The Effects of Climate Change on Natural Resources and Socio-economic Condition of Himalayan Communities of Uttarakhand, India

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Abstract— **Climate change is one of the most important environmental challenges that affect all the natural ecosystem of the world. This article provides a brief overview of climate change impacts on agriculture, water and forest ecosystems in the Uttrakhand Himalayan mountains based on the available literature and some anecdotal evidences of the local people and researchers. Number of studies has been carried out on various aspects of Himalayan ecosystems, however, only a few local studies has been available dealing with the climate change related aspects, primarily due to lack of systematic and focussed associated data. Therefore, the qualitative analysis reveals that there is an urgent need to strengthen climate data collection network to meet the requirement of researches on various aspects of climate change impacts, mitigation and adaptation. The synthesis reveals that the climate change impacts at local level also need to be categorized based on various climatic elements viz., rainfall, temperature, CO_2 concentration, including their cumulative responses. The use of sophisticated instruments and modern technologies with top down approach must be adopted, so that the research findings may be dove-tail with the people oriented policies. 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 due to their high synergy with respect to each other. Capacities of communities have to be enhanced and strategies are to be developed for adaptation to climate change at one hand and on the other several climate resistant tailor made technologies need to be promulgated and developed.**

Index Terms— **Ecosystem, Hydropower, Climate-sensitive, Livelihood, Glacier.**

I. INTRODUCTION

Climate change refers to changes in the earth's climatic conditions occurring over a period of time, either due to natural forces or from human activities. Climate change is a major challenge facing our planet today. Climate and natural ecosystems are closely related and depend on each other, and the stability of this relation is an important ecosystem service. This is an all encompassing threat that will pose significant environmental, economic, social and political challenges for years and decades to come. Exponential increase in green house gases (GHGs) like carbon dioxide, methane, nitrous oxide, CFCs, etc., in the atmosphere has resulted in Climate change [1]. 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) [2]. The increase in GHGs between 1970 and 2004 was approximately 70%. The mean temperature of the earth has increased by 0.74ºC during last century [1]. The review report [3] projecting the scenarios of global warming indicate that the global average surface temperature could rise by 1.4 to 5.8°C by 2100. 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 and global mean sea level is projected to rise by 0.18 to 0.59 m by the end of the current century [2]. 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 Climate Change. Mountains are early indicators of climate change [4]. 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 well-being of the people. 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 [5].

Manuscript received November 23, 2014.

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II. SOCIO-ECONOMIC IMPACTS OF CLIMATE CHANGE

Himalayan mountains are considered highly vulnerable to climate change, not only because of high physical exposure to climate-related disasters but also because of the dependency of its economy on climate-sensitive sectors (e.g. agriculture, forests, tourism, animal husbandry, fisheries etc.). Specific knowledge and data on human wellbeing in the Himalaya is limited, but effects of Climate change will be felt by people in their livelihoods, health, and natural resource security, among other things [6]. Poverty, poor infrastructure (roads, electricity, water supply, education and health care services, communication, and irrigation), reliance on subsistence farming and forest products for livelihoods and other indicators of development make the Himalaya more vulnerable to Climate change as the capacity to adapt is inadequate among the inhabitants [2]. Climate change has a significant impact on human health by directly or indirectly. Direct impacts of climate change on human health could include: Exposure to thermal extremes (cardiovascular and respiratory diseases) and altered frequency or intensity of other weather events – leading to injuries, psychological stress; damage to public health infrastructure, by floods & other natural calamities. Indirect impacts of climate change could include: effects on range and activity of infective vectors and parasites– leading to incidence of vector borne diseases (malaria, dengue fever and several types of encephalitis); altered local ecology of water borne and food borne ineffective agents because of higher temperatures – leading to changed incidence of diahorrea and other infectious diseases. Climate change also affect water availability through more evaporation which leads to less availability of fresh water, in turn leading to lack of hygiene and thus increase water born diseases [7]. With rise in surface temperature and changes in rainfall patterns, the distribution of vector mosquito species may change [8] and recently malaria mosquitoes have been observed at high altitudes [9]. 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 due to changing weather conditions which highly affect the human health as well as well being of the Himalayan community.

III. HIMALAYAN AGRICULTURE AND CLIMATE CHANGE

Agriculture is one of the most climate-sensitive industries, with outdoor production processes that depend on particular levels of temperature and precipitation. Although only a small part of the world economy, it has always played a large role in estimates of overall economic impacts of climate change. In the 1990s, it was common to project that the initial stages of climate change would bring net benefits to global agriculture [10]. As late as 2001, the U.S. Global Change Research Program still anticipated that U.S. agriculture would experience yield increases due to climate change throughout this century [11].Warmer weather was expected to bring longer growing seasons in northern areas, and plants everywhere were expected to benefit from carbon fertilization. The net increase in temperatures in the Himalayan region is projected to range between 1.7 ^{0}C to 2.2 ^{0}C and the forecasted precipitation is expected to increase by 60 to 206 mm in 2030s. The increase in annual rainfall with respect to 1970s ranges from 5 to 13 percent [7]. Productivity of most of the crops would decrease due to increase in temperature and decrease in water availability for irrigation. Mountain agriculture which is mostly rainfed (appx. 85 %), and driven by biomass energy of surrounding forests and confined to terraces carved out of hill slopes are highly affected by changing climate. Greater loss is expected in Rabi as compared to Kharif crops. Rise in temperatures could also result in shortening of maturity period of winter crops and increased pest infestation. Apple yields are expected to be affected. 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 favourable effect on bud-break and soil moisture [12]. The change in the fire frequencies would result in the change in the overall production of crops. These factors have led to loss in agro-diversity and change in crops and cropping patterns. Extreme drought events and shifts in the rainfall regime resulting into failure of crop germination and fruit set; invasion of weeds in the croplands and those are regularly weeded out by the farmers (e.g., *Lantana camara*, *Parthenium odoratum, Eupatorium hysterophorus* etc.); increased frequency of insect-pest attacks; decline in crop yield [13]. Temperature is one of the dominant factors affecting the growth rate and development of insect pests [14].

Traditional agriculture in the Himalayan mountains (Uttarakhand) has been a rich repository of agro-biodiversity and resilient to crop diseases. The 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 [15]. 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 1ºC temperature throughout the growth periods. Losses in other crops are still uncertain but they are expected to be relatively smaller, especially for kharif crops [16]. Alterations in the floral diversity due to landuse and land cover change and extinction of local cultivars will also affect the population of 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 [17].

IV. WATER RESOURCES AND CLIMATE CHANGE

Mountainous regions are vulnerable to climate change and have shown ‘above average warming’ in the 20th century. According to the IPCC (Intergovernmental Panel on Climate Change), impacts are expected to range from reduced genetic diversity of species to glacial melt in the Himalayas leading to increased flooding, which will ultimately affect water resources availability within the next few decades. With over 15 important perennial glacier fed rivers and over a dozen glaciers in the state, Uttarakhand is a valuable freshwater reserve. The IPCC again points to the fact that this alarming trend of glacial melts may lead to many rivers becoming seasonal rivers in the future, thus affecting the economic potential in their basin areas. As the River Ganga originates from the Gangotri, increased glacial melt due to climate change would have consequences on livelihoods of the people and ecological balances in the state as well. The thinning of glaciers and reduction in ice cover during the last century, across the globe, especially in mountain glaciers is seen as evidence of Climate Change [18]. At high elevations in the Himalaya, the warming of the climate is resulting in the recession of glaciers and formation of glacial lakes. Human activities including settlement, hydropower generation, mining and wilderness tourism in mountainous areas have increasing conflict with glacial hazards including moraine dam failures and glacial lake outburst floods (GLOFs), with potentially disastrous effects. Environmental changes pose a grave threat to the Himalayan glaciers more floods are a distinct possibility. The increase in global temperature will cause increased occurrence of GLOFs (Glacial lake outburst floods) and will affect the size of the glacial lakes. The breakage of such lakes can be extremely devastating to human habitations e.g. Kedarnath disaster of Uttarakhand in June 2013. The monsoon reached Uttarakhand almost two weeks earlier than normal, resulting in cloud bursts and very heavy (124.5 – 244.4 mm) rainfall in several parts of the higher reaches of the Himalayas. Further, the water surge was caused by a breach in the boundary of Chorabari Lake due to heavy rainfall upstream. This resulted in the release of huge volume of water along with large boulders, devastating the towns of Kedarnath, Rambara, Gaurikund and others in its way [19].

The Gangotri glacier, one of the major and important glaciers in the Himalaya, was measured 25 km long in 1930s and has now shrunk to about 20 km and the average rate of recession of this glacier between 1985 to 2001 is about 23 m per year [20]. Bali et al. (2009) have reported the retreat of Gangotri glacier at an average rate of 26.5 m per year between 1935 to 1971 and 17.15 m per year between 1971 to 2004. Kumar et al. (2008) have reported at an average retreat rate of 12.1 m per year between 2004 to 2005. 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 [21,22]. Bali et al. (2009) reported the retreat of Pindari glacier at an average rate of 26.23, 20.0, 7.62, 6.39 m per year between 1845-1906, 1906-1958, 1958-1996, 1996-2007 respectively. Shukla & Siddiqui (1999) monitored the Milam Glacier 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. These observations shows that most of the glaciers in Himalaya are receding however the rate of recession of some large glaciers such as Gangotri has slowed down over past few decades. The rates of recession indicate the influence of micro-climatic variability. The differences in the retreat of glaciers, suggest that global warming and Climate change has affected snow-glacier melt and runoff pattern in the Himalaya. As glaciers recede and snowlines move upwards, river flows are likely to change depending upon the glaciated area. The adopted changes in temperature (1 to 3^0C) and precipitation (-10 to +10%) suggest that rise of 2^0C in temperature may increase the runoff by 28% and changes in rainfall by ±10% may correspond to ±3.5% change in stream flow form Dokriani glacier [23]. Alteration in water flow regimes may lead to social conflicts, affect hydropower generation, endanger biodiversity systems/forestry, agricultural-based livelihoods and overall well being of the people. Mountain springs have been reported to decline the water yield or have gone dry mainly due to the erratic rainfall in the recent decades [24]. 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 and the winter rains have become unpredictable and lower in quantity. In many areas, a greater proportion of total precipitation appears to be falling as rain than before.

V. Forest Ecosystem and Climate Change

Climate is one of the most important factors controlling the growth, abundance, survival and distribution of species as well as regulating natural ecosystems in a variety of ways [25]. Climate change and habitat destruction are two of the greatest threats to global biodiversity [26]. The Third Assessment Report of IPCC (2001), concluded that the forest ecosystems could be seriously impacted by future climate change. Even with global warming of 1- 2^0C, much less than the most recent projections of warming during this century [27], most ecosystems and landscapes will be impacted through changes in species composition, productivity and biodiversity [28]. The area under forest in Uttarakhand is 3.4 million ha, which is 61.45 percent of total land. It has been demonstrated that upward movement of plants will take place in the warming world [29,30,31]. The FAO estimated the total area of the worlds forests in 2005 to be 3.8 bllion hectares or 30 % of the global land area [32]. According to FAO, the global rate of deforestation is reported to be 0.7% per year from 1990 to 1995. Nearly 1.8 % of the forests is estimated to be degraded every year, the major cause being deforestation [33]. There was a net decrease in global forest area of 1.7% between 1990 and 2005, at an annual rate of change of 0.11%. In Uttarakhand , Pithoragarh district found a net deforestation rate of -0.13 and a gross deforestation rate of 0.52% over a period of 30 years between 1976 to 2006 [34]. Net deforestation rate of 0.48 was estimated for Kuchgad micro-watershed in Almora district, Uttarakhand from 1967 to 1997 [35]. These authors concluded that with increasing human activities, the deforestation rate has increased over the years. Deforestation affects climate change because it releases the carbon stored in the plants and soils and alters the physical properties of the surface [36]. The various studies observed agriculture expansion with over-exploitation of broad leaved forests for economic purposes as a cause of deforestation. The analysis of different cases of Uttarakhand it is confirm that continued destruction and degradation of forests in spite of afforestation measures and protection contributed rise in global temperature.

Due to increase in temperatures, change in vegetation, rapid deforestation and scarcity of water, habitat destruction and corridor fragmentation may lead to a great threat to extinction of wild flora and fauna [2]. Phenology of the plants also shifts due to climate change. Changes in plant phenology act as important early warning of impending ecological change by altering the timing of activities that allow species to coexist. In the Himalayan mountains early flowering of several members of Rosaceae (e.g., Pyrus, Prunus spp.) and Rhododendrons has often been linked with global warming [2]. The phenophases of plants such as vegetative bud break, flowering, fruiting and leaf drop were found to be influenced by variations in temperature and rainfall changes over the years. Early bud break in *Betula utilis* has been recorded in 2010 as compared to earlier years [37]. The changes in phenological behaviour of species may be a strong indicator of climate change since many species are highly sensitive even smallest change in the long prevailing climate of any ecosystem. Shift in vegetation from lower elevation to higher elevation upto a variation from 200-500 m [38]. Changing climate also favours the spread of alien invasive species such as *Lantana camara, Parthenium, Eupatorium* and *Ageratum* spp. in the natural forests, which will have a competitive impact on existing species. Growth and life cycles of the species are already being disturbed because of reduced water from snow melt.

In the case of many dominant forest species of the region like sal (*Shorea robusta*), tilonj oak (*Quercus floribunda*) and kharsu oak (*Q. semecarpifolia*), rise in temperature and water stress may advance seed maturation, which might result in the breakdown of synchrony between monsoon rains and seed germination [4].

The forests of Uttarakhand contain 496 million t Carbon in their biomass and soil components and contribute significantly in terms of Carbon sequestration which has great significance from a climate change stand point. In least disturbed forests of various types, such as sal (*Shorea robusta*), pine (*Pinus roxburghii*) and oaks (*Quercus spp*) forests Carbon sequestration rates in total biomass range between 4.0 and 5.6 t C ha^{-1} yr^{-1}. The amount of Carbon accumulated in total forest biomass in the state is estimated at 6.61 M t y^{-1}, and valued at Rs. 3.82 billion at the rate of US$ 13 per t Carbon [39]. So, any change in the forest (distribution, density and species composition) under Climate Change would immensely influence economies like forestry, NTFPs and medicinal plants based livelihoods and many others.

VI. Conclusion

The sustainability of the Himalayan mountain ecosystem will depend on striking a balance between the fragile ecosystem components, namely forest, land, water. Sustainability of forest ecosystems is an essential component of environmental conservation efforts and any degradation of forests will have an adverse impact on various systems such as water resources, agriculture, biodiversity, environment, climate change and human health besides the subsistence and livelihood opportunities of forest dependent communities living in and around forests. Reforestation would help to mitigate global warming and also improve the sustainability of natural resources as well as provide livelihood opportunities of communities.

The conservation of the land and soil of the region requires operational land conservation and planning guidelines that will effectively regulate unplanned growth in the name of tourism and development. The Himalayan region should be considered broader than a commercial tourist destination and should be developed as a major ecotourism centre as well as for pilgrimage and adventure tourism.

The snow and glaciers of the Himalayan region, are key contributors to the sustenance of most of the glaciers fed rivers of the Himalaya. Unfortunately, the glaciers are showing signs of wear and decline, and this is of particular importance in the wake of climate change. Due to the increasing importance of water security conservation and protection measures need to be augmented to improve the natural water regimes of the Himalayan region. Establishment of an effective monitoring network for assessment and prediction of future changes of these vital resources along with conservation measures are urgently needed. The 'National mission for sustaining the Himalayan ecosystem' is a step in this direction. Global warming associated with upward migration of altitudinal boundaries and consequent change in snowline position and its biota could be an issue for future research and development.

Communities in the mountain areas are well aware that the "weather" is changing. The changes in weather as experienced and perceived by local people is confirmed by analysis of weather records, such as temperature are more variable, periods of drought are longer, rainfall is erratic, reduction in the duration of winter, and sudden weather fluctuations, some plant species are flowering earlier and some are decline, there is a vertical shifting of trees and crops, some natural resources are disappearing, and new and unfamiliar pests and diseases are emerging. Changes in rainfall patterns and temperature regimes have started influencing the local water balance and disturbing the optimal cultivation period available for particular crops, thus throwing food and agricultural production out of gear. The worst brunt of climate change will be borne by farmers in dryland and hill regions where agriculture is rainfed, conditions are marginal and only one crop is grown per year. The seasonal shift has led to a decrease in productivity. The yield is also supposed to be less nutritious. This change has worsened the condition of the already cash strapped farmers who are now abandoning agricultural practices or shifting to new crops – both of which are directly affecting our food security.

There is a tendency to compartmentalize and treat drought risk reduction, climate change adaptation, degradation of natural resources, and poverty alleviation separately. However, these issues are closely interconnected at the household and community levels, and constitute one complex problem encompassing livelihoods, food security and health.

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