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Human – Environment relations and climate change in Western Himalaya

Som Nath Thakur[1], Simrit Kahlon[2], Smita Bhutani[3]

1. Research Scholar, Centre of advanced Study in Geography, Panjab University, Chandigarh
2. Associate Professor, Centre of advanced Study in Geography, Panjab University, Chandigarh
3. Professor, Centre of advanced Study in Geography, Panjab University, Chandigarh

thakur.geog@gmail.com

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ABSTRACT

Mountains are among the most fragile ecosystems on Earth. Highly sensitive to climate change these ecosystems are being affected at a faster rate than other terrestrial ecosystems. The study of human-environment relations in mountain areas is important for both theoretical and practical reasons since mountain areas the world over suffer similar problems, namely resource exploitation, unemployment and natural hazards.

The present paper has two parallel objectives. The first is to discuss the land use and land cover change, and second to understand the climate variation in a tribal mountainous region of the Western Himalaya. A natural third objective that emerges is to establish the possible congruence between the two trends and highlight the implications of these changes. For the purpose of studying the land use and land cover change, data sets pertaining to two points in time viz. 1975 and 2011 were analysed and compared. Data for this purpose was procured in the form of satellite imageries from LANDSAT. The sensors that collected this data were Multi Spectral Scanner (MSS) and Thematic Mapper (TM). Base line information was obtained from the toposheets (1:250000) of the study area. For climatic variation, data on a monthly basis for the period from 1901 to 2002 (mean monthly temperature, mean monthly minimum temperature, mean monthly maximum temperature, total monthly rainfall and number of rainy days) has been sourced from the Indian Meteorological Department. This information was supplemented with ground reality and local perceptions. For this purpose, primary data has been collected using interview schedules and focus group discussions to understand the change in agricultural practices and perceptions regarding climate change.

The results indicate large scale modification of the study area. Both climate change and socio-economic forces are to account for this. There is an expansion in the area under agriculture, scrub land as well as the area under settlements. While this is likely to result in a further change in the human – environment interaction, it is also not without cultural implications for the study area.

Keywords: Human – environment relations, land use and land cover change and climate change

1. Introduction

The steady population growth and large-scale anthropogenic activities supported by technological advances particularly over the last two centuries have initiated rapid changes in the earth's natural system (Millennium Ecosystem Assessment, 2005; Steffen et al., 2005; An and Lopez-Carr, 2012). In fact, human impact on nature is so profound that Earth Science scholars have identified a new age in the Earth's history – the Anthropocene or "Age of the Human" (Crutzen, 2006; Steffen et al., 2007; Zalasiewicz et al., 2008; Lovbrand et al., 2009; Zalasiewicz et al., 2010; O'Brien, 2011; Steffen et al., 2011; Kolbert, 2011; Jones, 2011; Szerszynski, 2012; Lorimer, 2012; Glaser et al., 2012). This is to acknowledge that humans are now the main drivers of change in ecosystems and no part of the earth's surface remains untouched by human impact. A significant change in the earth's natural system attributed to human activity is the large scale shift in climate regimes. The present study seeks to understand the change in human – environment relations and climate change in a mountainous tribal region of the Western Himalayas. Comprising the districts of Kangra and Chamba, the study area lies in Himachal Pradesh. Land use and land cover pattern has been taken as an index of the nature of human – environment relations.

2. Conceptual framework

2.1 Human – environment relations

Human impact on the environment occurs through human – environment interaction. The extent and nature of this impact depends on the nature of human – environment relations. The study of human – environment relations is intrinsic to the discipline of Geography. It has been studied from a variety of perspectives over time ranging from "Environmental Determinism" to "Possibilism" to "Human Ecology" to Neo-Determinism and now "Coupled Human and Natural Systems". While the first four perspectives seek to rest agency in either humans or the environment, the last views human – environment relations in the light of a dynamic human – environment system. It conceptualizes the relationship between humans and their natural environment (Pickett et al., 2005; Liu et al., 2007; Werner and McNamara, 2007; An, 2012; Binder et al., 2013; Kahlon et al., 2014; Thakur et al., 2015) as a physical input-output process where materials, energy, information are extracted from the environment, processed within society (Alberti et al., 2011), partly accumulated as socio-economic stocks (e.g., buildings, infrastructure, durable consumer goods, etc.), and, finally, released into the environment, either as waste and emissions, or as deliberate discharges such as fertilizers or pesticides (Ayres and Simonis, 1994; Fischer-Kowalski, 1997; Matthews et al., 2000). One of the most important outputs of the coupled human – natural system is land use and land cover change (Turner et al., 1990; Lambin et al., 1999).

2.2 Land use and land cover change

Although both the terms land use and land cover deal with the impact of human activities and imprint on the landscape, there is a slight though significant difference between the two terms. The term land use denotes the human employment of the land (Turner and Meyer, 1994). The term land cover is defined "as the biophysical state of the earth's surface and immediate subsurface" (Turner et al., 1990). Land use and land cover change, also known as land change, is a general term for the human modification of Earth's terrestrial surface (The Encyclopaedia of Earth, 2013). Land use and land cover changes involve both changes i.e. in areal extent as well as conversion and modification of land at the micro-level (Turner et al., 1995; Skole, 1994). Numerous activities performed by humans in the name of development have left their legacy on the earth's landscape and this may best be studied through the process of land use and land cover change (Kahlon, 2015). Land use and land cover change in that sense is a strong indicator of human – environment relations. Penetration of land use and land cover changes are so pervasive that, when aggregated globally, these significantly affect key aspects of the Earth System's functioning (Geist, 2005; Geist et al., 2006).

2.3 Human – environmental relations, land use land cover change and climate change

Human activities are a major factor contributing to global climatic change, and have override in natural changes to ecosystems brought on by climate variations of the past few thousand years (Houghton et al., 1990, Turner et al., 1990, Ojima et al., 1991 and Mannon, 2014). Human developmental activities, particularly the combustion of fossil fuels, agricultural expansion, transport development, tourism development, forestry and land use and land cover change such as deforestation, urbanization, and shifts in vegetation patterns alter the climate, through changes in the reflectivity of the Earth surface (albedo), emissions from burning forests, urban heat island effects and changes in the natural water cycle (Lambin, 2001). Land use and land cover change is central to climate change as both the processes are linked with each other in a complex way at multiple spatial and temporal scales (Lambin et al., 2003). The changes in Land use and land cover alter the energy fluxes thereby affecting the climate, while climatic variability and change in turn affect the Land use and land cover patterns through the feedback mechanism (Sala et al., 2010). Land use and land cover change also propels climate change through the alteration of biogeophysical, biogeochemical and energy exchange processes within the terrestrial land surface and atmosphere (Hanjie et al., 2006; Dessler and Parson, 2010; Mahmood et al., 2010). They are likely to be further modified by expected changes in climate patterns e.g., seasonal amounts and distribution of rainfall and temperature (Ojima et al., 1994).

2.4 Climate change and mountain systems

Mountain systems are complex ecological entities endowed with vast resources (Chandel et al., 2013), that provide essential ecosystem goods and services (EGS) for both mountain dwellers and people living outside these areas (Huber at al., 2013). The study of human – environment relations in mountain areas is important for both theoretical and practical reasons, because most mountain areas face common problems, namely depopulation, unemployment, natural hazards and lack of infrastructure (Telbisz et al., 2015). Mountains are among the most fragile ecosystems on Earth system and they are highly sensitive to climate change and are being affected at a faster rate than other terrestrial ecosystems (Messerli and Ives, 1997; Beniston and Rebetez, 1996; Diaz and Bradley, 1997; Liu and Chen, 2000; Chettri et al., 2009; Ceppi et al., 2010; Rangwala et al., 2012; Kohler and Maselli, 2012). Several studies have revealed that mountainous systems warm at a faster pace than their low elevation counterparts often with greater increases in daily minimum temperatures than daily maximum temperatures (Beniston and Rebetez, 1996; Diaz and Bradley, 1997; Rangwala et al., 2009; Liu et al., 2009; Qin et al., 2009;

Pederson et al., 2010). A continuous warming trend at high altitudes since the last century (Beniston and Rebetez, 1996; Diaz and Bradley, 1997; Liu and Chen, 2000; Liu et al., 2009; Rangwala and Miller, 2012), has resulted in the modification of the hydrological cycles (Nijssen et al., 2001; Singh and Bengtsson, 2004; Hamlet et al., 2005; Kumar et al., 2007; Xu et al., 2009; Kohler et al., 2010), change in mountain snow and glaciers (Ageta, 1992; Dyurgerov and Meier, 2005; Haeberli et al., 2007; Sorg et al., 2012; Rai et al., 2016), shift in precipitation regime (Beniston and Rebetez, 1996; Beniston, 2003; Mauget, 2003; Theobald et al., 2016), change in biodiversity characteristics such as ecotone, species diversity, habitat characteristics, ecological succession and tree line altitude (Weltzin and McPherson, 2000;

Hampe and Petit, 2005; Thuiller, 2007; Xu et al., 2009; Willis and Bhagwat, 2009; Chen et al., 2011; Booth, 2012; Danelle et al., 2016) as well as the creation of mountain hazards (Beniston, 2005; IPCC, 2007; Keiler et al., 2010; Manandhar et al., 2015). The increasing world population and the development of science and technology have created new possibilities in the form of mineral and hydrological potential and nowadays even tourism (Wackernagel and Rees, 1998; Ibisch et al., 2010) within the mountainous areas. This has led a shift in the human – environment relations in the mountains which has implications both for the health of the areas as well as their inhabitants. It is in this context that the present paper seeks to unravel the changing nature of human – environment interaction and climate change in the Gaddi inhabited region of the Himalayan mountain systems.

3. Study area

The study area essentially covers the districts of Chamba and Kangra in Himachal Pradesh and is situated between 31° 38' 35" and 33° 13' 59" N and 75° 29' 9" and 77° 5' 4" E. It comprises the drainage basin of two rivers: Upper Ravi (Chamba) and Middle Beas (Kangra). The climatic conditions vary with altitude. The lower valley has a semi tropical character. The temperatures are relatively higher and the rainy season is well marked. The winter is mild with sporadic and light snowfall. At the higher altitudes climatic conditions are more severe and vary from the temperate to the semi-arctic. Semi-arctic conditions prevail along the high ranges for several months in winters and the passes are then blocked with snow. Recent road construction under planned development has improved accessibility. This has also resulted in an increased tourist influx bringing with it its own set of opportunities and problems. The region so is essentially rich in resource potential opportuning a change in human – environment relations and at the same time ecologically fragile and vulnerable to a variety of disasters including earthquakes and landslides.

The Gaddis, the main inhabitants of this region who originally inhabited the southern slopes of Pir Panjal and have since diffused to spread over both faces of the Dhauladhar mountain range, constitute one of the important tribes in Himachal Pradesh. A “transhumant agro-pastoral” tribe, the traditional occupation of Gaddis is to rear sheep and goats in the alpine grasslands found in the higher reaches of the Pir Panjal and Dhauladhar. For this purpose, they seasonally migrate from one ecological zone along the valley floors (which they inhabit in the winter) to another ecological zone on the heights of the mountain ranges (during the summer). In recent years however there is an increased tendency of this tribe to move out of their traditional occupation and practice settled agriculture. This tendency is stimulated by the development activity being carried out in this region. This has led to large scale changes in land use and land cover patterns which when viewed in the light of climate change at the global and regional level, may have significant implications for the region as well as its inhabitants.

4. Methodology

For the purpose of the present study the change in human –environment relations were studied through the prism of land use land cover patterns. To achieve this, land use and land cover patterns at two points in time viz. 1975 and 2011 were analysed and compared. Data for this purpose comprised satellite imageries and was procured from LANDSAT. The sensors that collected this data were Multi Spectral Scanner (MSS), and Thematic Mapper (TM). For the image classification hybrid classification technique (involving a merger of two techniques) was used. Unsupervised classification was carried out using K mean classifier method. Simultaneously manual interpretation was also done. Change detection matrix for the study period was generated. The land use and land cover categories identified were based on the classification provided by Anderson (1971) which has also been adopted by NRSC (National Remote Sensing Centre), Hyderabad. The classification was carried out till the second level and land use and land cover categories were thus identified in the study area. At level I seven categories and at level II fourteen categories of land use and land cover were identified.

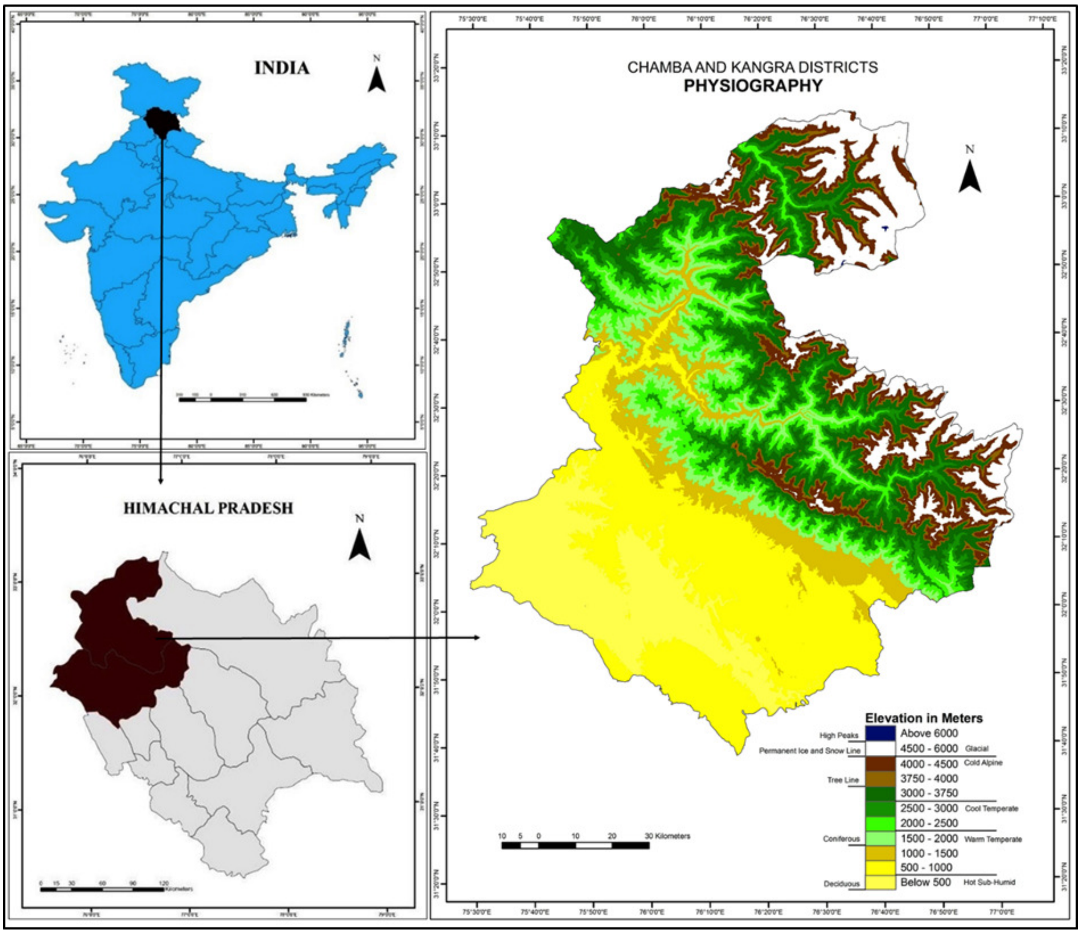

Figure 1: Location of Study Area

Climatic data on a monthly basis for the period from 1901 to 2002 (mean monthly temperature, mean monthly minimum temperature, mean monthly maximum temperature, total monthly rainfall and total number of rainy days) has been sourced from the Indian Meteorological Department. This data has been treated by parametric tests including the technique of linear regression analysis. Trends were studied over time and trend lines including the slope and R^2 value were calculated. This information was supplemented with ground reality and local perceptions. For this purpose, primary data has been collected using interview schedules and focus group discussions to understand the change in agricultural practices and perceptions regarding climate change.

4.1 Traditional Human – Environment Relations and Land Use and Land Cover Pattern in 1975

The land use and land cover pattern of the study area in 1975 provided an apt reflection of the traditional human – environment relationship that existed in the study area. From among the total fourteen land use and land cover categories identified, four categories alone accounted for close to 90 per cent of the total area. These were forests, grasslands, cropland and barren rocky surfaces (Figure 2).

Forests and grasslands formed the major resource base for the population of the region since the population practised transhumant pastoralism. That apart, forests comprise a significant land cover for any region, be it at the local or the global level. These maintain the ecological balance, and are the main, if not the only means of minimizing environmental pollution. Out of the total area of 12,35,400 hectares that comprised the study area, the largest proportion (5,91,580.82 hectares) was found to be under evergreen forest cover (Table 1.1). This accounted for close to half (47.89 %) of the total area. The trees included were: Himalayan Silver Fir, Himalayan Maple, Indian Horse Chestnut, Indian Birch, Bix Wood, Deodar, Nettle Wood, Indian Hazel, Himalayan Cypress, Himalayan Ash, Walnuts, Indian Junipers, Mulberry, Himalayan Spruce, Indian Poplar, Indian Willow, Himalayan Ban Oaks and Yew (Bhasin, 1988; Verma, 1996).

Small, scattered patches of deciduous forest (41,876.24 hectares (3.39 %) were observed on the southern aspect of the Dhauladhar. These included moist and dry types of deciduous vegetation like Bauhinia variegata, Dendrocalamus strictus, Eucalyptus citriodora, Ficus religiosa, Grewia optiva, Mallotus philippensis, Mangifera indica, Pyrus pashia etc. (Government of Punjab, 1897).

The other major land cover category in the study area was ‘Grasslands’. Covering an area of 1,83,325.86 hectares these accounted for more than one-seventh (14.84 %) of the total area. These grasslands which lie above the tree line and are in the nature of permanent pastures included Festuca gigantea (Neeru), Cyperus (Bagarmuth), Sibbaldia (Trodu), Phleum (Jawara), Artemesia (Masreen) and Potentila (Muthi). The grasslands during the summer are the temporary habitat of the transhumant Gaddi tribe whose abode this region is. Grasslands fall en route their path to Pir Panjal from Kangra.

Land available for sedentary agriculture was limited. The cold climate, high elevations and steep slopes do not lend themselves easily to agricultural use. It is no surprise then that only about one-eighth (1,56,115.73 hectares) of the total study area was devoted to agricultural activities in 1975. Cropland comprised 1,56,115.56 hectares while 573.03 hectares were under agricultural plantation. The crops cultivated included maize (Zea mays), rajmah (Phasseolus vulgaris), urd (Phaseolus radiatus) and phullan (millets) wheat (Triticum aestivum) and barley (Hordeum vulgare). These were primarily food crops. The other minor crops grown in the region included chinae (Panicum miliaceum), bhrace (Fagopyrum esculentum), kodra (Paspalum scrobiculatum) and sieul (Amaranthus amaranthoides), peas (Pisum sativum), mustard (Brassica compestris), kulth (Dolichos biflorus) and potato (Solanum tuberosum) (Jaglan and Thakur, 2006; Thakur et al., 2015). Sedentarisation of agriculture was more visible at lower elevations that were more hospitable to human activity as well as commercial agriculture. Agricultural plantations form a significant component of Himachal’s economy and the occupation of its people. However only 573.03 hectares (0.05 %) area has been classified as agriculture plantation in 1975. Most of this area lies in Kangra district. It included tea gardens, apple gardens, orange and mango gardens.

A little more than one-tenth of the land (10.89 %) was classified as rocky barren surface. This land lay at altitudes below the permanent snow line and above the grassland. The soil profile in these patches was still underdeveloped and hence there was no scope of supporting vegetal cover.

Less than one-twentieth of the area comprising 57,094.86 hectares (4.62 %) has been identified as snow fields. These are likely to be permanent snow fields since the image was taken in the first week of October when the summer sun has melted away all the fresh snow and the winter precipitation that comes in the form of snow in the months of December-February (Government of Punjab, 1897) is yet to fall. These snowfields are of immense relevance since they provide irrigation to the crops through snowmelt during the summer months. These snow fields are also of critical importance to the plain areas lying downstream along the Ravi since these feed the Ravi River as well. On the flip side the area remains vulnerable to avalanches owing to this extensive snow cover and the steep gradient of the slopes that they occupy.

Scrub land which accounted for about 33,696.43 hectares (2.73 %) of the total area is another significant land cover category. This is essentially degraded land that has poor quality skeletal soil and supports scrub like vegetation especially shrubs like Garol, Kehmel, Pappes, Shagal, Prih, Jammu, Kone, Akhron, Karrer, Bakul, Kirrer, Bakhrey, Sarnger, Sune, Adhatoda vasica, Agave americana, Duranta repens, Lantana camara, Murraya koenigii and Urtica dioica etc. (Bhasin, 1988; Verma, 1996).

There were hardly any settlements. The population numbers were limited and resource use was low. Settlements accounted for less than 0.2 per cent of the total area with rural settlements spread over 0.12 per cent and urban settlements spread over 0.07 per cent (Table 1.2).

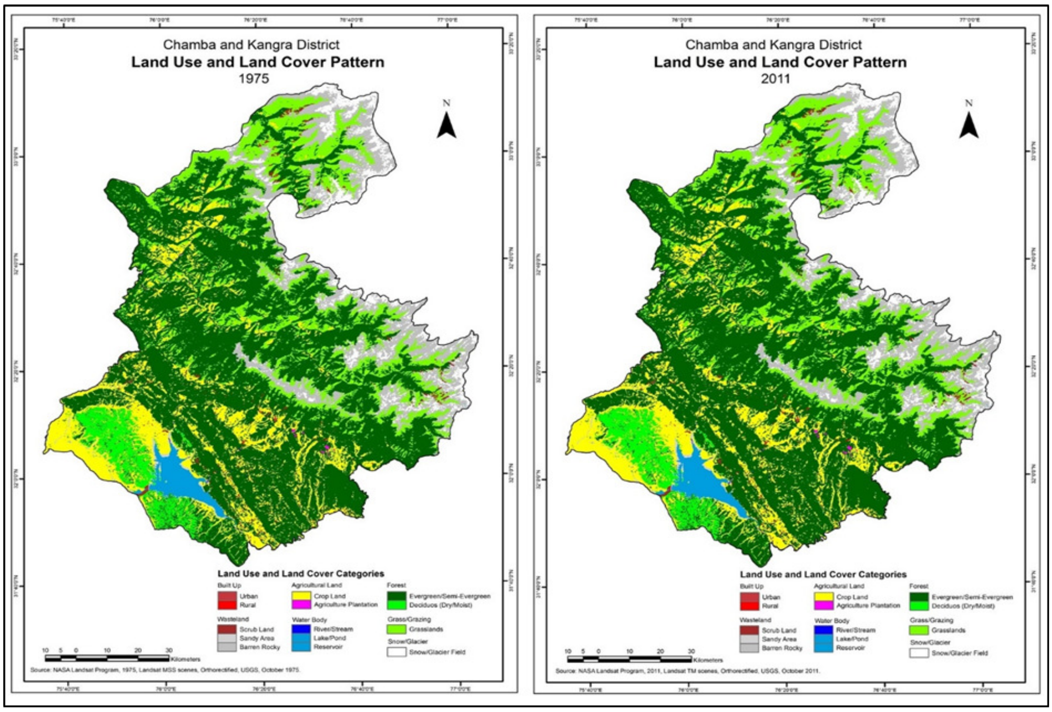

Figure 2: Land use land cover pattern 1975 and 2011

The human – environment relationship within the study area was harmonised through a symbiotic relationship between the natural environment and human activity. While the grasslands provided fodder for the livestock, the livestock helped manure the fields (Axelby, 2007). The forests provided timber for the limited construction and fuel wood requirements, and other naturally occurring resources such as plants with medicinal value, gum and resin. Both grasslands and forests were therefore maintained and sustained by the local population.

Such was the situation that existed prior to active domination of the landscape by human agency. Human agency initially began to dominate the landscape through the infusion of externally sourced technology and development programmes that sought to integrate such peripheral marginalised areas, as the study area, into the 'mainstream modernization' project. The study area and its inhabitants became the targeted recipients of a number of upliftment programs (Thakur et al., 2015). In the whole scheme of things, a not small consideration was the availability of immense forest and hydrological wealth in this area. The nature of human – environment relations began to change as did the land use and land cover patterns with in the study area.

4.3 Land Use and Land Cover Change, 1975-2011

Over a period of three and a half decades almost one-fifth of the total area of the study region has been transformed. The land use classes that have gained in a major way included cropland which has increased its area by 41 per cent; settlements which have increased their area by 127 per cent (Rural – 190 %; Urban – 135 %); agricultural plantation which increased by more than 300 per cent; (301.88%) scrub land which increased by 227 per cent and barren rocky surface which increased by 17.57 per cent (Table 1.1). The land cover categories that have lost area included forests, alpine grasslands and some minor categories like river and sandy area (Table 1.2). Forests have been the major loser in terms of area covered. In 1975 more than half the total area comprised forests both evergreen (47.89 %) and deciduous (3.39 %). Their combined share in 2011 stood at less than 40 % (39.5 %) with the share of evergreen forest reduced to 36.53 % and that of deciduous forest to 2.97 per cent of the total study area.

Table 1: Land Use and Land Cover Change 1975 – 2011

Categories	Area in Hectares		Percentage Change
	1975	2011	
Urban	821.43	1931.4	135.13
Rural	1489.23	4313.16	189.62
Cropland	156115.6	220135.9	41.01
Agriculture Plantation	573.03	2302.92	301.88
Evergreen/Semi	591580.8	451309.6	-23.71
Deciduous (Dry/moist)	41876.24	36663.05	-12.45
Alpine Grassland	183325.9	149747.4	-18.32
Scrub land	33696.43	110352.8	227.49
Sandy	6333.57	2726.55	-56.95
Barren Rocky	134522.8	158159.5	17.57
River	7078.77	6742.8	-4.75
Lake/ponds	52.92	52.92	0.00
Reservoir	20837.74	25608.06	22.89
Snow	57094.86	65353.61	14.46

Source: Generated through analysis

The area under forests has reduced by close to twenty-five per cent (24.59 %). In other words, one-fourth of the area under forests in 1975 has been transformed into other land use categories. The actual amount of deforestation actually may be higher because forests have in some areas expanded onto the area that was earlier under alpine grasslands.

Table 2: Land use and land cover change 1975 – 2011

Urban	Rural	Cropland	Agricultural Plantati	Evergreen/ Semi	Deciduous (Dry/	Grassland	Scrub land	Sandy	Barren Rocky	River	Lake/ ponds	Reservoir	Snow	Year Total 1975
821.43 (0.07)	0	0	0	0	0	0	0	0	0	0	0	0	0	**821.43 (0.07)**
0	**1489.23 (0.11)**	0	0	0	0	0	0	0	0	0	0	0	0	**1489.23 (0.12)**
52.11 (0.004)	271.8 (0.02)	**155693 (12.60)**	0	0.09 (0.0000	3.51 (0.000	94.59 (0.01)	0.18 (0.0001	0	0.45 (0.0004)	0	0	0	0	**156115.73 (12.64)**
0	0	0	**572.94 (0.05)**	0	0	0	0.09 (0.0001	0	0	0	0	0	0	**573.03 (0.05)**
937.44 (0.08)	1804.23 (0.14)	54795.4 (4.44)	675.99 (0.05)	**443196 (35.87)**	0	29002.5 (2.35)	56196.5 (4.55)	0	2690.91 (0.22)	0	0	686.97 (0.06)	1594.89 (0.13)	**591580.83 (47.89)**
0	317.61 (0.03)	1521.45 (0.12)	738.36 (0.06)	0	**36659 (2.97)**	0	2552.67 (0.21)	0	59.85 (0.005)	0	0	27.27 (0.002)	0	**41876.21 (3.39)**
115.11 (0.01)	296.91 (0.02)	7612.83 (0.62)	245.43 (0.02)	6460.38 (0.52)	0	**117593 (9.52)**	17762 (1.44)	0	31890.6 (2.58)	0	0	396.54 (0.03)	953.55 (0.08)	**183326.35 (14.84)**
5.31 (0.0004	133.2 (0.01)	0.99 (0.0001)	70.2 (0.01)	23.4 (0.002)	0	120.33 (0.01)	**33100.8 (2.68)**	0	214.47 (0.02)	0	0	27.72 (0.002)	0	**33696.42 (2.73)**
0	0	257.67 (0.02)	0	0	0	3.78 (0.0003	162 (0.01)	**2725.83 (0.22)**	105.12 (0.01)	0	0	3079.17 (0.25)	0	**6333.57 (0.51)**
0	0.18 (0.0001	246.78 (0.02)	0	1623.06 (0.13)	0	2933.01 (0.24)	571.23 (0.05)	0	**123190 (9.97)**	0	0	248.04 (0.02)	5710.23 (0.46)	**134522.53 (10.89)**
0	0	8.01 (0.001)	0	6.21 (0.001)	0.54 (0.000	0	7.47 (0.001)	0.72 (0.0001)	8.28 (0.001)	**6742.8**	0	304.65	0.09 (0.0001	**7078.77 (0.57)**
0	0	0	0	0	0	0	0	0	0	0	**52.92 (0.004)**	0	0	**52.92 (0.004)**
0	0	0	0	0	0	0	0	0	0	0	0	**20837.7 (1.69)**	0	**20837.7 (1.69)**
0	0	0	0	0	0	0	0	0	0	0	0	0	**57094.8 (4.62)**	**57094.8 (4.62)**
1931.4 (0.16)	**4313.16 (0.32)**	**220136.13 (17.82)**	**2302.92 (0.19)**	**451309.14 (36.53)**	**36663.05 (2.97)**	**149747.21 (12.12)**	**110352.94 (8.93)**	**2726.55 (0.22)**	**158159.68 (12.80)**	**6742.8 (0.55)**	**52.92 (0.004)**	**25608.06 (2.07)**	**65353.56 (5.29)**	**1235400 (100)**

Source: Generated through analysis

Categories	Urban	Rural	Cropland	Agriculture Plantation	Evergreen/Semi	Deciduous (Dry/moist)	Grassland	Scrub land	Sandy	Barren Rocky	River	Lake/ponds	Reservoir	Snow	Year Total 2011	

Forests have primarily transferred their share of the land to scrub land, cropland, grassland and settlements. The largest share has been usurped by scrub land. Clearly deforestation is at play and forests have been cut down; whether to make way for agriculture and settlements or to satisfy the consumptive greed of human beings is immaterial. Alpine grasslands have lost almost one-fifth (18.32 %) of their original share of the total area. Grasslands have been transformed in four ways. They have deteriorated into rocky barren surfaces, become covered by scrub land, transferred land to forests or these have been encroached upon by humans for purposes of agriculture and settlements. The transformation of grasslands into forest land, scrub land and crop land, on the one hand indicates an altitudinal shift of the tree line due to possible warming of the climate and on the other hand a shift in the human – environment relations with the local community shifting from agro-pastoralism to sedentary and even commercial agriculture. Agriculture has now become the mainstay of the economy of the study area, with close to one-fifth of the area under agricultural use.

4.4 Climate change

The present section analyses temperature and precipitation trends for the past more than hundred years. The aim is to understand the extent of and implications of climate change in the context of the changing human – environment relations. This has been done through an analysis of the trends of mean monthly temperature, mean monthly maximum temperature and mean monthly minimum temperatures for the districts of Chamba and Kangra. Further this has been linked with precipitation trends in terms of total precipitation received on a monthly basis and in terms of total number of rainy days in a month. Monthly trends for a period of more than hundred years starting from 1901 have been plotted. Trend lines have been marked/drawn and the R^2 value indicating the rate and direction of change over the years has also been calculated.

4.5 Temperature

The R^2 value for the trend line depicting the change in mean monthly temperatures for the district of Chamba and Kangra (Table 1.3) indicates a fall in temperature during the summer months of June, July, August and September. On the other hand, the winter months from November to January show a rise in mean monthly temperature. This is true for both Chamba and Kangra. The association of change with time is strongest for the months of February, March, November and December and in all four months there is a trend towards warming.

Table 3: Mean Monthly Temperature: 1901-2002

	Chamba			Kangra		
Months	Equation	Slope	R^2	Equation	Slope	R^2
Jan	y = 0.0066x + 7.8257	0.0066x	0.0251	y = 0.0053x + 10.78	0.0053x	0.0189
Feb	y = 0.0157x + 9.5933	0.0157x	0.1025	y = 0.0145x + 12.78	0.0145x	0.0921
Mar	y = 0.0129x + 14.595	0.0129x	0.0735	y = 0.0053x + 10.78	0.0053x	0.0189
Apr	y = 0.013x + 20.37	0.013x	0.0739	y = 0.0135x + 23.761	0.0135x	0.0717
May	y = 0.0063x + 25.074	0.0063x	0.0189	y = 0.0118x + 17.807	0.0118x	0.0627
Jun	y = -0.0033x + 28.35	-0.0033x	0.0132	y = -0.0042x + 31.86	-0.0042x	0.0191
Jul	y = -0.0041x + 27.462	-0.0041x	0.0448	y = -0.0055x + 30.2	-0.0055x	0.073
Aug	y = -0.0044x + 26.587	-0.0044x	0.0592	y = -0.0053x + 29.151	-0.0053x	0.0789
Sep	y = -0.00x + 24.70	-0.00x	0	y = -0.0028x + 27.74	-0.0028x	0.016
Oct	y = 0.0006x + 20.606	0.0006x	0.0005	y = -0.0015x + 23.72	-0.0015x	0.003
Nov	y = 0.0079x + 14.126	0.0079x	0.0758	y = 0.0082x + 16.865	0.0082x	0.0834
Dec	y = 0.0086x + 9.4618	0.0086x	0.0726	y = 0.0084x + 12.121	0.0084x	0.0697
Annual	y = 0.005x + 19.063	0.005x	0.1098	y = 0.0041x + 22.131	0.0041x	0.0761

Sources: Calculated using data from Indian Meteorological Department

This points towards two perceptible changes in the temperature regime. The first is a move towards a narrowing down of the annual range of temperature with the summer months becoming cooler and the winter months becoming warmer. The second is a shortening of the winter season with temperatures rising both during the onset months of the winter (November) and the withdrawal of winter (March). An analysis of mean monthly minimum temperature and mean monthly maximum temperature trends (Table 1.4 and 1.5) also exhibits, similar results. The warming of the climate regime is likely to have an impact on the precipitation trends as well.

Table 4: Mean Monthly Maximum Temperature: 1901-2002

	Chamba			**Kangra**		
Months	**Equation**	**Slope**	**R^2**	**Equation**	**Slope**	**R^2**
Jan	y = 0.0052x + 13.788	0.0052x	0.0163	y = 0.0041x + 17.31	0.0041x	0.0115
Feb	y = 0.0159x + 15.557	0.0159x	0.0885	y = 0.0147x + 19.272	0.0147x	0.081
Mar	y = 0.012x + 20.942	0.012x	0.0581	y = 0.011x + 24.606	0.011x	0.0501
Apr	y = 0.012x + 27.396	0.012x	0.0599	y = 0.0126x + 31.298	0.0126x	0.0602
May	y = 0.0051x + 32.406	0.0051x	0.0111	y = 0.0057x + 36.548	0.0057x	0.0124
Jun	y = -0.0049x + 34.955	- 0.0049x	0.0244	y = -0.0056x + 38.613	- 0.0056x	0.0301
Jul	y = -0.0055x + 32.39	- 0.0055x	0.0714	y = -0.0067x + 34.964	- 0.0067x	0.1004
Aug	y = -0.0058x + 31.12	- 0.0058x	0.0776	y = -0.0063x + 33.468	- 0.0063x	0.0933
Sep	y = -0.0008x + 30.301	- 0.0008x	0.0011	y = -0.0033x + 33.189	- 0.0033x	0.0182
Oct	y = -0.0007x +	-	0.0006	y = -0.0026x +	-	0.0082

	27.773	0.0007x		31.102	0.0026x	
Nov	y = 0.0074x + 21.482	0.0074x	0.0621	y = 0.0079x + 24.676	0.0079x	0.074
Dec	y = 0.0077x + 15.863	0.0077x	0.0534	y = 0.0076x + 19.066	0.0076x	0.0531
Annual	**y = 0.004x + 25.331**	**0.004x**	**0.063**	**y = 0.0032x + 28.676**	**0.0032x**	**0.0432**

Source: Indian Meteorological Department

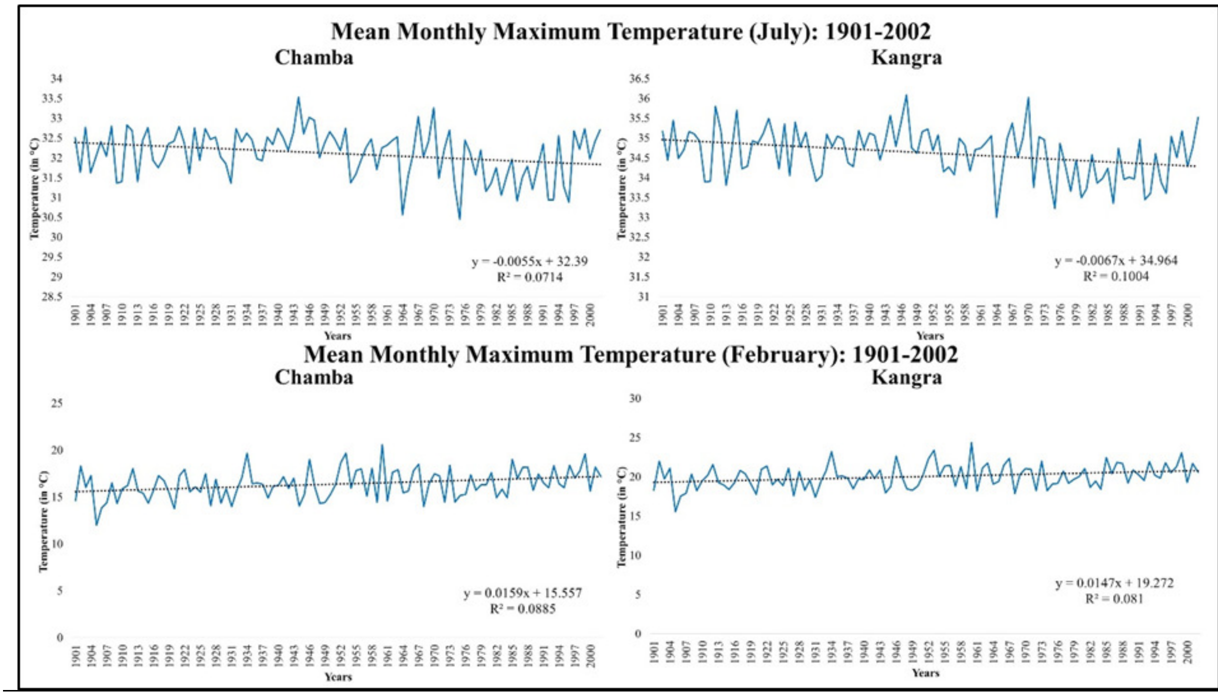

Figure 3: Temperature comparison

Sources: Calculated using data from Indian Meteorological Department

Table 5: Mean Monthly Minimum Temperature: 1901-2002

	Chamba			Kangra		
Months	Equation	Slope	R²	Equation	Slope	R²
Jan	y = 0.008x + 1.8795	0.008x	0.0313	y = 0.0064x + 4.2876	0.0064x	0.0236
Feb	y = 0.0155x + 3.6574	0.0155x	0.1079	y = 0.0142x + 6.3308	0.0142x	0.0944
Mar	y = 0.0139x + 8.2744	0.0139x	0.0861	y = 0.0127x + 11.053	0.0127x	0.0728
Apr	y = 0.014x + 13.381	0.014x	0.0853	y = 0.0141x + 16.271	0.0141x	0.0796
May	y = 0.0075x + 17.77	0.0075x	0.0282	y = 0.0076x + 21.055	0.0076x	0.0266
Jun	y = -0.0016x + 21.762	-0.0016x	0.0033	y = -0.0028x + 25.14	- 0.0028x	0.0089
Jul	y = -0.0027x + 22.557	-0.0027x	0.0159	y = -0.0044x + 25.471	- 0.0044x	0.0392

Aug	y = -0.003x + 22.071	-0.003x	0.0263	y = -0.0042x + 24.86	-0.0042x	0.0469
Sep	y = 0.0007x + 19.132	0.0007x	0.001	y = 0.002x + 22.302	0.002x	0.0079
Oct	y = 0.0019x + 13.477	0.0019x	0.0041	y = -0.0005x + 16.379	-0.0005x	0.0004
Nov	y = 0.0083x + 6.8049	0.0083x	0.0658	y = 0.0084x + 9.0811	0.0084x	0.0705
Dec	y = 0.0096x + 3.0791	0.0096x	0.076	y = 0.0093x + 5.1933	0.0093x	0.073
Annual	y = 0.006x + 12.82	y = 0.006x	0.1528	y = 0.0049x + 15.619	0.0049x	0.1066

Source: Indian Meteorological Department

4.6 Precipitation

The precipitation regime in the region has also undergone a change in the past hundred years. Precipitation trends were analysed in terms of total monthly rainfall and total number of rainy days. The trend of the total monthly rainfall received, the slope and R^2 value which depicts the direction and amount of change relative to time have been calculated (Table 1.6). It emerged that the total annual precipitation for both Chamba and Kangra has increased.

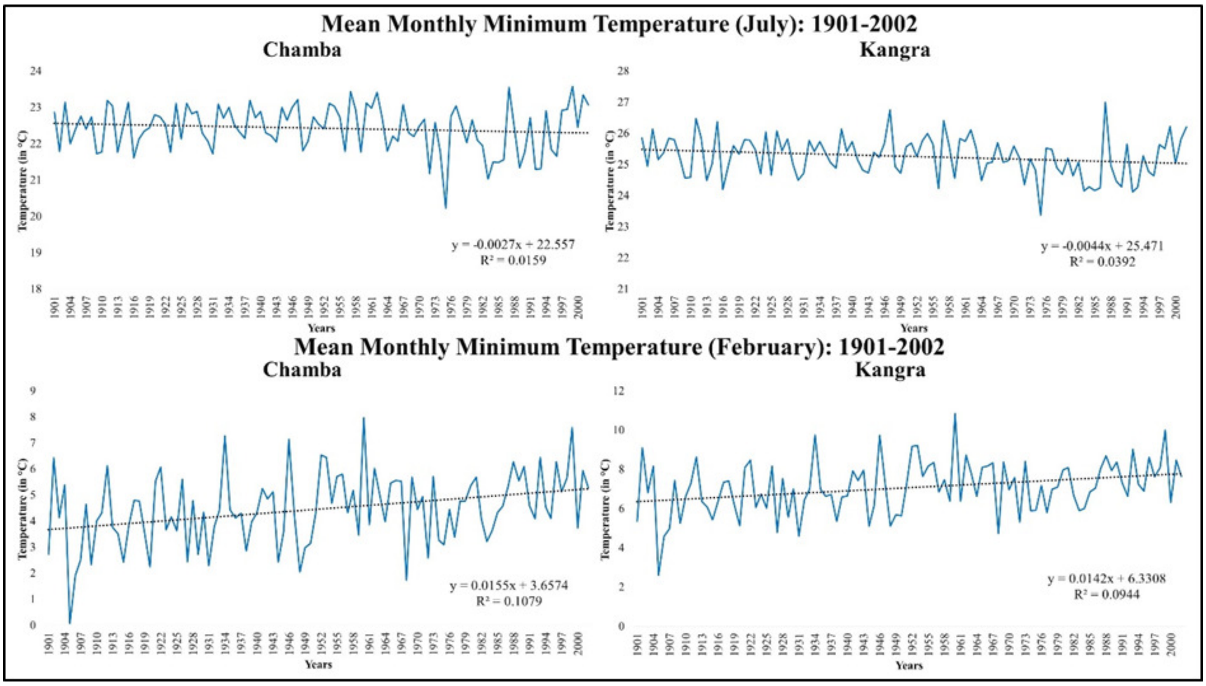

Figure 4: Temperature comparison

Sources: Calculated using data from Indian Meteorological Department

Simultaneously there is an increase in the total number of rainy days as well (Table 1.7). The increase and the rate of change however is not uniform over the different months of the year. The seasonal picture shows a decrease in the total number of rainy days in December and January and an increase in the total number of rainy days in almost all other months. The rate of increase is maximum for the month of February and March.

Table 6: Total Monthly Rainfall: 1901-2002

	Chamba			Kangra		
Months	Equation	Slope	R^2	Equation	Slope	R^2
Jan	y = 0.0108x + 38.813	0.0108x	0.0001	y = -0.0133x + 34.019	-0.0133x	0.0003
Feb	y = 0.1716x + 29.916	0.1716x	0.0369	y = 0.1275x + 25.928	0.1275x	0.0251
Mar	y = 0.2423x + 25.007	0.2423x	0.0756	y = 0.1694x + 21.393	0.1694x	0.052
Apr	y = 0.0777x + 23.934	0.0777x	0.0151	y = 0.0423x + 18.402	0.0423x	0.0072
May	y = 0.1012x + 22.918	0.1012x	0.0274	y = 0.1003x + 16.883	0.1003x	0.0401
Jun	y = 0.1071x + 77.156	0.1071x	0.0035	y = 0.1045x + 73.328	0.1045x	0.0033
Jul	y = 0.16x + 210.56	0.16x	0	y = 0.2418x + 209.38	0.2418x	0.0042
Aug	y = 0.1184x + 206.55	0.1184x	0.0011	y = 0.1877x + 203.81	0.1877x	0.0033
Sep	y = -0.0846x + 134.75	-0.0846x	0.0007	y = -0.0402x + 134.23	-0.0402x	0.0002
Oct	y = 0.0465x + 9.7988	0.0465x	0.0147	y = 0.0389x + 7.9027	0.0389x	0.015
Nov	y = 0.0374x + 6.0108	0.0374x	0.0102	y = 0.0255x + 5.3533	0.0255x	0.0062
Dec	y = -0.0287x + 19.775	-0.0287x	0.0025	y = -0.0493x + 17.853	-0.0493x	0.0088
Annual	y = 0.9586x + 805.19	0.9586x	0.0166	y = 0.9353x + 768.48	0.9353x	0.0173

Source: Indian Meteorological Department

The total monthly rainfall shows a rising trend for the months of February, March, May, October and November. On the other hand, there is a visible decrease in the precipitation received in the month of August, September and December. The amount of rainfall received during the remaining months of the year remains almost static. The rainfall requirement of the region has a quantitative as well as a distributional aspect. The agriculture regime of the region requires more rainfall in the months of August and early September as well as snowfall in the months of December and January. Such a distributional pattern of rainfall ensures a healthy yield of the monsoon crop and ample chilling hours for the winter crop.

However, the shift in distributional pattern of the precipitation does not augur well for the agricultural health of the region. While the decrease in rainfall in the months of August and September alludes to a reduction of the moisture available to the monsoon crops, the decrease in rainfall in the months of December and January and increase in rainfall in March means more precipitation in the form of rain rather than snow. This reduces the number of chilling hours available to the winter crop reducing its yield.

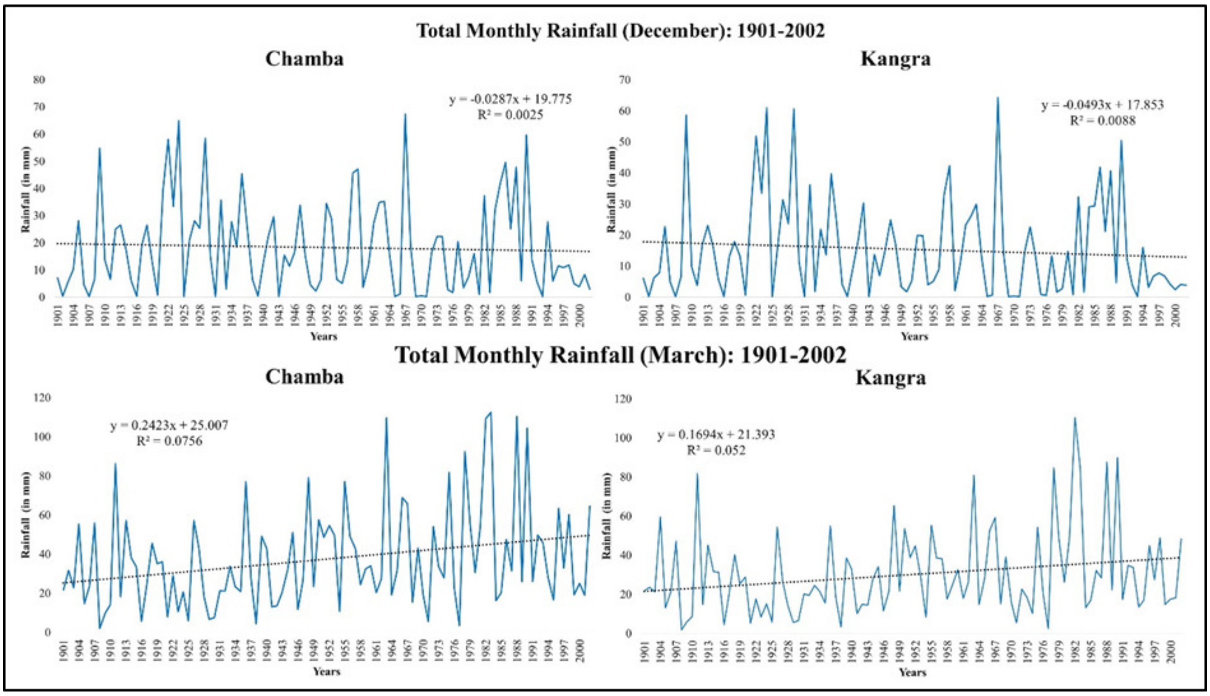

Figure 5: Rain fall comparison

Sources: Calculated using data from Indian meteorological department

4.7 Implications

The change in land use and land cover patterns and the shift in climate regime within the study area has complex implications for both the region and its inhabitants. The most immediate and visible impact of this shift is likely to occur through the medium of the agriculture system of the region. Agriculture in any region is a prominent land use as well as a major economic, social and cultural activity resulting from human – environment interaction that provides a wide range of ecosystem services (Howden et al., 2007). Agriculture in mountain regions is so closely linked to climatic parameters that the agricultural system has been widely used to delineate climate influences (Adhikary et al., 1996). The impacts of climate change and its variability on agricultural production is a significant research concern worldwide (Fischer et al., 2005). Climate change impacts the types, frequencies, and intensities of various crop and livestock pests; the availability and timing of irrigation water supplies; and the severity of soil erosion (Adams et al., 1998).

The study area was known for two types of agricultural practices: pastoralism in combination with subsistence agriculture at the higher elevations and commercial agriculture including plantation in the warmer lower valleys that were closer to the plains (Census of India, 1961). Whereas on the one hand land use and land cover change has resulted in an expansion of the area under agriculture, particularly at the higher elevations in the district of Chamba, on the other hand the natural land cover including forests and grassland has diminished. Simultaneously there has been a shift in the climate regime with the temperatures rising and the seasonal distribution of precipitation showing a shift.

Even though a linear causal relationship has not been established between the two trends in the region, the two cannot be said to be totally unrelated to each other either. Whatever be the dynamics or the causative mechanism of these shifts, the fact remains that agriculture and more particularly commercial agriculture has acquired primacy in the economic system of the region, with a close to 25 per cent growth in the area under agriculture and a shift towards commercial agriculture and even horticulture. This fact when seen in the light of the visible trend of climate change points to an increased vulnerability of the agricultural system. Climate warming is known to effect the horticulture system (Crops such as apples, cherries and pears that require long chill hours) of the mountainous regions (Luedeling, 2009). Temperate fruit and nut species require exposure to chilling conditions in winter to break dormancy and produce high yields (Campoy et al., 2011; Luedeling, 2013), which may not be possible due to a decrease in the amount of precipitation received in the form of snow in the study area. The above facts were supported by data collected from the field with regard to local perceptions.

Table 7: Total Number of Rainy Days: 1901-2002

	Chamba Rainy Days			Kangra Rainy Days		
Months	Equation	Slope	R^2	Equation	Slope	R^2
Jan	y = -0.0021x + 4.1729	-0.0021x	0.0013	y = -0.0031x + 3.2188	-0.0031x	0.0049
Feb	y = 0.0098x + 3.3856	0.0098x	0.0329	y = 0.0075x + 2.6277	0.0075x	0.0311
Mar	y = 0.0152x + 3.2697	0.0152x	0.0793	y = 0.0111x + 2.5136	0.0111x	0.0722
Apr	y = 0.0006x + 3.7191	0.0006x	0.0001	y = 0.0011x + 2.4763	0.0011x	0.0009
May	y = 0.0038x + 3.4359	0.0038x	0.0067	y = 0.0038x + 2.4669	0.0038x	0.0118
Jun	y = 0.0026x + 5.2065	0.0026x	0.0019	y = 0.002x + 4.1017	0.002x	0.0017
Jul	y = 0.01x + 9.7816	0.01x	0.0136	y = 0.0097x + 8.4726	0.0097x	0.0182
Aug	y = 0.0013x + 11.127	0.0013x	0.0002	y = 0.0045x + 9.1147	0.0045x	0.004
Sep	y = -0.0027x + 5.4425	-0.0027x	0.0014	y = -0.0008x + 4.3482	-0.0008x	0.0002
Oct	y = 0.002x + 1.5353	0.002x	0.0046	y = 0.0009x + 1.212	0.0009x	0.0017
Nov	y = 0.0031x + 1.129	0.0031x	0.0059	y = 0.0014x + 0.984	0.0014x	0.0018
Dec	y = -0.0017x + 2.2235	-0.0017x	0.0015	y = -0.0015x + 1.6763	-0.0015x	0.002
Annual	y = 0.0418x + 54.428	0.0418x	0.0351	y = 0.0366x + 43.213	0.0366x	0.044

Source: Indian Meteorological Department

The most significant change perceived by the local population in the study area was to do with an improvement in the infrastructure available. Access to electricity, drinking water, education and the transportation had increased. This had made life considerably easier for most of the natives. This had also led to a diversification of the occupational structure with more and more people giving up pastoralism and shifting to either settled agriculture or other occupations made available through government programs like 'MGNREGA'. The agricultural practices were also reported to have changed with more land being brought under the plough and food crops giving way to cash crops. The traditional cash crops like pulses were being replaced by hybrid varieties that needed less irrigation but more fertilizer.

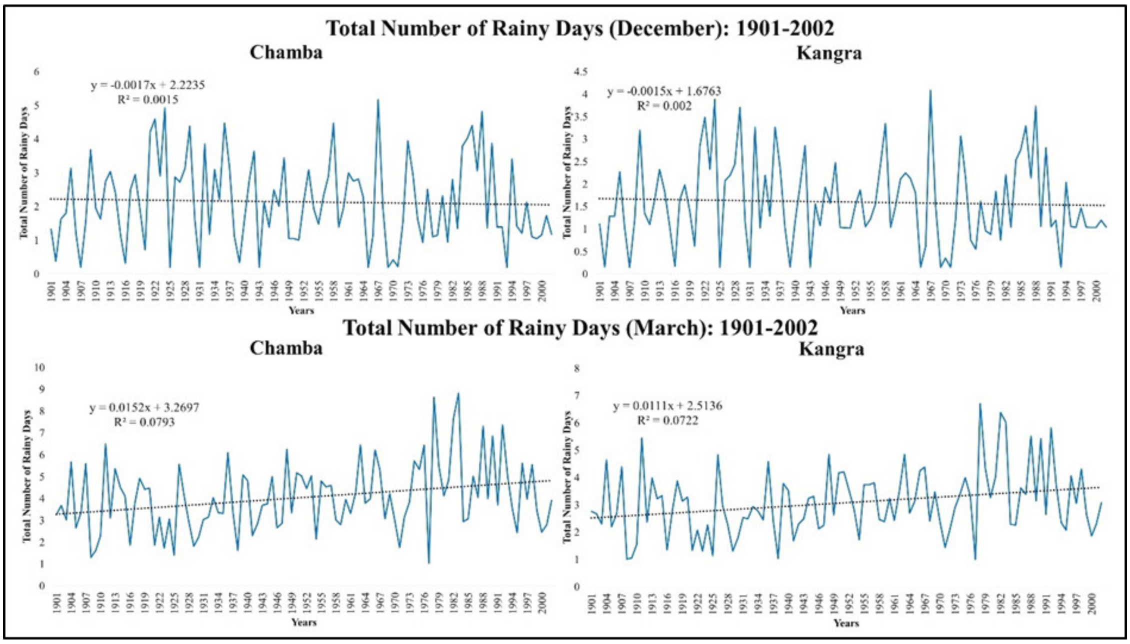

Figure 6: Rainy days

Sources: Calculated using data from Indian Meteorological Department

The earlier strong link with forest and pastures was beginning to weaken. The locals' reported less visits to the forests to collect fuel wood and medicinal plants/herbs. The reason they gave for this was that the thicker forests had now shifted up alitudinally and less fuel wood was available at lower more accessible heights. This could be because of clearing of the forests for purposes of agriculture or timber. The latter was more visible in Kangra while the former was more typical of Chamba. The grasslands too no longer supported the nutritious grasses of before. The local population blamed this on the change in the climatic regime. They reported that precipitation had become highly variable both in terms of quantity as well as temporal distribution. The winter precipitation in particular they felt had decreased and tended to arrive late. They also reported an overall warming of the climate. Both winters as well as summers they claimed had become warmer. The amount of snowfall in particular had significantly decreased.

Despite the fact that the local population could not establish a direct link between climate change and a shift in the human environment relations, it is fairly obvious from their responses that the human-environment relationship has become more exploitative with humans changing both the nature of land cover and seeking to draw out much more from the environment than before. This was being done through the addition of technology which increased the input costs. This when related to the unpalatable shift in temperature and precipitation trends pointed towards the development of an unsustainable ecosystem.

5. Conclusion

The present paper sought to study trends in climate change on the one hand and a shift in human – environment relation on the other in the Gaddi inhabited district of Chamba and Kangra. Human – environment relationship was gauged from the change in land use and land cover patterns over more than three decades. While there is an ample evidence available in literature relating the shift in climatic regimes to a change in human – environment relations, the present study does not claim to establish a direct relationship between the two. However, there is sufficient evidence to point towards the development of a more exploitative relationship between humans and the environment. On the one hand forests and pasture lands have been reduced and on the other hand the area under agriculture and settlements has increased. The nature of agriculture practiced has shifted from subsistence to commercial. At the same time there is distinct evidence of the warming of the climate, a narrowing down of the annual range of temperature and a shift in the temporal distribution of the rainfall. When considered in consonance with the shift in agricultural practices this does not augur well for the sustainability of agriculture in the region. This along with the increased stress on the environment is likely to have severe implications for the coupled human and natural system in the study area.

6. References

1. Adams, R.M., Hurd, B.H., Lenhart, S. and Leary, N. (1998), Effects of global climate change on agriculture: an interpretative review, *Climate Research*, 11(1), pp 19-30.

2. Adhikary S., Andressen, R., Guisan, A., Holten, J.I., Innes, J., Maitima, J., Price, M.F. and Tessier, L. (1996), *Impacts of climate change on mountain regions*. Second assessment report of the Intergovernmental Panel on Climate Change (IPCC), pp 191-213.

3. Ageta Y. and Kadota T. (1992), Predictions of changes of glacier mass balance in the Nepal Himalaya and Tibetan Plateau: a case study of air temperature increase for three glaciers, *Annals of Glaciology*, 16, pp 89-94.

4. Alberti, M., et al., 2011. Research on Coupled Human and Natural Systems (CHANS): Approach, Challenges, and Strategies, *Bulletin of the Ecological Society of America*, 92: 218–228.

5. An, L. (2012), Modelling human decisions in coupled human and natural systems: review of agent-based models. *Ecological Modelling*, 229, pp 25-36.

6. An, L., and López-Carr, D. (2012), Understanding human decisions in coupled natural and human systems, *Ecological Modelling*, 229, pp 1-4.

7. Anderson, J.R. (1971), Land-use classification schemes, *Photogrammetric Engineering,* 37, pp 379–387.

8. Axelby, R. (2007), ‘It Takes Two Hands to Clap’: How Gaddi Shepherds in the Indian Himalayas Negotiate Access to Grazing, *Journal of Agrarian Change,* 7(1), pp 35-75.

9. Ayres, R.U. and Simonis, U.E. (1994), *Industrial Metabolism, Restructuring for Sustainable Development*, United Nations University Press, Tokyo, New York, Paris.

10. Beniston, M. (2003), Climatic change in mountain regions: a review of possible impacts, *Climate Change*, 59, pp 5–31.

11. Beniston, M. (2005), The risks associated with climatic change in mountain regions. In *Global change and mountain regions: an overview of current knowledge*, eds., Huber, U., Bugmann, H. and Reasoner, M., Springer, Dordrecht, pp 511-520.

12. Beniston, M. and Rebetez, M. (1996), Regional behaviour of minimum temperatures in Switzerland for the period 1979–1993, *Theoretical and applied climatology,* 53, pp 231–243.

13. Bhasin, V. (1988), *Himalayan Ecology, Transhumance and Social Organisation*. Kamla-Raj Enterprises, Delhi.

14. Binder, C.R., Hinkel, J., Bots, P.W., and Pahl-Wostl, C. (2013), Comparison of frameworks for analysing social-ecological systems, *Ecology and Society*, 18(4), pp 26.

15. Booth, T.H. (2012), Biodiversity and climate change adaptation in Australia: strategy and research developments, *Advances in Climate Change Research*, 3(1), pp 12-21.

16. Campoy, J.A., Ruiz, D., and Egea, J. (2011), Dormancy in temperate fruit trees in a global warming context: a review, *Scientia Horticulturae*, 130(2), pp 357-372.

17. Census of India. (1961), A Village Survey of Brahmaur District Chamba: Hiamachal Pradesh, 20(5), part 6.

18. Ceppi, P., Scherrer, S., Fischer, A., and Appenzeller, C. (2010) Revisiting Swiss temperature trends 1959–2008, *International Journal of Climatology*, 32(2), pp 203-213.

19. Chandel Vishwa, B.S., Kaur, K.K., and Simrit, S. (2013), Land use/cover change and its implications for Kullu district of Himachal Pradesh, India, *International journal of geomatics and geosciences*, 3(3), pp 538-551.

20. Chen, I.C., Hill, J.K., Ohlemüller, R., Roy, D.B. and Thomas, C.D. (2011), Rapid range shifts of species associated with high levels of climate warming, *Science*, 333, pp 1024–1026.

21. Chettri, N., Eriksson, M., Jing, F., Mool, P.K., Sharma, E., Shrestha, A.B., and Tsering, K. (2009), Climate Change Impacts and Vulnerability in the Eastern Himalayas.

22. Crutzen, P.J. (2006), *The "Anthropocene"*. Springer Berlin Heidelberg.

23. Danelle M.L., Hurteau, M.D, Koch, G.W., North, M.P., and Hungate, B. A. (2016), Climate-driven changes in forest succession and the influence of management on forest carbon dynamics in the Puget Lowlands of Washington State, USA, *Forest Ecology and Management,* 362, pp 194–204.

24. Dessler, A., and Parson, E.A. (2010), *The Science and Politics of Global Climate Change: A Guide to the Debate*. Cambridge University Press, Cambridge.

25. Diaz, H.F., and Bradley, R.S. (1997), Temperature variations during the last century at high elevation sites. *Climate Change*, 36, pp 253–279.

26. Dyurgerov, M.B., and Meier, M.F. (2005), *Glaciers and the changing earth system: a 2004 snapshot (Vol. 58).* Boulder: Institute of Arctic and Alpine Research, University of Colorado.

27. Fischer, G., Shah, M., Tubiello, F.N., and Van Velhuizen, H. (2005), Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080, *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 360(1463), pp 2067-2083.

28. Fischer-Kowalski, M. (1997), Society's metabolism, on the childhood and adolescence of a rising conceptual star. In *The International Handbook of Environmental Sociology*, eds., Redclift, M. and Woodgate, G., Northampton, Edward Elgar, Cheltenham, pp 119–137.

29. Geist, H. (2005), *Our earth's changing land: an encyclopaedia of land-use and land-cover change*. Greenwood Publishing Group.

30. Geist, H., McConnell, W., Lambin, E.F., Moran, E., Alves, D., and Rudel, T. (2006), Causes and trajectories of land-use/cover change. In *Land-use and land-cover change*. Springer Berlin Heidelberg, pp 41-70.

31. Glaser, M., Krause, G., Ratter, B. M., and Welp, M. (Eds.). (2012), *Human-nature interactions in the Anthropocene: Potentials of social-ecological systems analysis*. Routledge.

32. Government of Punjab. (1897), *Gazetteer of the Kangra District: Parts II to IV*. Lahore: Govt. Printing Press.

33. Haeberli, W., Hoelzle, M., Paul, F., Zemp, M. (2007), Integrated monitoring of mountain glaciers as key indicators of global climate change: The European Alps, *Annals of Glaciology*, 46, pp 150-160.

34. Hamlet, A.F., Mote, P.W., Clark, M.P., Lettenmaier, D.P. (2005), Effects of temperature and precipitation variability on snowpack trends in the western U.S., *Journal of Climate*, 18(21), pp 4545-4561.

35. Hampe, A., and Petit, R.J. (2005), Conserving biodiversity under climate change: the rear edge matters, *Ecology letters,* 8(5), pp 461-467.

36. Hanjie, W., Weilai, S., and Xiaohong, C. (2006), The statistical significance test of regional climate change caused by land use and land cover variation in West China, *Advance Space Research*, 23(3), pp 355-364.

37. Houghton, J.T., Jenkins, G.J. and Ephraums, J.J., (Eds). (1990), *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, New York.

38. Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., and Meinke, H. (2007), Adapting agriculture to climate change, *Proceedings of the national academy of sciences*, 104(50), pp 19691-19696.

39. Huber, R., Rigling, A., Bebi, P., Brand, F.S., Briner, S., Buttler, A., Elkin, C., Gillet, F., Grêt-Regamey, A., Hirschi, C., Lischke, H., Scholz, R.W., Seidl, R., Spiegelberger, T., Walz, A., Zimmermann, W., and Bugmann, H. (2013), Sustainable land use in mountain regions under global change: synthesis across scales and disciplines, *Ecology and Society*, 18(3), pp 36.

40. Ibisch, P.L., Vega, A.E. and Herrmann, T.M. (Eds.). (2010), *Interdependence of biodiversity and development under global change*. Technical Series No. 54. Montreal: Secretariat of the Convention on Biological Diversity (second corrected edition).

41. IPCC. (2007), *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (Eds). Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

42. Jaglan, M.S. and Thakur, B.R. (2006). Ecology of Changing Cropping Pattern in Bharmaur Tribal Area of Himachal Pradesh, *Journal of Human Ecology*, 19(1), pp 13-20.

43. Jones, N. (2011), Human influence comes of age, *Nature*, 473(7346), pp 133-133.

44. Kahlon, S. (2015), Land use land cover change and human–Environment interaction: the case of Lahaul valley, *International Journal of Geomatics and Geosciences*, 6(2), pp 1568-1577.

45. Kahlon, S., Chandel, V.B. and Thakur, S. (2014), Changing Man – Environment Relations in Mountain Environments: Processes and Implications (The case of Lahaul valley). In *Managing Our Resources: Perspectives and Planning*, eds. Sharma, D. D. and Thakur, B. R. New Delhi: Bharti Publications, pp 53-65.

46. Keiler, M., Knight, J., and Harrison, S. (2010), Climate change and geomorphological hazards in the eastern European Alps, *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 368(1919), pp 2461-2479.

47. Kohler, T., and Maselli, D. (2012), Mountains and climate change. From understanding to action. FAO/CDE/SDC.

48. Kohler, T., Giger, M., Hurni, H., Ott, C., Wiesmann, U., Wymann von Dach, S., and Maselli, D. (2010), Mountains and climate change: a global concern, *Mountain Research and Development*, 30(1), pp 53-55.

49. Kolbert, E. (2011), Enter the Anthropocene: Age of man, *National Geographic*, 219(3), pp 60.

50. Kumar, V., Singh, P., and Singh, V. (2009), Snow and glacier melt contribution in the Beas River at Pandoh dam, Himachal Pradesh, India, *Hydrological Science Journal*, 52(2), pp 376–388.

51. Lambin, E.F., Baulies, X., Bockstael, N., Fischer, G., Krug, T., Leemans, R., Moran, E.F., Rindfuss, R.R., Sato, Y., Skole, D., Turner II, B.L., and Vogel, C. (1999), Land-use and land-cover change LUCC: Implementation strategy. IGBP Report No. 48, IHDP Report No. 10, Stockholm, Bonn.

52. Lambin, E.F., Geist, H.J. and Lepers, E. (2003), Dynamics of land-use and land-cover change in tropical regions, *Annual review of environment and resources*, 28(1) pp 205-241.

53. Lambin, E.F., Turner II, B.L., Geist, H.J., Agbola, S.J., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G. and Folke, C. (2001), The causes of land-use and land-cover change: moving beyond the myths, *Global Environmental Change*, 11(4), pp 261-269.

54. Liu J., Dietz, T., Carpenter, S. R., Folke, C., Alberti, M., Redman, C. L., Schneider, S. H., Ostrom, E., Alice, N. P., Lubchenco, J., Taylor, W. W., Ouyang, Z., Deadman, P., Kratz, T., and Provencher, W. (2007), Coupled human and natural systems, *AMBIO: A Journal of the Human Environment*, 36(8), pp 639-649.

55. Liu, X., and Chen, B. (2000), Climatic warming in the Tibetan Plateau during recent decades, *International journal of climatology*, 20, pp 1729–1742.

56. Liu, X., Cheng, Z., Yan, L., and Yin, Z. (2009), Elevation dependency of recent and future minimum surface air temperature trends in the Tibetan Plateau and its surroundings, *Global and Planetary Change*, 68(3), pp 164–174.

57. Lorimer, J. (2012), Multinatural geographies for the Anthropocene, *Progress in Human Geography*, 36(5), pp 593-612.

58. Lövbrand, E., Stripple, J., and Wiman, B. (2009), Earth System governmentality: Reflections on science in the Anthropocene, *Global Environmental Change*, 19(1), pp 7-13.

59. Luedeling, E., Kunz, A., and Blanke, M.M. (2013), Identification of chilling and heat requirements of cherry trees—a statistical approach, *International Journal of Biometeorology*, 57(5), pp 679-689.

60. Luedeling, E., Zhang, M., McGranahan, G., and Leslie, C. (2009), Validation of winter chill models using historic records of walnut phenology, *Agricultural and Forest Meteorology*, 149(11), pp 1854-1864.

61. Mahmood, R., et al., (2010), Impacts of land use land cover change on climate and future research priorities, *Bullen of American Meteorology Society*, 91, pp 37-46.

62. Manandhar, S., Pratoomchai, W., Ono, K., Kazama, S., and Komori, D. (2015), Local people's perceptions of climate change and related hazards in mountainous areas of northern Thailand, *International Journal of Disaster Risk Reduction*, 11, pp 47-59.

63. Mannion, D.A. (2014), *Global environmental change: a natural and cultural environmental history*, Routledge, New York.

64. Matthews, E., Amann, C., Fischer-Kowalski, M., H. Uttler, W., Kleijn, R., Moriguchi, Y., Ottke, C., Rodenburg, E., Rogich, D., Schandl, H., Sch. utz, H., Voet, E.v.d., and Weisz, H. (2000), *The Weight of Nations, Material Outflows from Industrial Economies*, World Resources Institute, Washington, DC.

65. Mauget, S.A. (2003), Multidecadal regime shifts in US streamflow, precipitation, and temperature at the end of the twentieth century, *Journal of Climate*, 16(23), pp 3905-3916.

66. Messerli, B. and Ives, J.D. (1997), *Mountains of the world: a global priority*, Parthenon Publishing Group.

67. Millennium Ecosystem Assessment. (2005), *Ecosystems and Human Well-being: Biodiversity Synthesis*, World Resources Institute, Washington, DC: Inland press.

68. Nijssen, B., O'Donnell G.M., Hamlet, A.F. and Lettenmaier, D.P. (2001), Hydrologic sensitivity of global rivers to climate change, *Climate Change*, 50, pp 143–175.

69. O'Brien, K. (2011), Responding to environmental change: A new age for human geography? *Progress in Human Geography*, 35(4), pp 542-549.

70. Ojima, D.S., Galvin, K.A., and Turner, B. L. (1994), The global impact of land-use change, *BioScience*, 44(5), pp 300-304.

71. Ojima, D.S., Kittel, T.G.F., Rosswall, T., and Walker, B.H. (1991), Critical issues for understanding global change effects on terrestrial ecosystems, *Ecological Applications*, 1(3), pp 316–325.

72. Pederson, G.T., Graumlich, L.J., Fagre, D.B., Kipfer, T., and Muhlfeld, C.C. (2010), A century of climate and ecosystem change in Western Montana: what do temperature trends portend?, *Climate Change*, 98, pp 133–54.

73. Pickett, S.T.A., Cadenasso, M.L., and Grove, J.M. (2005), Biocomplexity in coupled natural–human systems: a multidimensional framework, *Ecosystems*, 8(3), pp 225-232.

74. Qin, J., Yang, K., Liang, S. and Guo, X. (2009), The altitudinal dependence of recent rapid warming over the Tibetan Plateau, *Climate Change,* 97, pp 321–327.

75. Rai, P.K., Mohan, K., Mishra, V.N., Biswari, M., Sharma, A., and Rai, S. (2016), Changing regimes of gangotri and surrounding glaciers: A case study of Garhwal Himalaya, India, *Remote Sensing Applications: Society and Environment*, 3, pp 53-72.

76. Rangwala, I., and Miller, J.R. (2012), Climate change in mountains: a review of elevation-dependent warming and its possible causes, *Climatic Change*, 114(3-4), pp 527-547.

77. Rangwala, I., Barsugli, J., Cozzetto, K., Neff, J. and Prairie, J. (2012), Mid21st century projections in temperature extremes in the southern Colorado Rocky Mountains from regional climate models, *Climate dynamics*, 39(7&8), pp 1823-1840.

78. Rangwala, I., Miller, J. and Xu, M. (2009), Warming in the Tibetan Plateau: possible influences of the changes in surface water vapor. *Geophysical research letters*, 36, L06703.

79. Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Singh, S., Srivastav, S.K., Srivastava, V.K., Roy, A., Aggarwal, S.P., Nayak, R.S., Dwivedi and Roy, P.S. (2010), Human dimensions of climate change: A few initiatives. In *Earth Observation Applications in Climate Change Studies*. Bulletin of National Natural Resources Management System (NNRM) B 35, pp 118-126.

80. Singh, P. and Bengtsson, L. (2004), Hydrological sensitivity of a large Himalayan basin to climate change. Hydrological Processes, 18, pp 2363–2385.

81. Skole, D.L. (1994), Data on global land-cover change: acquisition, assessment, and analysis. In *Changes in Land Use and Land Cover: A Global Perspective*, eds., Meyer, W.B. and Turner II, B.L., Cambridge University Press, Cambridge, UK, pp 437-471.

82. Sorg, A., Bolch, T., Stoffel, M., Solomina, O., and Beniston, M. (2012), Climate change impacts on glaciers and runoff in Tien Shan (Central Asia), *Nature Climate Change*, 2(10), pp 725-731.

83. Steffen, W., Crutzen, P.J., and McNeill, J.R. (2007), The Anthropocene: are humans now overwhelming the great forces of nature, *AMBIO: A Journal of the Human Environment*, 36(8), pp 614-621.

84. Steffen, W., Persson, A., Deutsch, L., Zalasiewicz, J., Williams, M., Richardson, K., Crumley, C., Crutzen, P., Folke, C., Gordon, L. and Molina, M. (2011), The Anthropocene: From global change to planetary stewardship, *AMBIO: A Journal of the Human Environment*, 40(7), pp 739-761.

85. Steffen, W., Sanderson, A., Tyson, P.D., Jäger, J., Matson, P.A., Moore III, B., Oldfield, F., Richardson, K., Schellnhuber, H.J., Turner II, B.L. and Wasson, R.J. (2005), *Global change and the earth system: a planet under pressure*. Springer, New York.

86. Szerszynski, B. (2012), The end of the end of nature: The Anthropocene and the fate of the human, *Oxford Literary Review*, 34(2), pp 165-184.

87. Telbisz, T., Imecs, Z., Mari, L., and Bottlik, Z. (2015), Changing Human-Environment Interactions in Medium Mountains, the Apuseni Mts (Romania) as a Case Study, *Journal of mountain science*.

88. Thakur, S.N., Kahlon, S., and Bhutani, S. (2015), Development Impulses, Habitat Transformation and Ecological Vulnerability in Western Himalaya: A Case of Gaddi Tribe. In *Socio-Ecological Aspects of Development and Climate Change*, eds., Salariya, M. K. and Jha, P., Scholars' Press, Germany, pp 218-300.

89. The Encyclopaedia of Earth. (2013), Land-use and Land-cover Change.

90. Theobald, A., McGowan, H., and Speirs, J. (2016), Trends in synoptic circulation and precipitation in the Snowy Mountains region, Australia, in the period 1958–2012, *Atmospheric Research*, 169, pp 434-448.

91. Thuiller, W. (2007), Biodiversity: climate change and the ecologist, *Nature*, 448(7153), pp 550-552.

92. Turner II, B. L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T. and Meyer, W.B. (Eds.). (1990), *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years*. Cambridge University Press, Cambridge.

93. Turner II, B. L., Skole, D., Sanderson, S., Fischer, G., Fresco, L. and Leemans, R. (1995), Land-use and land-cover change, *Science/Research Plan*, IGBP Report No.35, HDP Report No.7, IGBP and HDP, Stockholm and Geneva.

94. Turner II, B.L., and Meyer, W.B. (1994), Global land-use and land-cover change: an overview. In *Changes in land use and land cover: a global perspective*, eds., Turner II, B.L., and Meyer, W.B., Cambridge University Press, Cambridge.

95. Verma, V. (1996), *Gaddi of Dhauladhar: A Transhumant Tribe of the Himalayas*, K. K. Publishers & Distributed, New Delhi.

96. Wackernagel, M., and Rees, W. (1998), *Our ecological footprint: reducing human impact on the earth (No. 9)*, New Society Publishers.

97. Weltzin, J.F. and McPherson, G.R. (2000), Implications of Precipitation Redistribution for Shifts in Temperate Savanna Ecotones, *Ecology*, 81(7), pp 1902–1913.

98. Werner, B.T. and McNamara, D.E. (2007), Dynamics of coupled human-landscape systems, *Geomorphology*, 91(3), pp 393-407.

99. Willis, K.J., and Bhagwat, S.A. (2009), Biodiversity and Climate Change. *Science*, 326(5954): 806–807.

100. Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y.U.N., and Wilkes, A. 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods, *Conservation Biology*, 23(3), pp 520-530.

101. Zalasiewicz, J., Williams, M., Smith, A., Barry, T.L., Coe, A.L., Bown, P.R., Brenchley, P., Cantrill, D., Gale, A., Gibbard, P. and Gregory, F.J. (2008), Are we now living in the Anthropocene? *Gsa Today*, 18(2), pp 4.

102. Zalasiewicz, J., Williams, M., Steffen, W., and Crutzen, P. (2010), The new world of the Anthropocene. *Environmental Science and Technology*, 44(7), pp 2228-2231.