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Impact of Climate Change on the Region of Himalayan Mountain Ecosystems: A Critical Study

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This article presents an overview of climate change impacts on agriculture, water and forest ecosystems in the western Himalayan Mountains based on literature review and some anecdotal evidences. A great deal of research work has been carried out on different aspects of western Himalayan mountain ecosystems but the findings have yet to be correlated in the context of climate change. There is a need to strengthen climate data collection network which is presently insufficient to meet the requirement of climate change research. The climate data in the region is scarce and in many instances does not involve uniform methodology and standard instrumentation. The data reliability thus is uncertain as the data are based on crude collection methods without quality control. Climate change impacts also need to be categorized according to various climatic elements viz., rainfall, temperature, CO2 concentration, etc. Coordinated efforts are required for adaptation and mitigation as the vulnerable mountain ecosystems and communities are likely to face greater risk of climate change impacts than other ecosystems. Research and documentation is also required to validate the indigenous methods of adaptations and coping up mechanisms. Capacities of communities have to be enhanced and strategies are to be developed for adaptation to climate change. There is also a need to network with other potential players in this subject to utilize the synergy in the best interest of survival, and ensuring livelihood security of the inhabitants of the region and that of the adjacent lowlands. The balance between economic interests and ecological imperatives is also essential

KEY WORDS: Adaptation and mitigation, climate change, Himalayan ecosystems, impacts.

INTRODUCTION

Climate change (CC) is a major challenge facing our planet today. This is an all-encompassing threat that will pose significant environmental, economic, social and political challenges for years and decades to come. Climate change has emerged as a global environmental issue that has engaged the world attention as it relates to global common atmosphere. It is scientifically least predictable, and its impacts are likely to affect adversely the vulnerable and poor people mostly, who have contributed least to the major causes of CC. Mountains are early indicators of climate change (Singh et al. 2010). As glaciers recede, and snowlines move upwards, river flows are likely to change, and alteration in water flow regime may lead to a plethora of social issues and affect hydropower generation, endanger biodiversity, forestry and agriculture-based livelihoods and overall wellbeing of the people.

CLIMATE CHANGE IMPACTS ON THE HIMALAYAN ECOSYSTEMS

At the outset it may be pointed out that research on CC vis-à-vis its impact on ecosystems (e.g., forests, water, agricultural resources, etc.) is still in an infancy stage in the Himalayan Mountains. As such there is a paucity of long-term climate data in the region, and data recorded do not employ uniform instrumentation and methodology hence the data quality is uncertain (Joshi & Negi 1995). Very limited studies are available which could demonstrate the impact of CC on the mountain ecosystems. However, with the release of recent IPCC report research on CC is occupyingthe agenda of many institutions. Preliminary studies indicate that the Himalaya seems to be warming more than the global average rate (Liu & Chen 2000; Shrestha et al. 1999), temperature increases are greater during the winter and autumn than during the summer; and the increases are larger at higher altitudes (Liu & Chen 2000). The Indian Institute of Tropical Meteorology, Pune has reported a decrease in precipitation over 68 per cent of India's area over the last century (Kumar et al. 2006). However, significant increase in rainfall was noticed in Jammu and Kashmir and some parts of Indian peninsula (Agarwal 2009). A study indicates that the mean annual temperature in the Alaknanda valley (western Himalaya) has increased by 0.15 ºC between 1960 - 2000 (Kumar et al. 2008a). Satellite imagery suggests almost 67 % of the glaciers in the Himalaya have retreated (Ageta & Kadota 1992). For example, in Nepal this process is as fast as 10 m year-1 (Ageta & Kadota 1992). The average temperature of Kashmir valley has gone up by 1.45 ºC over the last two decades (Sinha 2007). Impact of changing climate is also perceptible on vegetation. In some parts of the high altitude, the biodiversity is being lost or endangered because of land degradation and the over use of resources, e.g., in 1995, about 10 % of the known species in the Himalaya were listed as `threatened' (IPCC 2002). However, impact of CC on biodiversity and vegetation in the region is yet to be carefully studied to establish such a relationship. Exponential increase in greenhouse gases (GHGs) like carbon dioxide, methane, nitrous oxide, water vapour, CFCs, etc., in the atmosphere has resulted in CC change (World Climate News 2006). The concentration of CO2, mainly responsible for global warming, has reached to 379 ppm in 2005 from its pre-industrial value (i.e., 280 ppm). The increase in GHGs between 1970 and 2004 was approximately 70 %. The mean temperature of the earth has increased by 0.74 ºC during last century (World Climate News 2006). Globally, the sea level rose at the rate of 1.8 mm year-1 during 1961 to 2003, and faster (i.e., at the rate of 3.1 mm year-1) during 1993 to 2003. The review report (Pasupalak 2009) projecting the scenarios of global warming indicate that the global average surface temperature could rise by 1.4 to 5.8 °C by 2100. Global mean sea level is projected to rise by 0.18 to 0.59 m by the end of the current century. This article provides a brief overview of impacts on different components (people, agriculture, water and forest ecosystems) in the western Himalayan mountains based on literature review and some anecdotal evidences. Some important research areas for further investigation are also listed.

SOCIO-ECONOMIC AND HEALTH IMPACTS

Climate change can influence the socioeconomic setting in the Himalaya in a number of ways. It can influence the economy (e.g., agriculture, livestock, forestry, tourism, fishery, etc.) as well as human health. Specific knowledge and data on human wellbeing in the Himalaya is limited, but it is clear that the effects of CC will be felt by people in their livelihoods, health, and natural resource security, among other things (Sharma et al. 2009). The consequences of biodiversity loss from CC are likely to be the worst for the poor and marginalized people who depend almost exclusively on natural resources. Poverty, poor infrastructure (roads, electricity, water supply, education and health care services, communication, and irrigation), reliance on subsistence farming and forest products for livelihoods, substandard health indicators (high infant mortality rate and low life expectancy), and other indicators of development make the Himalaya more vulnerable to CC as the capacity to adapt is inadequate among the inhabitants. Climate change has a powerful impact on human health directly (e.g., impacts of thermal stress, death/injury in floods and storms) and indirectly through changes in the ranges of disease vectors, water-borne pathogens, water quality, air quality, food availability and quality (McMichael et al. 2003), cardiovascular mortality and respiratory illnesses, transmission of infectious diseases and malnutrition from crop failures (Patz et al. 2005). Climatic variations are likely to have a direct impact on the epidemiology of many vector-borne diseases. It is projected that the spread of malaria, bartonellosis, tick-borne diseases and other infectious diseases linked to the rate of pathogen replication will all be enhanced. Several studies using statistical models based on empirical weather data have concluded that CC impacts epidemics of vector-borne disease, such as Ross Virus Fever in Australia (Woodruff & Guest 2002). Climate change and variability are likely to highly influence current vector-borne diseases epidemiology as it is estimated that by the year 2100, average global temperatures will have increased by 1.0 - 3.5 ºC (Watson et al. 1997), increasing the likelihood of many vector-borne diseases. With a rise in surface temperature and changes in rainfall patterns, the distribution of vector mosquito species may change (Patz & Martens 1996; Reiter 1998). Malaria mosquitoes have recently been observed at high altitudes in the region (Eriksson et al. 2008). Temperature can directly influence the breeding of malaria protozoa and suitable climatic conditions can intensify the invasiveness of mosquitoes (Tong & Ying 2000). Another concern is that changes in climate may allow more virulent strains of disease or more efficient vectors to emerge or be introduced to new areas (Sharma et al. 2009). Aerosols have been considered the primary cause for the increase of the Earth's atmospheric temperature. In Himachal Pradesh, aerosols optical depth (AOD), obtained through Multi-wavelength Radiometer (MWR) has shown highest ever AOD at 500 nm as 0.55 ± 0.03 in May 2009 which was 104 % more than mean AOD value from April 2006 to December 2009 (Kuniyal et al. 2009). This value of AOD was found to be 0.056 ± 0.037 at Nainital (Pant et al. 2006), that is, far less to the values obtained at Kullu, indicating inter-regional variations in CC within the Himalayan region. Temperature rise due to radiative forcing from aerosols in the atmosphere based on per unit AOD increase at Mohal-Kullu (HP) was calculated as high as 0.95 kelvin (K) day-1 during summer (April-July) and as low as 0.51 K day-1 during winter season (December, January-March) (Guleria et al. 2010). Climate change will have a wide range of health impacts across the Himalaya. For example, increase in malnutrition due to the failure of food supply, disease and injury due to extreme weather events (Epstein et al. 1995), increase in diarrhea diseases from deteriorating water quality, increase in infectious diseases and cardio-respiratory diseases from the build-up of high concentrations of air pollutants such as nitrogen dioxide (NO2), lower tropospheric and ground-level ozone, and air-borne particles in large urban areas. Huge quantities of municipal waste produced in the western Himalayan Mountain towns are further compounding the problem of emission, sanitation and associated health hazards (Kuniyal 2002).

IMPACT ON AGRO-ECOSYSTEMS

Agriculture is highly dependent on weather, and changes in weather cycle have a major effect on crop yield and food supply. Mountain agriculture is mostly rain fed (appx. 85 %), and driven by biomass energy of surrounding forests and confined to terraces carved out of hill slopes. The small holdings (< 1 ha in majority of cases) are distributed over small parcels of land and the agricultural productivity is very low (6 - 13 q ha-1). The irrigation systems have been severely affected with the rainfall becoming erratic. In the Kullu valley (HP) it has been reported that the rainfall has decreased by about 7 cm, snowfall by about 12 cm, but the mean minimum and maximum temperatures have increased by 0.25 - 1 ºC, respecttively in 1990s as compared to 1880s (Vishvakarma et al. 2003). Various studies have reported that the rate of apple production in Kullu valley has significantly declined during the period 1981- 2000 (Vishvakarma et al. 2003; Vedwan & Rhoades 2001). These workers have observed that apple cultivation has shifted to higher altitudes and apple yield mainly in lower altitudes has declined due to inadequate chilling as the temperature at lower altitudes is rising due to CC in Himachal Pradesh. Because of the change in snowfall the chilling hours for apple trees are reduced, affecting the time of bud-break. Early snow (December to early January) is preferred for its favorable effect on bud-break and soil moisture. It provides a chilling period of about 10 weeks below 5 ºC, which is required to meet the internal condition necessary for bud-break in apples in springtime (Abbott 1984). Some of the documented impacts on mountain agriculture that are linked with CC in the Himalayan region are: (i) Reduced availability of water for irrigation; (ii) Extreme drought events and shifts in the rainfall regime resulting into failure of crop germination and fruit set; (iii) Invasion of weeds in the croplands and those are regularly weeded out by the farmers (e.g., Lantana camara, Parthenium odoratum, Eupatorium hysterophorus etc.); (iv) Increased frequency of insect-pest attacks; (v) Decline in crop yield (Negi & Palni 2010). These factors have led to loss in agridiversity and change in crops and cropping patterns. Traditional agriculture in the Himalayan mountains has been a rich repository of agro biodiversity and resilient to crop diseases. For example, in Uttarakhand over 40 different crops and hundreds of cultivars selected by farmers, comprising cereals, millets, pseudo-cereals, pulses and tuber crops are cultivated (Agnihotri & Palni 2007; Maikhuri et al. 1997). Mixed cropping of 12 crops (Baranaja) is another best example of rich agri-diversity of the region (Ghosh & Dhyani 2004). These crops are adapted to the local environmental conditions and possess the inherent qualities to withstand the environmental risks and other natural hazards. This adaptability has ensured the food and nutritional security of the hill farmers from generations. However, the area under traditional crops has drastically declined (> 60 %) particularly during the last three decades and many of the crops are at the brink of extinction, such as Glysine spp., Hibiscus sabdariffa, Panicum miliaceum, Perilla fruitescens, Setaria italica, Vigna spp., to name a few (Maikhuri et al. 2001; Negi & Joshi 2002). Recent studies at the Indian Agriculture Research Institute (IARI), New Delhi indicate the possible loss of 4 - 5 million tons in wheat production in future with every rise of 1 ºC temperature throughout the growth periods. Losses in other crops are still uncertain but they are expected to be relatively smaller, especially for kharif crops (Uprety & Reddy 2008). Deficit in food production in Kashmir region has reached 40 % in 2007 from 23 % in 1980 - 81 has been linked with CC (Sinha 2007). Alterations in the floral diversity due to landuse and land cover change and extinction of local cultivars will also affect the population of pollinators. In the Himalaya honey bees have been the important component of mountain agriculture as they provide honey with nutrition and medicinal value. Recent reports reveal that due to habitat loss through landuse changes, increasing monoculture and negative impacts of pesticides and herbicides, the diversity of native bees is declining in the region (Pratap 1999). Studies carried out by International Centre for Integrated Mountain Development (ICIMOD) reveal that declining apple productivity is a result of inadequate pollination (Pratap & Pratap 2003). The farmers are now compelled to rent colonies of honey bees for pollinating the apple orchards @ Rs. 500/colony (Ahmad et al. 2002), and devise short-term solutions until the "polliniser" trees in their orchards begin flowering. Bunches of small flowering branches of the pollinisers called "bouquets" are put in plastic bags filled with water and hung on the branches of commercially premium apple varieties to attract the pollinators. Climate change also leads to shift in pest incidence, migration and viability. A change in climatic conditions can cause a pest or disease to expand its normal range into a new environment, extending losses and affecting natural plant communities (Rosenzweig et al. 2001). Temperature is one of the dominant factors affecting the growth rate and development of insect pests (Baleet al. 2002; Patterson et al. 1999). High summer temperatures would favour growth of temperate zone insects leading to faster development and additional generations per year (Bale et al. 2002; Porter et al. 1991). High winter temperatures are likely to result into increased over-wintering thereby increasing population levels in the following season (Porter et al. 1991). It was found that aggressiveness (defined as the percentage of leaf area of a diseased plant) of the fungal pathogen Colletrotrichum gloeosporioides increased under CO_2 concentration double than the ambient level (Chakraborty & Datta 2003). More extreme weather events such as droughts and floods are likely to lead to pest and disease outbreaks (Rosenzweig et al. 2001). Drought stress affects plant physiology, causing some plants to become more susceptible to pests and pathogens, especially when combined with higher temperatures, which can suppress plant defense responses (Rosenzweig et al. 2001). Many of the crop species in the Himalaya vary in their response to CO_2. C3 crops such as wheat, rice, and soybeans respond readily to increased CO_2 levels. Corn, sorghum, sugar-cane, and millet are C4 plants that follow a different pathway. The initial short-term studies indicated that photosynthesis is stimulated more in C3 species as compared to C4 species in response to CO_2 enrichment (Uprety & Reddy 2008). A preliminary study (Joshi & Palni 2005) relating to response of crops to elevated CO_2 and temperature in the Himalayan mountains shows that Hordeum himalayans responds negatively to elevated atmospheric temperature and reduces photosynthesis by 25 - 30 % and consequently crop yields are low. However, the other species, H. vulgare, shows a reverse trend. Thus far, these effects have been demonstrated mainly in controlled environments such as growth chambers, greenhouses, and polyhouses. Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress; as a result there will be a need to develop crop varieties with greater drought tolerance (Rosenzweig & Hillel 1995). The positive effects of CC – such as longer growing seasons and faster growth rates at higher altitudes – may be offset by negative factors such as changes in established reproductive patterns, migration routes and ecosystem (Sharma et al. 2009).

IMPACT ON FOREST ECOSYSTEMS

Vegetation patterns (distribution, structure and ecology of forests) across globe are controlled mainly by the climate. Several climate-vegetation studies have shown that certain climatic regimes are associated with particular plant communities (Thornthwaite 1948; Walter 1985; Whittaker 1975). The Third Assessment Report of IPCC (2001) concluded that the forest ecosystems could be seriously impacted by future CC. Even with global warming of 1 - 2 ºC, much less than the most recent projections of warming during this century (IPCC 2001a), most ecosystems and landscapes will be impacted through changes in species composition, productivity and biodiversity (Leemans & Eickhout 2004). It has been demonstrated that upward movement of plants will take place in the warming world (Cannone et al. 2007; Kelly & Goulden 2008; Pauli et al. 2003). Due to increase in temperatures, change in vegetation, rapid deforestation and scarcity of drinking water, habitat destruction and corridor fragmentation may lead to a great threat to extinction of wild flora and fauna. In the western Himalayan mountains early flowering of several members of Rosaceae (e.g., Pyrus, Prunus spp.) and Rhododendrons has often been linked with global warming. Negi (1989) found that forest trees along an altitudinal gradient of 600 - 2200 m altitude in Kumaun Himalaya vary with respect to periodicity of phenolphases such as vegetative bud break, flowering, fruiting and leaf drop. These phenophases were found to be influenced by variations in temperature and rainfall changes over two consecutive years (1985-1987). For example, at approx. 2000 m altitude leaf initiation was advanced by a week in 1985 (spring temperature in March and April were 17.6 & 20.9 ºC, respectively) as compared to that in 1986 (spring temperature in March = 14.8 ºC and April = 16.5 ºC). However, this annual shift in occurrence of phenophases was not observed for all the species. In the year 1985 when the spring temperature was higher as compared to 1986 flowering was also advanced by 1-3 weeks (in tree species like Quercus spp., Rhododendron arboreum, Pinus roxburghii - the dominant forest trees) in 1985 as compared to 1986 (Negi 1989). It appears that plant taxa are impacted differently by CC calling for further detailed investigations. Spread of alien invasive species such as Lantana, Eupatorium and Parthenium spp.) in the natural forests has also been linked with CC, which will have a competitive impact on existing species. Research on alpine vegetation suggests that many species are able to start their growth with the supply of snow-melt water well before the monsoon begins in June (Negi et al. 1991). Growth and life cycles of these species are already being disturbed because of reduced water from snow melt. Increased incidences of forest fire are another prominent change that is linked with CC. The frequency, size, intensity, seasonality, and type of fires depend on weather and climate in addition to forest structure and composition. In 2005-2006, a record 8,195 hectares of forest in Himachal Pradesh was lost to fire (Bhatta 2007). In four districts of Uttarakhand (Almora, Chamoli, Tehri and Pauri Garhwal), in one of the most devastating forest fires of recent decades on 27 May, 1995 a total of 2115 km2 (between altitudes 600 m to 2650 m) was damaged severely (Semwal & Mehta 1996). A comparison of air temperatures during the fire season for the two years 1994 (no fire event) and 1995 (large fire events) in Binsar Wildlife Sanctuary, Kumaun Himalaya showed that in 1995 the air temperature was higher (Sharma & Rikhari 1997). It is expected that with the CC, scenario of the forests, both in terms of structure and functioning, is likely to change substantially. In the case of many dominant forest species of the region like sal (Shorea robusta), tilonj oak (Quercus floribunda) and kharsu oak (Q. semecarpifolia) seed maturation and seed germination coincide with monsoon rainfall. In wet conditions these species show vivipary. A rise in temperature and water stress may advance seed maturation, which might result in the breakdown of synchrony between monsoon rains and seed germination (Singh et al. 2010). Forests are also the source of NTFPs (including medicinal plants). The oak forests of the region are the storehouse of biodiversity, NTFPs and a variety of medicinal plants. For example, Morchella esculenta (an edible fungi) that is found in the oak-conifer forests of this region in the Niti valley of Chamoli distt. is collected by the local people. A family on an average collects about 1.5 kg dry wt. of Morchella every year which is sold @ Rs. 5000/kg (Prasad et al. 2002). Another such example is that of Kafal (Myrica esculenta) fruits collected by the local people from the forests that are sold raw in the nearby markets @ Rs. 20-40/kg. It has been estimated that in the Kumaun region alone people can earn appx. Rs. 1.4 million per season from selling this fruit (Bhatt et al. 2000). It is expected that with the increase in drought cycles and concomitant increase in forest fires the pine (Pinus roxburghii) forests will encroach upon the area under oak (Quercus spp.) forests and also reduce the yield of non-timber forest products (NTFPs). Apart from the direct benefits accrued from these forests the ecosystem services generated would also alter (Semwal et al. 2007). Inevitably, any change in the forest (distribution, density and species composition) under CC would immensely influence economies like forestry, agriculture, livestock husbandry, NTFPs and medicinal plants based livelihoods and many others. World over, many studies have been conducted on the effects of elevated CO2 on photosynthesis and yield of plants. The so called “CO2 fertilization effect” is often examined using greenhouses, growth chambers and open top chambers (Nowak et al. 2004; Pendall et al. 2004). In the western Himalaya, oak (Quercus spp.) and other fodder trees (e.g., Grewia, Celtis, Boehmeria spp.) show over 50 % higher photosynthesis under elevated CO2, whereas Betula utilis (a tree of alpine habitat) exhibited a reverse trend (Joshi et al. 2007). In a recent study (Ravindranath et al. 2008) it was reported that under two scenarios of 740 ppm CO2 (A2) and 575 ppm CO2 (B2), vegetation response model for the forests of India projected for the year 2085, showed that 77 % and 68 % of the forested grids are likely to experience shift in forest types under A2 and B2 scenarios, respecttively. The impacts of CC on forest ecosystems include shifts in the latitude of forest boundaries and the upward movements of tree line to higher elevations; changes in species composition and in vegetation types; and an increase in net primary productivity (Ramakrishna et al. 2003). Increase in temperature is known to enhance a ground-level ozone concentration which is one of the GHGs and a phyto-toxic air pollutant that leads to serious injury in plant tissues and reductions in their growth and productivity (USEPA 1996). It has been shown that exposure to O3 concentration of more than 50 ppb is sufficient to cause damage to certain species (Aneja et al. 1991). Ozone exposure to plants during the day brings about biochemical changes resulting in decreased photosynthesis (Musselman & Massman 1999). In Himachal Pradesh, ozone episodes have shown 86.7 ppb at 1500 h IST at Mohal (Kuniyal et al. 2007), which increased up to 95.19 ppb at 1700 h in 2007.

IMPACT ON WATER RESOURCES

The Himalayan region represents one of the most dynamic and complex mountain systems and extremely vulnerable to global warming (Bandyopadhyay & Gyawali 1994). The Himalayan Mountains

are important sources of water to the Indo-Gangetic plains through the perennial glacier fed rivers. During the Pleistocene era (2 million years ago) glaciers occupied about 30 % of the total area of the Earth as against 10 % at present (Bahadur 1998). The IPCC has stated that thinning of glaciers since the mid-19th century has been obvious and pervasive in many parts of the world. The reduction in ice cover during the last century, across the globe, especially in mountain glaciers is seen as evidence of CC (IPCC 2001 b). At high elevations in the Himalaya, an increase in temperature could result in faster recession of glaciers and an increase in the number and extent of glacial lakes - many of which have formed in the past several decades. The rapid growth of such lakes could exacerbate the danger from glacial lake outburst floods (GLOFs), with potentially disastrous effects. Studies on selected glaciers of Indian Himalaya indicate that most of the glaciers are retreating discontinuously since post-glacial time. The Gangotri glacier, one of the major and important glaciers in the Himalaya, was 25 km long when measured in 1930s and has now shrunk to about 20 km (Hasnain 1999). The average rate of recession of this glacier between 1985 and 2001 is about 23 m per year (Hasnain 2002). Thakur et al. (1991) have reported the retreat of Gangotri glacier at an average rate of 18 m per year.

While with the use of Differential Global Positioning System, it has been reported that the Gangotri glacier has retreated at much lower rates (11.80 ± 0.035 m per year) between the years 2005 - 2007 (Kumar et al. 2008b; Raina 2009). The Siachen & Pindari glaciers retreated at the rates of 31.5 m and 23.5 m per year, respectively (Vohra 1981). Shukla & Siddiqui (1999) monitored the Milam Glacier in the Kumaon Himalaya and estimated that the ice retreated at an average rate of 9.1 m per year between 1901 and 1997. Dobhal et al. (1999) monitored the shifting of snout of Dokriani Bamak Glacier in the Garhwal Himalaya and found 17.2 m per year retreat during the period 1962 to 1997. The average retreat was 16.5 m per year. Matny (2000) found Dokriani Bamak Glacier retreated by 20 m in 1998, compared to an average retreat of 16.5 m over the previous 35 years. Geological Survey of India studied the Gara, Gor Garang, Shaune Garang, Nagpo Tokpo Glaciers of Satluj River Basin and observed an average retreat of 4.22 - 6.8 m year-1 (Vohra 1981). The Bara Shigri, Chhota Shigri, Miyar, Hamtah, Nagpo Tokpo, Triloknath and Sonapani Glaciers in Chenab River Basin retreated at the rate of 6.81 to 29.78 m year-1. A massive glacial retreat rates of 178 m year-1 in Parbati Glacier in Kullu District during 1962 to 2000 has been observed (Kulkarni et al. 2004). These observations, irrespective of the differences in the retreat of glaciers, suggest that global warming and CC has affected snow-glacier melt and runoff pattern in the Himalaya. When assessing the warming effects on glacier melting in the Himalaya, the role of black carbon (BC) cannot be neglected (Ming et al. 2008). In the Himalayan region, solar heating from BC at high elevations may be just as important as carbon dioxide in the melting of snowpacks and glaciers (Ramanathan & Carmichael 2008). The first historical record of BC deposition of about 80 ng m-3 during 1951 - 2001 in a 40-m shallow ice core retrieved from the East Rongbuk Glacier in the northeast saddle of Mt. Qomolangma (Everest) during the past ~50 yrs in the high Himalaya (Ramanathan & Carmichael 2008). The rise in BC in South Asia could penetrate into the Tibetan Plateau by climbing over the elevated Himalaya. In the northwestern Indian Himalayan region, BC concentration at Mohal-Kullu (H.P.) showed bimodal peaks- one at 0600 to 0900 h IST and another at 1800 h IST showing hourly average value always above 2500 ng m-3 (Kuniyal 2010). However, highest ever value on hourly basis was 15657 ng m-3 in January 2010 followed by 15006 ng m-3 in December 2009. In the morning hours due to shallow boundary layer in the hills the BC recorded a peak. Again in the evening the BC recorded a peak value due to dispersion of C produced by biomass burning, vehicular emission and other aerosols (Kuniyal 2010). Mountain springs have been reported to decline the water yield or have gone dry mainly due to the erratic rainfall in the recent decades (Valdiya & Bartarya 1989 a; Negi & Joshi 2004). A survey in the Gaula river catchment in the Central Himalaya revealed that about 45 % of springs have gone dry or become seasonal (Valdiya & Bartarya 1989 a). Studies on aquifer response to regional climate variability in a part of Kashmir Himalaya (Jeelani 2008) revealed that out of forty major perennial springs monitored under different lithological controls, the average monthly spring discharge is high in Triassic Limestone-controlled springs (Karst springs) and low in alluvium- and Karewa-controlled springs. In general, the measured monthly spring discharges show an inverse relation with the monthly precipitation data. However, a direct correlation exists between the spring discharges and the degree of snow/ice melt. Rainfall patterns have been changed in the recent decades. The monsoon rains are delayed and continuing rainfall for seven days (Satjhar)- a phenomenon which was a characteristic feature of monsoon season has almost disappeared now. Similarly, the winter rains have also become unpredictable and lower in quantity. In many areas, a greater proportion of total precipitation appears to be falling as rain than before. As a result, snowmelt begins earlier; this affects river regimes, drought and flood cycles, natural hazards, water supplies, and people’s livelihoods and infrastructure. Erosion has increased five-fold to 1 mm per year (Valdiya & Bartarya 1989b). The rivers carry large amounts of sediment at rates of 16.5 ha-meters per 100 km2 of the catchment area per year (Valdiya & Bartarya 1989).

RESEARCH & DEVELOPMENT ISSUES FOR FUTURE ACTION

Considering the potential impacts of CC on the Himalayan ecosystem following few important areas need attention both of the researchers and policy planners. Some of the important areas of research could be: (i) Collection of meteorological data involving standard methodology and instrumentation, (ii) Understanding drought and flood cycles, climate variability and other extreme events, (iii) Plant taxa vulnerable to CC and survival strategies of plants, (iii) Global warming associated with upward migration of altitudinal boundaries and consequent change in snowline position and its biota, (iv) Habitat requirements and corridors for upward migration of plants and animal species, (v) Impact of CC (involving eco-physiological studies such as drought, elevated CO2 and atmospheric temperature) on important food crops, timber spp., medicinal plants which may affect the food security and revenue generation for the region, (vi) Studies on air pollutants (AODs, GHGs) and temperature rise to observe the impact of aerosols, GHGs and other pollutants on the atmospheric temperature, (vii) Invasion of weeds, such as Lantana, that compete with the native flora for soil nutrients and (viii) Documentation of local traditional knowledge of climate variability and coping-up strategies can be useful in formulating strategies to adapt to the impact of CC.

CONCLUSION

Human pressures on the natural ecosystems of the Western Himalayas are intensifying, and this requires new research efforts and management strategies.

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