CLIMATE CHANGE
IN RELATION TO THE HIMALAYAS

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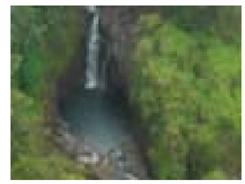


In a nutshell

1. There are evidences to indicate that Himalayas are warming at a higher rate than the global average rate. It is a matter of great concern as (i) the region has more snow and ice than any other region in the world outside the Polar caps, (ii) Himalayas are the maker of climate of much of the South Asia, (iii) to the Himalayas glaciers are connected 9 river basins including the Gangetic basin, which alone has about 500 million population; and (iv) the Himalayas glaciers are receding faster than glaciers of the other parts of world.

2. Alpine ecosystems are particularly vulnerable to warming. It may also affect recreational tourism like skiing.

3. Many important forest species are likely to fail to regenerate if the synchrony between their seed ripening and commencement of monsoon rains is broken due to the climate change.

4. A study of apple cultivation in Himachal Pradesh indicate that the knowledge of people's perception of climate change is important for developing adaptation strategies to address this crisis.

5. Carbon forestry by local communities holds a potential, but it requires taking several steps at the state level. A well managed community forest can sequester sizeable amount of carbon (average of 3.7 t C ha^{-1}), in addition to meeting day to day needs of the people.

Most of the research papers published in peer-review journals during last 4-5 years indicate that the planet is already under climate change, though doubts about it have been raised by some lay persons from time to time. The mean temperature of the earth is estimated to have risen by 0.75 ^{O}C during last century. Some of the well known evidences for global warming are: 11 of the 12 years of the period 1995-2006 are among the 12 warmest years since 1850, retreat of glaciers, melting of the polar ice caps, increase in the area of summertime snow melt in Greenland and decrease in winter hunting period of polar bears, rise of ocean level, advancement in leafing time in trees, and delay in autumnal leaf shedding, and upward movement of woody species in mountains. In 2005, the atmospheric carbon dioxide (the principal green house gas, see box 1) increased by 2.6ppm- the largest annual increase since scientist began to record. The impact of global warming on coastal regions has drawn more public attention because some of the largest cities of the world are located there. However, alpine areas in mountains might see more changes and may disappear altogether from some mountain regions because they occur near mountain tops. Alpine plants and animals will have no place to march upward as temperature rises. Mountains are known to affect nearly 40% people of the world, living in mountains and connected river basins. In many regions, they represent much of the wilderness where species could migrate to escape warming. They are particularly important in tropical regions, being the only source of snow and snow-melt water.

Forming 3000 km east-to-west arc, the massive Himalayan mountain chains represent one of the largest wilderness areas of the planet. The evolution of monsoon rainfall pattern of Asia is attributed to the rise of the massive Himalayan mountain chains. The Himalayas are geoecologically important fosr the adjacent Gangetic Plain where nearly 500 million people live (Fig.1). People have been doing agriculture in this region for several thousands years, and the region is famous for the green revolution that helped India to solve its foodgrain problem.

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 centered on glaciers melt. How natural ecosystems and agriculture are going to be affected is hardly considered.

This article on climate change in the Himalayan region (i) gives a preliminary account of evidences of global warming that are being noticed in the region; (ii) speculates the impact of warming on Himalayan ecosystems and ecological connections between them and the connected plains, and (iii) analyses the importance of the Himalayan ecosystems with regard to carbon sequestration and species migration in a tropical country. It may be emphasized that temperatures in tropical regions would be near the upper limits of tolerance ranges of many species, therefore they are more vulnerable than organisms of temperate regions.

Himalayas and ecosystems background

The massive Himalayas are one of the major geological features of the planet. Not only the highest peak, Everest occurs (Table. 1) here, it has also 9 out of the 14 tallest peaks of the world. The rise of the Himalayas and evolution of the Asian monsoon occurred simultaneously. The high mountain ranges intercept cold winds from the north and trap moisture from the wind rising from oceans in the south. They have created a maritime climate in a continental location (Singh & Singh 1992). The adjacent Gangetic plains are far more humid than their precipitation values indicate. To what extent vapors released from the forest cover occurring up to 3-4 km altitudes contribute to the high humidity in northern India subcontinent needs to be investigated. Winters are mild allowing cultivation of crop throughout the year (Zobel and Singh 1997).

The young and rising mountains have immature topography,that is why slopes particularly in the Greater Himalaya are very vulnerable to erosion causing heavy silt load in the rivers originating from the Himalayas. For example, the silt load in Ganga in Bangladesh is reported to be 15.7 t/yr, compared to o.8 to 5.1t ha/yr for the rivers of the trans-Himalaya region (Holeman1984).

The amount of precipitation varies widely in Himalayan ranges, some of the areas in the south of the main Himalayan ranges getting more rain than the tropical rain forest areas of Amazonia, while in the north of main Himalayan ranges there occur some of largest rain shadow areas of the planet. The Himalayas have more area under glaciers, 35,100 km than any other region of the world outside polar caps. These glaciers are source of the major river systems of the Indian subcontinent. The adjacent Gangetic plain is easily one of the largest and oldest agricultural belts of the world. Along the Gangetic river system there are about 10 cities each with over 2 million populations, and some of them, viz., Varanasi, Allahabad and Patna are major centers of uninterrupted civilizations.

Almost all kinds of forest ecosystems and extensive grasslands occur in these mountains, ranging from tropical sal (*Shorea robusta,* a dipterocarp) to extensive oak forest to deciduous birch forest and alpine grasslands and scrubs. Within an aerial distance of 30 km, one can see a whole range of forest types that would require several thousands miles in plains. More importantly these forests can have cooling effect through their evpotranspiration. Of total geographical area 593572 Km^2 of Indian Himalayas, about 38% is under the cover of various forest types. These forests have 5.4 billion t C (biomass + soil) and accumulate carbon in biomass at the rate of about 65 million t yr^{-1}. Which is about 15 % of India's emission from fossil fuel combustion. A sizeable area of the region is under alpine meadows (locally called 'buggyals') famous for precious medicinal plants, and their use for sheep and goats grazing. The alpine meadows are rich in soil carbon, particularly where peat lands develop. Himalayas are also rich in small lakes, around which are based much of the tourist activities. Among them, Nainital and Kashmir lakes are quite famous. However, because of high pollution and eutropification these lakes are losing their recreational values. Global Warming may increase algal blooms and release of toxins from there.

Are Himalayas warming more?

The data available on temperature in Himalayas indicate that warming during last 3-4 decades has been more than the global average of 0.75% over last century. Some of the values indicate that Himalayas are warming 5-6 times more than the global average (Table.2).Temperature increases are more during winter and autumns than during summers, and they clearly increase with altitudinal rise (Lin and Chen 2000). For example, decadal temperature rise remains upto $0.2^{O}C$ up to 2000 m altitude, while above 2000 m it often exceeds 0.3 ^{O}C.

Glaciers melt and its impact and its impact

In higher reaches of Himalayas (generally above 3000m) snowfall builds up year-after- year to form glaciers that are long-term reservoirs of water. Though reliable data are not available, the higher Himalayas and the inner Asian ranges together have the largest glaciated areas out side the polar regions (Dyurgerov and Meier 2005). The Himalayan ranges alone have 35,110 sq. km of glacier and ice cover, with 3,735cu km of ice volume. Nearly half of the ice reserve is attributed to the glaciers of Ganges (Table.3). Glacial melt accounts for from about 6% to 45% of average river flow across the Himalayan rivers studied. (Table. 4). However, glacial melt may account for up to 70% of the flow during summers .The river waters have cross-country connections. For example, the Nepal contributes 40%of the average annual flow in the Ganga basin and 70% to the dry season flow.

According to a UNEP report a number of glaciers in Nepal and Bhutan are retreating at the rate of 2-100 m per year. In Uttarakhand, Gangotri glacier, the source of the Gangetic river system retreated during the last 30 years at a rate nearly three times higher than the preceding 200 years. The rate of glaciers melt would increase further as glaciers become smaller. Glaciers in Nepal are retreating at rates between less than 5m and 20m/ yr (Fujita et at.2001). In general, Himalayan glaciers are melting faster than the world average (Fig. 2; also see Table 4) (Dyurgerore and Meier 2005).However, there is a widespread evidence of expansion or down slope redistribution of ice in Karakoram(Hewitt2005). The rivers and adjoining grassland and forest ecosystems would be severely affected by the phase of rapid snow melt and subsequent phase of the absence of the snow melt water forever with the loss of glaciers.

The rapid release of melt water and rainfall may combine to trigger debris flows and flash flood in higher ranges, including the formation of potentially dangerous lakes. These lakes may breach suddenly, resulting in discharge of huge volume of water and debris. Decrease in snow pack size and duration will be crucial factors in water availability at a local scale.

Many species of the alpine grasslands are able to start their growth with the supply of snow melt water, well before the commencement of monsoon in June-end (Singh & Singh , 1992). Obviously, their growths and life cycles are to be disrupted because of the lack of snow- melt water once glaciers are gone. Several organisms and ecosystem process requiring flow of water are going to be affected once snow reserves are gone. The species composition and structure and functioning of alpine meadows (buggyals) are going to change both because of increased temperatures and loss of snow. How local people are going to be affected in various ways because of their disturbances. Subsequent to glaciers retreats the land would be released for primary succession, and establishment of early successional communities.

Several organisms and ecosystem processes requiring flow of water are going to be affected once snow reserves are gone. Pollutants in rivers are to stay longer, and intensify during summer months once glacier-melt water is no more available.

Problems can be severe in Gangetic plains where population density is over 400 per km^2 land (Table 5). Water scarcity, pollution and on water borne diseases are already serious problem in the Gangetic plains.

High vulnerability of alpine ecosystems

Being located near the mountain tops, alpine species are highly vulnerable to global warming (Benniston 2003). They would have little scope to march upwards with the temperature rise, which is predicted to be more in Himalayas. Species depending on snow cover for protection would be exposed to frost, and others which require winter chilling for bud- break may not get sufficiently low temperature over sufficiently long period

There are records that indicate that some alpine species like C*arex curvula* survived a major climate change of over a thousand years (Steinger et al.1996). They from tussocks and have a clonal growth strategy. Investigation needs to be carried out to identify and study them in the Himalayas. Such species populations with long longevities may remain stable in the condition of climate change.

There would be drastic changes in the life style of several animals living in alpine areas. For example, pikas depend on hoarding food for their survival during winters when they live under the snow cover. In a warming world a species in alpine ecosystem might be faced with very different condition, including different competitors, predators and food base.

Reports are there to indicate that rhododendrons and other woody species have begun to invade alpine meadows in valley of flowers of Uttarakhand. Grazing sheep, goats and horses and cattle may restrict the establishment of woody plants, but composition of plants and animals in meadows is certainly going to change. They are going to witness arrival of many species of lower ranges, provided anthropogenic pressure other than climate warming does not become an overriding factor. More tourism and cultivation of crops can lead to major landuse changes

Alpine belts are also likely to witness more hydrological disturbances. Because of low air temperature the runoffs are estimated to be 4-5 times greater in this belt than in lower ranges for a given rainfall. Since warming is predicted to enhance hydrological cycle, more erosion and landslides are expected to occur in high Himalayas. According to an estimate the Greater Himalaya is the largest contributor to silt load on rivers among all landforms of the Himalaya. In brief, the alpine belt is likely to be affected by several factors including glaciers melt, enhanced hydrologic cycle, erosion and others mass movements, species migration and more movements of people. However, recreational activities like skiing which require certain snow depth will be adversely affected in many areas.

Himalayas as the refuge for migrating species

Since seasonal temperature variation is limited in tropics, species occurring there are likely to be more vulnerable to global warming large temperature changes, compared to temperate zone species which experience wide seasonal variations. More events of extreme temperatures are expected to be associated with climate warming. Furthermore, many tropical species are already living at temperatures close to their upper limits of tolerance ranges. Therefore, species living in low land areas of Indian subcontinent would have to migrate to cooler areas to servive. The Himalayas make a large wilderness area with favourable climate up to considerably high altitude. The adjacent plains are heavily populated, with few fragments of natural vegetation. Obviously, Himalayan Mountains are the only refuge for species migrating from low land areas. Migration of tropical species, including some pines (e.g., *Pinus merkusi*) from low land areas of south Asia to Himalayas are indicated to have occurred in the geological past during one of the warming phases of climate. There are several tropical trees which have been able to penetrate deep inside Himalayan ranges along rivers that have cut deep into mountains. *Bombax ceiba* and *Butea frondosa* are some of the examples of species having unusually wide range of distribution, starting from south India to more than 100 km inside Himalayas. However, species migration at present could be impeded by lack of continuity of suitable habitat. They may need corridors and stepping stones to march upward through a landscape affected by urban development, dams, roads and agricultural field. Much of the Gangetic Plains are under agricultural fields, having only a few remains of natural vegetation. Thus, only alien exotic species are left to migrate to Himalayan ranges. Already *Eupatorium* spp. and *Parthenium* sp. have spread all over the places in mountains along roads and rivers.

Spread of diseases

A warmer and highly variable climate can affect human health in several direct and indirect ways: by increasing transmission of diseases to new areas, by adversely affecting agricultural production, and causing malnutrition in some of the least developed countries including the Himalayan region, by decreasing water supply in warm seasons and increasing disease load, and by causing hazardous extreme weather. The people who are likely to bear the most of the disease burden are poor, particularly children and women (WHO 2008). In mountains women and children often make most of the populations of villages where migration is high. Climate change is expected to increase the incidences of diseases like diarrhea, vector- borne diseases like malaria and infections associated with under nutrition (WHO 2008). If the warming were to affect grain production in plains of India, people in the mountains are expected to be worst hit because of their outside dependence for food. The food production of Gangetic plains can be severely affected by shortage of water in rivers during summer months once glaciers in Himalayas are severely depleted, and extreme droughts become more frequent. The number of people living in water-stressed basins of the world are to rise from 1.5 billion since 1990 to 3.6 billion by 2050. The situation can be alarming if warming were to cross the dangerous level. According to an estimate by the 2090's, warming may cause doubling in the frequency of extreme drought events, a six-fold increase in mean of droughts duration; and 10-30 fold increase in land area affected by it. In extreme droughts poor water availability leads to contamination of water, and more of water borne diseases. Until now *Anopheles* mosquitoes failed to effectively breed above 1500 m altitude (Craig et al. 1999). The global warming along with human movement and transport of food from low land areas is going to promote their upward movement. Many hill stations in Himalayas are located around 2000 m (Nainital, Mussoorie, Shimla and Darjeeling). They are likely to come in the grip of malarial infection.While to escape these diseases people would like to migrate to high mountains, hazards of landslides, scarcity of productive land and lack of facilities relating to like health, education and employment may discourage people to stay in high ranges.

Phenological responses

How species are going to respond to warming in the Himalayan region, which is going to be more than the global mean? Warming, in general is suggested to increase the intensity of monsoon in much of the Himalayas, but a milder winter and hotter summer is likely to intensify summer-time drought (Lal et al. 2001), when most species produce leaves. One of the features of dominant Himalayan tree species is that in them new leaf production and leaf shedding occur simultaneously during spring, in evergreen species the former often inducing the latter. Even many deciduous species including those of adjacent low land areas drop their leaves during summer at the height of drought, and then start producing new leaves after a few weeks when conditions are still dry. Normally an increase in temperature hastens the spring time leaf production. But warming may lead to extreme droughts by increasing evapotranspiration, such as the one experienced a few years ago when pre-dawn water potential in an evergreen oak dropped to -6 MPa, compared to - 2.0 to -2.3 MPa during normal years (Singh et al. 2006). Such extreme events are expected to enable various populations that species consists of to express themselves.

In a study at Nainital we found that Banj oak (*Q leucotrichophora*), instead of advancing leafing time, withheld leaf production (Singh SP and Tewari A, unpubl.) because of carbon drain. What seemed to have happened was that the water stress caused by a relatively warmer spring hastened the seed development. Since trees were not left with enough carbon after investing in a rapid seed development, they withheld the spring-time leaf production. Disturbance in leaf phenology such as this can affect several other processes, such as insect herbivory, litter decomposition, predation by birds and mammals. Since local people depend on natural forests for their day –to-day living, knowledge of these changes are important for them.

Effects on regeneration of dominant species

In many dominant forest species like Sal, Tilong anf Kharsu (*Shorea robusta*, *Quercus floribunda*, and *Q. semecarpifolia* respectively) seed maturation and seed germination coincide with monsoon rainfall. In a wet condition these species show varying degrees of vivipary (germination of seeds while they are still on trees). Rise in temperature or water stress may advance seed maturation, which might result in the breakdown of the synchrony between the commencement of monsoon rains and seed germination. These species would find difficult to regenerate and march upward in such a situation. Already larger oak seeds than in the past are being observed in springs, which are signs of early seed development.

Regeration in Sal (*Shorea robusta)* is known to be a problem, partly becuase its seeds are ready to germinate by mid-June when the commencement of monsoon is uncertain. The warming-induced early maturation of seeds can easily disrupt this delicate relationship of the events.

The problem with vivipary is that a seed fallen at an unfavourable place or an unfavourable point of time (e.g., a rainless week) has no chance to become a seedling. Vivipary limits the migrating ability of species. The oaks have large acorns which tend to roll down. Therefore, largely through birds and squirrels seeds can be dispersed to higher ranges.

Adaptation in relation to Agriculture

One of the major consequences of global warming is going to be the change in crop selection and increase in the altitudinal range of cultivated land. Tropical crops like yellow pulse (*Cajanus cajan*), corn and some millets are likely to be preferred crops in lower ranges. Among fruits, mangoes, which are already in cultivation in low valleys, may expand in area. People seasonally migrating to alpine areas along with their animals may spend several more months than in the past. In some of alpine meadows cultivation of crops like potato may become a regular feature and expand.

The other major change is likely to be the enhanced decomposition of soil organic matter and the release of CO2. Since 1850, 160 million metric tons of CO2 have been emitted from soils and biomass worldwide (Houghton 2003). There are indications, however, that agricultural soils can become net CO2 accumulator by increasing productivity, improving cropping practices, erosion control measures, and reduced tillage (Paustian et al. 2006). In much of the Himalayas forest floor litter is collected and composted along with livestock dung. The partly decomposed organic matter is then transported to cropfields while preparing beds for seed sowing. Given that the global warming would enhance soil CO2 emission, more forest litter would be required to maintain soil carbon level. An efficient use of manure can give a good result for GHG mitigation.

No-till is a practice in which seeds are sown by cutting a narrow slot in the soil, and weeds are controlled with herbicides. Because soil disturbance is in the least amount, carbon accumulation in no-till practice is more. In any case, cropfield soils in mountains would need special attention, as with better management they could become carbon sinks.Similarly, degraded hill slopes could be used to grow grasses and legumes. This in turn would promote soil carbon sequestration.

Perceptions of apple growers in Kullu with regard to climate change

Kullu valley in Himanchal Pradesh is famous for its apples, but its apple production has declined after the peak production year of 1988-1989. It is serious problem because the rise in apple cultivation from about 600 ha in 1960- 61 to about 1100,000 ha in 1995-96 was considered one of the success stories in mountain development. Apple cultivation is the main source of income to about 35,000 families. Apple cultivators perceive that over the years (i) the amount of snowfall has decreased, and (ii) snowfall occurs late. These observations they relate to climate change. In a way, farmers looked at climate change primarily in relation to decrease in apple production, and as a deviation from the weather cycle ideal to apple production. The reduction in the amount of snow reduced the chilling hours, and thereby affected the time of bud break. Early snow (in December and early January) is preferred for its favorable effect on bud-break as well as on soil moisture. A chilling period of about, 10 weeks below 5^{o}C (Abbott 1984) is required to meet internal conditions, necessary for bud break at the spring time. Late snow (in late January and February), on the other had is less durable, more watery and transitory and its restricts bees activity, and hence pollination (Vedwan and Rhoades 2001). Furthermore, a water snow at the time of ripening is seen as a source of diseases, damaging fruit quality. Incidence of canker, that causes trees to decay has increased, requiring an increase in the spray of pesticides from 4 per year in 1970's to 12 per year sprays in 1990's (Vedwan and Rhoades 2001); it is already a serious environmental problem. In order to understand how farmers would respond to climate change, an understanding of their perceptions of climate change and related environment is important (Vedwan and Rhoades 2001). This experience also showed that adaptation to climate change in the case of poor people can be very difficult because of the costs and efforts involved. The apple cultivation requires a massive start up investment. Trees are nurtured over an 8 year period before they begin to bear fruit. Small farmers once hit by crop failure, find difficult to revive.

Scope for Carbon forestry

As pointed earlier the Indian Himalayan forests sequester nearly 65 million t C per year, equal to 15 - 20% CO_2 emissions from fossil fuels combustion from India around the year 2000. Obviously, the

Himalayan region contributes substantially to a balanced carbon budget as a whole at the country level. A study carried out under the project "Kyoto: Think Global Act Local" (led by Dr. Margaret of the University of Twente, The Netherlands. the project is being carried out in several African countries, Nepal and India) indicates that a well managed community forest in Uttarakhand (Lamgarah block of Kumaun commissionery) can sequester a considerable amount of carbon, apart from meeting day-to-day needs of firewood, fodder, leaf litter and others (Table 6) However, a community is required to take several protective measures, and the forest area needs to be at least twice as large as agricultural area. Further, people might require economic incentives through various schemes, including employment guarantee scheme to conserve and develop forests. Unfortunately, carbon savings by avoiding deforestation (reduction in forest area) and degradation (reduction in carbon inside a forest) remains out of Kyoto Protocol.

Raising new tree plantations will not be attractive to poor farmers as it takes several years to realize a meaningful rate of carbon sequestration from them. Furthermore, nurturing trees planted at a degraded site can be a difficult task, and may take a long time to establish a plantation. Raising grasses mixed with fodder bushes and trees could be more feasible as villagers start getting some feed for their cows and buffaloes only after 2-3 years from them. Here credit for carbon saving could be claimed for soil carbon sequestration. On degraded site, one could notice perceptible changes in soil carbon within a couple of years.

Research on developing suitable feed stocks for biofuels from forests and degraded lands may go long way in improving energy supply at local level.

Table 1. A few features about the Himalaya

- Area of Himalaya, also called the Asian upland is about 3.4 million km^2 (width between 150-400 km and length over 2500 km) between latitudes 20-38^O N, and longitudes 63-104^{O}E
- Easily the highest physical feature on the planet, with average elevation of 6100 m in the Greater Himalayan belt, and 9 out of the 14 tallest peaks of the world (Everest 8,848m, Kanchenjunga 8,598m).
- Himalayan countries are Afghanistan, Bangladesh, Bhutan, China, India, Mayanmar, Nepal and Pakistan.
- Himalayas are drained mainly by Ganga (generally called Ganges in the west), Indus, and Bramhaputra river systems; they are known to originate from some of largest glaciers of the world.
- Very young mountains, 30 million years old, compared to the age of the earth 4500 million years and the Indian peninsular shield 600 million yrs.
- Population of the Himalayan region is about 150 million, and cultural diversity is very rich.
- Encompassing almost all kinds of vegetation from tropical to alpine within altitudinal ranges of 3000-4000 m that support plants, the Himalayan region has about 9000 plant species of which, nearly 30% are endemic to the Himalayas.
- Forests include those dominated by dipterocarps (*Shorea robusta*), pines, evergreen oaks, silver fir, birch and rhododendrons.

Table: 2 Warming trends in Himalayas

Global average rise of temperature 0.75^{O}C per decade over the last 100 years (IPCC 2007)

In Nepal: 0.6^{O}C per decade during 1977-2000 or 1.4 ^{O}C in 23 yrs (Shrestha et al. 1999)

Tibetan plateau, during 1955-1996: 0.16^{O}C per decade (mean), i.e., 0.64^{O}C in 40 yrs

- winter time 0.32 ^{O}C per dcecade 1.28 ^{O}C in 40 yrs (Liu and Chen 2000)
- autumn and winter in another part of Tibet between 1951-2001: 0.2-0.6^{O}C per decade i.e. 1-3^{O}C in 50 yrs
- Length of growing season (daily temperature > 10^{O}C) has increased by 15 days in last 30 years

Nainital (about 2000 m): 0.6^{O}C during 1960-2000 (Sharma Subrat unpubl.)

Warming in relation to altitude: decadal rise 0.1^{O}C below 1000 m, between 0.1 and 0.2 ^{O}C between 1000-2000 m altitudes and above 0.2^{O}C above 2000 m (see in Jianuchu et al. 2007)

Table: 3. Glacier resources in Himalayas by drainage basins (from Q in 2002)

Drainage basin	**No. of glaicers**	**Total area area (km^2)**	**Total ice volume (km^3)**
Ganges river	6,696	16,677	1971.5
Indus river	6,057	8,926	850.4
Bramhmaputra	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 other glacial resources of the Central region are KaraKoram with area (16,600 km^2) Tien Shan (15,417 km^2), Pamir (12,260 km^2) and Kulun Shan (12,260 km^2), Hindu Kush (3,200 km^2).

Table: 4. Principal river systems of the Himalayan region (sources, see in Jianchu et al. 2007)

River			**River basin**			
	Mean discharge (m 3/5)	**Glacial melt in river flow (%)**	**Area (km^2)**	**Population (million)**	**Population density (no/km^2)**	**Water availability (m^3/person/yr**
Yangtze	34,30	18.5	1,722,193	368.5	214	2,909
Ganges	18,691	9.1	10,16,124	407.5	401	1,447
Bramhmputra	19,824	12.3	651,335	118.5	182	5,274
Irrawady	13,565	Small	413,710	32.7	79	13,089
Mekong	11,048	6.6	805,604	57.2	71	6,091
Indus	5,533	44.8	1,081,718	178.5	165	978
Tarim	146	40.2	1,152,448	8.1	7	571

Table 5. Rate of glacier retreat of Glaciers from different parts of Himalayas (from Mukhopadhaya 2006)

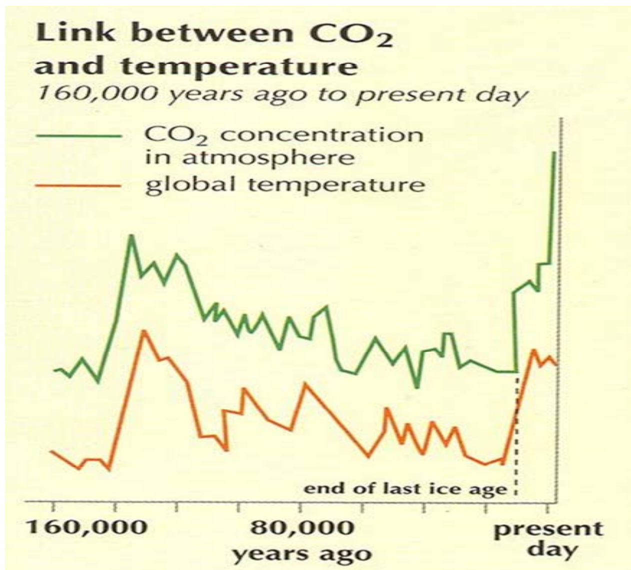
Glaciers and region	**Rate of retreat (m/yr)**
Kashmir and Himanchal	
Barashigri, Chandan basin of Eastern Lahul	44
Tajiwas Nar, sindh basin of Kashmir	5
Stock, Ladak	6
Gangstang, Bhara basin of western Lahul	12
Garhwal	
Trisul, Nanda Devi sanctuary	10
Betharti, Nanda Devi sanctuary	8
East Kamet,	5
Gangotari, Bhagirathi Basin	15
Satopanth –Bhagirathi glaciers complex, Alaxnanda	12
Kumaun	
Milam, Gouri Ganga basin	13.5
Poting, Gouri Ganga basin	5

Shankalapa, Gouri ganga basin	23
Sikkim	
Tista Khangse, Tista basin	8
Zemu, Tista basin	8

Table 6. Carbon sequestration rate in three community forests (Van Panchyat, VP) of Lamgarha block of Uttarakhand, studied under the project, Kyoto Think Globally Act locally (Singh S. P., Tewari A and Phartiyal P. Unpabl.) Values in parentheses indicate period of data collection.

VP forests	Mean rate of C sequestration rate (t C $ha^{-1}yr^{-1}$)
Dhaili (mean of 3 yrs)	
Even-aged banj oak	3.4
Dense mixed banj oak	4.2
Mixed banj oak-chir pine-degraded	2.2
Toli (means of 3 yrs)	
Mixed Banj oak-Chir pine-young	4.05
Mixed Chir pine-Panj in bush from*	3.05
Chir pine-young	4.25
Guna (means of 2 yrs)	
Chir pine-young	3.8
Mixed banj oak	4.4
Mean sequestration rate (of all 8 forests)	3.7

* While chir pine trees were healthy, banj oak trees were severely lopped, resulting in a bush form.



Box 1. Green House Gases- induced warming

The present global warming is attributed to the increase in atmospheric concentrations of green house gases (GHG's) during the industrial period (from 1750 to 2005): CO_2 (carbon dioxide) 280 to 280 ppm (parts per million) , N_2O (nitrous oxide) from 270 to 319 ppb (parts per billion), CH_4 (Methane) 730 to 1852 ppb, topospheric O_3 (ozone) from 25 to 34 ppb, CCl_4 (carbon tetra chloride) from 0 to 94 ppt (parts per trillion, and others. The global GHG emission have increased 70% from 1970 to 2004 (IPCC 2000). The sector wise increase between 1970-2004 have been as following: 145% in energy supply 120% in transport, 65% industry, and landuse, landuse change and forestry 40%. While CO_2 accounts for 53% of global warming, CH_4 contributes 17% , N20 5%, O_3 13% and others 12%. Globally about .248 billion tones CO_2 equivalents were emitted in year 2000, of which two-thirds were due to burning of fossil fuels (oil, coal and natural gas) primarily for electricity, transportation, heating and cooling, and industrial source of CO_2 emissions. Records of past show a direct relationship between atmospheric CO_2 concentration and global mean temperature.

Box 2: Main Forest Types in Central Himalaya (Primarily based on Uttarakhand) Altitudes indicate centers of forest types at present.

Dominant Forest Type	Altitudinal centre (m)	Nature of leaves
Sal (*Shorea robusta*)	< 300	
Chir Pine *(Pinus roxburghii)*	1000-1700	e-1, needle leaved
Banj oak *(Quercus leucotrichophora)*	1200-2000	e-1, soft leaved
Tilonj (also called mora) oak (*Quercus floribunda)*	2000-2200	e-1 highly sclerophyllous
Kharsu Oak (*Quercus. semicarpifolia*)	2500-3000	e-1 highly sclerophyllous
Silver fir (*Abies pindrow*)	2800-3200	e-2, short needle leaved
Birch (*Betula utilis*)	3000-3400	d

e-1, evergreen (stands are never entirely naked) with about one-yr leaf-span;e-2, evergreen with 2-4 yrs leaf life span; d = deciduous (stands become naked for a certain period in a year.

Several other forest types can occur along the above altitudinal gradients: *Acacia catechu-Dalbagia sissoo* (d) forest along rivers in Sal belt; Alder (*Alnus nepalensis*) (e-1) on landships upto a considerable altitudinal range, but generally 1200-2200 m; Deodar *(Cedrus deodara* (e-2) is common in Himachal Pradesh and some parts of Uttarakhand at 1800-2000 m; blue pine (Pinus wallichiana) (e-2) and spruce *Picea smithiana* (e-2) generally occur above 2400 m; tree Rhododendron (*Rhododendron arboreum*) is a common undercanopy species over a considerable elevational range (generally 1400-2400 m) throughout oak belt; *Machilus duthei* (e-1) and several species of *Litsea umbrosa* and other lauraceous species in relatively moist and shaded sites at 1500-2500 m altitudes; *Mallotus phillipensis* is the common undercanopy of sal

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