ZIBELINE INTERNATIONAL™ PUBLISHING
ISSN: 2633-4062 (Print)
ISSN: 2633-4070 (Online)
CODEN: ECCCB9

Ecofeminism and Climate Change (EFCC)

DOI: http://doi.org/10.26480/efcc.01.2025.18.24

RESEARCH ARTICLE

LOCAL PERCEPTION TO LONG-TERM TRENDS AND IMPACTS OF CLIMATIC VARIABILITY AND CLIMATE CHANGE WITH PRECISE EVIDENCE IN THE DARJEELING HIMALAYA

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ARTICLE DETAILS

Article History:

Received 10 February 2025
Revised 18 March 2025
Accepted 15 April 2025
Available online 21 May 2025

ABSTRACT

In the present scenario, Climatic variability and Climate change have an increasing impact on biodiversity, human health, and livelihoods over the Himalayan Mountain belt. This approach was adopted and extended to the Darjeeling Himalaya conducting 353 household surveys, Participatory Rural Appraisal (PRA), Focus Group Discussions (FGDs), and Key Informant Interviews (KII). A perception studies and an empirical analysis with scientific evidence was prepared using valid historical datasets based on nature and elements of climate with serious environmental and social consequences. Over the last 40 years, the increasing trend of temperature with irregular and erratic events of rainfall is the common sensitivity across the elevation. Local people at different elevations have perceived various consequences due to climate change i.e. less water availability in agriculture with drying up of water sources, less livestock productivity, introducing new crop pests, etc. From the present study, the outcomes were obtained to provide proper and significant information to decision-makers and policy planners in the climate-sensitive areas of Darjeeling Himalaya.

KEYWORDS

Participatory Rural Appraisal, Darjeeling Himalaya, Climate change, livelihood, biodiversity

1. INTRODUCTION

In the face of growing impacts attributed to climate change, climate The climate of a region is a key factor to determine various features and distribution of the natural and managed system, consisting of the cryosphere, hydrology, marine and freshwater resources, biological systems, agriculture, and forestry but for the mesoscale i.e. (IPCC 2007). Darjeeling Himalaya, the impacts of climate are determined by local topographic expressions (Chalise and Kanal 2001). Climate change is one of the most critical moments in human livelihood and has impacted globally in all sectors in the form of a transformation in seasons and by temperature, precipitation, wind, and rise in sea levels that were once caused by anthropogenic activities (Hartter et al., 2018). On the other hand, climate changes have adverse effects on ecosystems, forests, water resources, and agriculture as well (Hennessy et al., 2007; Change, 2014). Changes in precipitation patterns as spatial and temporal is a direct influence of global climate change while increasing temperature in a region leads to greater evaporation consequently drying the land surface and increasing the intensity of rainfall and droughts (Nepal 2018; Trenberth 2010). In the present context, none other than India is one of the most susceptible countries to climate change among the developing countries (INCCA, 2010).

In India, most people live in rural areas and are predominantly dependent on climate-sensitive sectors, especially forestry and agriculture (Census of India, 2011). The impacts of climate change are significantly observed over the world on human livelihoods, natural resources, and ecosystems also that are highly exposed to climate change (IPCC 2014). Exposure to climate change is context-dependent and is slow changing phenomenon resulting by the dynamic interaction of the local environment and people as well as their social arrangement (Kasperson and Kasperson 2005). To achieve the sustainable development goals (SGDs) it is essential to admit the adverse impacts of climate variability and change on various sectors and to communicate an understanding of climate impact assessment to policymakers and local communities (Hassan 2021).

In accordance to IPCC, the poor and marginalized segments of society are more susceptible to these effects, especially rural poor people in developing countries, because of their increased exposure to extreme climatic events, high dependence on natural resources, pervasive poverty, marginalization, and limited options for adaptation (IPCC, 2014; Parmesan and Yohe, 2003). The Darjeeling Himalaya comprises of hills with their altitudinal range standing abruptly against the misty snow-clad Kanchenjunga at 8510 m in Nepal, and low-lying plains to its south (DDMP-GoWB 2021). The environment of which land is a vital component acts as a highly sensitive system to provide the means of sustainability to all forms of life. Darjeeling Himalaya has been bestowed with some outstanding natural features, however, presently this beautiful hill station faces severe problems from climatic variability and change. Keeping this point, the present study was conducted to find out the impact of various weather and climatic variability on the Darjeeling Himalaya ecosystem. Loss of biodiversity is another problem that can be very much influenced by climate shifting patterns (Dhiman, 2013).

Nowadays, the climate of the hilly tract in Darjeeling Himalaya is warm and humid with mild summer (maximum temperature barely crossing 25^{0}C). The monsoon season (June to September) is characterized by torrential monsoon rainfall that lashes the Darjeeling Himalayas (DDMP-GoWB 2021). The Himalayas are experiencing rapid climate change that is likely to significantly impact local ecosystems, biodiversity, agriculture, and human well-being. However, the scientific community has been slow to examine the extent and consequences of climate change. Local communities have been coping with environmental change for millennia.

Quick Response Code	Access this article online	
	Website: www.efcc.com.my	**DOI:** 10.26480/efcc.01.2025.18.24

Cite The Article: Dipankar Das, Krishna Barman, Ranjan Roy (2025). Local Perception to Long-Term Trends and Impacts of Climatic Variability and Climate Change with Precise Evidence in The Darjeeling Himalaya. *Ecofeminism and Climate Change, 6(1): 18-24.*

Thus, they often have considerable knowledge about environmental change and the means to cope with its consequences (Chaudhary et al., 2011).

As a result, the mountain community has to be the most adversely affected by climate change, rendering them even more vulnerable. Therefore, climate change vulnerability assessment of local people is important to design favourable adaptation strategies which in turn will affect the livelihoods of the local people. Furthermore, the ability of the mountain poor to enhance their coping ability is constrained by a range of related social and economic barriers, which necessitates evaluating to access the vulnerability and identifying the bio-physical drivers of the vulnerability of these communities to design suitable adaptation practices (Jha et at., 2017). Moreover, a variety of essential goods and environmental services provided by bio-physical drivers, on which local people around the study sites fully or partially depend, are in harm due to climate change and climate variability (Braatz, 2012). As a result, the local community would be the most adversely affected by climate change, rendering them even more vulnerable.

2. DATABASE AND METHODOLOGY

The Darjeeling Himalaya is situated in the transitional region of the Central and Eastern Himalayas of India and is mainly covered in hilly and rugged mountainous terrain. Jointly these districts cover an area of 3914sq.km. Their search site is bounded within the 26°46'N to 27°13'N latitudes and 87°59'E to 88°53'E longitudes (Figure 1). The altitude of the study area ranges from 300 m to 3602 m above the mean sea level and the region is influenced by the south-west and north-east Indian monsoon. The wet summer and the dry winter seasons with cold temperatures and the monsoon rainfall in this region are mainly orographic in nature, resulting in distinct variations in rainfall with elevation from the southern slopes of the Himalayas to a northern extent (Mei'e et al., 1985). The temperature of this region can drop close to zero degrees. According to the Indian metrological department, the rainfall of this region ranges from 1877 mm to 2333 mm. For the study, the Darjeeling Himalaya has taken into consideration conducting different field-based surveying methods in 6 individual selected villages (Figure 1) grouped by elevation into two categories i.e. low-elevation villages (<2000m) and high-elevation villages (>2000m). The major economic activities of these regions are tea plantations, agriculture, daily wages, and tourism.

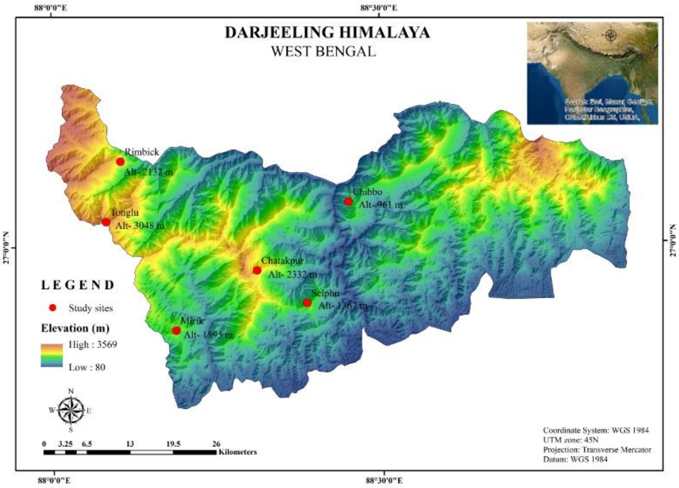


Figure 1: Location of the study area

Table 1: Distribution of sample size across the study villages.

Elevation	Altitude (m)	District/State	Selected villages	Actual household	Surveyed household (10% taken)
Low (<2000m)	961	Kalimpong, West Bengal	Chibbo	439	44
	1367	Darjeeling, West Bengal	Selphu Khasmahal	354	35
	1336		Mirik Khasmahal (P)	954	95
High (>2000m)	2132		Rimbick	1406	141
	2332		Chattakpur	52	05
	3048		Tonglu (Singalila Forest)	329	33
Total				**3534**	**353**

In the present study firstly, to spatially exhibit the climatic variability and change in Darjeeling Himalaya with all types of existing historic evidence and to understand its trends and impacts. The study of critical climatic moments and their impact utilized by mixed methods approach to identify stress periods. This may be effective and achieved through the use of both quantitative and qualitative survey methods. The quantitative survey was aided through the structured questionnaire while qualitative critical-moments assessment follows a participatory research approach i.e. Participatory Rural Appraisal (PRA), Focus Group Discussions (FGDs), Key Informant Interviews (KII) and household survey adopted (Groot et al., 2017). Here we have taken 10% of sample households (Table 1) i.e. 353 out of in total 3534 existing households of different selected study sites and we collected individual responses as perceptions from selected indicators of climate change using by structured questionnaire for quantitatively and qualitatively analysis. The PRA, FGDs, and KII have also been conducted in selected study villages to test the validity of household responses by assessing the contents of results obtained from the objective of the present study (Chaudhary and Bawa, 2011).

The participants included mostly vulnerable people who appear more sensitive to climatic variability and climate change including farmers, daily wage workers, local administration, and local NGO representatives, among others. After this data acquisition document brief details of long-term climate change and site-specific information to evaluate its environmental impacts using suitable methods and techniques. In this regard to test the consistency of the responses, the Pearson's Chi-square tests (χ^2) were used to determine whether there is a statistically significant difference among the responses for different elevation. Alongside primary data collection in this study the data has also been collected from various secondary sources i.e. collation and compilation of old studies carried out by assessment report of District Census Handbook, Indian Meteorological Department on climate change and occurrences of climatic variability in the Darjeeling Himalayan Region which were taken up in this present study and different relevant books, journals and papers are also referred to review and analyzed (District Census Handbook, 2011). Various relevant maps will be prepared by using geo-spatial techniques on the Remote Sensing and GIS platform (ArcGIS 10.8) to shape this research. The data presented in this compendium are divided into two broad sections– i) occurrences of different types of climatic variability on various scales in Darjeeling Himalaya, and ii) site-specific evaluation of some obvious climatic changes and their impacts on biodiversity and human livelihood.

3. Results and Discussions

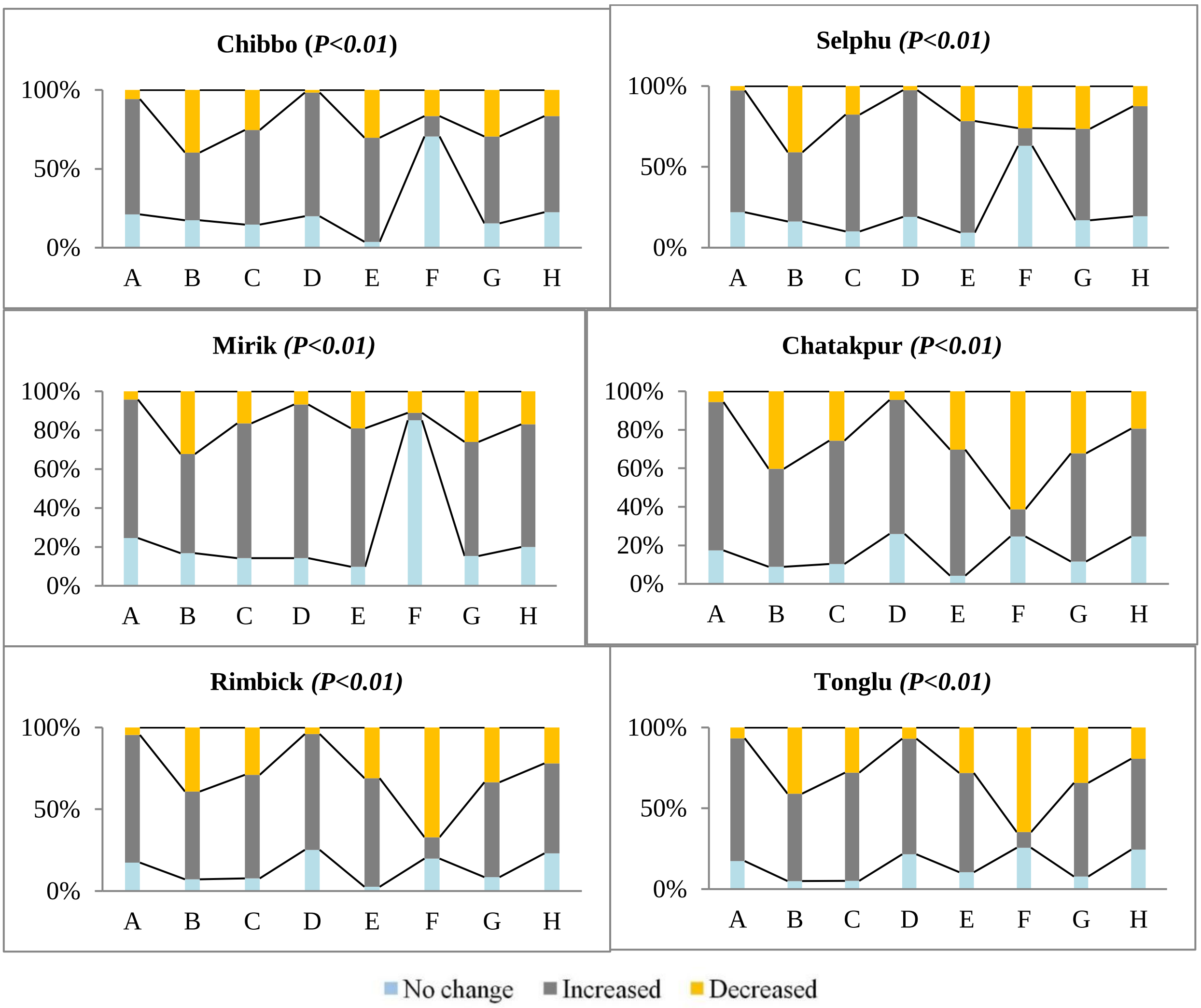
Darjeeling Himalaya is an important mountain system having fragile bio-physical conditions, complex climate, and socio-economic conditions as well. The Darjeeling Himalaya is set apart with adequate rainfall, but an overwhelmingly high proportion of the same is restricted to the monsoon season and natural groundwater recharge is hampered by high levels of surface runoff. Rather than gushing surface water, groundwater discharge, trickling, and flowing in the form of mountain springs ensure water security for a sizeable part of the rural population. However, the Darjeeling Himalaya as a part of the Himalayas displays huge climatic variability with long period duration (Eriksson et al., 2009). Climate change indicates an uncertain but potentially serious threat to vulnerable populations (Bohle et al., 1994). There is a growing perception that climate change impacts, manifested in the form of rising annual average temperatures, more intense precipitation patterns, and longer winter droughts, have further reduced the natural groundwater recharge (Tambe et al., 2011). This pattern of a shrinking monsoon season and the resulting drying up of natural springs and declining base flow of streams has been recently documented in the eastern Himalayas as well (Rawat et al., 2011).

The unavailability of water resources in the form of lakes, rivers, streams, and natural springs is one such example in this respect. In addition, recent studies in different parts of Darjeeling Himalaya indicate the perceived impact of climate change in the form of less snow in the mountains and intense but short episodes of rainfall that increase runoff, causing poor accumulation and recharge of water, thereby resulting in the drying up of water sources (Chaudhary et al., 2011). In the present research, we correlate the near-universal community perception that the short period of monsoon and decreasing amount of rainfall to declining spring discharge at an alarming rate (Tambe et al). About this, we collected various perceptions and responses through FGDs and key informant interviews that considered the climatic variability and existing climate changes at different scales.

3.1 Perception of long-term trends of climate variability and change

To address the adverse variability of climate and impacts of climate change it is analyzed to conduct FGDs, PRA, and KII to understand the local Perception of weather variability and climate change that is from the current situation to 40 years back in Darjeeling Himalaya. Our analysis reveals that there are spatial and temporal changes have taken place in Darjeeling Himalaya but it varies from its elevation at various scales. It shows that erratic events of rainfall have increased during the last 40 years believed by the local people i.e. 78.59% at low elevation and 70.6% at high elevation and the respondents observed that the nature of rainfall has become more frequent with high intense or irregular heavy rainfall with hailstorm at very short duration in monsoon; furthermore, average annual rainfall has less increased compared to its seasonal intensity.

Apart from rainfall, 64.37% of respondents at high elevations (>2000m) have reported that annual snowfall becoming less with increasing dry days as compared to previous years. Our analysis also shows that a majority of the local people across the different elevations perceive an annual temperature as getting warmer (Figure 2); What's more perceptions concerning average temperature in summer are not about linear narrative while the average temperature in winter has increased across the different altitude in Darjeeling Himalaya. So, the FGDs at different altitudes reveal that the mean monthly temperature over the year is greater than before compared to the last 40 years.



A - Annual average temperature B - Average temperature in summers

C - Average temperature in winter D - Erratic events of rainfall

E - Average annual rainfall F - Annual snowfall

G - Annual hailstorm H - Number of dry days

Figure 2: Perception *(n=353)* of weather variability and climate change to the current situation compared to the last 40 years in Darjeeling Himalaya.

Table 2: Variation on climatic parameters and events based on Darjeeling Himalaya [Prepared through ***Participatory Rural Appraisal*** (PRA)]

Events	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature												
Hotness		+	+	++	++	++	+++	+++	++	+	+	
Coldness	−−−	−	−	−							−	−−−
Rainfall												
Pattern	−	−	−	−	−	+	+++	++	++	−	−	−
Rain storms					++	++		+	++	+++		
Wind												
Wind storms			+	+	++					+	+	
Hail storms							++	++				
Hot winds			++	+++	+++	++						

Temperature: Hotness: **+** normal **++** hot, **+++** very hot; Coldness: **−** normal, **−−** Cold, **−−−** very cold

Rainfall: **+** sometimes rainfall occur, **++** normal rainfall, **+++** heavy/ erratic rainfall, **−** no rainfall period;

Rainstorms: **+** normal, **++** destructive rainstorms;

Wind/Hail storms: **+** normal, **++** destructive;

Hot winds: **+++** very hot.

3.2 Long-term trends in Precipitation change

Considering the spatial and temporal variability of precipitation and its trend in mountainous areas remains a key challenge (Lutz and Immerzeel 2016). Point measurements are often used in this study to determine the spatial distribution and trends of precipitation. Based on an empirical study, In Darjeeling Himalaya, there is large variability in receiving rainfall between different gridded products by comparing them for multiple years. From the time series analysis of climatic data, it is observed that an annual average rainfall trend analysis for 1981 to 2020 suggests maximum rainfall showing increasing by a linear trend (R^2=0.040) with higher fluctuation of actual data while with lesser fluctuation of actual data, the trend of average annual rainfall is slightly increasing linear trend (R^2=0.110). It is also noted that in higher altitudes, the trends of average annual rainfall have increased (R^2=0.116) by higher fluctuation compared to low elevation where it has also been increasing nature (R^2=0.091) but having lesser flux.

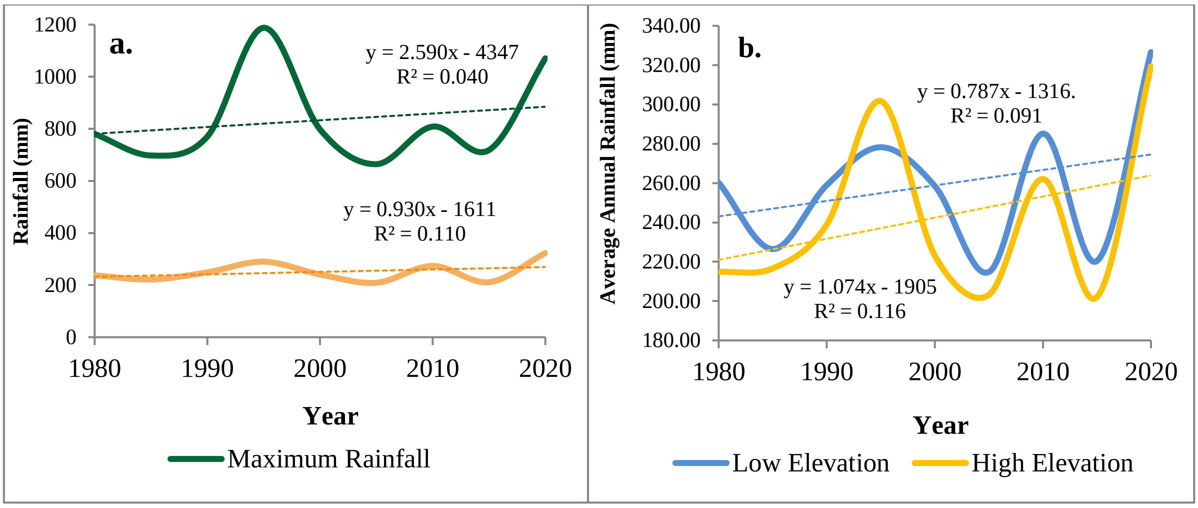


Figure 3: Zonal averages of (a.) maximum and annual average rainfall and (b.) annual average rainfall for high and low elevation from 1980 to 2020.

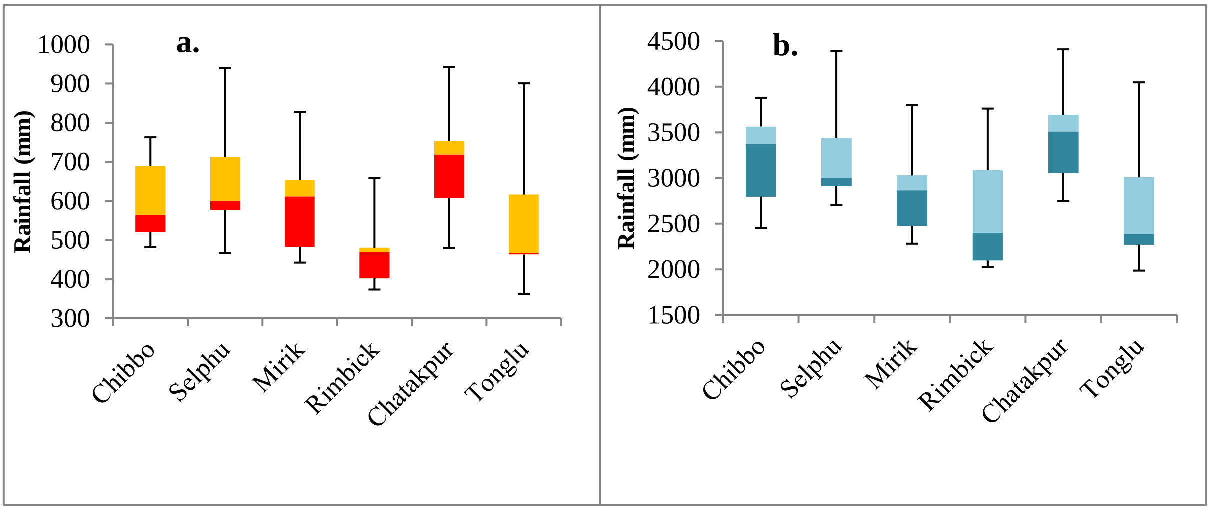


Figure 4: Rainfall dispersion graph showing the nature of (a.) average monsoon rainfall (June to September) and (b.) annual precipitation sum for 1980 to 2020.

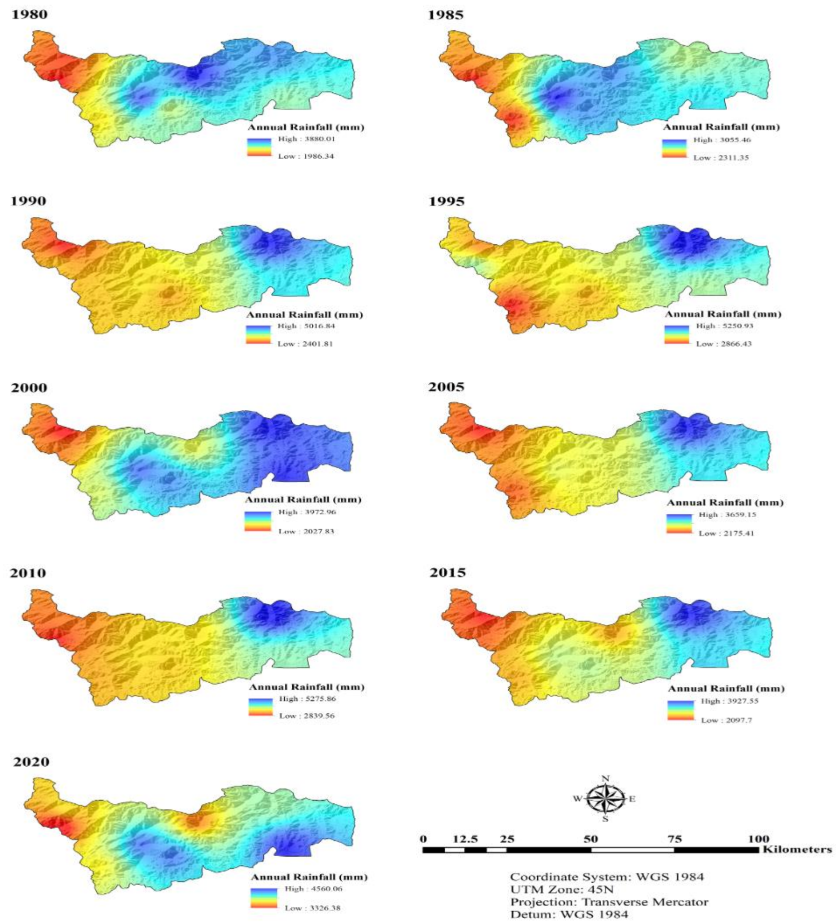


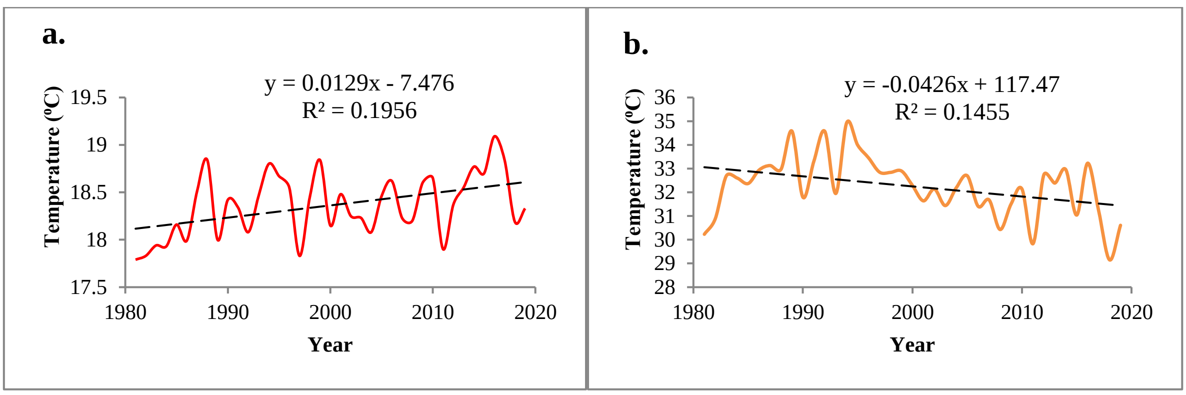
Figure 5: Spatial and temporal distribution of annual precipitation sum in Darjeeling Himalaya

The monsoon season (July to August predominantly) is characterized by torrential monsoon rains that lash the Darjeeling Himalayas. In particular, the pattern of rainfall in Darjeeling Himalaya has been changing the total amount of rainfall received in 10 days occurred 15 years back but now a day, the same amount of rainfall has occurred in two or three days allowing high discharge of run-off in the mountain belt. In the study area, it is a concern that higher rainfall intensity (about 3000mm) is frequent with short duration during peak monsoons (July to August) in the last decade principally. At Darjeeling Himalaya, occurrences of Landslides are a common natural phenomenon on set of monsoons and sometimes these events were widespread and disastrous remained in the study area as it is very likely that the precipitation necessary to supply the high amount of discharged water is occurring at high altitudes. As far as The landslide frequency in the mountain belt and flood frequency at Darjeeling plain are considered frequent occurrences during monsoons in the period of last three decades with a different fluctuation. An effort is made through this study to establish that there is a considerable role of high-intensity rainfall at a short duration in the occurrences of landslides and floods in the Darjeeling Himalaya and Sub-Himalaya respectively.

3.3 Long-term trends in Temperature change

Using numerous gridded datasets, since many of the existing gridded data products include temperature at a near-surface level to determine the trend of temperature that reflects the long-term climatic variability. From the analysis of climatic data, it is observed that an annual average temperature trend analysis for 1980 to 2020 suggests an increasing linear trend (R^2=0.195) and a trend of maximum temperature trend analysis showing a falling by a linear trend (R^2=0.145) with higher fluctuation of actual data while the trend of minimum temperature with the higher fluctuation of actual data is slightly increasing (R^2=0.005).

The analysis shows mean temperature grids for the 39-year reference period. Means over the entire period are shown for mean air temperature, maximum air temperature, and minimum air temperature along with summer air temperature, and winter air temperature. As expected, this mean temperature is increasing over the whole period. This shows that the temperature and precipitation datasets are physically consistent. The climate of the hilly tract in Darjeeling Himalaya is of warm and humid with mild summer (maximum temperature barely crossing 22^{0}C) whereas the plains experience hot humid conditions (maximum temperature as high as 39^{0}C). The atmosphere is highly humid and ranges from 75% to 80%. Linear regressions of relative humidity trends show slightly increasing or neutral trends (R^2=0.374) for the study area as a whole. Winter average temperature at winter averaging between 12^{0}C to 14^{0}C.



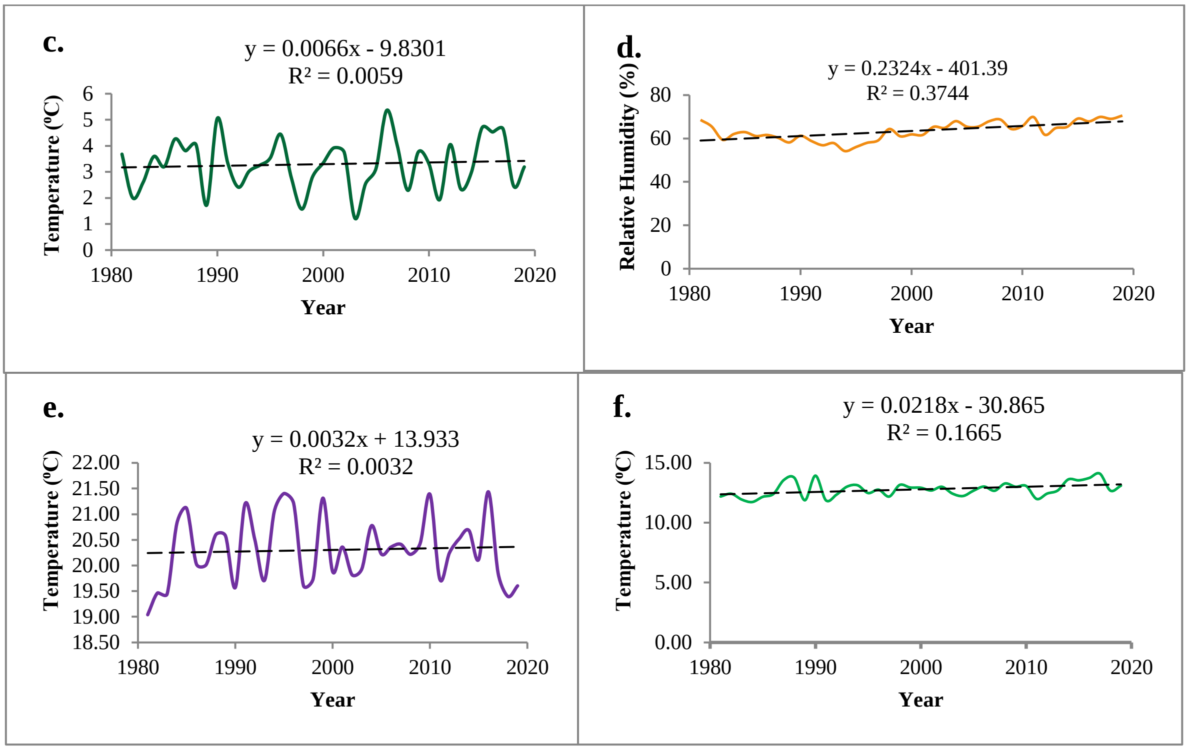
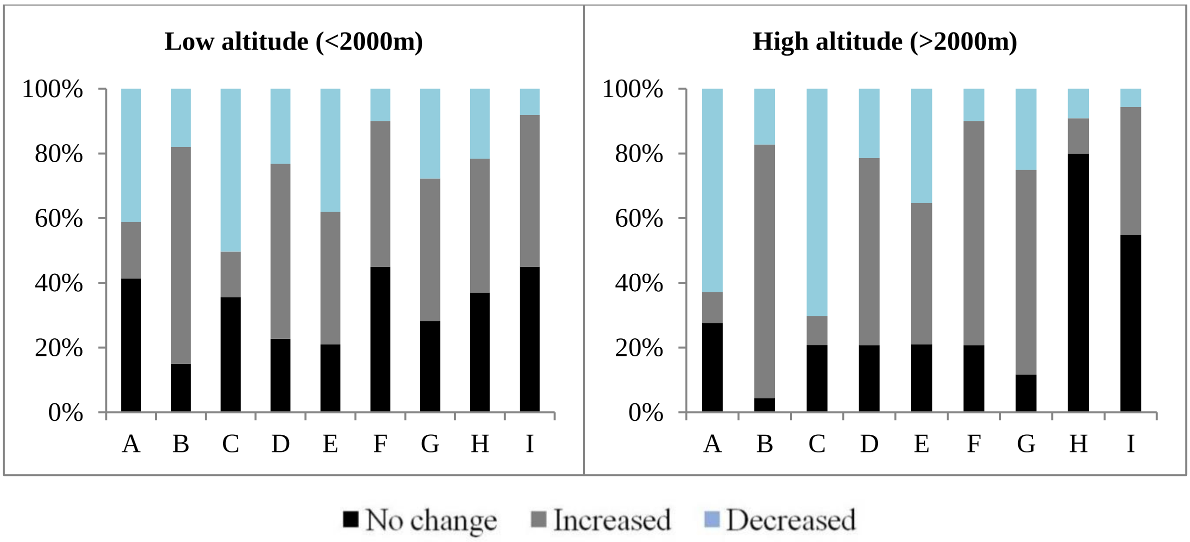


Figure 6: Nature and elements of climate in the Darjeeling Himalaya **(a)** Trend analysis of average annual temperature (1881 – 2019) **(b)** Trend analysis of maximum temperature (1881 – 2019) **(c)** Trend analysis of minimum temperature (1881 – 2019) **(d)** Trend analysis of Relative Humidity (1881 – 2019) **(e)** Trend analysis of Average summer temperature (1881 – 2019) **(f)** Trend analysis of Average winter temperature (1881 – 2019).

3.4 Perception of impacts of climate variability and change

Across the different elevations, the perception of households about the consequences or different impacts of climatic variability on biodiversity, human life, and livelihood is provided in Figure 7. It reveals that the major issues at different elevations that decreasing water availability for domestic uses and farming and livestock with drying up of fresh water sources i.e. springs, natural reservoirs, etc. Alongside incidences of diseases like pests attacking crops have increased nowadays due to increasing temperature. 46.80 And 39.61 percent of respondents of the total population of low and high elevation respectively observed crop pests are major issues in agricultural productivity.



A - Water availability for domestic use B - Drying up spring water sources

C - Water availability for farming & livestock D - Livestock productivity

E - Incidence of livestock diseases F – Early budburst

G - Early flowering H - Occurrence of sickness in local people

I - Incidence of disease/pests in crop

Figure 7: Perception *(n=353)* of households about different impacts of climatic variability compared to 40 years back in Darjeeling Himalaya.

Meanwhile, agricultural production has successively decreased only because of less water and increasing incidences of pest attacks. In the same way, decreased livestock productivity and increasing incidences of livestock diseases have presently been observed by 55.94 and 42.43 percent of respondents, reasons of increasing temperature and lack of water. FGDs have been conducted to demonstrate the impacts of climate change on biodiversity as noted by advanced flowering and budburst for various species specifically at the high altitude of Darjeeling Himalaya. It is also perceived that the distribution of some species has mildly shifted towards the high elevation with declining some species. It is evident by the assessment report of IPCC, 2007 that various plant species and animal ranges had shifted towards the high elevation with changing population size and life-cycle events. In recent times climatic stress moments and different health problems among the local people have directly or indirectly increased due to climatic variability and its irregular nature (Crane et al., 2017). At low elevations, 41.36 percent of local respondents responded that their occurrences of sickness have increasingly threatened.

4. Conclusions

The above study provided a serious consciousness of biodiversity and human livelihood which are vulnerable to severe consequences of climate variability and change. In this regard, the Indian State Action Plan on Climate Change aimed to create a synthetic overview of vulnerability in the country. Through perception study and several scientific pieces of evidence, it has been depicted that there is a significant correlation between climatic variability and the production of agriculture and agricultural allied activities. Moreover, the study reveals that there is a marked spatial and temporal variability of weather elements i.e. long-term rising temperature and long-term increasing rainfall with lesser and higher fluctuation respectively. From the present study, the qualitative and quantitative assessment document the people's perception of Climate variability and change and its impact on Darjeeling Himalaya which needs to respond and cope with the adaptation practices to manage biodiversity and human livelihoods.

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