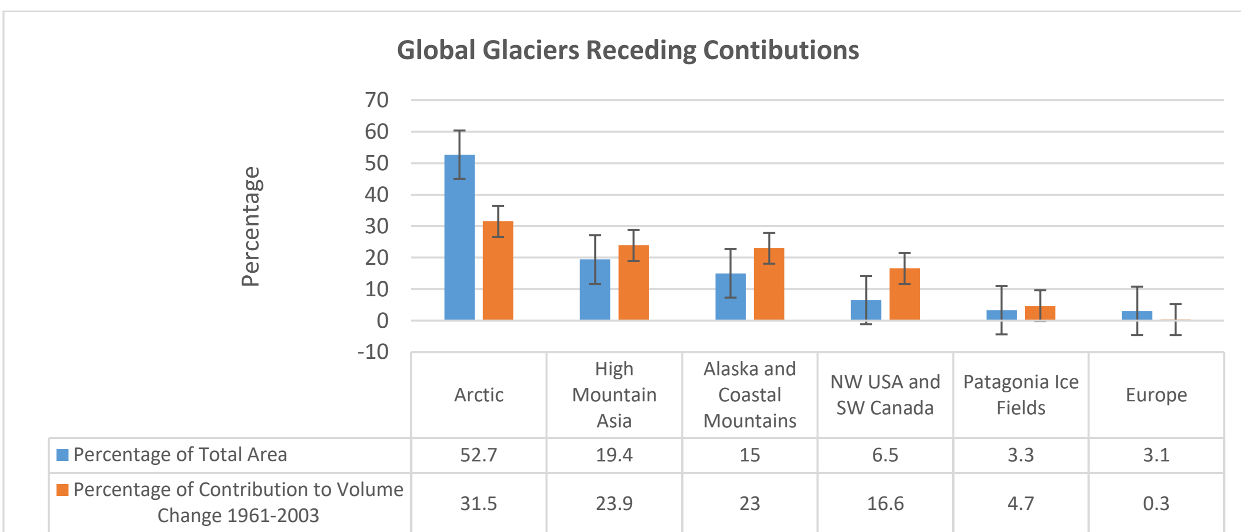


Figure 2: Last five decades temperature variations. (Source: PMD)

In recent years climate has fluctuated in a distinctive way. The effects of global warming were studied in mountainous areas by Barry, (2002) with a clear manifestation of the shrinking glaciers and a decrease in the duration of snow cover. Analysis of temperature revealed an approximate receding of 1 km of snowline from its previous spread 25 years ago. This has also resulted in an upward shifting of the constituent flora and fauna as well (Rasul, 2006).

Clues of Glaciers Receding: Climate change stimulates glaciers melting: Many of the global and regional glacier changes has been measured as integrated work of scientists and organizations, the observation of world mountain ranges show glaciers retreat since little ice age (Figure-3). At global level World Glaciers Monitoring Service (WGMS), NSIDC, GLIMS, and in regional monitoring ICIMOD have compiled the data on glacier retreat to predict future scenario. At global scale World Glaciers Monitoring Service (WGMS), investigation of glacier retreat is in process of re-construction with the monitoring of recession since Little Ice Age. The global review was documented by Hoelzle *et al*. (2003), Grove (2004), Zemp *et al.* (2009), and WGMS (2008) with regional studies demonstrated by Chinn (2001) for New Zealand, Kaser and Osmaston (2002) for tropical glaciers, Andreassen *et al.* (2005) for Norway, Kotlyakov (2006) for Russia, Casassa *et al.* (2007) for the Andean glaciers, Molnia (2007) for Alaska, and Zemp *et al.* (2009) for the European Alps.



	Arctic	High Mountain Asia	Alaska and Coastal Mountains	NW USA and SW Canada	Patagonia Ice Fields	Europe
Percentage of Total Area	52.7	19.4	15	6.5	3.3	3.1
Percentage of Contribution to Volume Change 1961-2003	31.5	23.9	23	16.6	4.7	0.3

Figure 3: Global Glacier Receding (Adopted from: http://nsidc.org/glims/glaciermelt/index.html)

Himalayan glaciers were studied in similar perspectives by Ageta and Kadota, (1992) and Naito *et al.* (2001), and concluded that Himalayan glaciers were more sensitive to recent global warming due to their characteristic of peak accumulation in the summer months. Not all glaciers are receding but in specific time periods like from 1986 to 1996, studies of Hewitt (1998a) show that 6 of a possible 9 Karakorum glaciers showed surge type behavior between 1997 and 2002, 13 advancing glaciers of intermediate size (10 to 20 km in length). Some of the largest glaciers i.e. 40 to 70 km long, have also been reported to display a thickening of 5 to 15 m over a considerable area of the ablation zone, locally more than 20 m (Hewitt, 2005).

The response of debris-covered glaciers in the Karakoram Mountains to the current warming climate was concluded to be a long term negative mass balance with the magnitude decidedly smaller than for debris-free glaciers. Moreover, the debris cover has an insulating function once a critical debris thickness is exceeded (Nakawo and Takahashi, 1982; Nakawo and Young, 1981). For instance in the studies of Smiraglia *et al* 2007, Baltoro glacier, the largest debris-covered glaciers chosen as a main field test site, seems to be only slightly changed in respect to its past dimensions. On contrary Liligo was advancing, but it might be deceptive to construe this advance in term of direct response to regional climate change, rather than due to an oscillatory change (i.e. surge).

Detailed mapping inventories of glaciers of the high mountains of Central Asia from WGMS (World Glaciers Monitoring Service), GLIMS: (Global Land Ice Measurements from Space), ICIMOD (International Centre for Integrated Mountain Development), ISRO (Indian Space Research Organization), PMD (Pakistan Meteorological Department, 2009) and Chinese National Committee for International Association of Cryospheric Science (IACS) have identified strong retreating of glaciers and also loss of area throughout the region since 1990 with the exception of Karakoram. The source of these records is the repeated imagery from ASTER, Corona, Landsat, IKONOS and SPOT imagery.

Studies show that by the year 2100, monsoonal temperate glaciers are expected to shrink by 75–80% with an area of 9,900 Km^2 and overall shrinkage will be like 45% (Su and Shi 2002). Expectedly the permafrost on the Tibetan plateau and in north eastern China will undergo substantial retreat (Su and Shi 2002). Many small glaciers will evaporate and retreat in larger glaciers will be quantifiable, causing increased variability in river run-off (Shi and Zhang 1995). The rate of relative sea-level rising is expected to increase rapidly in the 21st century (Wu *et al.* 2003), but according to Cui and Zorita, (1998), seasons will influence the rate of this rapid increase in sea-level while Chen (1997) suggests regional variability as the influencing factor in this regard. Only the Karakorum glaciers area will get some expansion (Hewitt, 1998). Divergent results with exceptional and different frequency may be observed in HKH region with the increasing intensity of heat waves over the southern slope (Rasul *et al*, 2008).

Clues for Glacial Lake Outburst Flood (GLOF): Central Asian region has an estimated ice cover of 114,800 km^2 in total with 99,221 km^2 of Tibet plateau and associated cryosphere (figure 4). The Himalaya is the dominant mountain range of the region harbouring most of the glaciers (8.6 x 106 m^3 of water is annually provided by 33,050 km^2 of these glaciers, Dyurgerov and Maier, 2005). The adjacent mountain ranges along with their corresponding ice areas include: Karakoram (16,600 km^2), Pamir (12,260 km^2), Qilian (1,931 km^2), Kunlun (12,267 km^2), Qiangtang Plateau (2,581 km^2), Tanggula (2,213 km^2), Gangdise (1,760 km^2), Nyainqingtanglha (9,120 km^2), Hengduan (1,579 km^2), Gindukush (3,200 km^2), Hinduradash (2,700 km^2) mountains (Yao *et al* 2012).

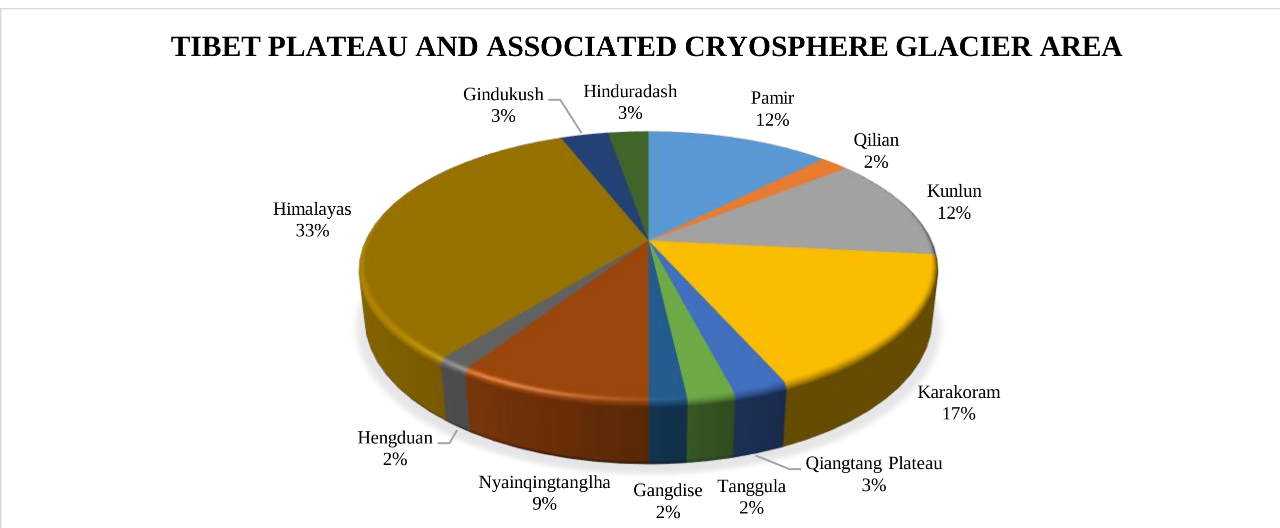


Figure 4: Tibet Plateau and associated cryosphere glacier areas.

There are conclusive evidences that usually when glaciers retreat, an escorted growing of debris cover on many glaciers termini results in glaciers lakes development and with a prospective threat of outburst floods in the downstream areas (Ageta *et al.* 2000; Wessels *et al*. 2002; Kotlyakov *et al*.2008). With the climate change proceedings GLOF events are frequently increasing the devastating mountain hazards. With help of GIS from five different points (Figure-5) glaciers have been monitored and Figures 6 to 109 provide an evidence of receding glaciers and formation of lakes in the past three decades in the Himalaya Range, Karakorum Range and Tibetan region.

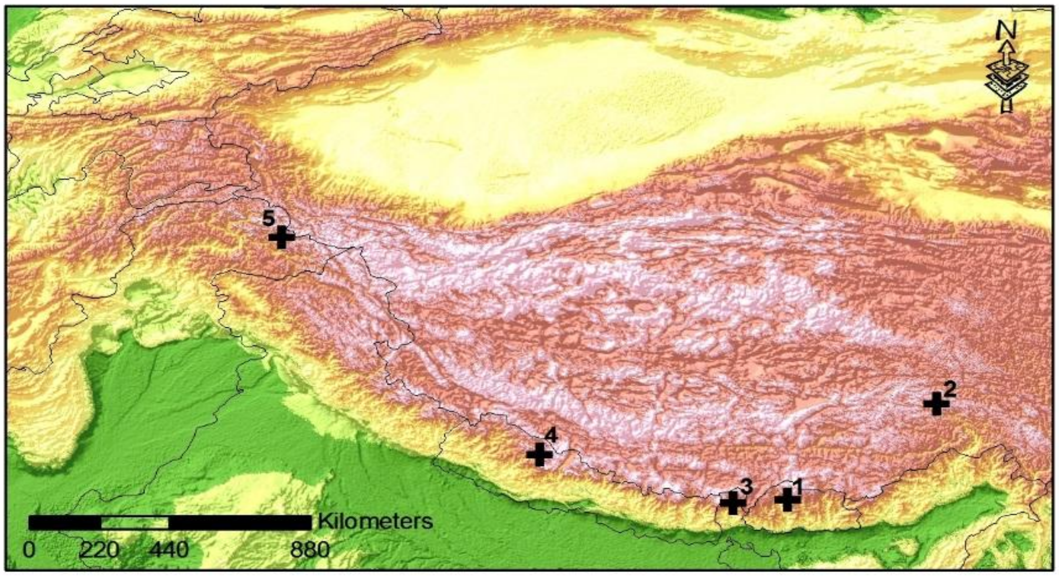


Figure 5: Locations of the images at Tibet Plateau and associated cryosphere.

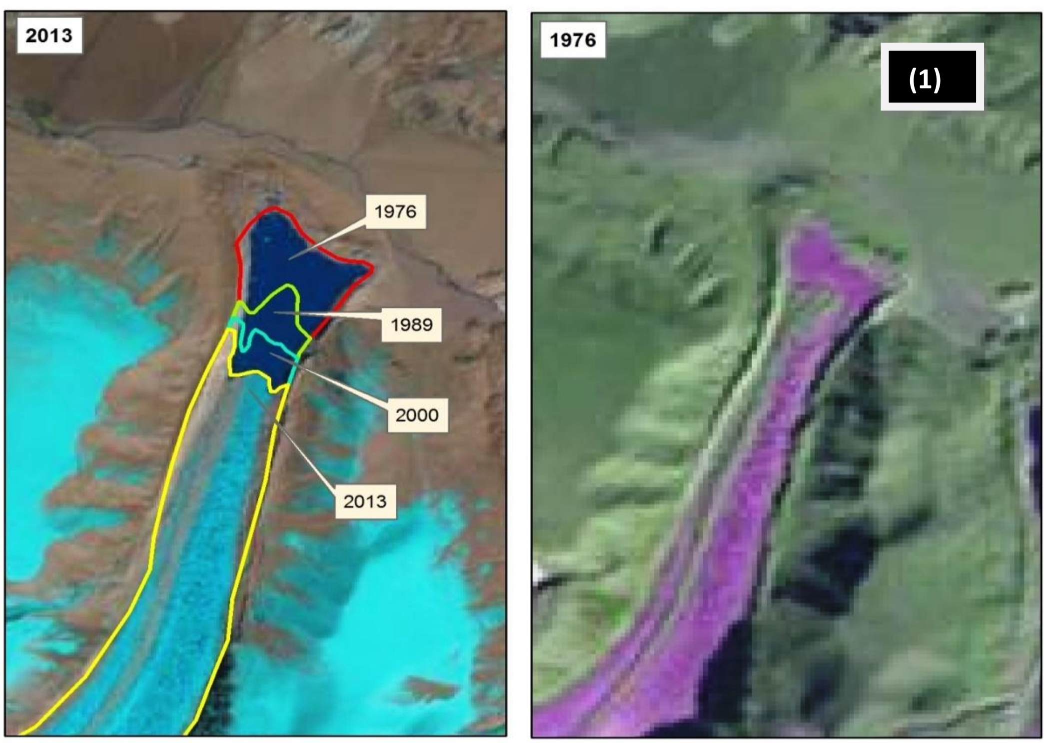


Figure 6 (1): Glacial retreat and formation of glacial lake (1976 to 2013) in the Himalayan Mountains of Bhutan,

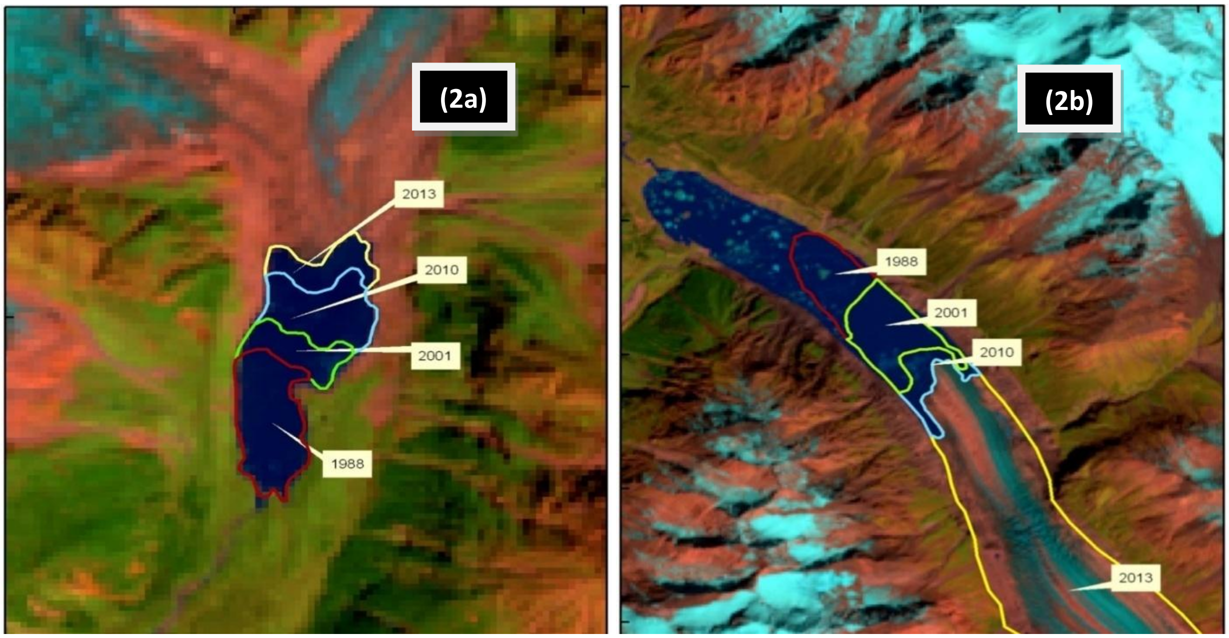


Figure 7 (2a): Glacial Retreat (1988 to 2013) from Tibetan region, China, (2b) Glacial lake extent change (1988 to 2013) in Tibetan region, China,

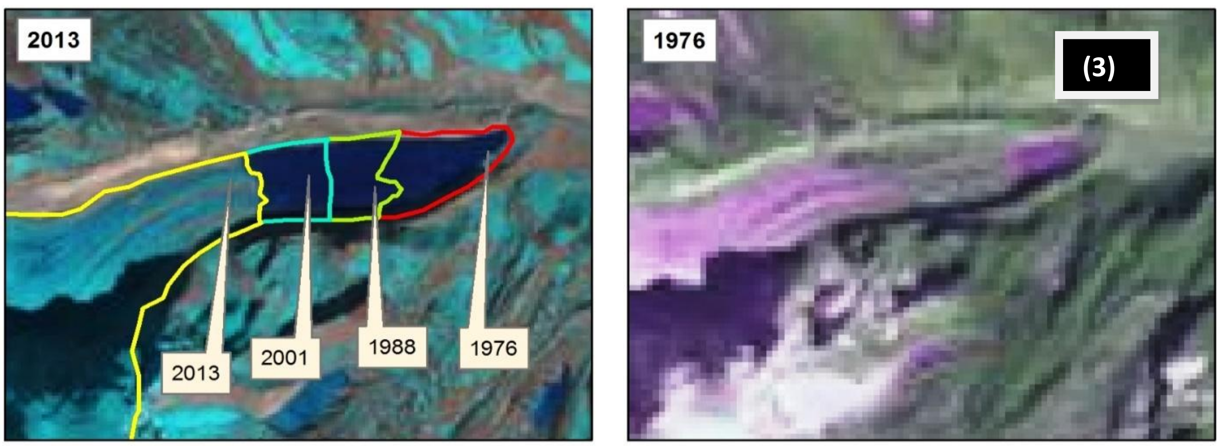


Figure 8 (3): Glacial retreat and formation of glacial lake (1976 to 2013) in the Himalayan mountains of India

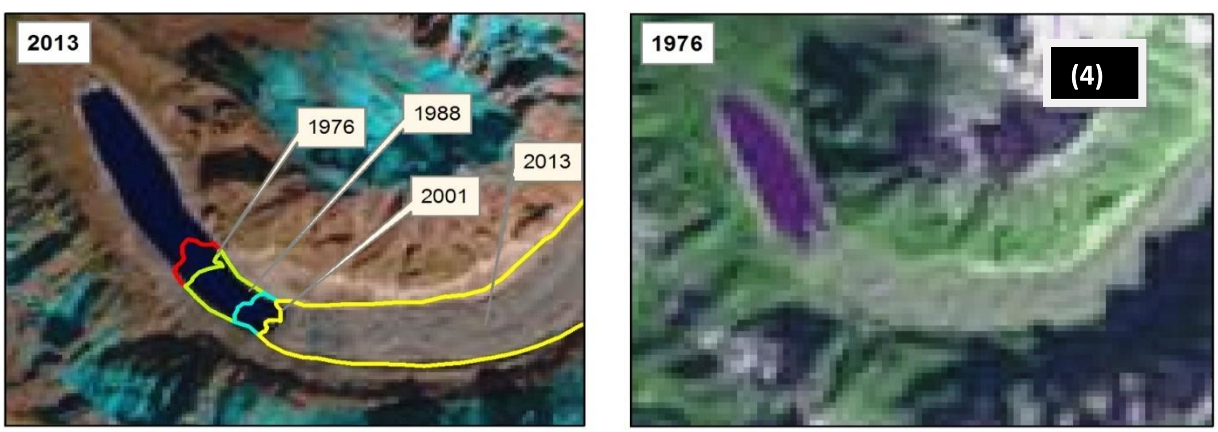
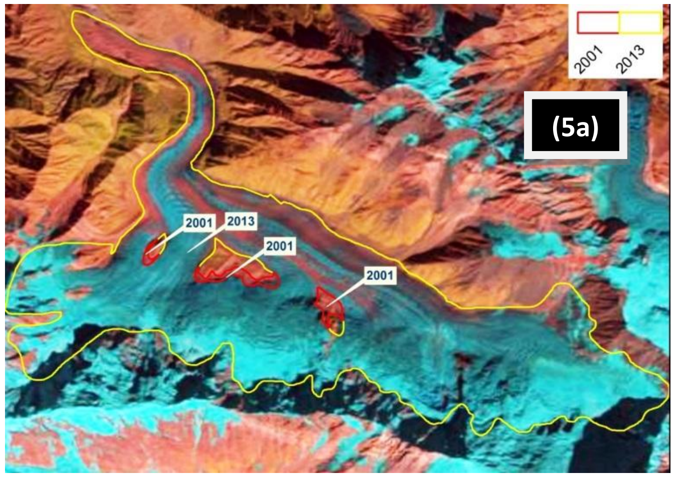


Figure 9 (4): Glacial retreat and formation of glacial lake (1976 to 2013) in the Himalayan mountains of Nepal



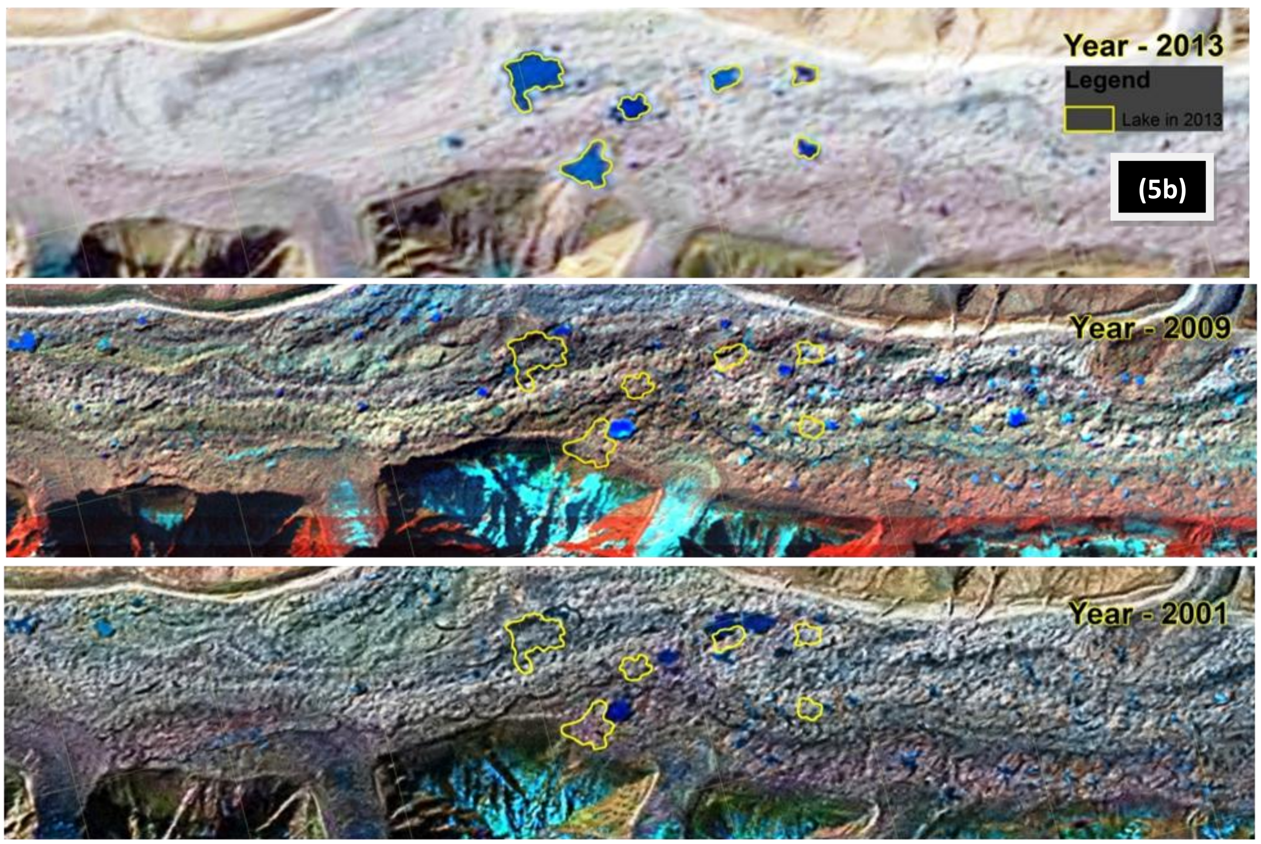


Figure 10(5a): Glacial retreat (2001 to 2013) from Karakorum, Pakistan (5b) Formation of glacial lake (2001 to 2013) from Karakorum, Pakistan.

GLOF sways: Glacier melting is an important indicator of climate change that leads to flood hazards. There are conclusive evidences that the region is facing 5.5 % shrinkage in volume of glaciers during the last 30 years. Usually the pace of retreating of valley glaciers and small glaciers has quickened; so has the formation and expansion of resulting glacial lakes. In the last fifty years glaciers melting speed was so quick that is comparable to 50,000 years in case of natural deglaciation. Subsequently the frequency of occurrence of GLOF events recorded in the region has also increased with at least one event between 3 to 10 years. The trans-boundary impact of these GLOF events is a precursor of loss of human lives and property as well as increased vulnerability of species.

Ecosystem health is jeopardizing by warming atmosphere, perhaps none is more visible than or as acutely dangerous as outburst flooding in the Tibet and associated cryosphere. The glacial melt from the mountainous regions is altering the ecology of the area by contaminating the water sources and spreading illnesses plaque in the water sheds apart from events such as windstorms, floods, droughts and wildfires. The disappearing glaciers are increasing the vulnerability of species as their habitats are disturbed in ten of the major Asian river systems- the Indus, Ganges, Brahmaputra, Irrawaddy, Amu Darya, Yangtse, Yellow, Salween, Mekong, and Tarim. This scenario is a warning of what is to come in the coming years.

Potential impacts on Ecosystem Thresholds

Grasslands: The frequency and intensity of floods of the rivers would determine the fate of these moist grasslands. If flood frequency and intensity increase in tune with the projected increase in climate variability, these grasslands would be maintained or even increase. Local precipitation changes would also determine the composition of grassland versus woodland in the floodplains.

Grasslands at elevation of 1500-2500 m are a mixture of C3 and C4 grasses. Increased CO_2 would favour the C3 plants over C4 plants; thus not only the composition of these grasslands would change but also there could be invasion by C3 woody plants. Alpine meadows at high elevation in the Himalayas may be adversely affected by increased temperatures that would enable the upward relocation of woody plants and associated fauna into these habitats.

Freshwater ecosystems: Freshwater ecosystems perform numerous valuable environment functions such as recycling of nutrients, purification of water, recharging the aquifers, augmenting and maintenance of the stream flow, and least but not last, provision of habitat for a vast variety of plants and animals. Rapid melting of glaciers with increase in temperature will affect the ecosystem by change. Changes in the thermal cycle of the lakes, solubility of oxygen and other compounds, loss of ice cover during winters and a reduction in available oxygen in water can have a detrimental effect upon the community structure and loss of species diversity as well, with the situation getting more worse in case of eutrophication from surrounding land use. Organization level within a community may also be disturbed as lake levels change due to increased temperature and deviation in precipitation (Cohen and Rind, 1991).

Agriculture: A general speculation is that climate change may facilitate the increased yield of food crops in the mountainous regions owing to an increase in CO_2 concentrations and length of growing season (GSL) leading to the possibility of wheat cultivation for grains above 1500 m a.s.l. and benefitting other crops and fruits as well (Hussain, 2004).

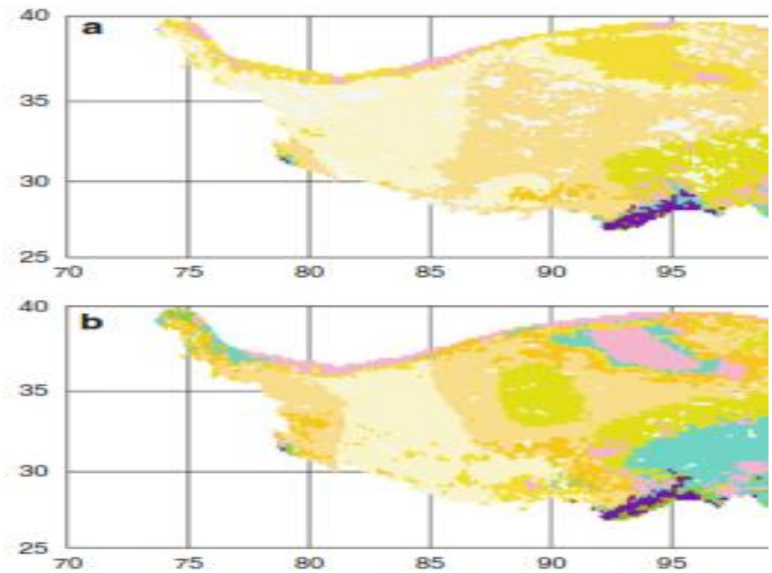
However, these problems would be worsened instead of improving due to climate change. Irrigated agriculture in arid and semi-arid environments is at present being carried out under exceedingly high temperatures (Ahmad, 2005). Increased rates of evapo-transpiration would mean supplying additional water for growth and cooling in an already water deficient area. On the other hand, increased utilization of marginal quality ground water would result in increased salinity of the soils rendering them unfit for cultivation.

In selected districts of Punjab, Pakistan for assessing the impact of changes in temperature and corresponding changes in wheat yield in selected cropping systems over time econometric model have been used (Malik *et al*., 2005). The results reveal that wheat yield was inversely related to rise in temperature.

It is estimated that wheat yield could decline by 9 to 30% to a temperature increase of 1 to 4ºC. In marginal communities, particularly in the mountain environments as well as in arid areas, with increasing temperature and low rainfall, crops, livestock, and on-farm agro-forestry productivity is declining at even alarming levels (Amir, 2005). Droughts reduced the value associated with livestock and livestock products, which results in out-migration. In these communities farmers are unwilling to sell water during droughts, indicating the high value placed on this resource.

Natural ecosystems: Climate change scenario with different climate model simulations was studied by Ni, 2011 with conclusive evidences that increases in temperature, changes in precipitation regime and CO_2 concentration enrichment will happen in the future in the mountains. The projected climate scenarios will significantly influence ecology of the area, desertion of boreal forest from northeastern China, subsequent in a northward shift of all forests, an eastward move of grasslands (increase) and deserts (decrease), new tropical forests and woodlands move into the tropics, a lessening in alpine vegetation and an upsurge in net primary productivity of most vegetation types.

Tibetan Plateau: The topographic configuration and atmospheric circulation determine the horizontal differentiation between natural vegetation zones (Figure-11). From the southeast to the northwest of the Plateau, vegetation changes successively from mountain forest, through shrub and alpine meadows and alpine steppe, to the arid desert (Rasul, 2008).



Temperate Conifer Forest
Temperate Deciduous Forest
Temperate Broadleaved Evergreen Forest
Tropical Seasonal and Rain Forest
Temperate Shrubland/Meadow
Temperate Steppe

Temperate Desert
Alpine Meadow/Shrubland
Alpine Steppe
Alpine Desert
Ice/Polar Desert

Fig. 11 Climate change evidences from Tibet Plateau with vegetation changes9Present) and b climate scenario with CO_2 concentration at 500 ppmv (from Ni 2000)

Climate Change in increased CO_2 concentration scenario, studies showed same response of vegetation shift. Different researchers (Ni, 2000, Song *et al*, 2005 and Ni, 2011) used BIOM3 and BIOM4 models under the HadCM2 and HadCM3 climate change scenario respectively during twenty first century (Table-1) and projected a major northward shift of alpine meadow and a reduction in shrub- dominated montane steppe. They concluded a reduction in the area of alpine desert and an increase in the spread of the montane desert.

Table 1 Regional changes in vegetation of Tibet Plateau under climate change scenarios

Region	Model	Climate scenario	Time	Vegetation change	References
Tibetan Plateau	BIOME3	HadCM2 $2xCO_2$	2100	Vegetation shift	(Ni, 2000)
	BIOME4	HadCM3 $2xCO_2$	2100	Vegetation shift	(Song *et al*., 2005)
	Bioclimatic model	HadCM3 $2xCO_2$	2100	Species shift	(Song *et al*., 2004)

One of the most sensitive areas to global climate change is the Tibetan plateau. Sixty-seven percent of glaciers are receding at a confounding rate in the Tibet and associated cryosphere with climate change being identified as the major culprit (Ageta and Kadota, 1992; Yamada *et al*., 1998). The changes in temperature studied at the high altitude sites of the plateau can consequently be a useful indicator of global warming. For instance, in the regional scenario in figure 12 and 13, projection in precipitation changes has been demonstrated from now to 2050.

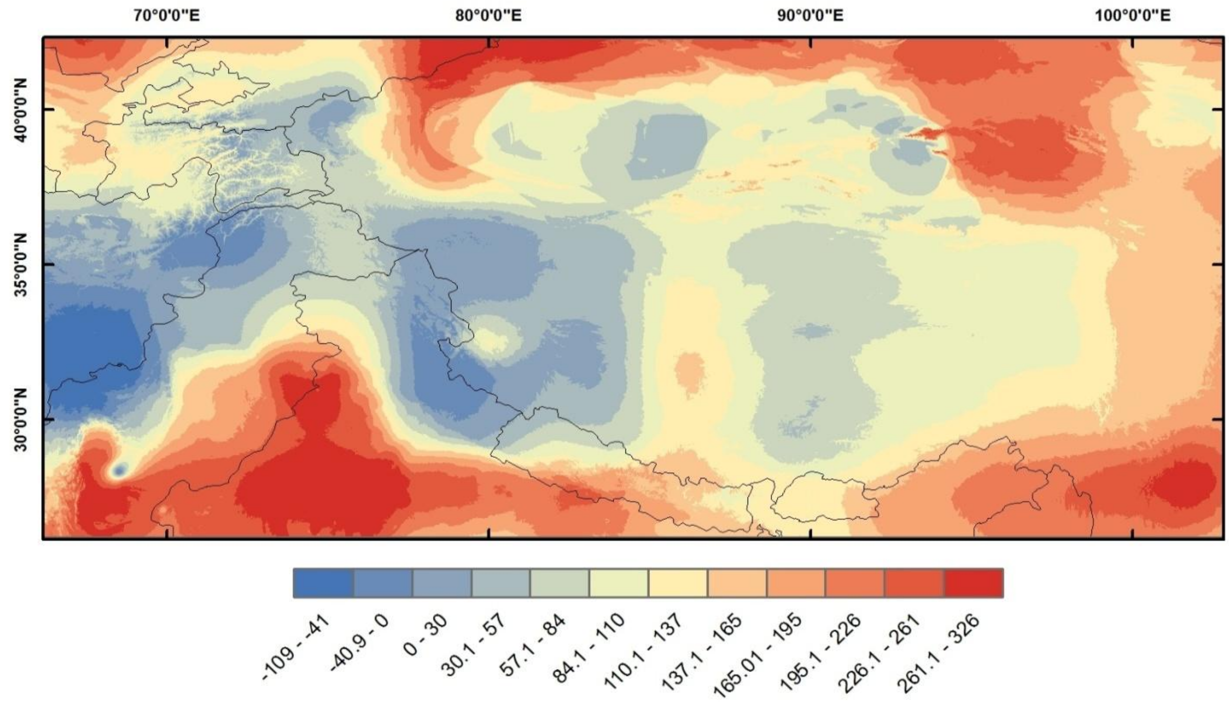


Figure 12: Expected annual mean precipitation variation/change, mm/y, in Hindu Kush, Himalaya, Karakorum and Tibetan region.

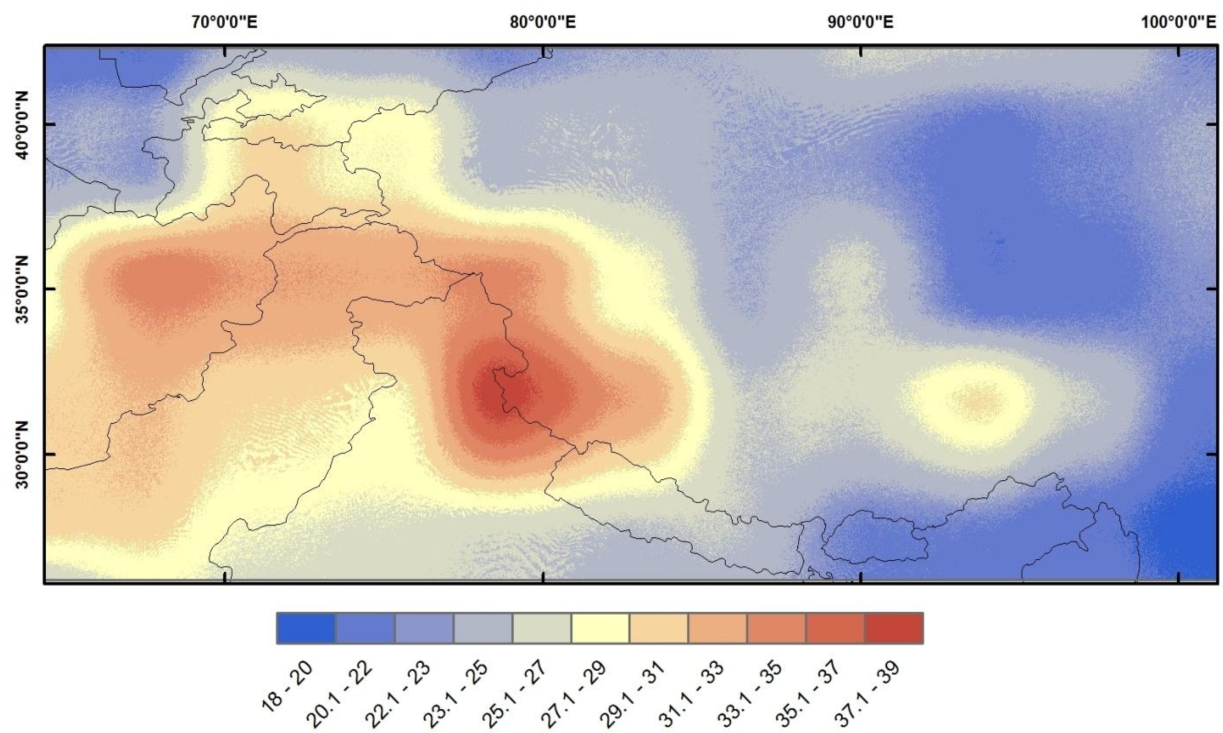


Figure 13. Expected annual mean temperature variation (2000 – 2050) in Hindu Kush, Himalaya, Karakorum and Tibetan region.

Precipitation depends on many physical and dynamical processes, such as large scale motion of moist air, orographic lifting, convection (Ebert *et al*., 2003). Therefore, near real-time satellite-derived estimates of precipitation, which are becoming increasingly available in recent years, provide a valuable tool to the scientific community for analyzing and investigating the physical processes associated to the water cycle, due to their spatial and temporal resolution over large areas. The quantitative precipitation forecasts shown in figures 12 and 13 shows the expected annual mean precipitation and mean annual temperature change calculated from the IPCC4 current (1950-2000) and projected future (2000-2050) bioclimatic datasets. This clearly shows that annual mean temperature of Hindu Kush, Himalayan, Karakorum and some parts of the Tibetan region will rise in the future and it is also expected that the region will receive considerably less precipitation if the current trend of precipitation continues in the future.

As the glaciers retreat with a rise in temperature, some of the studies (Kuhn, 1993; Oerlemans, 1994; and IPCC, 1996) show that a quarter of alpine glaciers will disappear by 2050 and fifty percent will be lost by 2100. Freshwater flows is likely to be affected by this glacial melt with subsequent unrestrained and opposing impact on the biodiversity as well as people and their livelihoods. In the long run this may have a possible repercussion on regional food security.

As a consequence of these predicted events, a net shrinkage of glaciers and their retreat will increase the frequency of GLOFs in the years to come which will in turn not only cause an increase in the number of glacial lakes but also the size of existing lakes. All these factors will have an ultimate strong influence on the life and property of the mountain dwelling human populations.

The impact of climate change on glaciers and subsequently riverine ecology causing ecosystems to cross the thresholds is a major issue at regional as well as trans-boundary level. The occurrence of ecological thresholds is due to the external factors causing system instability and thus leads to irreversible changes that proliferate in a domino-like fashion. Crossing of an ecological threshold means that reverting to the original state is almost impossible for the ecosystem under question (Orostegui, 2010). To tackle this ecosystem distress and to address the adaptive measures, a regional co-operation is in process of focusing on the key issues requiring future interventions (ICIMOD, 2008).

With a predicted level of CO_2 to be 500 ppmv in year 2100 under a climate scenario (HadCM3), different predictions were analyzed. It was projected that future changes on the Tibetan Plateau will not be confined to the vegetation patterns but also to species distribution. According to the bioclimatic model projection, the distribution of the tree species (*Abies spectabilis, Picea likiangensis* var. linzhiensis, *Pinus densata*, *Larix griffithiana* and *Quercus aquifolioides*) would spread northward and westward, with a northward shift of *Betula utilis* with some area shrinkage (Song *et al*. 2004). Conversely, Klein *et al* 2004 pointed out that plant species diversity could decline at higher elevations meadows over short time frames.

Ecological thresholds would achieve as augmented in past observations. Temperature increasing and precipitation is fragmented with little increase in some areas. Droughts occur frequently, such changes generally alter the associated ecosystems. Generally speaking, prolonged growing season of plants as a result of climate change has affected the plant phenology (Ni, 2011).

Change in vegetation shift in support of change in ecology of the area is well braced by Ni, 2011 predictions. As the European Union adopts a target of 2ºC global mean warming above preindustrial (European Climate Forum, 2005), following changes in China vegetation under a 2ºC warming have been hypothesized and summarized in (Table-2).

With the predicted climate models and current climate change scenario in China, human activities should be reduced to control desertification. Otherwise desertification will be intensified by climate (Chen and Tang 2005). Similar findings were made by Ni, 2000 on the Tibetan Plateau.

Tree Line Shift and drivers towards Ecosystem Thresholds: The upward shift of vegetation has been observed in South Asia, as the alpine areas getting warmer condition the tree-line is found to be shifted uphill up to 388 ± 80 m. (Singh *et al* 2012).The process and dynamics that shape mountain ecosystems start at the top, the degree to which snow is stabilized by high elevation vegetation, for instance can influence the amount of water storage and release. Alpine tree-line ecotone where trees struggle to live at heights of mountains is an indicator of climate change with the movement of line shifts upward or downward, that reflects broad scale climate change in mountains. (Fagre, 2009).

The flora of timber line or tree-line at high altitudes is exceedingly sensitive to climate change and therefore can be a useful indicator to assess the past and present variations in climate. An analysis of the shifting trend of alpine tree-line in parts of Indian Himalaya by Singh *et al*. 2012 using remote sensing revealed that vegetation line has shifted from the elevation of 3447 meter to 4158 meter in the last 40 years, i.e. almost 700 upward shift of tree-line in alpine areas.

Stress for ecosystem thresholds: Climate Change also drives ecosystem towards a threshold where transition starts and the mosaic ultimately brings changes forcing a shift in the geographical ranges, distributions and phenologies of many a species, change in the spread of biomes and modifications in the ecosystem functions and configuration (Table-3).

Table 2. Changes in Chinese ecosystems and species below and above 2 C warming

Climate Scenario with Temperature increase (^{0}C)	Ecosystems change	Species changes
<2	• Vegetation will shift to Northward • Tropical rain forest will expand while coniferous cold forest will be reduced by 2050 • Net primary productivity will increase by 1.5–2 ton/hectare/year	
>2	• Changes in vegetation composition • Increase in primary productivity • Increase in tree biodiversity by 2050 • Herb NPP decreases and shrub NPP increases in the Inner Mongolian steppe	Korean pine (*Pinus koraiensis*) distribution decreases by 12–45% in northeastern China by 2030
2-3	• Increase in forests by 15% • Decrease in desert and alpine vegetation by 9 and 4%, respectively	Distribution of dominant conifer tree species (*Abies spectabilis, Picea likiangensis var. linzhiensis, Pinus densata, Larix griffithiana*) shift and extend northward and westward, and deciduous tree (*Betula utilis*) shifts northward but its area shrinks on the Tibetan Plateau by 2100
3-4	• Deseret and alpine tundra will be reduced • Boreal forest will be shift more towards poles • NPP increases by 2100	

Source (Ni, 2011).

Table 3. Climate change drivers towards ecosystem thresholds

Climate Change Impact	Outcomes of Ecosystem Threshold
• More stress on biodiversity and ecosystems	• land use change and the consequent habitat fragmentation and degradation
• Many species to shift their geographical ranges, distributions, and phenologies altering ecosystem structure and functioning	• Terrestrial species are moving up in elevation at rates 2 to 3 times greater than initial estimates.
• Population declines and localized extinctions	• Ecological specialists and species that live at high altitudes and latitudes are particularly vulnerable to climate change.
• Range shifts will result in new community assemblages, new associations among species	• Changes in the spatial distribution and seasonal timing of flora and fauna within aquatic, and terrestrial environments can result in trophic mismatches and asynchronies.
• Promote interactions among species that have not existed in the past.	• Novel species assemblages can also substantially alter ecosystem structure and function and the distribution of ecosystem services.
• Changes in precipitation regimes and extreme events	• Changes in extreme events affect systems differentially, because different thresholds are crossed. For example, more intense storms and increased drought coupled with warming can shift grasslands into shrub lands, or facilitate domination by other grass types (for example, mixed grass to C-4 tall grass).
• Ecosystem transitions, increase transport of nutrients and pollutants to downstream	• More heavy rainfall also increases movement of nutrients and pollutants to downstream ecosystems, restructuring processes, biota, and habitats. As a consequence, regulation of drinking water

ecosystems, overwhelm the ability of natural systems to mitigate harm to people from these events.	quality is very likely to be strained as high rainfall and river discharge lead to higher levels of nitrogen in rivers and greater risk of waterborne disease outbreaks.
• Changes in winter have big and surprising effects on ecosystems	• Changes in soil freezing, snow cover, and air temperature have affected carbon sequestration, decomposition, and carbon export, which influence agricultural and forest production. Longer growing seasons and warmer winters are enhancing pest outbreaks, leading to tree mortality and more intense and extensive fires.
• Coastal habitats are especially vulnerable to sea-level rise and more severe storms.	• Loss to egg laying and sex determination for reptiles at the coast

Adopted from: Impacts of Climate Change on Biodiversity, Ecosystems, and Ecosystem Services (Michelle *et al* 2012)

IPCC observations on climate change impacts for Snow and Ice, River and Lakes, Flood and Drought, Terrestrial Ecosystems: Therefore IPCC 2013 has their observation on climate change with impact, adaptations and vulnerability at global scale given hereunder:

Asia

- Degradation of permafrost in regions of Siberia, Central Asia and the Tibet plateau
- Receding of mountain glaciers across Asia
- Affected water availability in many Chinese rivers due to land use change
- Increase in flow of rivers as glaciers are retreating in the Himalayan and Central Asian region
- Early onset of spring floods in Russian rivers
- Decreased moisture in soils of North Central and Northeast China
- Deterioration of surface water in parts of Asia
- Changes in plant phenology and growth resulting in earlier greening of plants in many parts of Asia
- Shifting of many animal and plant species towards higher altitudes, particularly in northern Asia
- Invasion of larch forests in Siberia by Pine and Spruce during the last few decades
- Habitat shifting of shrubs towards Siberian tundra

Hydrologic and ecological drivers: Wetlands are a complex ecosystem involving interaction of ground and surface water. Comparatively, the role of ground water in the hydrology of the wetlands may sometimes be incomprehensible as it is not directly observable. The surface water that is flowing from glaciers vary with distance from glaciers, location to the watershed area and also change in its ecological features, as Dougall, (2007) assessed that in case of loss of glacial stream habitat which would cause a decline in the insect population in return, the bottom of alpine food web would be the most affected. The larvae of the flying insects are a food source for other insect, birds and fishes and any disturbance may lead to a scarcity of food supplies for the fishes downstream.

As the flora and fauna of a region are affected by the recession of glaciers, new terrains are exposed for the successional colonization of species (Gobbi *et al*. 2006). Amphibians are closely tied to the melting of snow due to their reproductive phenology for which environmental cue is of more significance than the temperature (Com, 2003). The ongoing environmental changes are affecting the reproduction behaviours of the hibernating and migratory species during the warmer months at high altitudes. Marmots are emerging earlier than their normal routine while birds are invading their wintering grounds earlier than usual to quote a few examples. Species migrating to lower elevations during the months of cold may also be affected by the changing pattern of snow formation and disappearance.

Floods: Recurrence of heavy precipitation over most regions is predicted during the 21st century. This recurrence is likely to initiate risk of flash floods. A multi-model analysis in this regard has been proposed by Palmer and Räisänen (2002) predicting an increased risk of a very wet winter related to mid-latitude storms thereby causing extreme precipitation levels. Likewise a rise in global temperature by 2ºC may cause a 23-29% increase in flooded area in Bangladesh (Mirza, 2003). The rivers fed by glacial melt can be inundated as there is increased runoff of melt water due to reduction in firm cover on glaciers which in turn is being induced by global warming.

Droughts: The latest observations by IPCC (2014) regarding droughts have led to the deductions that a likely increase in drought affected areas is possible. Melting of snow is projected to occur before time which is likely to increase the risk of droughts in snowmelt-fed basins during the summer and autumn seasons. Moreover, areas which are strongly dependent upon the snow melt of glaciers as main water source during the dry season are more risk prone to droughts (Bamett *et al*. 2005). Consequently, water supply will suffer strongly in areas fed by the waters coming from the melting glaciers form the Hindu Kush and Himalayas and upon which hundreds of millions of people in China, Pakistan and India depend (Barnett *et al*., 2005).

DISCUSSION

Glaciers are considerably more sensitive to climate change as rapid melting increases the frequency of GLOF events which subsequently affect the riverine ecology. It has been realized that climate change is occurring in the presence of a multitude of natural and human induced stressors, majority of which are already active contributors in ecosystem degradation.

Glaciers chronologies obtained different parts of the world have demonstrated that glaciers respond in different ways to climatic triggers. Predictions of future climate trends and glaciers response must therefore avoid general statements about the linkage between recent glaciers variations and climate change. A warmer climate does not, however, necessarily mean that all the glaciers will disappear, because some regions may experience increased precipitation during the accumulation season. The warming of the Tibet Plateau and associated cryosphere will certainly hasten the melting of snow, ice, and permafrost.

With the glacier retreats different impacts can be quantified. Especially in those areas that are heavily dependent on glaciers retreat water in summer months, will be more vulnerable with the less flow of water after glacier volume significantly reduced. Crops irrigation and agriculture regime will change similarly dams and reservoir restocking will be affected.

In the context of wetlands ecology the flora and fauna contained are adapted to cold waters in glacier receding areas and to some extent some fish species need cold water to reproduce and survive. So reduction in glaciers runoff will lead to less water in the streams with increased temperature gradients that may cause those species to flourish.

Increased freshwater input from the rapid melting of glaciers and the probable changes to the thermo-haline circulation of the oceans around the globe can cause variations in the oceanic currents thereby affecting the existing fisheries upon which humans also depend (Cazenave *et al* 2009; OECD, 2011).

In the changing climate like drought conditions glaciers melt water play a role as buffer and it's a kind of hydrological insurance as the Tibetan high altitudes and HKH region is serving. For the time being with speedy glaciers melt more water will be available with a dilution effect, but in the longer run hydrological insurance will be problematic.

It is a catastrophe that glaciers are melting in a decade with a speed that is comparable with the 5000 years in evolutionary period and that is the human induced tipping in changing paradigm and that shift will be more hazardous after ecological collapse of the system.

Bates *et al* 2008 were of the view that global warming does have effects and cryosphere in shape of water dilution at enhanced rate with ultimate consequences on contained biota.

Glaciers recession can contribute to sea level rise as expected in 21st century with altering ecology of sea shores, although glacier variations have minimal effects on global climate (Meier 1984; IPCC 1996). Therefore the areas like Tibet plateau and associated mountains where runoff from glaciered basins is used for irrigation and hydropower, involve significant hydrological and ecosystem impacts.

In the flood prone areas operative ecological knowledge, water needs for viability of the system, natural water resources use planning depends with the mechanism of understanding and what factors are causing glaciers to retreat and their mass balance change under current scenario. As WGMS is quantifying frontal variations of glaciers with series of mass balance records and glaciers lakes developments (WGMS, 2014).

Ecosystem are resilient by virtue of their existence, they are selected survivor of billions of years of upheavals and perturbation. Therefore, the tipping point (threshold) needs to be identified (Figure, 14) where the resilient triggers with rising temperature and make the ecosystem less diverse in its nature. Functional groups will be mislaid with the loss of resilience arising from environmental changes such as significant climate change, poor forest management practices or adequately large or incessant alteration of natural disturbance regimes (Folke *et al*. 2004).

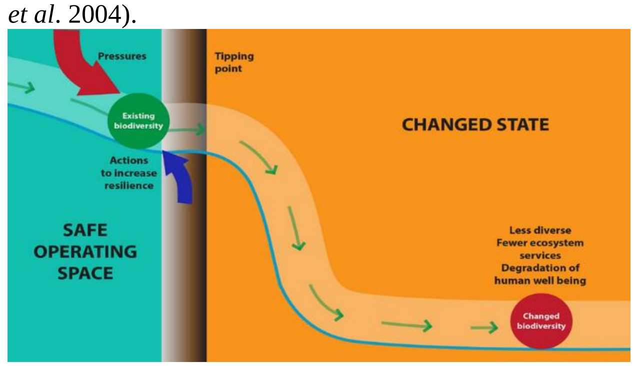


Figure: 14. Tipping Points for environmental change (Source: Secretariat of the Convention on Biological Diversity, 2010)

The future projections related to the impact of climate change during and beyond the 21st century involve the loss of a large proportion of both land-dwelling and aquatic species, exclusively as climate change interrelates with other stressors including habitat alteration, over-exploitation, pollution, and invasive species.

Furthermore, in 21st century many species will not be able to track appropriate climate. The species with less adaptive capacity will extinct rapidly although some species will acclimatize with new environments.

Global climate change cover the past century has resulted in the dramatic retreat of glaciers throughout the world, particularly in the Tibet and surroundings (Yao *et* *al*. 2012). With the GLOF risks and ultimate indemnities to downstream ecology and destruction of habitats, home ranges, territories sometime effects the natural distribution of animals and plants (Byers, 2007). Likewise many mountain forests may not be irrepressible to climate change in the long run, if the current and projected trend persists, with reduced rainfall and increased famine (Scholze *et al*., 2006, Malhi *et al*., 2008). Climate change has also affected the alpine plant species, although the rate of shifting of treeline varies with varying species and their sensitivity to climate.

The GLOF occurrences in Tibet and associated mountains intensify land degradation, increase variations in the hydrological regime, destroy biodiversity, and initiate many socioeconomic externalities. Consequently the climate related changes will not only amplify and hasten these impacts but will also burden the existing human and natural systems over a wide range extending beyond the mountain ecosystems.

Determination of the ecological thresholds is a requisite step in identification of limits of adaptations. In case of embracing the assumed 2°C change in temperature, the IPAT equation (Impact= Population x Affluence x Technology) may not be applicable (Table 4). Due to this reason IPCC is projecting something like 1.1-6.4°C in 2100. The 1.1°C is not a thrill-it is less than twice that we got: 0.8°C in comparison to other limit is above 6°C. It is an Ice age cycle difference over 5000 years, occurring in a century. The third assessment of IPCC further elaborate that still a 5-17% chance that sensitivity could be higher.

Table: 4 .Temperature increasing impacts on ecosystems and species thresholds (IPCC, 2007).

1990's Temp.	1C	2C	3C	4C	5C
		Up to 30% of species at increasing risk of extinction			Significant extinctions around the globe
		Increased coral bleaching		More coral bleached	Widespread coral mortality
		Increasing magnitudes of changes in species			

For viability of ecosystems and survival of species in the wide range of potential climate scenarios, combinations of corresponding inflow and threshold water requirement parameters are required, for instance if inflow is varied from 10 to 90 percent exceedance probability using 10 percent increments and the water requirement is varied from +2.5, +5 to +20 percent, corresponding to 1 – 4.5 C temperature increase (possibly occurring around 2020s and 2080s, respectively (based on IPCC-AR4, 2007). Furthermore, since much of the waters in the system originates from the glaciated mountains, climate change impacts (using corresponding temperature and precipitation changes) on snow and ice in the glaciers and ultimately on the inflows into the rivers basin are included.

For a successful risk management related to ecological thresholds, the ability to forecast such events and to formulate alternative management scenarios is essential. Owing to the multi-scale nature of thresholds, the major requirements encompass the better incorporation of existing information from local platforms towards largest dimensions in order to evaluate and pinpoint the already fragile ecosystems undergoing critical transitions (Julius *et al*. 2008)

If climate change is pushing more cryosphere to melt with more ecosystems towards thresholds what can be done although the science of ecological threshold is so far in its early stages and our existing knowledge of many characteristics and impending impacts of these thresholds is qualitative yet. For a strong comprehension and to be better equipped for ecological thresholds and their subsequent impacts, it is necessary to improve the flexibility of the existing ecosystems so as to slow down or prevent altogether the threshold crossings and to identify early warnings of forthcoming ecological disasters (Orostegui, 2010).

Climate warming and increasing deglaciation will further intensify the situation for a scientific database for quantitative assessment of climate warming impacts on snow and ice reserve; scientific understanding of growth mechanism of glacial lakes and national & regional strategies to cope and mitigate GLOF events. For the vulnerabilities and potential impacts of climate change additional external stress for people and ecological systems should be analyzed with ecological and socio-economic systems are successive to the magnitude and the rate of climate change.

METHODOLOGY

To see the trends in glacial retreat and glacial lake formation from the study area historic and recent Landsat satellite images (Landsat OLI, Landsat ETM+, Landsat TM and Landsat MSS) were downloaded from Landsat data archive of USGS Earth Resource and Science Centre website www.glovis.usgs.gov. These images were further processed using ERDAS Imagine 11 software. Image enhancement was carried out to improve the low contrast satellite images to enhance their interpretation level. 'Standard Deviation Stretch (SDS)' algorithm was applied to improve the images' contrast. Temporal change analysis of glaciers and glacial lakes was carried out by the on-screen digitization and visual interpretation techniques using ArcGIS 10.2 software.

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