

## Long Term Climate Change Assessment During 1907 - 2015 in the Kumaun Himalaya, Uttarakhand

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### ABSTRACT

Climate change is considered as a significant man-made global environmental challenge currently faced by the mankind today. The warming has a direct impact on the temperature sensitive snow and ice cover, geo-hazards and water supply. Objective of this study is to assess the long term climate change in the Kumaun Himalaya region. Monthly temperature and rainfall India Meteorological Department (IMD) data of years from 1907 to 2015 has been processed in the study. Monthly trend and statistical significance of rainfall and temperature were estimated using Mann-Kendall (MK) Test and the Sen's Slope Estimator. The results show that monthly, annual and seasonal air temperature has increasing trend at significant level during the past 109 years, as against the global average of 0.5°C. The overall monthly and annual precipitation has decreasing trend at significant level in all weather station under study except Mukteshwar. Annual mean minimum temperature of the Kumaun Himalaya region showed a very significant increasing trend and has increased by 1.026°C per 110 years during the period 1907-2015. This warming is mainly contributed by the winter and post-monsoon seasons, which have shown increasing trend at significant level as compared to other seasons in the last century. The rainfall over the region showing significant decreasing trend in monthly rainfall over the time. In monsoon season, rainfall is showing decreasing trend at significant level all over the Kumaun region but winter, pre monsoon and post monsoon season showing high degree of variability in trend and magnitude of rainfall.

**Key words:** Climate change, The Kumaun Himalaya, IMD, Mann-Kendall (MK) Test and Sen's Slope Estimator.

### INTRODUCTION

Climate change is considered as a significant man-made global environmental challenge currently faced by the mankind. It is also recognized as one of the most prominent threats for existence of human civilization. Evidences related to the climate change suggest that the temperature rise has been about 0.85°C since 1885, which is highest in the recorded history of the instrumental records and last three decades are the warmest (IPCC 2001, 2013, Allen et al. 2018). According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, the global mean surface temperatures rose by 0.74±0.18°C over the last 100 years (1906–2005). The rate of warming over the last 50 years (0.13±0.03°C/10 year) is nearly twice that over the last 100 years (0.07±0.02°C/10 year). The long-term trends in precipitation were also observed from 1900

to 2005 over many large regions (IPCC 2007a). The increase in the global mean temperatures by 2100 could range from 1.4 to 5.8°C, depending on the climate model and greenhouse gases emission scenario used for the change prediction. In the Indian sub-continent, temperatures rise is predicted to be about 3.5 to 5.5°C by 2100 (Lal 2002).

Climate change is outcome of wide range of human activity resulting in anthropogenic global warming (IPCC 2007b, 2014a, Allen et al. 2018). The climate change has been accelerated through the anthropogenic changes (Singh and SenRoy 2002), and has impacted the natural and human systems. In addition the extreme climatic events have also increased, imposing new levels of threats and risks to the human society (Mal et al. 2019, SREX 2012, IPCC 2014b, UNEP 2009). Anthropogenic warming has been 1°C above pre-industrial levels till 2017 and it is expected if the warming continues at the

present rate till 2040, the warming level will rise by 1.5°C. Further, there are enough evidences that support the fact that this anthropogenic warming led to increase precipitation extreme events across the world (Borgaonkar et al. 2001, Kumar et al. 2006, Hoegh-Guldberg et al. 2018, IPCC 2014c).

The climate change has cascading effects on the natural and human systems. The impacts on the physical and or natural systems include loss of ice and snow, increased river runoff seasonality, soil erosion, lowered capacities of river valleys and reduced water holding capacities and consequent flooding. The variation in climate has led to changes in freshwater regimes and is likely to affect the domestic and industrial water supplies, changes in biodiversity, agriculture and allied industrial-domestic activities etc. The Indian Himalayan region covers vast areas, with about 17% of the region being under permanent snow cover and glaciers, and about 30-40 per cent under seasonal snow cover, forming a unique water reservoir. Over the last decades, the Himalayan regions have gone up warmed by up to 1.6 degrees Celsius in last decades (Kumar et al. 2006, Bhutiyani et al. 2007, MoEF 2010). Recent studies on the Himalaya glaciers indicate a long-term climate variability, which may accelerate their melting (Lau et al. 2008, Prasad et al. 2009, Raina 2009, IPCC 2014b). Other studies have also suggested snowfall decline in recent decade as caused by winter warming specifically. The snowfall as a main source of feeding to the glaciers in this region also led to increased loss of glaciers mass (Eriksson et al. 2009). In the Himalaya, nature determined environmental fragility scores high. As glacial recession is taking place at a faster pace, a new equilibrium at the cost of loss of entire habitats is possible. For this reason, the Kumaun region has been identified as major critical regions in the Himalaya (IMD 2009, 2017, Scott et al. 2019). Rising temperatures are responsible for glacial fluctuation and climate change related geo-hazards in the Kumaun Himalaya region (Shrestha 1999, Singh 1998). In the face of global warming, most glaciers in the northern part of Kumaun Himalaya region have been retreating with greater pace. According to the Fourth Assessment Report of the IPCC (2007a), smaller glaciers are more vulnerable to a warmer world and climate change (Rosenzweig et al. 2008).

The total impact of all natural and anthropogenic factors is reflected in the variation of climate over different time scales (Singh et al. 2008).

## STUDY AREA

The Kumaun Himalaya region, the land of natural beauty, lush green forests, scenic valleys bubbling streams, emerald meadows, enchanting lakes, eternal snow, ethnic communities, and colorful people decorated with religious and mythological sites; is situated in the lap of the north-western Himalaya, is characterized by a mountainous topography and varied relief. The Kumaun Himalayan region which is lies within administrative boundary of Uttarakhand and the Kumaun Mandal has been taken as representative of the region. The total geographical area of the region is 21034 km<sup>2</sup> which is 39.33% of the total area of Uttarakhand state (Kumaun: Samajik-arthik sameeksha 2017). It stretches between 28°44' N to 30°49' N Latitudes and 78°45' E to 81°1' E Longitudes and geographically located in the eastern side of Garhwal Himalaya in the state Uttarakhand (Fig. 1). In the north, it is separated with international boundary from China by the Indo-Tibetan water divide, in the east Kali river defines its another international border with Nepal; the Gangetic plains of Uttar Pradesh makes its southern boundary; and in the west the region shares its boundaries with Chamoli and Pauri district of the Garhwal division. Geographically, situated between the plateau of Tibet in the north and the Gangetic plains in the south and the Kumaun region has a unique geographical location.

## DATA SOURCES

The present study aims to find out the changing trends of surface temperature, atmospheric temperature and rainfall of the Kumaun Himalaya region. In this study, try to analyze the most important climatic variables viz., 1) temperature and 2) precipitation for analyzing their trend. Before analyzing climate change and variability of study area, it is important to give details of type of climatic data and sources of data which has to be analyzed (Table 1). After a critical scrutiny and on the basis of percentage data availability, only seven IMD weather

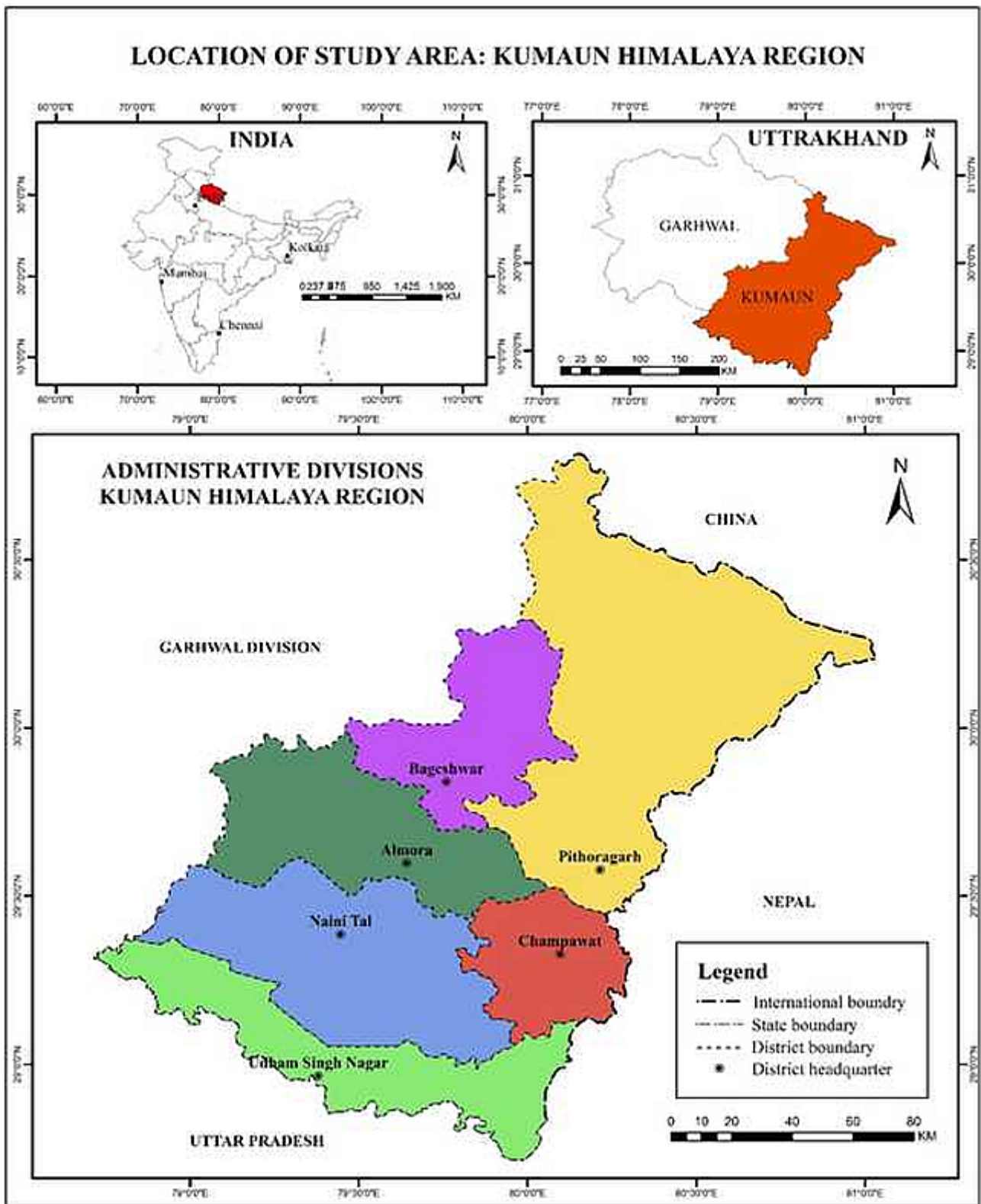


Figure 1. Location map of the study area  
 Source: Based on the Atlas of Uttarakhand (NATMO 2003)

Table 1. Details of available rainfall and temperature data used in the study

STATIONS	Lat. (deg.)	Long. (deg.)	Altitude (m)	Range	Availability (%)	Variables
ALMORA	29.59 N	79.65 E	1676	1901-2016	94.49	Rainfall
CHAMPAWAT	29.33 N	80.11 E	1638	1901-2016	83.48	Rainfall
HALDWANI	29.22 N	79.53 E	348	1901-2015	89.90	Rainfall
MUKTESHWAR	29.47 N	79.65 E	2311	1901-2015	98.16 and 96.33	Rainfall and Temperature
PITHORAGARH	29.58 N	80.22 E	1650	1901-2016	81.65	Rainfall
RAMNAGAR	29.38 N	79.12 E	360	1901-2016	86.23	Rainfall
RANIKHET	29.64 N	79.42 E	1824	1901-2016	85.32	Rainfall

Source: IMD tab-2 data

stations that have relatively good quality data (missing values less than 5 per cent) are chosen due to their close proximity to glaciated region and also for regular data recording for a common period of 1907-2015. The IMD weather station in the region namely Almora, Champawat, Haldwani, Mukteshwar, Pithoragarh, Ramnagar and Ranikhet are selected for the climate change assessment on the basis of data availability. Only two climatic variables such as temperature and rainfall have been taken in to consideration to find out climate change in the region. All the data gaps were filled up by the normal ratio method using IMD data from seven weather stations.

## METHODOLOGY

Global warming is a comprehensive weather phenomenon but magnitude of warming has been vary from particular region to region and place to place. Quantitative assessment of the spatio-temporal distribution of change in temperature and rainfall are the powerful tools to assess the status of climate change at global, national, regional and local level. In order to analyze climate change and variation in study area, temperature and rainfall data of last 109 years has been tabulated in MS word excel sheet. Monthly temperature and rainfall IMD long term time series tab-2 data of years from 1907 to 2015 has been processed in the study. Monthly trend and statistical significance of rainfall and temperature were estimated using Mann-Kendall (MK) Test and the Sen's Slope Estimator. Three variables related to temperature, viz. mean maximum, mean minimum and average monthly temperature, were considered

for climate change analysis on monthly, annual and a seasonal basis. Monthly rainfall data has been analyzed to assess the monthly, annual and seasonal trend and magnitude climate change in the Kumaun Himalaya. Seasonal series were prepared from the monthly data to match the definition of seasons given for Uttarakhand (Bhutiya et al. 2007). The whole year has been divided in to four season i.e. winter season (December, January and February), pre monsoon (March, April and May), monsoon season (June, July and August) and post monsoon season (September, October and November). The temperature and rainfall data has been clubbed and classified on the basis of season. The tabulated and well-arranged data run through Matlab 9.5 software. Then non-parametric Mann-Kendall trend test and Sen's slope estimator were employed at 95 per cent confidence level to determine the possible trends and the magnitudes of trend in Rainfall and Temperature at monthly, annual and seasonal level for each surface station. The trend analysis is used to determine mean maximum, mean minimum and average trend in temperature and rainfall data for 1907 to 2015, acquired from India Meteorological Department (IMD) Pune.

### Mann-Kendall

Mann-Kendall trend is frequently used for trend analysis in climate change study. It is not affected by data gap and inaccurate measurement in a time series data. In this study, Mann-Kendall trend has been applied to detect the existing trend in annual, monthly and seasonal trends in climate variables. Non-parametric Mann Kendall trend analysis (Mann 1945, Kendall 1955, Partal and Kahya 2006, Ahmed

et al. 2014) test has applied to find the exiting monthly, annual and seasonal trend in climate variables at 95% confidence level and 5 per cent significance level. The MK test statistics (S) and sign are defined as follows:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sgn}(x_j - x_i) \dots\dots\dots (1)$$

Where N is the number of data points. Assuming  $(x_j - x_i) = \theta$ , the value of  $\text{sgn}(\ )$  is computed as follows:

$$\text{sgn } \theta = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \dots\dots\dots (2)$$

A positive value of ‘S’ indicate rising trend and vice-versa. The significance of ‘S’ is checked by computing standardized test static ‘Z’. This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples ( $N > 10$ ), the test is conducted using a normal distribution. With the mean and the variance as follows:

$$E [S] = 0$$

$$\text{var}(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^n t_k(t_k-1)(2t_k+5)}{18} \dots\dots\dots (3)$$

Where n is the number of tied (zero difference between compared values) groups and  $t_k$  the number of date points in the  $k^{\text{th}}$  tied group. The standard normal deviate (Z-statistics) is then computed as.

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} & \text{if } S > 0. \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}} & \text{if } S < -0 \end{cases} \dots\dots\dots (4)$$

The statistically significant trend is calculated using the Z value at the level of significance. If the compute of  $[Z] > z_{\alpha/2}$ , the null hypothesis (H0) is rejected at  $\alpha$  level of significance in a two-sided test. In the

analysis, the null hypothesis was tested at 95% confidence level and 5 per cent significance level i.e.  $\alpha = 0.05$ , which is rejected if  $|Z|$  value less than 1.96. Positive values of Z represent increasing trends, while negative values indicate decreasing trends. The null hypothesis (H0) of no trend is accepted.

**Sen’s slope estimator**

Sen’s slope estimator has been broadly used for determining the magnitude of trend in hydro-meteorological time series climatic data. For the present study, exiting trend in temperature and rainfall have been computed by Mann–Kendall and magnitude of the change over the period as percentage of mean estimated by San’s slope estimator (Yue and Hashino 2003). In this method, the slopes (Ti) of all data pairs are first calculated by-

$$T_i = \frac{x_j - x_k}{J - K} \quad \text{for } i = 1, 2, \dots, N. \dots\dots\dots (1)$$

Where  $x_j$  and  $x_k$  are data values at time J and k ( $J > k$ ), respectively. The median of these N values  $T_i$  is Sen’s slope estimator of slope, which may be calculated as

$$\beta = \begin{cases} \frac{T_{N+1}}{2} & \text{N is odd} \\ \frac{1}{2} \left( \frac{T_{N/2} + T_{N/2+1}}{2} \right) & \text{N is even} \end{cases} \dots\dots\dots (2)$$

A positive value of  $\beta$  indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

**RESULTS AND DISCUSSION**

Climate change is a comprehensive weather phenomenon but magnitude of climate change has been variation vary from particular region to region and place to place. Change in the land surface temperature and the pattern of rainfall and temperature increases have occurred all over the world. In another study, the temperature and precipitation values through trend analysis of the Kumaun Himalaya was said to be particularly sensitive to climatic changes (Dimri and Kumar

2008). The assessment of climate change over the Kumaun Himalaya region is based on IMD climate data analysis for the period 1907 to 2015 give some indications of higher than average impacts of climate change in the region. From the studies covering over 109 years of records, average air temperatures were found to be 1.6°C higher than that in the 1901's, as against the global average of 0.5°C; the Kumaun Himalaya region trend indicates significant increasing trend in past century. An analysis of rainfall data over the period shows significant negative trend in the Kumaun Himalaya region.

### Temperature trend over the Kumaun Himalayan Region

Temperature is the most important climatic factor and has a significant role in the identification of global climate variability. Temperature is rising more rapidly in the Himalaya than the global average (UNFCCC 2004, USAPCC 2012, IMD 2009). In order to demonstrate the statistical significance of the trends in long-term mean maximum, mean minimum and average temperature values of the Mukteshwar station in the study area has been done through Mann-Kendall test and Sen's slope estimator. Long-term (1907-2015) monthly mean maximum, mean minimum and average temperature IMD data of the Mukteshwar station in the Kumaun region are analyzed to examine the potential climatic changes

at monthly, annual and seasonal parameters.

Result indicates that the regional trends of the temperature series generally agree with national level. In order to evaluate the result, the significant rising trend in long-term temperature have occurred in the Kumaun Himalaya for mean maximum, mean minimum and average temperature at monthly, annual and seasonal level. The temperature has increased gradually and continuously over this period. This warming was mainly due to increasing temperatures in the winter and post-monsoon seasons. These results validated with the predictions made by IPCC 2014 climate change report for Himalayan region.

### Monthly average temperature trend

Estimation of long-term change in trends and magnitude of temperature trends has been the subject matter of a large number of studies. The snow cover and glacial region of the northern Kumaun Himalaya are very sensitive to that increasing trend in temperature in last century and finally pose the negative impact on glaciers mass balance and may increase the risk of associated geo-hazards in near future. In order to demonstrate the statistical significance of the trends in long-term monthly mean maximum, mean minimum and average temperature values of the Mukteshwar station in the study area, result indicates the increasing trend in temperature

Table 2. Monthly temperature trend 1907-2015

Months	Mean MAX		Mean MIN		Average	
	Mann-Kendall	Sen's slope	Mann-Kendall	Sen's slope	Mann-Kendall	Sen's slope
January	<b>3.10</b>	0.02	<b>-2.09</b>	-0.01	1.60	0.01
February	<b>4.68</b>	0.03	-0.14	0.00	<b>4.31</b>	0.02
March	<b>3.02</b>	0.02	-1.37	-0.01	<b>2.14</b>	0.01
April	<b>3.91</b>	0.03	<b>-2.29</b>	-0.01	<b>2.78</b>	0.01
May	<b>2.60</b>	0.01	<b>-4.03</b>	-0.02	1.82	0.01
June	1.49	0.01	<b>-2.84</b>	-0.01	1.11	0.00
July	1.45	0.00	<b>-2.37</b>	-0.01	<b>2.84</b>	0.01
August	<b>2.97</b>	0.01	<b>-2.13</b>	0.01	<b>3.01</b>	0.01
September	<b>2.92</b>	0.01	<b>-2.45</b>	-0.01	<b>2.58</b>	0.01
October	<b>3.49</b>	0.02	<b>-2.68</b>	-0.01	1.92	0.01
November	<b>5.88</b>	0.03	-1.84	-0.01	<b>2.12</b>	0.01
December	<b>4.62</b>	0.03	-0.92	0.00	<b>2.48</b>	0.01
Annual	<b>7.05</b>	0.02	<b>-2.66</b>	-0.01	<b>4.86</b>	0.01

has been continue during 1907 to 2015 (Table 2).

Mean monthly temperatures showed a significant warming trend in all months during 1907-2015. According to the Mann-Kendall test, results statistically significant rising trends in average temperature have occurred in the region where they vary between + 1.11 in June to + 4.31 in February. Significant increasing trend in average monthly temperature observed in of February, March, April, July, August, September, October, November and December except January, May and June (Fig. 2).

The monthly mean maximum temperature during 1907-2015 also showed an increasing trend with significant increasing trend in January, February, March, April, April, August, September, October, November and December maximum temperature, and relatively lower significant trend in June and July. The significant increasing trend in mean minimum monthly temperature in month of January, April, April, June, July, August, September and October and significant increasing trend February, March, November and December indicate the comparatively shorter winter season. The magnitude of the warming trend in mean maximum temperature has been observed in month of January, February, March, April, October, November and December. Shorter winter time definitely accelerate the rate of glacial melting and posing negative impact on glacier mass balance in the area. Mean maximum and mean minimum temperature monthly trend line plotted on graph is showing increasing trend in almost in all month but magnitude of the trend comparatively higher in the month of March, April, April, June, July, August, September, October, November and December. The solid saffron, green and yellow color curve represents the monthly trend variation smoothed with a binomial filter.

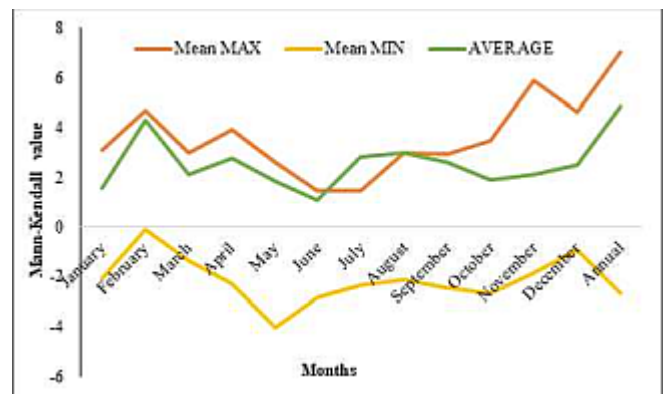


Figure 2. Monthly and annual temperature trend, 1907-2015

### Seasonal temperature trend

For the Kumaun Himalaya region as a whole, Season wise Annual Maximum Temperature shows an increasing trend during all the four: winter, pre-monsoon, monsoon and post monsoon season over the period 1907–2015 (Table 3). On the seasonal level, the trends in the frequency of occurrence of temperature extremes are slightly different. The homogeneous trend shows in monsoon season but winter and summer seasons show a significant fluctuating trend in all three parameter.

On this scale, pronounced warming trends in average temperature were observed in winter season and accelerated warming has been observed in the recent period 1977–2015, mainly due to intense warming. However, for the recent period only, winter and post-monsoon temperatures showed significant warming trends and the other seasons showed a warming tendency (trend not significant). Mean maximum temperature for all season is showing increasing trend from the year 1907 to 1015. The plotting of the maximum temperature data shows a tendency of rapid increase 1990 onward. The winter

Table 3. Seasonal temperature trend 1907-2015

Seasons	Mean MAX		Mean MIN		Average	
	Mann-Kendall	Sen's slope	Mann-Kendall	Sen's slope	Mann-Kendall	Sen's slope
Pre-Monsoon	<b>4.52</b>	0.02	<b>-3.11</b>	-0.01	<b>2.96</b>	0.01
Monsoon	<b>3.10</b>	0.01	<b>-2.69</b>	-0.01	<b>2.95</b>	0.01
Post-Monsoon	<b>5.90</b>	0.03	<b>-2.22</b>	-0.01	<b>2.56</b>	0.01
Winter	<b>6.05</b>	0.03	-1.26	0.00	<b>4.20</b>	0.02

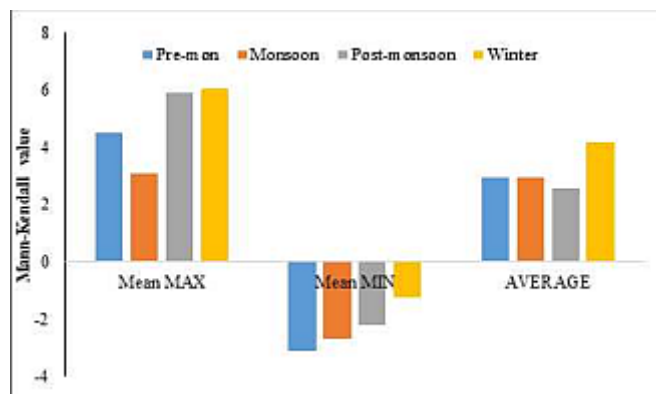


Figure 3. Seasonal temperature trend 1907-2015

and post-monsoon season show comparatively highest increasing trend in seasonal mean Maximum Temperature. In contrast, the mean minimum temperature over Kumaun indicates increasing trend at significant level in all seasons during 1907 to 2015 but highest increasing trend observed in pre-monsoon season as compared to winter season (Fig. 3).

The mean minimum temperature in winter season estimated insignificant increasing trend that indicate the almost negligible increasing trend in winter season. This warming is mainly contributed by the winter and post-monsoon seasons, which have shown increasing trend at significant level as compared to other seasons in the last century. The mean maximum temperature of pre-monsoon and monsoon temperatures also indicate a warming trend at significant level. Monsoon season follows the pre-monsoon and the seasonal temperature variation is considerably modified by the southwest monsoon. The temperature has increased gradually and continuously over this period. This warming was mainly due to increasing temperatures in the winter and post-monsoon seasons. Kothawale and Rupa Kumar (2005) reported earlier that over this region, pre-monsoon maximum temperatures have increased significantly. The significant decreasing trend in cold days over these two regions may be a manifestation of the increasing trend in seasonal maximum temperatures. Further, Kripalani et al. (2003) have reported that the “spring snow cover of Western Himalaya has been declining and that the snow is melting faster from winter to spring after 1993”, which is consistent with the trends observed in the present study. During the pre-monsoon (April and May) and early winter (September, October and

November) season, the Indian region is marked by clear skies, which, coupled with intense as well as increased solar radiation, results in high temperatures.

#### Annual temperature trend

Indian annual mean temperature showed significant warming trend of 0.51 °C per 100 year, during the period 1901–2007 (Kothawale et al., 2010). Accelerated warming has been observed in the recent period 1971–2007, mainly due to intense warming in the recent decade 1998–2007. The overall annual average temperature in the Kumaun Himalaya region showed (Table 4) an increasing tendency with significant increasing trend in all three parameters e.g. mean maximum, mean minimum and average annual temperature. Highest increasing trend observed in mean maximum temperature and relatively lower increasing trend in mean minimum temperature during 1907 to 2015.

Table 4. Annual temperature trend, 1907-2015

Temperature	Mann-Kendall	Sen's slope
Mean Max	<b>7.05</b>	0.02
Mean Min	<b>-2.66</b>	-0.01
Average	<b>4.86</b>	0.01

The magnitude of monthly mean maximum temperature is highest (0.02%) as compared to mean minimum and average temperature. Highest increasing trend in mean maximum accelerate the glacial melting followed by increase the risk of geohazards in the region.

#### Rainfall trend over the Kumaun Himalayan Region

The Kumaun Himalaya region with highly diverse rainfall conditions and observations of rainfall and temperature suggest that climate of the Kumaun Himalaya is dry and cold because of its higher elevations and location in the interiors of Greater Himalaya (Khacher 1978). Rainfall over the Kumaun region as a whole during the SW monsoon season, which is the principal rainy season was normal. Rainfall data of seven rain gauge station in the Kumaun Himalaya region has been selected for trend

analysis. In the surface weather station, the Almora, Champawat, Haldwani Ramnagar are located in southern and Mukteshwar and Pithoragarh in the northern part of Kumaun Himalaya. The Haldwani and Ramnagar are lower elevation observatories (southern most parts) and Almora, Champawat, Mukteshwar, Pithoragarh and Ranikhet are upper elevation observatories (Table 5). Decreases of significant trend above 1.92 and magnitude greater than 0.01 were shown according to seven weather station. Change percentage test was able to detect all the increase/decrease that is significant statistically.

The result of the data processing is showing negative trend and magnitude in rainfall in the area. Results emphasize the uneven rainfall distribution in the Kumaun Himalaya region. It was found that all selected rain gauge are showing significant decreasing trends computed using Mann-Kendal test at 5 per cent significance level. Overall results indicate that the decrease is visibly more pronounced in the southern part of the region and generally consistent in northern part of the region. Generally, the intense rainfall events in many parts of the Kumaun Himalaya has increased, which have been causing many extreme events in the region including floods, landslides, and debris and mud flows, while on the other end the amount of rainfall has decreased over the period of time (Izrael and Anokhin 2001, Ruosteenoja et al. 2003, Zhai and Pan 2003, Gruza and Rankova 2004). Total and extreme precipitation trends have strong variability, with mixed trends observed in different parts and seasons of the Kumaun Himalaya region.

**Monthly average rainfall trend**

Rainfall trends, including extremes, are characterized by strong variability, with almost decreasing trends observed in the region over the time. In the Kumaun region as a whole, annual total rainfall day has decreased, while rainfall from extreme rain days has increased, but climate variability and trends differ vastly across the region and between stations. In the northern part of Kumaun, the observations indicate some insignificant increasing trends in February, March, April and May at Mukteshwar rain gauge. Monthly precipitation result of Almora station showing negative trend at significant level in month

Table 5. Monthly and annual rainfall trend 1907-2015

RAIN GAUGE	Trend details	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
ALMORA	Mann-Kendall	-2.06	-2.14	-1.79	-2.46	-2.25	-3.70	-3.21	-2.51	-1.68	-2.28	-1.64	-2.34	-4.68
	Sen's slope	-0.03	-0.04	-0.02	-0.02	-0.05	-0.54	-0.65	-0.30	-0.01	0.00	0.00	0.00	-2.77
CHAMPAWAT	Mann-Kendall	-3.84	-4.73	-4.42	-4.12	-5.06	-5.29	-3.19	-4.55	-4.71	-3.60	-3.54	-2.98	-5.29
	Sen's slope	-0.27	-0.42	-0.33	-0.13	-0.47	-1.84	-1.87	-2.23	-1.27	-0.04	0.00	0.00	-9.900
HALDWANI	Mann-Kendall	-4.39	-4.89	-4.07	-2.02	-4.24	-4.44	-3.79	-5.15	-3.82	-3.09	-1.88	-3.15	-5.34
	Sen's slope	-0.16	-0.23	-0.05	0.00	-0.14	-1.92	-3.88	-4.78	-1.79	0.00	0.00	0.00	0.64
MUKTESHWAR	Mann-Kendall	-0.53	0.38	0.09	0.27	0.16	-1.79	-2.13	-1.16	-0.57	-1.24	-1.07	-1.15	-1.86
	Sen's slope	-0.05	0.04	0.01	0.01	0.02	-0.53	-0.92	-0.54	-0.19	-0.04	0.00	0.00	-2.04
PITHORAGARH	Mann-Kendall	-3.52	-4.60	-3.97	-4.07	-3.70	-5.19	-3.77	-4.78	-3.70	-2.76	-2.69	-2.29	-5.22
	Sen's slope	-0.13	-0.24	-0.15	-0.13	-0.32	-1.60	-1.70	-2.22	-0.90	-0.02	0.00	0.00	-7.61
RAMNAGAR	Mann-Kendall	-5.01	-5.02	-3.95	-3.08	-4.44	-4.95	-5.39	-6.01	-5.47	-3.39	-2.09	-3.83	-6.56
	Sen's slope	-0.22	-0.21	-0.12	0.00	-0.11	-1.2	-3.93	-4.26	-1.67	0.00	0.00	0.00	-13.71
RANIKHET	Mann-Kendall	-3.82	-3.64	-3.06	-3.80	-3.74	-2.96	-3.91	-4.54	-4.22	-3.69	-2.65	-2.70	-4.9
	Sen's slope	-0.17	-0.15	-0.09	-0.11	-0.17	-0.35	-1.17	-1.55	-0.75	-0.02	0.00	0.00	-5.24

of January, February, April, May, June, July, August, October, and December and insignificant decreasing trend March, September and November. July and August.

As far as magnitude of change are concerned, highest magnitude of change observed in June. In contrast, Champawat station showing negative trend at significant level in all month. Highest magnitude of change in monthly rainfall are observed in month of January, February, March, April, May, June, July and August. In Haldwani, the downward trend observed in all months at significant level. The magnitude of rainfall decrease is very high in month of June, July, August and September. In Pithoragarh rain gauge, downward trend at significant level observed in Monthly rainfall pattern in all month. As far as magnitude of change are concerned, highest magnitude of change in Pithoragarh rain gauge observed in June, July and August. In Ramnagar and Ranikhet weather station, significant decreasing trend observed in all months.

The magnitude of rainfall decrease is very high in Ramnagar month of July, August and September followed by July and August in Ranikhet. Weather station situated on high altitude e.g. Almora and Mukteshwar recorded lower decreasing trend in rainfall as compared to rain gauge situated at low altitude e.g. Haldwani, Ramnagar, and Ranikhet. Data analysis from seven stations for showed highly significant decreasing trend mean monthly rainfall over the Kumaun Himalaya region during the period 1907-2015. This substantial decrease in monthly rainfall which may be due to cascading impact of increasing temperatures in the region (Fig. 4).

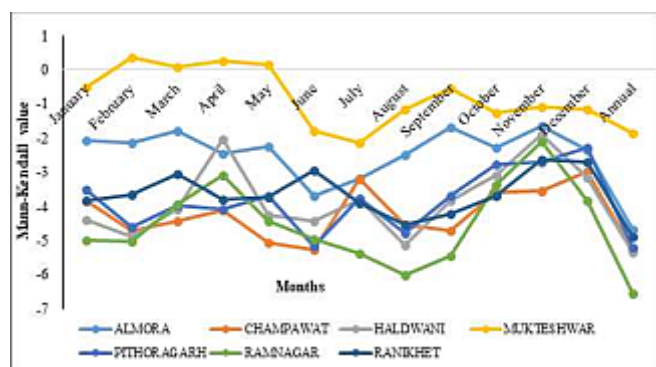


Figure 4. Monthly and annual rainfall trend 1907-2015

Though the linear presentation of monthly data, however station wise rainfall data paints a very different picture. Out of total seven selected weather station in the Kumaun Himalaya region, five rain gauge namely Champawat, Haldwani, Pithoragarh, Ramnagar and Ranikhet indicate high significant decreasing and fluctuating trend in monthly rainfall as compared to Almora and Mukteshwar rain gauge during 1907-2015.

Overall monthly rainfall distribution (Table 6) in the region has been highly scattered and also witnessed unusual rainfall events. The district wise percentage monthly departure for year 2016 were also showed the substantial decrease in monthly rainfall in almost all months and increase in extremely high rainfall in few months.

District wise monthly rainfall data shows a very different picture. All the six districts in the Kumaun Himalaya region received deficit rains in months of in all months except May and June. The incident of extreme rainfall over the region observed in May and months of January, November and Decembers receives almost 100 per cent less rainfall.

#### *Seasonal average precipitation trend*

The results of station-wise seasonal rainfall IMD data showing highest percentage of rainfall occur during monsoon season. Overall seasonal distribution of rainfall over the region showing significant decreasing trend during 1907-2015 (Table 7).

On the seasonal scale, the rainfall over the region showing significant decreasing trend in all seasons during the period 1907–2015. The southwest monsoon season is the principal rainy season over the region. In the Kumaun region as a whole, annual total rainfall day has decreased, while rainfall from extreme rainy days has increased, but climate variability and trends differ vastly across the region and between different seasons. While an increasing frequency of extreme rainfall events has been reported high in the region. Of the total annual rainfall, about 73% is received in the southwest monsoon season (June, July and August), about 9% is received in the winter season (December, January and February), about 11% is received in the pre-monsoon season (March, April and May) and about 6% is received in the post-monsoon season (September, October and November). The percentage

Table 6. District-wise monthly departure (%) of rainfall-2016

District	January	February	March	April	May	June	July	August	September	October	November	December
Almora	-92	-70	31	-70	21	-41	42	-16	-48	-100	-100	-98
Bageshwar	-100	-84	16	-90	310	49	91	-6	-56	-94	-100	-100
Champawat	-94	-71	-55	-87	77	-25	30	-45	-29	-75	-100	-100
Nainital	-97	-58	61	-72	163	10	39	-11	-24	-83	-100	-98
Pithoragarh	-72	-44	-31	-72	122	-21	0	-40	-51	-40	-100	-56
Udham Singh Nagar	-99	-90	-71	-13	132	-34	-14	-68	-60	-99	-100	-72

Table 7. Seasonal rainfall trend 1907-2015

RAIN GAUGE	Trend details	Pre-monsoon	Monsoon	Post-monsoon	Winter
ALMORA	Mann-Kendall	<b>-2.50</b>	<b>-3.90</b>	<b>-2.79</b>	<b>-3.12</b>
	Sen's slope	-0.18	-1.75	-0.06	-0.30
CHAMPAWAT	Mann-Kendall	<b>-5.07</b>	<b>-4.74</b>	<b>-4.74</b>	<b>-5.35</b>
	Sen's slope	-1.24	-7.34	-0.24	-1.41
HALDWANI	Mann-Kendall	<b>-4.25</b>	<b>-5.00</b>	<b>-3.75</b>	<b>-6.66</b>
	Sen's slope	0.07	0.47	0.01	0.06
MUKTESHWAR	Mann-Kendall	0.16	<b>-1.94</b>	-1.54	-0.69
	Sen's slope	0.03	-1.77	-0.12	-0.15
PITHORAGARH	Mann-Kendall	<b>-3.90</b>	<b>-5.12</b>	<b>-3.6</b>	<b>-4.59</b>
	Sen's slope	-0.96	-6.70	-0.11	-0.94
RAMNAGAR	Mann-Kendall	<b>-4.43</b>	<b>-6.55</b>	<b>-4.48</b>	<b>-6.60</b>
	Sen's slope	-0.43	-11.75	-0.06	-1.06
RANIKHET	Mann-Kendall	<b>-3.76</b>	<b>-4.55</b>	<b>-4.43</b>	<b>-4.65</b>
	Sen's slope	-0.61	-4.03	-0.11	-0.76

of the seasonal number of rainy days with respect to the annual number of rainy days is 63% for the southwest monsoon season, 16% for the pre-monsoon season, 7% for the post monsoon season and 13% for the winter season. In monsoon season, rainfall is showing decreasing trend at significant level all over the Kumaun region but winter, pre monsoon and post monsoon season showing high degree of variability in trend and magnitude of rainfall.

The Kumaun region as a whole, rain gauge station wise trend analysis of seasonal precipitation over the region showing negative trend at significant level in all station with high magnitude of the change. As far as magnitude of change are concerned, highest magnitude of change observed in monsoon season. Seasonal precipitation result of Almora, Champawat, Haldwani, Pithoragarh, Ramnagar and Ranikhet station showing negative trend at significant level in all season but highest magnitude of negative trend observed in monsoon season with varying rate. Among these, the highest magnitude of negative change in monsoon season observed in Ramnagar (-11.75) rain gauge. In contrast, Mukteshwar rain gauge station showing negative trend at significant level only in monsoon season with highest magnitude of change. In Mukteshwar rain gauge, a weak but non-significant downward trend in mean seasonal precipitation observed in post-monsoon and winter season and non-significant upward trend observed in pre-monsoon season, although with an increase in intense weather events. Data analysis from seven stations for showed highly significant decreasing trend mean seasonal rainfall over the Kumaun

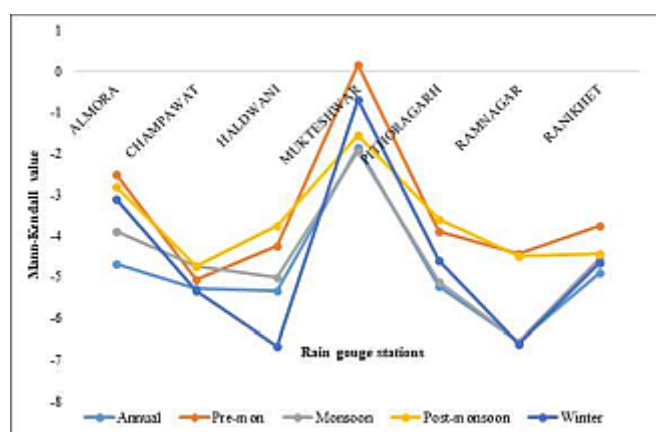


Figure 5. Annual and seasonal rainfall trend 1907-2015

Himalaya region during the period 1907-2015 (Fig. 5).

In the region, seasonal rainfall shows inter-decadal variability, noticeably a decreasing trend with more frequent deficit of rainfall in south-west monsoon season. There is a substantial decreasing trend in seasonal rainfall and particularly highest in south west monsoonal rainfall, that may be an indication of climate change in the Kumaun Himalaya region.

Overall district wise seasonal and annual rainfall distribution (Table 8) in the Kumaun Himalaya region showing very different picture and also witnessed unusual rainfall events. The district wise percentage seasonal rainfall for year 2016 were also showed the substantial decrease in winter and post-monsoon season as compared to rainfall in pre-monsoon and monsoon season. In Bageshwar district increase in extremely high (106%) rainfall in pre-monsoon season. District wise annual rainfall data shows a very different picture.

Table 8. District-wise departure (%) of seasonal and annual rainfall-2016

District	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Almora	-81	6	0	-99	-13
Bageshwar	-92	108	28	-96	17
Champawat	-83	-1	-12	-82	-20
Nainital	-79	86	7	-86	2
Pithoragarh	-57	30	-25	-51	-23
Udham Singh Nagar	-96	54	-43	-97	-25

Out of total six districts in the Kumaun Himalaya region, four districts namely Almora, Champawat, Pithoragarh and Udham Singh Nagar have received deficit rains in a year, whereas two districts which include Bageshwar and Nainital have got rainfall in excess. The Champawat district have receive deficit rainfall in all season followed by annual rainfall. The highly fluctuating trend of seasonal and annual rainfall in Kaumaun Himalaya region indicates the status of climate change in the region.

#### Annual average precipitation trend

Trend estimation of annual rainfall at seven rain gauge in the Kumaun Himalaya region is done in

this study. The results Mann-Kendall test indicate that majority of rain gauge stations show decreasing trend in annual rainfall at significant level during 1907-2015. Comparatively higher decreasing trends are found in low altitude region than high altitude regions of the Kumaun Himalaya. The total annual rainfall in the region is maximum over the northern part. Decreasing annual rainfall will result in a decrease in water availability in the region. Change is detected in the mountainous part of the Kumaun Himalaya region shows that high altitude regions in gets affected earlier due to climate change (Table 9 and Fig. 6).

Table9. Annual rainfall trend 1907-2015

RAIN GAUGE	Mann-Kendall	Sen's slope
ALMORA	-4.68	-2.77
RANIKHET	-4.9	-5.24
CHAMPAWAT	-5.29	-9.9
HALDWANI	-5.34	0.64
MUKTESHWAR	-1.86	-2.04
PITHORAGARH	-5.22	-7.61
RAMNAGAR	-6.56	-13.71
RANIKHET	-4.9	-5.24

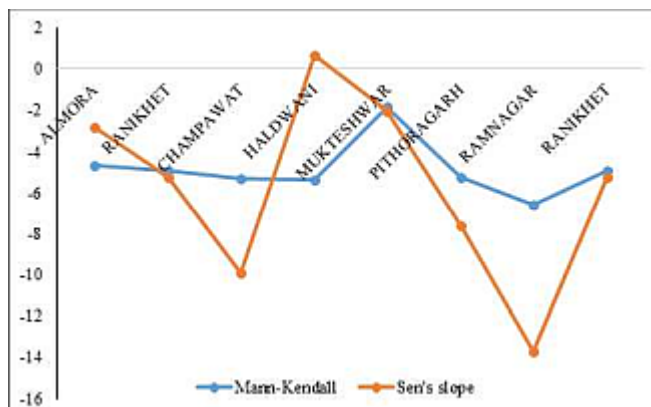


Figure 6. Annual rainfall trend 1907-2015

Annual mean rainfall trend plotted for selected weather stations are clearly indicate the negative trend and magnitude of yearly rainfall but the magnitude of change vary from station to station. Mukteshwar station situated on higher altitude showing lowest change in annual rainfall. Maximum change in trend and magnitude of annual rainfall

observed in Ramnagar and Ranikhet station.

## CONCLUSION

The trend and magnitude analysis in the climate parameters such as temperature and precipitation revealed a significant change in climate during 1907-2015. Analysis of recent climatic trends reveals a significant warming trend in recent decades which has been even more pronounced in the region. Before discussing the micro level trend/relationship a general assessment of climate profile of India has been dealt in brief. Analysis of data for the period 1907-2015 suggests that annual mean temperature for the country as a whole has risen by 0.56°C. The Kumaun Himalaya region as a whole, the annual and monsoon rainfall for the period 1907-2015 show any negative trend at significant level in all rain gauge station except Mukteshwar. Decreasing rainfall will result in a decrease in water availability. But in the region as a whole, significant negative trend and magnitude of change at monthly, annual and seasonal level has been noticed in the region where mean annual temperature is showing an increase. Increase in temperature has resulted into retreat in snow area. Overall climate change is the result of season wise changes in temperature, cloud cover and the timing, intensity, duration, and form of precipitation (i.e. snow versus rain), all of which are equally important determinants of glacial retreat in the area. Climate change is also affecting the amount of snow and ice and rainfall patterns in the Kumaun Himalaya region as well as Himalayan region. Change in trend and magnitude of climatic variables under climate change scenarios are useful for better understanding of the future climate.

**Authors' contributions:** All authors contributed equally

**Conflict of interest:** Authors declare no conflict of interest

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