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Climatic Trends in Rainfall Pattern and Impacts Towards Lichen Availability in Two Himalayan Districts of India

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ABSTRACT

The paper aims to present long time trend (117 years' time series data) for rainfall in two mountain districts (Almora and Nainital) of Uttarakhand, India. The rainfall data was analyzed for monthly, seasonal and annual trends in rainfall as well as the concentration and variability of precipitation for the two districts using Precipitation Concentration Index (PCI). The PCI values indicate that both the districts have highly irregular rainfall distribution and concentration across the months which have disturbed the local economy either in agriculture or tourism of local people. It has also been observed that seasonal precipitation is either uniformly or moderately distributed and contribution of monsoon rainfall is about 85% of the mean annual rainfall for both the districts. There is significant increase in pre-monsoon rainfall and significant decrease in monsoon and annual rainfall for Almora whereas, highly significant increasing trend in pre-monsoon rainfall and increasing but not significant trend for annual rainfall has been observed for Nainital. The significant change in precipitation pattern and fluctuation in rainfall amounts of the two districts indicate climate change which has highly affected environment for humans and vegetation of the area and lichens in particular which is supported by the people's perception study.

Key words: Climate change, Himalayan districts, Lichen, Precipitation Concentration Index (PCI), Recipitation and Rainfall.

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INTRODUCTION

Climate change has been defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" by United Nations Framework Convention on Climate Change (UNFCCC) (United Nations, 1994). As per third assessment report of the Intergovernmental Panel on Climate Change (IPCC), analysis of the frequency of heavy rainfall events indicates a probability of more than 90% that a 2 to 4% increase in frequency has occurred during the past 50 years in the Northern Hemisphere (IPCC, 2001). Two main environmental parameters viz. temperature and rainfall are used for monitoring the climate change by various researchers (Jaswal et al., 2015; Kumar and Jain, 2010). Precipitation is very important primary weather parameter for study of climate change (Mason et al., 1999) because among all the climatic parameters of environment, precipitation varies significantly both in time and space (Kripalani et al., 2003; Sahai et al., 2003). It has been reported in various studies that extreme rainfall events have increased with time in recent past throughout the world (Ajayamohan et al., 2010; Goswami et al., 2006; Guhathakurta et al., 2017; Iwashima and Yamamoto, 1993; Krishnamurthy et al., 2009; Rajeevan et al., 2008; Rakhecha and Soman 1994; Roxy et al., 2017; Yu and Neil, 1991; Yu and Neil, 1993), which are the most common reason for disaster particularly in hilly areas. According to the IPCC (2007) climate change will affect agriculture, increase the risk of hunger; water scarcity, and will lead to rapid melting of glaciers in future. It is evident from various studies that climate change affects the life of flora and fauna on the earth (Dutta et al., 2014; Kumar et al., 2012; Malik, 2014;

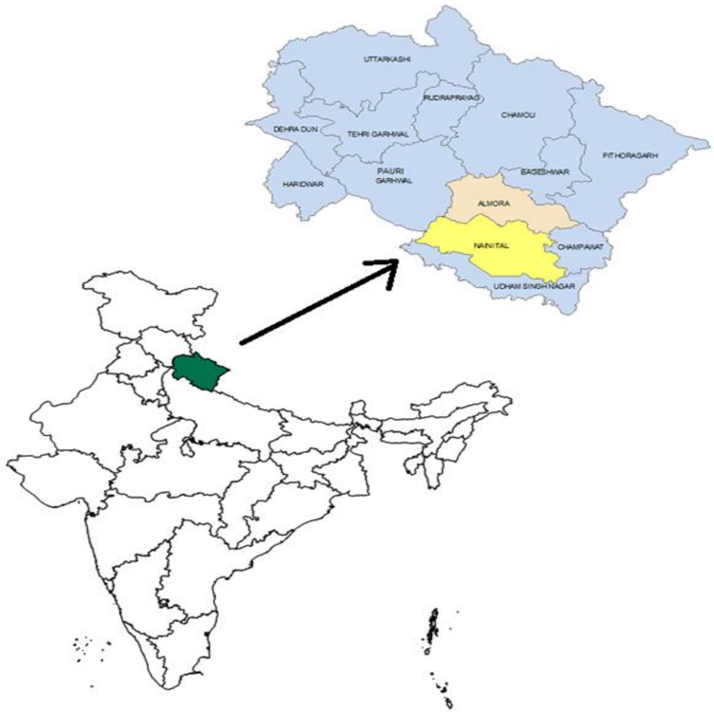

Figure 1. Study area.

Parmesan, 1996; Parmesan et al., 1999; Primack et al., 2004; Thomas and Lennon, 1999). Lichen is combination of algal and fungus components which live in symbiotic association. Lichen has been found a dependable bio-indicator of climate change of the area (McCune, 2000; van Herk et al., 2002; Song et al., 2012).

The local people's perception has indicated that main threats for lichens are climate change, habitat degradation and loss, habitat fragmentation, overexploitation and air pollution. Lichens are very sensitive to environmental parameters and their growth, abundance and diversity depend on the amount of moisture, temperature, light, wind, altitude, air pollution and other anthropogenic factors (Gupta et al., 2014; Srivastava and Bhattacharya, 2015). The Himalayan area is very much vulnerable to climate change. Two districts viz. Almora and Nainital under Kumaun region of Uttarakhand state were chosen for the study of climate change and its effect on lichens in the area. The districts were recently often in news for disastrous conditions due to extreme rainfall events in July, 2004, August, 2009 and June 2013. The topography of the region plays a dominant role by increasing the convection and hence the intensity of rainfall. There has been very limited study in these sites. Lichen availability in the area is high, which was considered to know the impact of climate change using people's collection practice. In the present study, temporal variation and decadal pattern of rainfall in two Himalayan districts of Uttarakhand viz. Almora and Nainital for the period 1901 to 2017 have been analyzed. Temporal variation and concentration of rainfall using Precipitation Concentration Index (PCI) (Oliver, 1980) have also been studied. We have tried to understand the people's perception about the climate change with reference to rainfall and its impact on lichen availability in the study area.

MATERIALS AND METHODS

Study Area

Almora district extends between 29° 20' N to 29° 56' N latitude and 79° 17' E to 79° 47' E longitude with total geographical area of 3139 km^2 (Figure 1). The altitude of Almora ranges from 1200 to 2800 m above mean sea level (amsl). The Kosi River and its tributaries, such as Suyal, Nani Kosi, Khulgad and Jamthara Gad etc. drain the study area. Surya River drains a small north-eastern part of Almora district. Climatically, the study area has cool temperate conditions. Nainital is located approximately in between 78°80' to 80°14' E longitude and 29°00' to 29°05' N latitude and has total geographical area of 4251 km^2. The elevation of Nainital ranges from 600 to 2500 m amsl. The Himalayan ranges lie on the northern side while on the southern side lie plains making the climate of the district very pleasant. The highest peak of Nainital district is Baudhansthali which is 2,623 m high near Binayak adjoining Nainital town. The hilly region of the district has many lakes like Bhimtal, Sattal, Naukuchiatal, Khurpatal, Nainital, Malwatal, Harishtal, Lokhamtal etc. The foothill area of the district is known as Bhabhar, named after a tall grass growing in the region. The level of underground water is very deep in the district. Kosi, the main river of the district, is arising out of Koshimool near Kausani and flows on the western side of Nainital. Most of the small rivulets like Gaula, Bhakra, Dabka, Baur, etc. have been dammed for

Table 1. PCI value and its classification.

PCI values	Significance (Temporal distribution of precipitation)
Less than 10	Uniform distribution
Between 11 to 15	Moderate distribution
Between 16 to 20	Irregular distribution
More than 20	Strongly Irregular distribution

Table 2. Monthly, annual mean and seasonal rainfall, SD, CV and trend for Almora district for 1901 to 2017.Trend values significance at 99% level (**) and at 95% level (*).

	Mean (mm)	SD (mm)	CV (%)	Trend (mm/year)	
January	27.3	21.79	80	0	
February	28.9	27.00	93	0.03	
March	23.9	22.03	92	0.11	*
April	16.7	13.55	81	0.04	
May	34.2	24.61	72	0.14	*
June	138.4	89.11	64	-0.11	
July	317.1	126.35	40	-0.39	
August	318.7	125.77	39	-0.96	**
September	172.0	112.73	66	-0.13	
October	32.4	40.33	125	-0.05	
November	4.5	6.66	148	0	
December	10.8	13.60	126	0	
Annual mean	93.7	21.85	23	-0.13	*
Winter	56.2	34.95	62	0	
Pre-monsoon	74.9	39.61	53	0.31	
Monsoon	946.1	253.84	27	-1.88	**
Post-monsoon	47.6	42.22	89	-0.11	
Annual	1124.8	262.21	23	-1.55	*

irrigation purposes. Both the districts under study fall in temperate region and have more or less similar tree vegetation and climatic condition and hence about more or less similar lichen flora. Main source of income is from the agriculture sector. Being hilly region the most of the agriculture in the area is rain-fed. About 7% and 60% of the cultivated area is irrigated in Almora and Nainital, respectively.

The crops in rain-fed as well as irrigated areas are highly affected by time, duration and the amount of precipitation. In rain-fed areas, the sowing time, crop duration and productivity are directly related to the quantum and distribution of rainfall, while in irrigated areas the distribution of rainfall affects germination and harvesting of crops. Therefore, the growth of food grain production is quite variable in the areas. Out of the cultivated land, about 50% of the land holdings are sub-marginal and a further 21% of the land holding is between 0.005 and 0.01 km^2. About 70% of the land holdings are less than 0.01 km^2 in size and cover about 27% of the area under cultivation, while about 26% of the land holdings are between 0.01 km^2 and 0.04 km^2, covering about 51% of the total cultivated area. About 3% of the land holdings are above 0.04 km^2 and cover about 22% of the total cultivated area. As per year 2017 assessment, the forest area in Almora is 1718 km^2 and in Nainital is 3048 km^2. Almora district has 199 km^2 very dense, 837 km^2 moderately dense and 682 km^2 open forests while Nainital district has 765 km^2 very dense, 1742 km^2 moderately dense and 541 km^2 open forests.

Data Source

The data on homogeneous monthly precipitation series for both the districts for a period of 117 years from 1901 to 2017 were collected from the archives of National Data Centre of India Meteorological Department (IMD). To study the changes in the rainfall, one calendar year has been divided into four seasons: winter (January to February), pre-monsoon (March to May), monsoon (June to September) and post monsoon (October to December).

Data Analysis

Annual and seasonal time series of rainfall have been prepared from the monthly rainfall data. The averaged monthly seasonal and annual means, standard deviations and coefficient of variations of rainfall for Almora and Nainital have been computed and given in tables 2 and 3 respectively. The temporal variations of seasonal and annual rainfall during 1901 to 2017 for the two districts have been shown in Figure 2(a to e) and Figure 3 (a to e).

The trend has been carried out using non-parametric Mann-Kendall test (Kendall, 1976). The test assesses the probability that there is a trend which is statistically different from zero. Sen's method (Sen, 1968) has been used to evaluate the trend of slope in the time series of rainfall for the period 1901 to 2017.

The Mann-Kendall test statistic S is calculated as

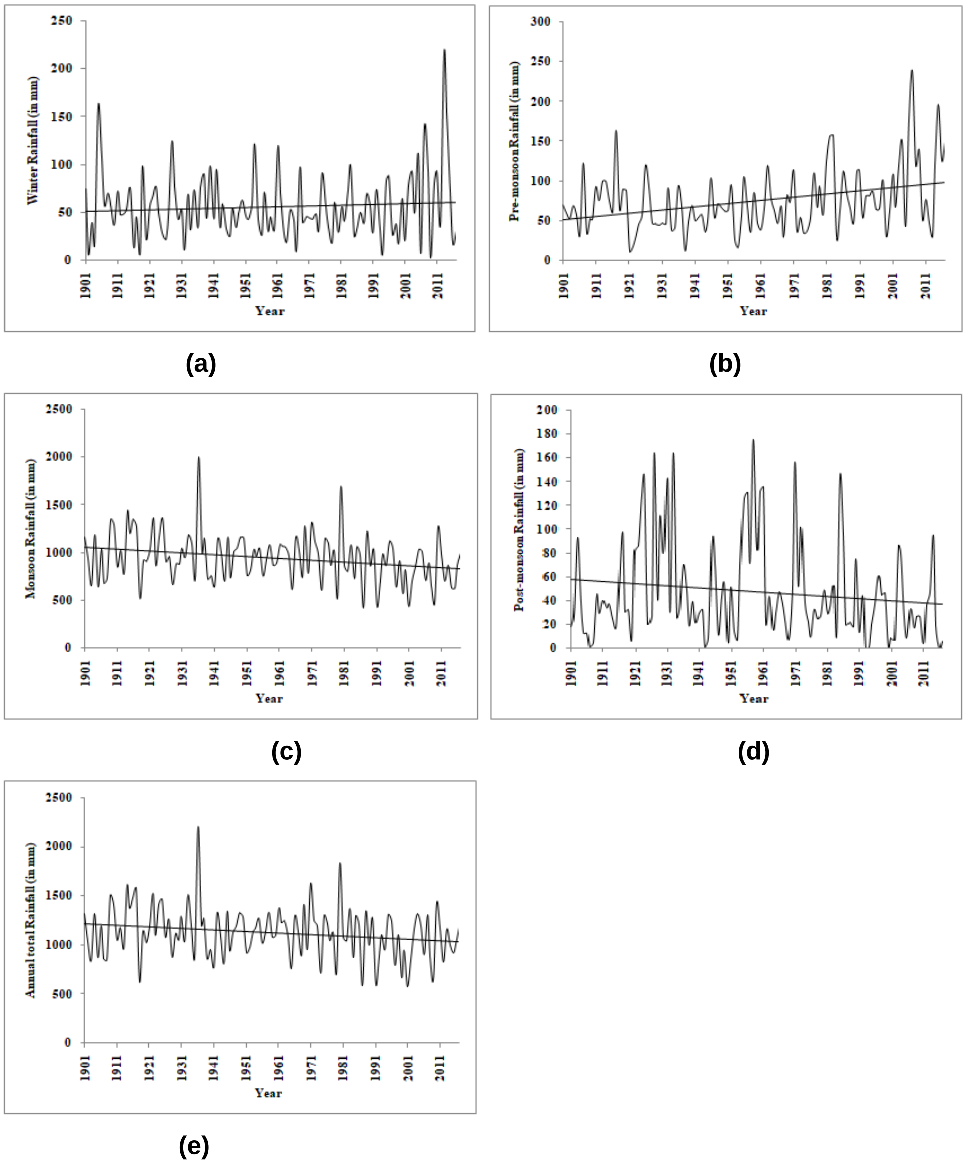

Figure 2. Temporal variation and linear trends in (a) Winter, (b) Pre-monsoon, (c) Monsoon, (d) Post-monsoon and (e) Annual Rainfall for Almora for 1901-2017.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \qquad (1)$$

Where n is the length of the data set, x_j and x_k are the annual values in year j and k, respectively, and the function sgn (x_j - x_k) is defined as:

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} +1, \text{ if } (x_j - x_k) > 0 \\ 0, \text{ if } (x_j - x_k) = 0 \\ -1, \text{ if } (x_j - x_k) < 0 \end{cases} \qquad (2)$$

If we take the hypothesis for independent and randomly distributed variables when n > 10, the S is approximately normally distributed (Helsel and Hirsch, 1992) with zero mean. The variance of S is given by:

$$\mathrm{VAR}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \qquad (3)$$

Where, t_p is the number of data values in the p^{th} group and q is the number of tied groups. The test statistic Z is computed as follows (Hirsch et al., 1993):

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \qquad (4)$$

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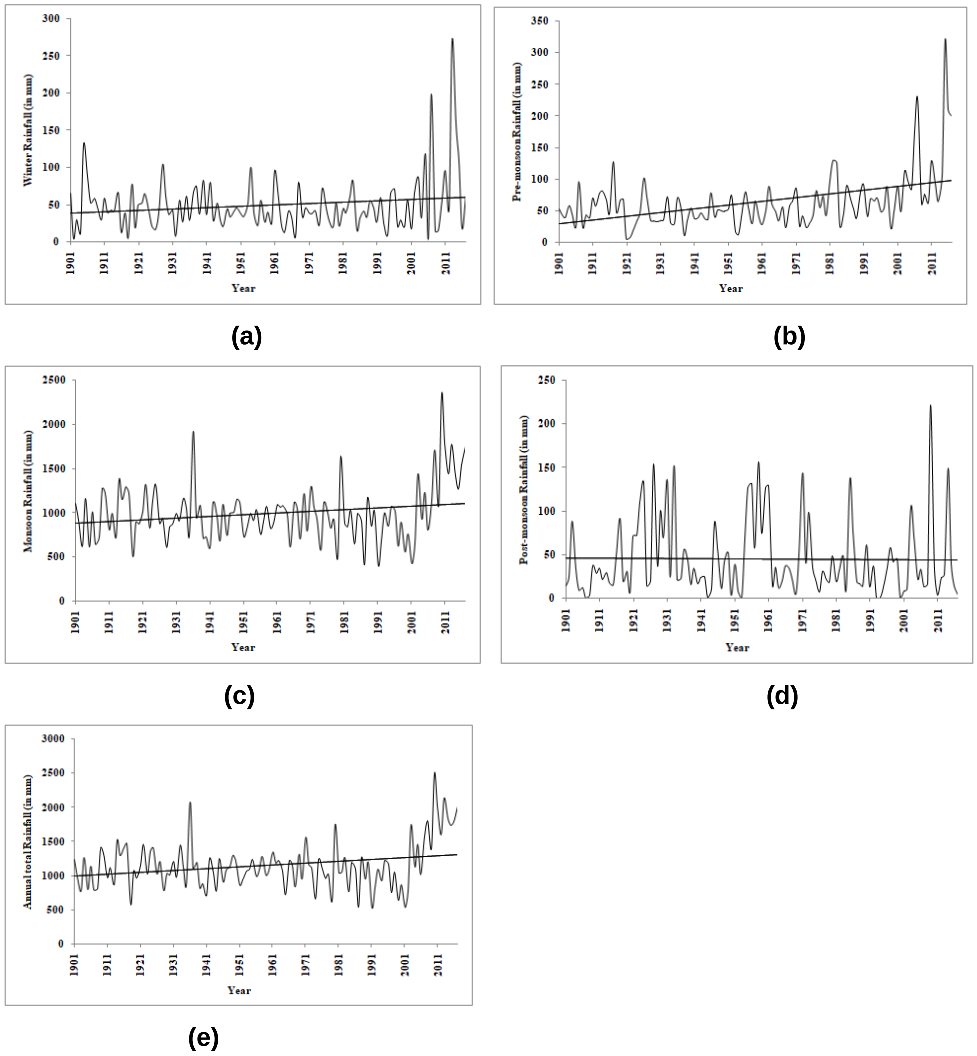


Figure 3.Temporal variation and linear trends in (a) Winter, (b) Pre-monsoon, (c) Monsoon, (d) Post-monsoon and (e) Annual Rainfall for Nainital for 1901-2017

To estimate the slope of a linear trend the Sen's nonparametric method is used. The Sen's estimator of slope is given by

$$\text{Sen Slope} = \text{median}\left[\frac{(x_j - x_k)}{j-k}\right] \text{ for all } j>k \quad (5)$$

The temporal variation and concentration of rainfall in Almora and Nainital districts were analyzed using PCI (Oliver, 1980). PCI has been found to be very powerful index to study the temporal distribution and variability of precipitation (de Luis et al., 2011; Jaswal et al., 2014; Nery et al., 2017). The annual PCI value is calculated using following equation

$$\mathbf{PCI_{annual}} = \frac{\sum_{i=0}^{i=12} P_i^2}{(\sum_{i=0}^{i=12} P_i)^2} \text{ X } 100 \quad (6)$$

Where P_i is the monthly total rainfall for the month i and the multiplication factor 100. in the formula represents 12 months of the year for PCI_{annual}. The winter PCI value is calculated using following equation

$$\mathbf{PCI_{winter}} = \frac{\sum_{i=0}^{i=2} P_i^2}{(\sum_{i=0}^{i=2} P_i)^2} \text{ X } 16.67 \quad (7)$$

Where the multiplication factor 16.67 in the formula represents 2 months (January and February) of the year for PCI_{winter}. The pre-monsoon PCI value is calculated using following equation

$$\mathbf{PCI_{pre\text{-}monsoon}} = \frac{\sum_{i=0}^{i=3} P_i^2}{(\sum_{i=0}^{i=3} P_i)^2} \text{ X } 25 \quad (8)$$

Where the multiplication factor 25 in the formula represents 3 months (March, April and May) of the year for $PCI_{pre\text{-}monsoon}$. The monsoon PCI value is calculated using following equation

$$\mathbf{PCI_{monsoon}} = \frac{\sum_{i=0}^{i=4} P_i^2}{(\sum_{i=0}^{i=4} P_i)^2} \text{ X } 33.33 \quad (9)$$

Where the multiplication factor 33.33 in the formula represents 4 months (June, July, August and September) of the year for $PCI_{monsoon}$. The post-monsoon PCI value is calculated using following equation

$$PCI_{post\text{-}monsoon} = \frac{\sum_{i=0}^{i=3} P_i^2}{(\sum_{i=0}^{i=3} P_i)^2} \text{ X } 25 \qquad (10)$$

Where the multiplication factor 25 in the formula represents 3 months (October, November and December) of the year for $PCI_{post\text{-}monsoon}$. The significance of PCI values according to Oliver (1980) has been tabulated in Table 1.

In order to know the people's perception about climate change and impact of climate change on lichen flora of the region, a survey was conducted by personal interview of the people. Lichen has been found very good bio-indicator of climate change due to its sensitivity towards climate change as it grows in pollution free forest areas where availability of moisture is more. Three villages in each district - Dalar, Ayarpani and Dinapani villages in Almora and Kilbury, Pangot and Ghuggu Kham in Nainital district have been selected. The data for climate change and possible effects of rainfall variability on the growth and regeneration of lichens as well as lichen availability were collected from the field survey of the study areas through participatory method involving local communities using participant's observation and have been analyzed. It involves the indigenous knowledge and experience available with the local peoples who are involved directly or indirectly in the lichen collection and trading process. The people's perception towards Lichen availability was measured through local community's information, trends was assessed by comparative valuation matrix. Focus group discussion was practiced, under PRA (Participatory Rural Appraisal) technique in different villages. Local units were considered for Lichen availability. Market survey was also followed for cross checking of information on the status of production, collection pattern and nature of local trade of lichens.

RESULTS AND DISCUSSION

Monthly, Seasonal, Annual and Decadal Mean Rainfall

The long term monthly, seasonal and annual mean rainfall for the period 1901 to 2017 have been prepared and shown in Figure 2(a to e) and Figure 3(a to e) for Almora and Nainital districts, respectively to get an overview of changes in the rainfall for the two districts under study. The mean, standard deviation (SD), coefficient of variation (CV) and trends of rainfall on monthly, seasonal and annual scales are given in Tables 2 and 3, respectively for Almora and Nainital districts. The monthly mean rainfall is highest in August (318.7 mm for Almora and 342.1 mm for Nainital) followed by July (317.1 mm for Almora and 331.6 mm for Nainital). The contributions of the rainfall for these two months are approximately 56.5 and 58.7% of annual rainfall for Almora and Nainital districts, respectively. For the months of July and August the CV values are 40 and 39% for Almora while for Nainital are 45 and 37%. The month of November shows the lowest long term mean rainfall of 4.5 mm for Almora and 3.0 mm for Nainital with highest CV values of 148% for Almora and 153% for Nainital.

The values of CV have been found very high (125, 148 and 126% for Almora) and (125, 153 and 139% for Nainital) for October, November and December. It suggests that the rainfall in both the districts is highly variable in October, November and December. Long term mean annual rainfall is 1124.8 mm with SD of 262.21 mm and low CV of 23% for Almora. Mean annual rainfall for Nainital is 1154.8 mm with SD of 350.22 mm with CV of 30% for Nainital. The contribution of monsoon rainfall is about 85% of the mean annual rainfall for both the districts suggesting most of the rainfall is received in the monsoon season. The post-monsoon season receives lowest rainfall of 47.6 mm with CV of 89% and 45.3 mm with CV of 97% for Almora and Nainital, respectively. Rest of seasons contribute equally (~5% each) to the mean annual rainfall. The trend analysis of the monthly rainfall suggests significant decreasing trend for August (-0.96 mm/year) and the significant increasing trend for March (0.11 mm/year), May (0.14 mm/year) for Almora. Significant increasing trend for March (0.09 mm/year), April (0.06 mm/year) and highly significant increasing trend in May (0.21 mm/year) for Nainital has been observed. Seasonal rainfall trend (Table 3) reveals that there is significant increase in pre-monsoon (0.31 mm/year) and significant decrease in monsoon (-1.88 mm/year) for Almora. Highly significant increasing trend in pre-monsoon rainfall (0.36 mm/year) has been observed for Nainital. On annual scale, it is depicted that there is significant decreasing trend (-1.55 mm/year) for Almora while it is increasing (1.58 mm/year) but not significant for Nainital. The data analysis for number of rainy days (days with rainfall above 2.4 mm) shows that total number of rainy days in a year have decreasing trend of -1.9 days/decade which is statistically significant at 95% level for Almora while Nainital has decreasing trend of -0.8 days/decade but the trend is not significant. The maximum number of rainy days 79 was reported in 1979 for Almora and 124 was recorded in 1977 for Nainital.

The one-day heaviest rainfall trend reveals that there is increasing trend 3.6 mm/decade for Almora and 13.3 mm/decade for Nainital. The trend for Almora is not statistically significant while it is significant for Nainital at 95% level. As per records, one day heaviest rainfall received by Almora was 173.1 mm in 2010 and by Nainital was 466.1 mm in 2013. The decadal mean rainfall for all the months, four seasons and annual total has been shown in the Figure 4 (a to q) for Almora and Nainital districts for the period 1908 to 2017. It is evident from the charts that there are significant changes in the rainfall pattern for these districts during last two decades. The decadal rainfall for Almora was more than Nainital during months of January, April, May, June, November, December as well as for pre-monsoon season for all the decades except 2008 to 2017. The study reveals that the decadal rainfalls

Table 3. Monthly, annual mean and seasonal rainfall, SD, CV and trend for Nainital district for 1901 to 2017. Trend values significance at 99.9% level (***), 99% level (**) and at 95% level (*).

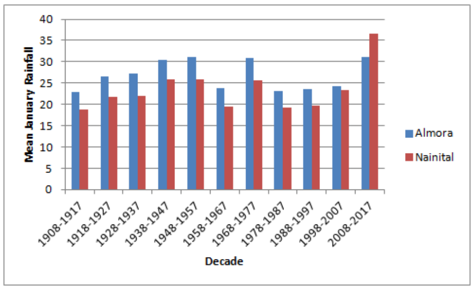
	Mean (mm)	SD (mm)	CV (%)	Trend (mm/year)	
January	23.7	19.43	82	0.03	
February	25.6	27.84	109	0.04	
March	20.4	23.50	115	0.09	*
April	13.6	12.87	95	0.06	*
May	29.8	25.89	87	0.21	***
June	140.6	101.51	72	0.24	
July	331.6	149.70	45	0.48	
August	342.1	127.78	37	0.31	
September	182.1	120.59	66	0.39	
October	33.3	41.53	125	-0.01	
November	3.0	4.52	153	0.00	
December	9.0	12.58	139	0.00	
Annual mean	96.2	29.19	30	0.13	
Winter	49.4	37.09	75	0.00	
Pre- monsoon	63.8	44.62	70	0.36	***
Monsoon	996.3	320.27	32	1.05	
Post-monsoon	45.3	43.99	97	-0.05	
Annual	1154.8	350.22	30	1.58	

for Nainital has been more than Almora for last two decades that is, 1998 to 2007 and 2008 to 2017 for annual, the months of March, July, August and October as well as during monsoon and post-monsoon seasons while the trend was reverse before the decade of 1998 to 2007. The month of September shows that the decadal rainfall for Almora has been less compared to rainfall for Nainital during 1988 to 1997, 1998 to 2007 and 2008 to 2017 decades while the pattern was opposite previous to the decade of 1988 to 1997. In the recent years, Almora has received deficient monsoon rainfall during 2014 and 2015. Similar results have been reported for Himanchal Pradesh (Jangra and Singh, 2011; Jaswal et al., 2015; Prasad and Rana, 2010), Kashmir Valley (Kumar and Jain, 2010), Europe (Parry, 2000) and Tibet in central Himalaya (Duan and Yao, 2003).

Seasonal and Annual Precipitation Concentration Index

The PCI values have been calculated for Almora and Nainital districts on seasonal and annual scales. The calculated annual PCI values for Almora range from the lowest value of 15 in 2007 to the highest value of 33 in 1948 and for Nainital, these values range from the lowest value of 16 in 2007 to the highest value of 34 in 1943, 1948 and 1976. The average value of annual PCI is 23 for Almora and 24 for Nainital. The calculated annual PCI values for 117 years (1901 to 2017) for Almora and Nainital districts show that only 1% of the years fall within moderate distributed precipitation pattern ($11 \leq PCI \leq 15$), while 17 and 6% of the years fall within irregular ($16 \leq PCI \leq 20$) and 82 and 93% of the years fall within strongly irregular distributed precipitation pattern ($PCI > 20$) for Almora and Nainital districts, respectively. It indicates that both the districts have highly irregular rainfall distribution and concentration across the months and most of the precipitation occurred in four months of monsoon. Winter PCI values show rainfall within uniform distribution ($PCI \leq 10$) for 47 and 48% of the years and moderate distribution ($11 \leq PCI \leq 15$) for 39 and 38% of the years for in Almora and Nainital districts, respectively. It is observed from calculated PCI values that during pre-monsoon or summer season, 37 and 32% of the years were under uniform distribution and 43 and 45% of the years were under moderate distribution for Almora and Nainital districts, respectively.

The PCI values for monsoon season suggest that 42 and 40% of the years were under uniform distribution for Almora and Nainital districts, respectively and 32% of the years were under moderate distribution for both the districts. The PCI values for post-monsoon season show that 42 and 41% years fall within moderate distribution of precipitation, and 27 and 30% of years are under strongly irregular distribution of precipitation for Almora and Nainital districts, respectively while 21% years fall within irregular distribution of precipitation for both the districts. It suggests that there is high rainfall variability and more concentrated precipitation in post-monsoon season. The coefficient of variation in PCI is the highest in post monsoon season with values 30 and 29% for Almora and Nainital districts, respectively and the lowest in monsoon season with value 15% for both the districts. It is also observed that almost 84% of the total rainfall occurred in the four months of monsoon season in Almora district while 86% in Nainital district. The temporal variations of significant PCI time series for Almora and Nainital for winter, pre-monsoon, monsoon, post-monsoon and annual have been shown in Figure 5(a to e) and 6(a to e), respectively. The PCI values show decreasing trend for annual, winter and post-monsoon seasons and increasing trend for pre-monsoon and monsoon seasons for Almora. For Nainital, trend in PCI values has been found to be decreasing for annual, winter, post-monsoon and monsoon seasons and increasing for pre-monsoon season but not significant. The trend is significant only in post-monsoon at 95% level of confidence for both Almora and Nainital. The reslts are supported by the findings of



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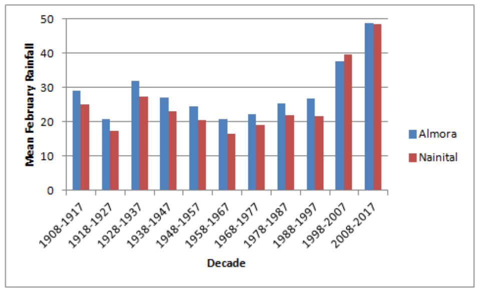

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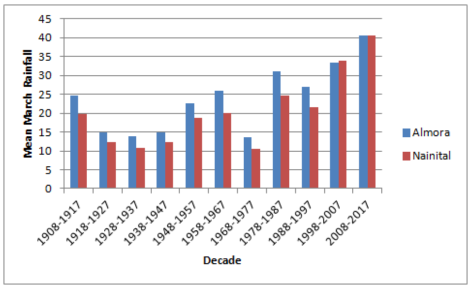

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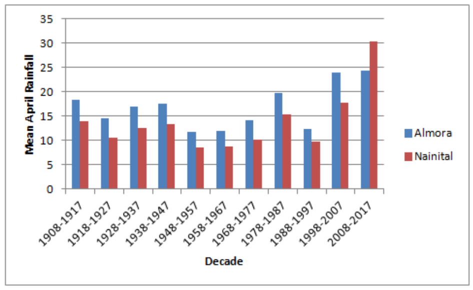

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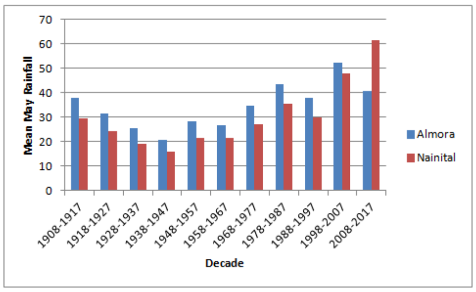

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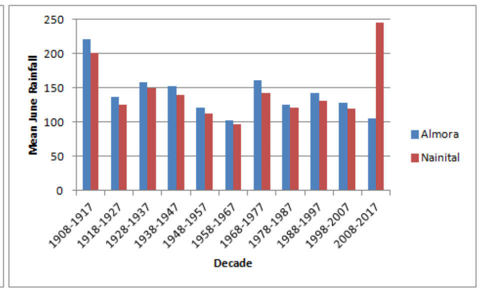

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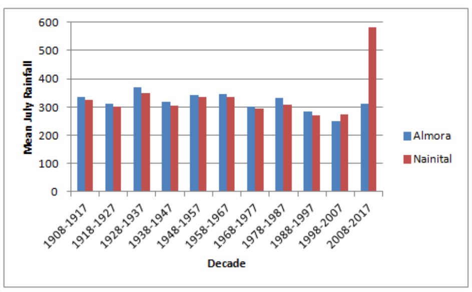

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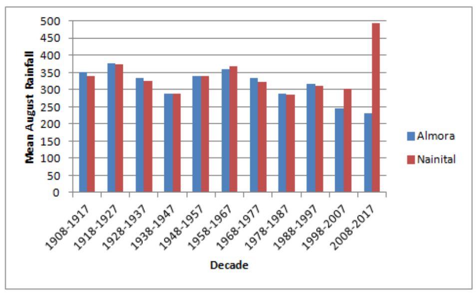


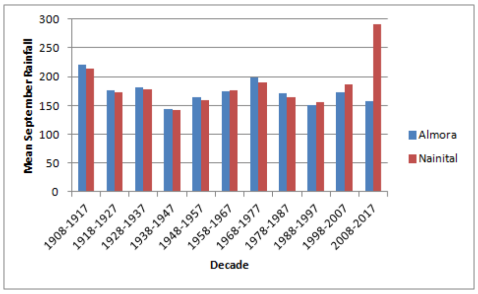
(h)

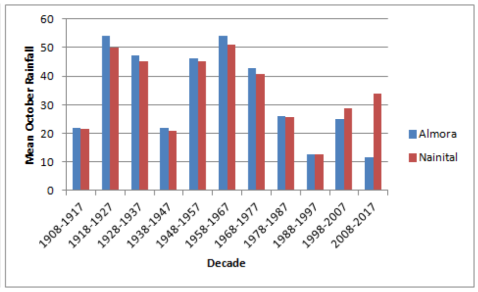
Figure 4. Decadal mean rainfall in (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November, (l) December, (m) Winter, (n) Pre-monsoon, (o) Monsoon, (p) Post-monsoon and (q) Annual for Almora and Nainital for the period 1908-2017.

de Luis et al. (2011); Jaswal et al. (2014); Nandargi and Aman (2018) and Nery et al. (2017).

People's Perception Study

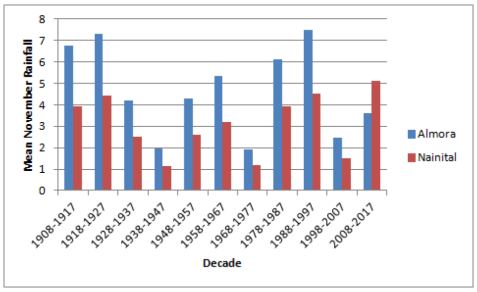
The people's perception study reveals that out of 105 respondents 86% were of the opinion that the climate of the study area has been changed during last 20 years. The main source of their income for the local inhabitants is from tourism, forest products (lichen collection) and agriculture. Most of the local peoples are dependent on rainfall for farming, as irrigation practices are not developed and they are shifting the cropping pattern grain production to vegetables. The Table 4 shows the Lichen distribution in Almora and Nainital districts (Mishra, 2011). The availability of lichens in the forest has also reduced due to various reasons like overharvesting, reduction in the number of rainy days and forest fire incidences. As per people perception, in recent years, the variability in rainfall has been more, the intensity of rainfall has increased, the amount of rainfall has come down and a greater number of heavy rainfall events has been observed which supports the results of meteorological data (Jangra and Singh, 2011; Jaswal et al. 2015; Kumar and Jain, 2010). All of these affected the availability of lichens in the area as lichen requires a

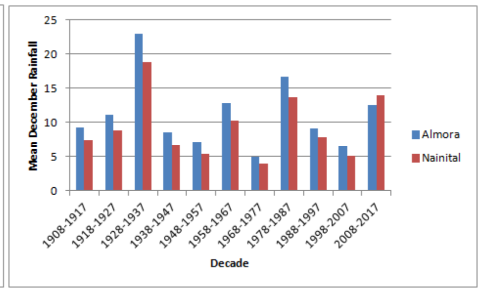




(i)

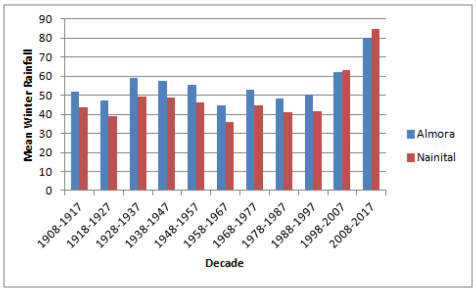
(j)

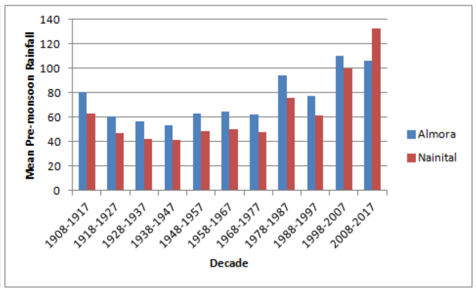




(k)

(l)

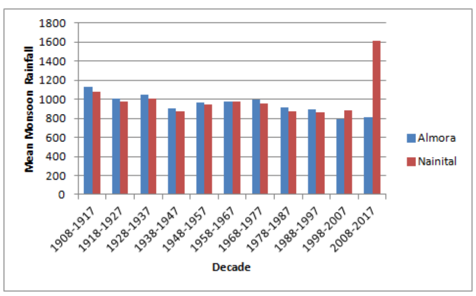


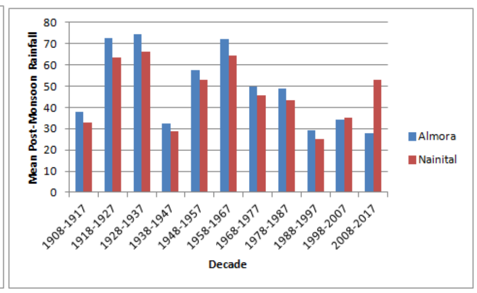


(m)

(n)

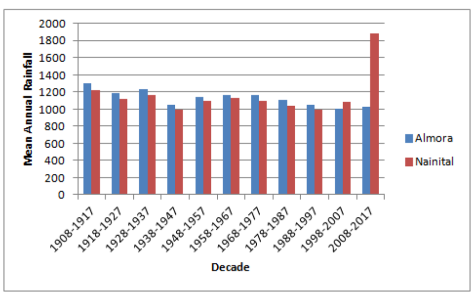
Figure 4 (continuation). Decadal mean rainfall in (i) September, (j) October, (k) November, (l) December, (m) Winter, (n) Pre-monsoon, for Almora and Nainital for 1901 to 2017.





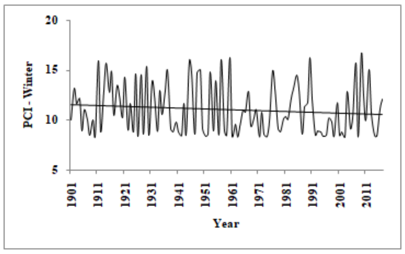
(o)

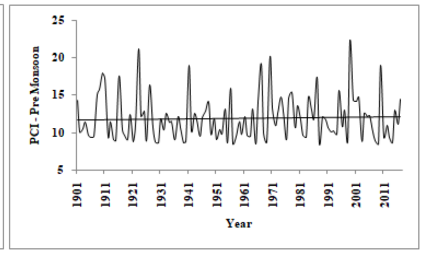
(p)



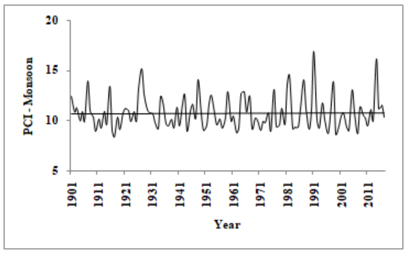
(q)

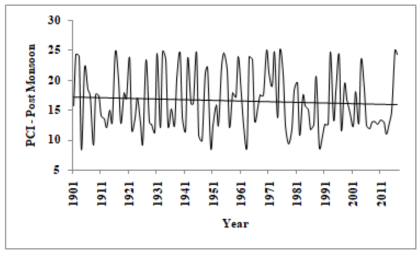
Figure 4 (continuation). Decadal mean rainfall in (o) Monsoon, (p) Post-monsoon and (q) Annual for Almora and Nainital for 1901 to 2017.



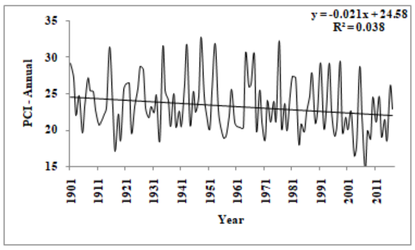


(a) (b)



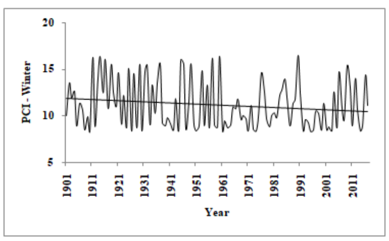


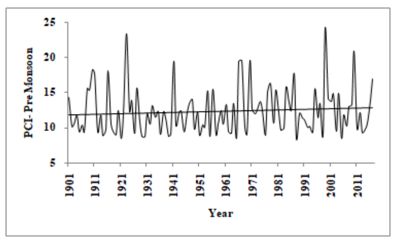
(c) (d)



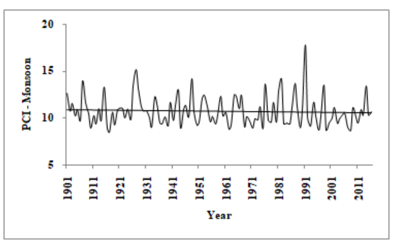
(e)

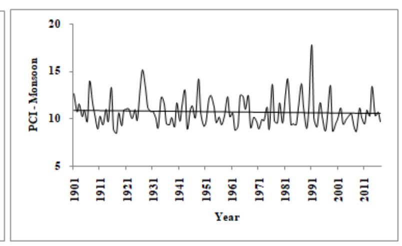
Figure 5. Temporal variations of significant PCI time series for Almora during (a) Winter, (b) Pre-monsoon, (c) Monsoon (d) Post-monsoon and (e) Annual.



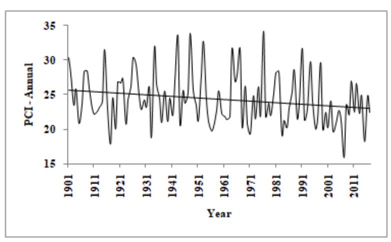


(a) (b)





(c) (d)



(e)

Figure 6. Temporal variations of significant PCI time series for Nainital during (a) Winter, (b) Pre-monsoon, (c) Monsoon (d) Post-monsoon and (e) Annual.

Table 4. Lichen distribution in Almora and Nainital districts.

District	Lichens	Dominant genera	Dominant species	Dominant Lichen family	Local Area	Tree Associates
Almora	112 species of lichens belonging to 41 genera and 20 families	*Heterodermia* (13 Species), *Lecanora* (10 Species) *Parmotrema* (10 Species) and *Usnea* (10 Species)	*Parmotrema tinctorum*, *Phaeophyscia hispidula* and *Usnea eumitrioides*	Parmeliaceae (11 genera, 36 species) Physciaceae (7 genera, 27 species)	The route from Ranikhet to Chaubattia, Binsar Wild Life Century, Binsar forest, Dalar Village, Khali estate, Ayarpani, Dinapani etc.	Moist, dense Forest of the smooth barks of trees. *Syzygium cumini*, *Shorea rubosta, Quercus leucotrichopora, Quercus floribunda, Quercus semecarpifolia, Pinus wallichiana, Pinus roxburghii*, *Rhododendron arboreum*, *Cedrus deodara, Alnus nepalensis* and *Betula utilis*
Nainital	105 species belonging to 48 genera and 21 families	*Heterodermia* (8 Species), *Caloplaca* (7 species) and *Lecanora* (7 species)	*Bulbothrix setschwanensis, Leptogium delavayi, Phaeophyscia hispidula*	Parmeliaceae (11 genera, 26 species) Physciaceae (8 genera, 20 species)	Kilbury, Snow view, D.S.B. campus, Ayarpatta, Pangot, Ghuggu Kham, Betal Ghat, Kunjakhara, Kosi Range, Nathuakhan, Naina Range	

greater number of rainy days of the year which supports their growth and reproduction. In the species of Oak (*Quercus leucotrichopora, Quercus floribunda, Quercus semecarpifolia*), Deodar (*Cedrus deodara*), Betula (*Betula utilis*), there is moisture due to heavy moss growth, where lichen also grow profusely. They have observed that availability of many common lichen species has come down in the area which may be attributed to change in rainfall pattern because lichen growth depends mainly on the monsoon rainfall and availability of moisture during post-monsoon and winter seasons. The perception of the respondents supports the analysis of observed rainfall that both, Almora and Nainital districts have high rainfall variability and more concentrated precipitation in post-monsoon season as PCI trend over the 117 years shows that there is decreasing trend for post-monsoon and winter seasons in both the districts. The people's perception about climate change is in agreement with the studies of other researchers (Aggarwal et al., 2015; Bhagat et al., 2018; Toan et al., 2014).

Conclusion

The study indicates that both the districts have highly irregular rainfall distribution and concentration across the months and most of the precipitation occurred in four months of monsoon. It also suggests that there is high rainfall variability and more concentrated precipitation in post-monsoon season. The total rainfall has significant increase in pre-monsoon and significant decrease in monsoon for Almora. Highly significant increasing trend in pre-monsoon rainfall has been observed for Nainital. The annual rainfall for both the district shows an increase in frequency of extreme rainfall as well as inter and intra-annual variability. On annual scale, there is significant decreasing trend for Almora while it is increasing but not significant for Nainital. The number of rainy days in a year have significant decreasing trend for Almora while it has decreasing trend for Nainital also but the trend is not significant. The trend of one day heaviest rainfall is increasing for both the districts and is not statistically significant for Almora but significant for Nainital. Less growth and regeneration of lichens in Almora and Nainital districts of Uttarakhand also suggests the changes in the rainfall pattern leading to climate change in the study area. Such region-specific long-term micro level studies are important to understand climate change impact and pattern in the rainfall particularly in the Himalayan belt towards agriculture and forest vegetation. The local people's perception and their holistic observation on climate vulnerability are important in justifying the long-term meteorological data interpretation. Based on the above, we suggest few broad recommendations:

1.Both overharvesting of lichens and low rainfall in the area are affecting lichen population status so we must control the harvest practice of lichens.

2.Such long-term study can be taken up in Forest Patches which are in protected areas where harvesting is restricted.

3. Climate Change vulnerability is already realized by local community and is disturbing the local farming practices therefore people's participation is very important towards mitigation and adaptation in the Himalayan districts.

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