ALPINE TREELINE RISE, CLIMATE CHANGE RESPONSE AND ITS EFFECT ON SUSTAINABLE DEVELOPMENT IN HIGH MOUNTAINS IN THE NORTHWESTERN INDIAN HIMALAYA

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©Ontario International Development Agency ISSN: 1923-6654 (print)
ISSN 1923-6662 (online). Available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html

Abstract: Alpine forest treeline is one of the important natural features of high altitude mountain ecosystem that plays a vital role in human well-being by nurturing sustainable livelihood and facilitating development process in the form of natural resource conservation, biological diversity, geo-hydrological cycle, water resources, atmospheric circulation and other eco-system benefits. Treeline is very sensitive to climate change and register the prevailing scenario by its spatial dynamics as a climate marker. Ecologically treeline rise is a direct indication of shrinking snow and glacier regime alongwith the various changes in natural resources and overall climatic set-up of the region which is bound to hit the sustainable development and even the survival of the human being, especially of deprived section of society.

Himalaya is the youngest and highest mountain chain of the World located in Asian sub-continent and because of its vast water reservoir and unique terrain, it is globally known as Water Tower of Asia and Roof of the World. The main Himalayan range forms an arc of 2,400 km. and serves as a source of some of the world's major river systems encompassing 18 countries. In spite of being rich in natural resources, climate change impact has become a serious environmental concern in Himalaya, because of profound influence and potential threat on natural resources, ecological cycles, biodiversity and socio-economic affairs in the region. The sustainable productivity in Himalayan region depends on the inter-related ocean-atmosphere and terrestrial system that control the Asian monsoon and winter Westerlies. The estimated weakness and continuing delay in the Asian monsoon / Westerlies is predicted to generate resource crunch, productivity loss, socio-economic constraints and various environmental stresses and ultimately hamper the sustainable development in the region.

Amongst the various rivers emerges from the mighty Himalaya, the alpine treeline region of river Ganga in northwestern Indian Himalayan part, has been selected for the present study. The Ganga basin covers an area of nearly 10, 89370 sq. kms in China, Nepal, India and Bangladesh and its regional importance can be realized by the fact that it is the most heavily populated river basin in the world and provides food, shelter and ecological services to the nearly half of the earth population, i.e., over 747 million people.

The spatial position of altitudinal treeline has been estimated from 3048 to 4110 m asl with variable rate of treeline rise in various parts of Himalaya but these results are obtained under variable climatic domain, geographic set-up and environment and hence are not comparable at uniform scale and environmental condition. While the present study carried out in Chorabari and Dokriani glacier valleys contains same climatic domain and geo-environmental condition.

In order to evaluate the change in treeline vis-a-vis climate and its effect on sustainable development in recent past, the spatial existence of altitudinal treeline has been investigated for the period of 1962 to 2009. The past existence of treeline is determined with the help of benchmarked 1962 Survey of India topographic map, relevant floristic records and their at-the-spot validation, while present status is investigated and delineated by detailed ground checks. A UNESCO standard and sampling method-field practice has been adopted during field investigation. It is revealed that in the proximity of glacial snout, treeline shift towards higher altitudes was at the rate of 10.21m/year in Chorabari and 1.70m/year in Dokriani glacier valleys. This treeline dynamics is attributed to the climate change, however sharp difference of 08.51 m in treeline rise rate under similar climatic domain is strongly suggestive of dominance of local site conditions, rather than regional and global climate system. During field investigation it has also been observed that moisture ridden north-facing slopes have encouraged growth of broad leaved *Betula utilis*, *Rhododendron companulatum*, *Sorbus acuparia* species while species such as *Taxus baccata, Juniperus squamata*, *Abies spectabilis* flourished on the drier south facing slopes. The treeline advance to the erstwhile snow-ice boundary, replacement of dominant *Quercus semicarpifolia* by *Rhododendron companulatum*, *Betula utilis* and *Sorbus acuparia* in current treeline are bound to invite ecological implication such as increased carbon sink area but to decreased frozen water resource which consequently will alter carbon sequestration potential, radiative energy balance and hydrological regime in alpine ecosystem.

These observed changes in high altitude ecosystem feature, especially of treeline, are attributed to the climate change which create silent but disparaging effects on sustainability of natural resources, livelihood and eco-systemic services to the people of Himalayan region in general and Ganga basin in particular.

Keywords: Climate marker, Ganga basin, Himalayan region, Sustainable development, Treeline rise,

INTRODUCTION

Alpine forest treeline is one of the important natural features of high altitude Himalayan mountain ecosystem that plays a vital role in human well-being by nurturing sustainable livelihood and facilitating development process in the form of natural resource conservation, biological diversity, geo-hydrological cycle, water resources, atmospheric circulation and other eco-system benefits. Alpine treeline is very sensitive to CC and register the prevailing scenario by its spatial dynamics as a climate marker. Ecologically treeline rise is a direct indication of shrinking snow and glacier regime alongwith the various possible influences on natural resources, radiative energy balance, carbon sequestration potential of alpine ecosystem and overall climatic set-up at local, regional and global scale which is bound to hit the sustainable development and even the survival of the human being, especially of deprived section of society.

Himalaya is a youngest and highest mountain chain of the World located in Asian sub-continent and because of its vast water reservoir and unique terrain, it is globally known as Water Tower of Asia and Roof of the World. The main Himalayan range forms an arc of 2,400 km and serves as a source of some of the world's major river systems. The entire NIHM region including northwestern and northeastern, is drained by two major twin river systems viz. Indus and Ganges and is a important part of IGB. As a whole nearly 10, 89370 sq. kms area of IGB basin provides livelihoods and other life supporting services to its nearly 1 billion population which is about 1/ 7 of the world's population and therefore, both population density and poverty is very high in the region. [1].

The IGB basin is rich in natural resources and hence offers important base for sustainable development to the area inhabitants and downstream population but CC impact has become a serious environmental concern, because of profound influence and potential threat on natural resources and their associated ecosystem products such as ecological cycles, biodiversity and socio-economic affairs in the region. And incidentally majority of the rural population of IGB basin depends on climate-sensitive livelihoods such as agriculture, horticulture and other agro-pastoral activities and hence possible CC impact are severe and may raise the question of survival, especially for the under privileged population.

METHODS AND MATERIALS

Study Area

With in the IGB and amongst the various rivers emerging from the mighty Himalaya, the alpine treeline area of Ganga River catchment in Northwestern Indian Himalayan (NIH) has been selected and studied at the Dokriani and Chorabari glacier valley. These two glacier valleys represent same NIH climatic domain but are exposed to the different set of geomorphic conditions and anthropogenic impacts. Two glacier valleys with different conditions were selected in order to ascertain the role of site specific conditions in relation to the regional and global climate system as a treeline driver.

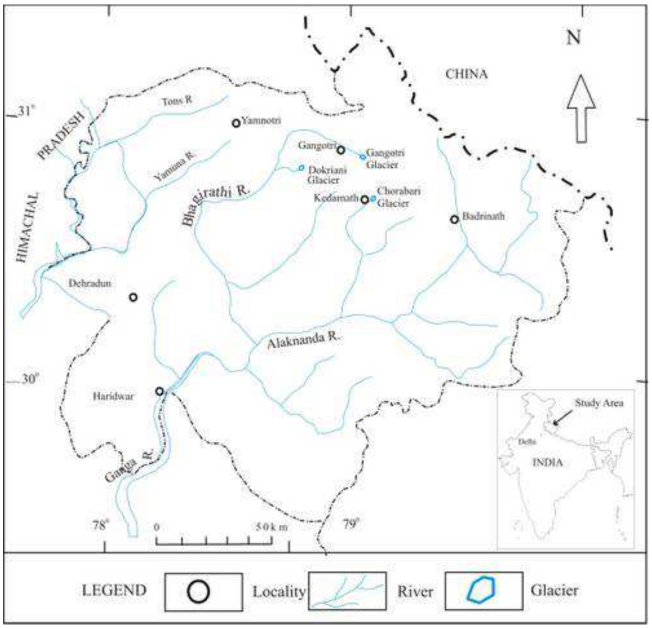

Figure 1: Area used in the study

Figure 2: Isolated and climax tree line at the hill top

Figure 3: Leafy *Betula utilis* at 3600m asl

Figure 4: Tree line with successive generation

Figure 5: Leafy *Betula utilis* at 3850m asl

The Chorabari Glacier Valley represents south facing aspect and drains its water to the Alaknanda River and its specific alpine treeline area located between the latitude 30^0 39'30"N and 30^0 45'10" N, and longitude79^0 01' 30"E and 79^{0}5'20"E in the proximity of glacier snout was considered for study. While Dhokriani glacier Valley is oriented towards the north face and is a part of Bhagirathi River catchment. Its precise alpine treeline area located between the latitude 30^0 50' 16"N and 30^0 53'18" N, and longitude 78^0 45' 20"E and 78^{0}48'20"E was studied in detail with respect to glacier snout along with the vicinity area (Figure 1).

Sampling and data collection

Ground based investigation is one of the powerful methods to detect landscape change over a period of time and hence it is applied in present study. The harsh climate ridden study area offers limited time period for field study, i.e., only during the month of May - June and October-November and accordingly field work has been carried out between the years 2009 to 2011. The elevation belt transects in glacial snout proximity has been investigated as a sampling sites. The basic approach included visits to the sampling sites and measurements of present and past tree line positions along with the their associated floristic composition. The authentic and oldest available survey of India topographic maps at 1:50,000 scale for the year 1962 were taken as base line records. The past status of treeline characteristics such as elevation, species composition, etc., was determined with the help of geomorphic and floristic information recorded in the base line map and literature and spatial recognition and validation thereof in the field. The prominent topographic information such as perennial and dry channels, contour elevation, landscape gradient, cliff, large scattered rock mass and exposed rock faces, treks, floristic composition and old trees, snow and ice area, etc., marked at base maps were used as key determinants to delineate and validate past tree line status. Ground reference and sampling points are identified along past treeline elevational transects and required data was collected. The present status of alpine treeline is established on the basis of on-the-spot field check and investigation of treeline attributes at highest elevation with respect to glacial snout proximity.

While conducting the identification, validation and delineation of past and present treeline attributes in the field, the support of the hand-held GPS (Global Positioning System) and barometric altimeter are also taken along with the historical topographic map. The morphological attributes of dominant tree species, such as height, habit and stem girth are only considered while characterizing the tree, treeline and its floristic composition. Globally recognized United Nations Educational, Scientific and Cultural Organization (UNESCO) sampling method and associated field practices were adopted during the selection of sample plots, demarcation of tree and non-tree flora except benchmark of minimum tree height of 5 meter is further refined to 3 meter [2],[3]. Three meter benchmark height is considered in order to cover the impact of highly diversified Himalayan climate on tree height. Otherwise it will not be adequate and ecologically justified to merge the qualitative benchmark over the quantitative one. Moreover area in treeline proximity generally remain snow covered for 4 to 6 months in a year and hence even the established tree species such as *Juniperus squamata*, *Rhododendron companulatum*, *Betula utilis* become dwarf, multi-stemmed and prostate, up to the limit that tree and shrub are hardly differentiable on the basis of height. The phenomenon of altitudinal effect on tree height is well discernible in study area and also identified in other mountain regions of the world [4], [5], [6]. The eco-tonal zone of minimum 50 meters elevation difference or 100 meters distance on a slope is taken as minimum requisite for treeline sample site. And only eco-tonal zones representing successive treeline species are considered for sampling, while single, isolated trees or tree patches, climax vegetation tree lines, etc., are not covered during the identification of treeline. The reason behind considering only the area of successive age group species and ignoring single or isolated trees and climax or mature treeline ecotone during the treeline investigation, is to follow the ecological principal. Because single or isolated trees may be the relics of past events or product of some other micro-climatic habitat but certainly not related to the current treeline and its associated ecological manifestation. Similarly due to the ecological compatibility and other factors mature treeline ecotone does not witness any young successive tree saplings and hence bound to lead incorrect results if examined as a sample plot for the study. The support of conventional aerial photographs and remote sensing data to acquire spatial information is not considered much useful because of (i) non availability of modern aerial photographs/ remote sensing data for entire study period (ii) study being a ground based (iii) debris covered glacial snout area (iv) cloud prone alpine area and narrow valley topography that limit the use of remote sensing data specially for at-the-spot treeline validation and delineation due to possible error during shadow and atmospheric correction processes. The annual treeline rise rate is determined by dividing the total altitudinal gain in treeline by the number of years constitutes the study period. The field samples collected from treeline floristic composition were processed, prepared and mounted in the laboratory and identified with routine and established practice [7]. The identity of species was further confirmed by matching to the authenticated herbarium specimens at Forest Research Institute (DD) and Botanical Survey of India (BSD), Dehra Dun, India.

As per as standard method for more realistic and impact discernible study, both anthropogenically influenced, i.e., Chorabari glacier valley as well as undisturbed, i.e., Dokriani glacier valley treeline sample area were investigated for data collection during field work [8]. The ecological compatibility of treeline species with respect to climate change is also investigated. Since glacial snout is also an alpine climate marker and demarcate between glacier and non-glacier regime in an eco-system, hence the treeline status is correlated with known snout positions. The possible factors responsible for treeline dynamics were identified. The significant difference in the rate of treeline rise in both the glacier valleys was investigated and discussed in relation to associated forcing factors, local versus regional and global climate system. To ascertain the reliability of present work, results have been compared to the regional treeline dynamics study based on the remote sensing data of similar climatic domain. The alpine ecosystem changes such as conversion of erstwhile snow-ice regime into treeline ecotone and change in floristic composition has been discussed with respect to hydrological regime, carbon sequestration potential along with some of the possible treeline drivers, viz., the global warming, ambient CO_2 concentration and deflected precipitation system. The possible linkage of observed changes and sustainable development, livelihood and eco-systemic services in general and study area in particular have been discussed with special reference CC along with some of the important resources such as forest, agriculture and glaciers, etc.

RESULT AND DISCUSSION

Intensive investigation revealed that spatial position of alpine treeline in Dokriani glacier valley was at the altitude of 3880 m in the year 1962 and migrated higher to the 3960 m asl up to the year 2009 along with the current aerial distance of 1.7 Km and altitude difference of 40 m to the glacier snout. While in Chorabari glacier valley treeline was reported at the altitude of 2920 m in the year 1962 and it moved uphill to the altitude of 3400 m up to the year 2009 along with the aerial distance of 3.7 Km and altitude difference 466 m to the glacier snout (table 1). The alpine treeline dynamics towards the higher altitude @10.21m/year in Chorabari and @1.70m/year in Dokriani glacier valleys with in the period of 47 years is mainly attributed to the CC and anthropogenic impact on the ecosystem features. The relative difference of 08.51m to the rate of treeline rise in both valleys of similar climatic domain is strongly indicative of dominance of site specific conditions and associated local factors. Another study based on remote sensing data, also reported nearly similar treeline dynamics variability, i.e., from 10 m to 11.9 m/year in different parts of same climatic regime of himalayan region for the period of 1970 to 2006. And in majority of areas treeline elevation was reported between 3000-4000 m but in some cases treeline was found below than 3000 m and above than 4000 m asl [9]. The current findings based on field as well as remote sensing study are suggestive that concept of existence of regional treeline need to be revised with respect to area specific attributes in himalayan region [10]. Studies confirmed that treeline dynamics is not uniform in all regions and it is hardly governed by global climate system and looks to be a product of prevailing micro-climatic scenario [11], [12], [13]. Since temperature is considered as a principal treeline driver worldwide and hence it can be concluded that "uniform global warming impact" is barely discernible in the region under study. The site specific and interlinked factors such as altitude, topography, geology, snow and water precipitation, photoperiod, light intensity, air-soil temperature and moisture regime, soil content, wind velocity and aspect of the slope, forest fire and anthropogenic activities, etc., are considered possible determinants and important players in the treeline uphill dynamics. The influence of location specific treeline drivers appears to be dominant over the global drivers in the Himalayan region like some of the other mountain regions of the world [14].

The treeline up hill dynamics imply that periodically forest land use area is increasing and vegetation is expanded in the areas which were otherwise restricted to the herbs, shrubs and trees growth due to adverse climatic conditions, especially of low temperature, air pressure and moisture. The invasion of the treeline to the erstwhile snow/ice regime is the ecological indication of shrinkage in frozen water resource in alpine ecosystem. And it is further evident by the gradual loss of snow and ice mass balance in the Dokriani and Chorabari glaciers when monitored duly [15]. Treeline drivers identified are diverse not even in same valley but also in different valleys belonging to the different watersheds. With in the watershed of Bhagirathi river and away from Dokriani glacier snout at the elevation of 3880 m near Tela hill top, the treeline is being controlled by the factors such as species ecological compatibility, altitudinal limitation, traditional livestock grazing and high wind velocity. Being climax vegetation no successive young trees were reported as a sign of treeline rise and it can be concluded that further rise of treeline is presently stopped (figure 2). Whereas close to the Dokriani glacier snout at the elevation of 3960 m, the site specific geomorphic location factor like wind velocity, high gradient and tough accessibility prevent livestock grazing. However area represents suitable altitudinal limitation and ecological compatibility to the invader species and therefore, treeline is rising towards higher altitude with successive generation (Figure 3). In Chorabari glacier valley under Alaknanda river watershed, faster rate of treeline rise is attributed to the substantial impact of high anthropogenic pressure along with other natural factors. The ever increasing anthropogenic pressure on the local resources can be visualized by the fact that the number of pilgrims and tourists to visit Lord Shiva Kedarnath Temple in the valley, was 1, 17,774 in the year 1990 but with in a period of 21 years it increased nearly five times and reached to 5, 70,000 in year 2011 [16]. The infrastructure development and other associated facilities required to manage this huge crowd in alpine treeline vicinity influence the local ecosystem. The hot air and gasoline aerosols released by powerful engines of nearly 32 helicopter visits per day during peak season in the valley is also expected to contribute to the treeline drivers. Amongst the natural factors such as high relative difference of 466 m in altitude and 3.5 Km in aerial distance between spatial existence of Chorabari glacier snout and treeline, are identified as major contributing drivers associated to the faster rate of treeline rise in Chorabari glacier valleys. Considering the overall influence of all factors, present study is suggestive of that proximity and elevation difference of glacier snout and treeline worked as decisive factors while anthropogenic factor also play substantial role to determine the relative rate difference in treeline dynamics (Table 1).

Treeline progression towards higher altitudes is an ecological indicator for prolonged temperature rise in ecotonal zone and it is considered as a global warming implication by some of the researchers [17], [18], [19], [20]. But instrumental records are not indicating any warming signals [15], [21], [22], [23], [24], [25].

Table 1: Comparative study of Dokriani and Chorabari Glacier in Indian Himalayan region

Attribute	Dokriani Glacier Valley Year 1962	Dokriani Glacier Valley Year 2009	Chorabari Glacier Valley Year 1962	Chorabari Glacier Valley Year 2009
Treeline elevation (asl)	3880 m	3960 m	2920 m	3400 m
Glacier snout elevation(asl)	3810 m	3920 m	3815 m	3866 m
Aerial distance between treeline and glacier snout, their elevation difference & treeline rise rate	1.7 Km, 40 m asl & @ 1.7 m/year		3.7 Km, 466 m asl @10.21 m/year	
Site specific and regional treeline driving factors	Northern aspect, High snout proximity, deflected snow precipitation system		Southern aspect, Low snout proximity, deflected snow precipitation system	
Possible effect on ecosystem	Dominance of broad leaved species, high carbon capture potential		Dominance of narrow leaved species, low carbon capture potential	

Table 2: Population of India and Indian parts of Ganga basin

Basin	Total population (millions)				Urban population (millions)				Rural population (millions)			
	1991	2001	2025	2050	1991	2001	2025	2050	1991	2001	2025	2050
Indus	39	46	61	56	10	14	28	40	29	32	33	17
Ganga	362	445	684	868	82	105	220	411	280	340	464	457
Basin total	401	491	745	924	92	119	247	451	309	372	497	474
% of India	48%	49%	54%	58%	42%	43%	49%	56%	49%	51%	57%	61%
India	844	1007	1389	1583	218	278	510	807	627	728	879	776

Source: Amarasinghe *et a*l 2007.

Table 3: Water withdrawals of India and Indian part of Indus and Ganga basin

Basin	Irrigation water demand (km^3)			Domestic water demand (km^3)			Industrial water demand (km^3)		
	2000	2025	2050	2000	2025	2050	2000	2025	2025
Indus	94	81	71	1.6	3.1	4.0	2.4	5.0	7.6
Ganga	256	272	260	13.9	31.0	54.0	13.6	40.0	75.6
Basin total	350	353	331	16	34	58	16	45	83
% of India	58%	52%	52%	46%	52%	57%	38%	49%	52%
	605	673	632	33	66	101	42	92	161

Source: Sharma *et al* 2008. Estimates based on PODIUMSim model.

Hence it can be concluded that ecotonal ground temperature rise may be related to the change in freezing temperature bearing snow-ice covered landscapes into the near to atmospheric temperature after periodic snow-ice meltdown. This shortage of snow availability may be attributed more to the weakened monsoon and deflected snow precipitation system rather than global warming [26].

The change and difference in floristic composition of old and current treeline is an indication of variable ecological compatibility of specific species with respect to climate change. The current treeline mainly dominated by *Rhododendron companulatum*, *Betula utilis*, *Abies spectabilis, Juuniperus squamata, Sorbus acuparia* while old treeline is purely composed of *Quercus semicarpifolia and Taxus baccata*. During the morphological investigation oldest *Betula utilis* of 12 m height and 135 cm diameter has been reported from the 1962 treeline proximity.

It is observed that due to the lack of proper snow precipitation, the moisture regime on certain slopes is changing and consequently effecting the floristic composition. The moisture ridden north-facing slopes have encouraged growth of broad leaved *Betula utilis*, *Rhododendron companulatum*, *Sorbus acuparia* species while narrow leaved species such as *Taxus baccata*, *Juniperus squamata*, *Abies spectabilis* flourished on the drier south facing slopes. The moisture driven conversion of broad leaved forest cover into narrow leaved forest cover is expected to influence carbon capture potential and radiative energy balance of alpine ecosystem in near future. Because broad leaved species provide larger leaf area size and hence increase relative carbon sequestration potential than the narrow leaved coniferous species. This process is also reported in the Canadian mountain forest with twofold higher photosynthetic rate in broad-leaved species [27].

The some of the important elements of ecosystem such as forests, agriculture-population and glaciers play pivotal role in sustainable development and hence has been examined and discussed below with special reference to the CC. However due to the lack of long term climate data, uniform and standardize methodology and instrumentation, the findings are yet to be matched with long term studies for higher degree of reliability [28].

Forest

Forest is a one of the integral parts of alpine as well as downstream ecosystem in IGB and in addition to the food, shelter, fuel wood, fodder and other major-minor forest products essentially required for sustainable development, it also provide various ecosystem services for the sustenance of basin population. In addition to climate change impacts specifically discussed so far with reference to treeline dynamics, various others possible implications are evident and discussed herewith. Present investigation in Dokriani and Chorabari Glaciers Valley suggest that alpine ecosystem is witnessing by change in plant species composition, productivity and biodiversity which is also being reported in other major ecosystems of the World [29]. The various seasonal phenomenon of the forest species such as leaf sprouting, leaf fall, flowering, fruiting, etc., have been reported to advance by 1-3 weeks in some of the central Himalayan species *viz Quercus leucotrichophora, Q. floribunda*, *Rhododendron arboreum, Pinus roxburghii* [30]. Even in alpine tree species i.e. *Betula utilis*, the marked difference has been observed by the author in leaf development with in Gangotri Glacier Valley at the altitudinal difference of 250 m asl in the year 2011. At the elevation of 3600 m asl near Chirbas, tree was reported with full of leaves (Figure 4) and at the elevation of 3850 near Bhojbas, same species was reported leafless at same time frame i.e. May 23, 2011 (Figure 5). While in the year 1985 both the localities were reported to display same climatic effect *i.e.* leafless trees. This change is attributed to the shifting of snowline towards higher altitude and vacating a relatively suitable area for tree growth in erstwhile snow covered area. The upward shifting of snowline is generating moisture stress for alpine vegetation, especially to herbaceous species and affecting their productivity. In central Himalayan region, the encroachment of less useful tree species *i.e. Pinus lonifolia* into the domain of much useful species *i.e.Quercus leucotrichophora* is also linked to the moisture stress. The fast invasion of exotic species such as *Lantana camara, Eupatorium* spp. and *Parthenium* spp. in the Himalayan region is also assigned to the change in floristic composition and looks to be related to CC impact [31]. The forest fire is one of the natural and man made calamity which destroy the forest, wild life resource and local ecosystem up to worst extant. Rapidly increasing fire affected area in Himalayan region is a matter of serious concern and seems to be associated with climate change, especially of moisture stress. In one of the Himalayan states *i.e.* Uttrakhand, the fire affected area in the year 2001 was only 825 hectares and it increased to 3652 hectare in the year 2006 and in recent year *i.e*. 2010 it reached to the 4115 hectares [32]. It may be predicted that some of the Himalayan forest species may adopt themself according to the climate change scenario. Because under dry condition, the seed maturation and seed germination period coincides with monsoon rainfall in few dominant tree species such as in Sal (*Shorea robusta*), Moru (*Quercus floribunda*) and Kharsu (*Q. semecarpifolia*), while in wet conditions, these species show vivipary. The water stress may advance seed maturation, which might result in the breakdown of synchrony between monsoon rains and seed germination [33].

Agriculture, Water and population

Agriculture is a main source of subsistence to the IGB population with net cropped area114 million hectares. And poverty is substantially higher in rural areas where agriculture is the main source of livelihood. High rate of population growth remain a cause for concern in terms of water and food security, poverty alleviation and resource conservation. IGB is likely to have some of the highest growth of population in South Asia in the first half of this century. Especially India’s population is increasing, but projected to be stabilized around 1,583 million in the middle of this century. By this time (2050), about half of the India’s population shall be living in cities. Table 2 shows that, due to high population growth, more than 61% of the rural population and 56% of the urban population of India will live in IGB by 2050 [34]. Table 3 shows that in Ganga Basin, 90% of the annual water is still being used for agriculture followed by 7.8 per cent for domestic use in IGB. In Indus, the share of agriculture in total use is as high as 96%. However, the major drivers of increasing water demand in the future will be from the domestic and industrial sectors [1].

Although glaciers are the birth place to all Himalayan perennial rivers but main portion of their water discharge in downstream basin areas is contributed by rain water rather than snow /glacier melt water. The glacial melt water component has been estimated 44.8% for Indus, 9.1% for Ganges, 12.3% for Brahamputra, 8.8% for Salween, 18.5% for Yangtze, 1.3% for Yellow and 40.2% for the Tarim River [35] , [36], [37]. The examined sources and availability of water for irrigation are evident that majority of Himalayan region is rain fed and water received from the monsoon still is principal driver for sustainable productivity in IGB. The basin is mainly fed by the Asian Monsoon and winter Westerlies but continuous weakness, delaying trend and erratic behavior of the these sources of precipitation is predicted to generate resource crunch, productivity loss, socio-economic constraints and various environmental stresses and ultimately hamper the sustainable development in the region [26], [38], [39]. The considerable decline in productivity in various crops and fruits due to CC especially of change in weather pattern and cycle has been reported in various parts of India in the IGB [40], [41], [42], [43], [44]. Author has observed decline in productivity of traditional crops due to delayed and erratic monsoon in Ganga River catchment and some times well grown crops and fruits are destroyed due to excessive rains during the harvesting period. And consequently productivity of both dry-land and wet-land crops and fruits such as Wheat (*Triticum* spp.), Rice (*Oryza* spp.), *Sorgham* (Juar), Ragi (*Eleusine* spp.), Bajra (*Pennisetum* spp.), Maize (*Zea mays*), Black Gram (*Phaseolus mungo*), Pea (*Pisum sativum*), Lentil (*Lens culinaris*), Soya bean (*Glycine max*), Potato (*Solanum tuberosum*), Mango (*Mangifera indica*), Orange(*Citrus reticulata*), Sugarcane (*Saccharum officinarum*) etc, have been severely affected by CC.

Glaciers

Glaciers are the unique frozen water resource in alpine region of IGB and behave as a climate marker. Most of the perennial rivers in Himalayan Ecosystem originate from these glaciers and feed most of the populated regions including northern part of India. But due to CC impact their conventional enrichment system has been deteriorated. Glaciers are getting less snow precipitation and some time precipitation followed by rain fall do not allow them to hold snow-ice mass. The disbalance between the snow precipitation received and snow-ice melt is results into negative mass balance every year and consequently most of the Himalayan glacier are in the phase of recession. The Himalayan region represents one of the most dynamic and complex mountain systems of the World and is extremely vulnerable to CC [45]. Due to the harsh climatic condition and difficult terrain, studies on Himalayan Glaciers have been scanty and limited to a few glaciers only. In fact decrease in snow-ice cover during the last century, across the globe, especially in mountain glaciers is seen as impact of CC [46]. Studies carried out on some of the important Himalayan glaciers revealed that due to different climatic setting, site specific geomorphic conditions and study time frame, their recession rate is variable.

The recession rate of Gangotri glacier has been estimated about 28.33 m per year between the years 1990 and 1996 [47], while between the years 2005 – 2007, it was receded by nearly 11.80 m per year [23] ,[48]. In Siachen and Pindari glaciers recession was at the rates of 31.5 m and 23.5 m per year [49], in Milam Glacier it was 9.1 m per year between 1901 and 1997 [50], in Dokriani Bamak Glacier, recession was recorded 16.6 m per year from the years 2001-2007 [15], in Gara, Gor Garang, Shaune Garang, Nagpo Tokpo Glaciers of Satluj River Basin it was reported between 4.22 - 6.8 m per year [49]. The variable recession rate behavior of glaciers is also confirmed in the most detailed satellite-imagery based study ever done in the Himalayas. Study revealed that 75% of these glaciers have shown annual retreat rate at an average of 3.75 m, 8 % have shown an advance and rest of 17 % have exhibited stable position [51]. The overall prevailing scenario of glacial regime is suggestive that water reservoir in the form of Himalayan Snow-glacier is depleting with non-renewable phase which is bound to create water and geo-hydrological crises to hamper various activities related to the sustainable development.

The global warming is also attributed to the glacier recession and treeline dynamics in some of the studies [18], [42], [45],[46], [51], [52], [53]. However, recent studies conducted in the western Indian Himalaya and other parts suggests that global warming impact is hardly evidenced in instrumental records as well as in natural archives. The general slowdown in the rate of glacial retreat has been reported during late nineties and in the decade of year 2000 in the Himalayan region [24], [49]. Study based on observational records and tree rings suggest a pre-monsoon temperature cooling during the later part of the 20th century [21]. Dokriani glacier area has also not witnessed any air temperature rise trend in instrumental records and followed by slight decrease in snout recession in comparison of preceding years [15]. The presumed rapid melting of snow-glaciers due to warming need to be reflected through increasing annual glacial water discharge but in Gangotri glacier more or less a decreasing trend has been reported during 2000-2006 melt season [54]. Glacier fed rivers such as Beas, Chenab, Ravi and Satluj also have not witnessed increasing trend of overall water discharge [22]. It appears that ever weakening monsoon for long period has created poor snow precipitation system and negative mass balance which consequently has resulted into overall recession in most of the glaciers. Recent study also established weakened summer monsoon circulation in general, during the period of years 1951-2004 [26].

CONCLUSION

(a) The significant treeline expansion in erstwhile snow-ice covered area has increased carbon sink area which is bound to improve carbon sequestration potential and alter radiative energy balance in space and time. And hence logically ambient air CO_2 level can not be increased in alpine ecosystem to generate global warming. The discussed instrumental records and dendrochronological evidences are also inconsistent to warming trend. Therefore, before acknowledging the role of global warming in treeline dynamics and glacier recession, the inconsistency of evidences need to be addressed scientifically. Otherwise it seems to be more related to the deflected precipitation system in Himalayan region. (b) The ever depleting glacier-snow resource is creating moisture deficit on Himalayan slopes. Due to which on drier slopes broad leaved species are being replaced by narrow leaved species, leading to change in overall floristic composition. The periodic change in availability of particular species may have substantial impact on day-to-day and long term forest based requirements of vicinity and downstream population. And ultimately sustainable development of the region will be hampered along with the ecosystem services.

ACKNOWLEDGEMENTS

Prof. Anil Kumar Gupta, the Director, Wadia Institute of Himalayan Geology (WIHG) is acknowledged for providing basic facilities and encouragement to present this work at international conference. Partial travel support from Uttarakhand State Council for Science & Technology, Dhera Dun, is thankfully acknowledged. A thank is also due to the Dr.Deepak Srivastava, consultant, center for glaciology, WIHG, for pre-publication correction and valuable suggestions.

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