

The Impact of Climate Change on Rainfall Variability: A Study in Central Himalayas

L.N. Thakural, Sanjay Kumar, Sanjay K. Jain and Tanveer Ahmad

Abstract The impact of anthropogenic activities on the earth atmosphere and its systems has been an area of extensive research and engaging the attention of planners, governments, and politicians worldwide. The countries across the world are engaged in working out the impacts and associated vulnerabilities to the projected climate change. In India, the meteorological records indicate rise in the mean annual surface air temperature by 0.4 °C with not much variations in absolute rainfall. However, the rates of change in temperatures and precipitation have been found to be varying across the region. The intensity and frequency of heavy precipitation events have increased in the last 50 years. No change in the total quantity of rainfall is expected, however, the spatial pattern of the rainfall is likely to change, with rise in number and intensity of extreme rainfall events. The continuous warming and resulting change in rainfall pattern over different regions of Indian may adversely impact the natural resources on which majority of the population is dependent. Thus there is an ever increasing recognition of the need for micro and macro level assessments for greater understanding about the impact and implication of the current climate variability especially in eco-sensitive Himalayan region, where such studies are limited due to lack of adequate observational sites and related data. This study investigates the rainfall variability trends on annual and seasonal scales in the central Himalayan region. Eight observational sites at Almora, Nainital, Ranikhet, HawalBagh, Mukteshwar, Mukhim, Dehradun, and Mussoorie situated at different altitude in the central Himalaya region are considered for the study. These sites are situated within the altitude range of 682–2311 m. Statistical tools such as Mann–Kendall test, Sens’s estimator of slope method (nonparametric) and regression (parametric), have been applied to analyze the rainfall variability trends at these observational sites. The significance of these trends has been tested at the 95% confidence level. The results indicate that there is decreasing trend at all the stations annually, however; only two stations show significantly decreasing trends at 95% confidence level. At seasonal scale, monsoon rainfall indicates decreasing trends at most of the stations in the region, whereas

L.N. Thakural (✉) · S. Kumar · S.K. Jain · T. Ahmad
National Institute of Hydrology, Roorkee 247667, Uttarakhand, India
e-mail: lnt@nih.emet.in

winter rainfall also shows the similar patterns. These temporal and spatial patterns of rainfall variability in central Himalayas may provide useful insights for the long-term planning and management of water resources and also useful for climatic studies in this region.

Keywords Climate change • Mann–kendal test • Regression analysis
Sen's estimator

Introduction

Water is of paramount importance and precious for the livelihood, from crucial drinking water to food production, production of energy to development of industries, and from the management of natural resources to environment conservation. The scarcity of water resources and its tremendous increasing demand, which is the outcome of growing population, intensification of agriculture sector, industrial and urban expansion, has necessitated its proper planning and management. Moreover, global warming and climate change have further added more intricacy. Himalayan region aptly called the water tower of Asia is to be greatly affected due to change in climatic conditions and impact the streamflow of snow-fed rivers originating from the region. The Himalaya is the youngest, highest and one of the most unstable regions of the world for which, the ecosystem is particularly fragile and more susceptible to the impacts of rapid climate change.

The changes in temperature, precipitation, and other climatic variables are likely to influence the amount and distribution of runoff in all river systems globally. Rainfall is an important factor in shaping the hydrology, water quantity and quality and the vegetal cover throughout the earth. A higher or lower rainfall or changes in its distribution would influence the spatial and temporal distribution of runoff, soil moisture, and ground water reserves and would increase the frequency of droughts and floods. The detection of trends in hydro-climatic data, particularly temperature, precipitation, and streamflow is essential for the assessment of impacts of climatic variability and its change on the water resources of a region. Trend analysis may thus focus on the overall pattern of change over time, help temporal and spatial comparisons for deriving future projections. Estimates of rainfall and temperature anomaly were better estimated using long-term series data. Several statistical methods apply parametric and nonparametric approach for the detection of trends.

Several studies in India have been carried out to determine the changes in temperature and rainfall and its association with climate change. Long-term trends in the maximum, minimum, and mean temperatures over the north-western Himalaya during the twentieth century (Bhutiyan et al. 2007) suggest a significant rise in air temperature in the north-western Himalaya, with winter warming occurring at a faster rate. Dimri and Ganju (2007) simulated the winter temperature and precipitation over the western Himalaya and found that temperature is underestimated and precipitation is overestimated in Himalaya. The changing trends of

temperature and precipitation over the western Himalaya were examined and it was found that there was an increasing trend in temperature and decreasing trend in precipitation at some specific locations. Sharma et al. (2000) found an increasing trend in rainfall at some stations and a decreasing trend at other stations in Koshi basin in eastern Nepal and Southern Tibet. Similar trends in rainfall were found by Kumar et al. (2005) for the state of Himachal Pradesh. Basistha et al. (2009) investigated changes in the rainfall pattern for 30 stations during the twentieth century in the Indian Himalayas. They found that there was an increasing trend up to 1964 after which trend decreased during 1965–1980 for this region and changes were most explicit over the Shivaliks and southern part of Lesser Himalayas. Kumar and Jain (2010) analyzed rainfall and rainy days time series at five stations in Kashmir valley of India. They observe decreasing rainfall at four stations and increasing rainfall at one station, but none of the observed trends in annual rainfall were statistically significant. Choudhury et al. (2012) analyzed the long-term data (1983–2010) to detect a trend in the in Umiam located at mid altitude in Meghalaya. The results of the study indicated that there was a nonsignificant increasing trend (3.72 mm/year) in the total annual rainfall. Rai et al. (2010) investigated the persistence, trend, and periodicity in hydro-climatic variables in Yamuna river basin. The results indicated a significant difference in the patterns of monsoon and non-monsoon rainfall in terms of persistence and periodicity and about 20% of rainfall time series indicated the presence of persistence. They also observed an overall declining trend in the annual and monsoon rainfall, annual and monsoon rainy days and aridity index along with a rising trend in the onset of effective monsoon.

However, in Himalaya due to the poor and inadequate network of hydro-meteorological observations owing to inaccessibility for being rugged, dangerous with harsh climatic conditions, there is absence of relatively long-term consistent data. In the present paper, an attempt is made to analyze the trend of rainfall on seasonal and annual scales in the central Himalaya region.

The Study Area

The study is conducted for the eight stations of which five lie in the Kumaon region while other three stations lie in the Garhwal region of Uttarakhand state. Spatial distribution of the metrological stations is shown in Fig. 1. Uttarakhand state is located in the fragile region of Central Himalaya, India. The state has a total geographical area of 53,484 km² out of which 93% is mountainous, of which 65% is covered by forest. The state lies on the southern slope of the Himalaya range and has a highly varied topography with snow covered peaks, glaciers. Most of the northern part of the state is covered by high Himalayan peaks and glaciers. Two Indian largest rivers namely the Ganges and the Yamuna originates from the glaciers of Uttarakhand and fed by numerous lakes, glacial melts, and streams. It lies in the Northern part of India between the latitudes 28° 43'–31° 27'N and longitudes

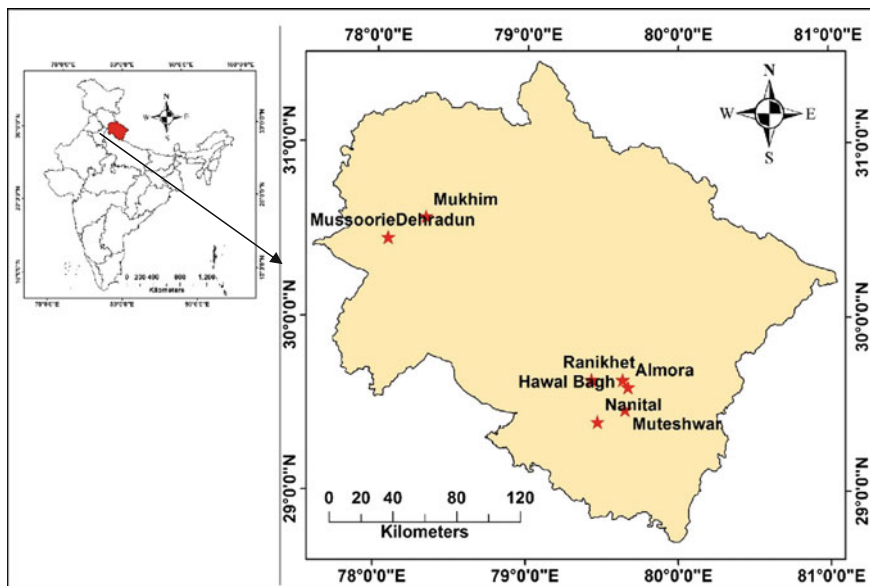


Fig. 1 Location of the metrological stations over central Himalaya

77° 34'–81° 02'E having a maximum dimension of east-west 310 and 255 km north–south covering an area of 53,484 km² with the elevation ranging from 210 to 7817 m above msl. The climate and the vegetation vary greatly with elevation, from glaciers at the highest elevations to subtropical forests at the lower elevations. The highest elevations are covered by ice and bare rock. Below them, between 3,000 and 5,000 m are the western Himalayan alpine shrub and meadows.

Data Used

For the present study, records on rainfall data have been collected from the IMD, Pune and Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, and were further used for analysis. Moreover, the rainfall records at these stations were selected for different periods having continuous rainfall data. The meteorological stations used in the study and their details are shown in Table 1. For investigation of changes in rainfall at different time scales, a year was divided into four principal seasons:

1. Pre-monsoon season prevailing from March to May
2. Monsoon season prevailing from June to September
3. Post-monsoon season prevailing from October to November
4. Winter season prevailing from December to February

Table 1 Details of the meteorological stations located in the study area

Station	Longitude (dms)	Latitude (dms)	Altitude (m)	Period
Almora	79.67	29.6	1585	1980–2012
Dehradun	78.08	30.45	682	1957–2007
HawalBagh	79.634	29.642	1242	1981–2009
Mukhim	78.33	30.57	1945	1957–2007
Mukteshwar	79.65	29.47	2311	1901–1950
Mussoorie	78.08	30.45	1988	1930–1986
Nainital	79.47	29.4	1953	1953–1978
Ranikhet	79.43	29.643	1778	1974–2013

For evaluation of trend in rainfall, daily data have been used to form monthly totals. Monthly data of rainfall were further used to compute the seasonal and annual time series, which were in turn used for the investigation of trend on seasonal and annual time scale.

Methodology

Trends in data can be identified by using either parametric or nonparametric methods, and both the methods are widely used. The nonparametric methods do not require normality of time series and also are less sensitive to outliers and missing values. The nonparametric methods are extensively used for analyzing the trends in several hydrologic series namely rainfall, temperature, pan evaporation, wind speed etc. (Chattopadhyay et al. 2011; Dinpashoh et al. 2011; Fu et al. 2004; Hirsch et al. 1982; Jhajharia and Singh 2011; Jhajharia et al. 2009, 2011; Tebakari et al. 2005; Yu et al. 1993).

The present study analyzes the trends of rainfall series of each individual station using simple regression (parametric), Mann–Kendall test and Sens's estimator of slope (nonparametric).

Determination of Anomalies

For a better understanding of the observed trends, first of all, seasonal and annual anomalies of rainfall for each station were computed with reference to the mean of the respective variable for the available records. Further, these anomalies were plotted against time and the trend was examined by fitting the linear regression line. The linear trend value represented by the slope of the simple least square regression provided the rate of rise or fall in the variable.

Regression Model

One of the most useful parametric models to detect the trend is the “Simple Linear Regression” model. The method of linear regression requires the assumptions of normality of residuals, constant variance, and true linearity of relationship (Helsel and Hirsch 1992). The model for Y (e.g. precipitation) can be described by an equation of the form:

$$Y = at + b \quad (1)$$

where,

t time (year)

a slope coefficient; and

b least-squares estimate of the intercept

The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is significantly different from zero, statistically, it is reasonable to interpret that there is a real change occurring over time. The sign of the slope defines the direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative.

Magnitude of Trend

The magnitude of trend in a time series was determined using a nonparametric method known as Sen’s estimator (Sen 1968). This method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series (Lettenmaier et al. 1994; Yue and Hashino 2003; Partal and Kahya 2006). In this method, the slopes (T_i) of all data pairs are first calculated by the following:

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

where x_j and x_k are data values at time j and k ($j > k$) respectively. The median of these N values of T_i is Sen’s estimator of slope, which is calculated as follows:

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & \text{if } N \text{ is odd,} \\ \frac{1}{2} \left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}} \right) & \text{if } N \text{ is even.} \end{cases} \quad (3)$$

A positive value of β indicates an upwards (increasing) trend and a negative value indicates a downwards (decreasing) trend in the time series.

Significance of Trend

To ascertain the presence of a statistically significant trend in hydrologic climatic variables such as temperature, precipitation, and streamflow with reference to climate change, the nonparametric Mann–Kendall (MK) test has been employed by a number of researchers (Yu et al. 1993; Douglas et al. 2000; Burn et al. 2004; Singh et al. 2008a, b). The MK method searches for a trend in a time series without specifying whether the trend is linear or nonlinear. The MK test was also applied in the present study. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of an increasing or decreasing trend. Following Bayazit and Onoz (2007), no pre-whitening of the data series was carried out as the sample size is large ($n \geq 50$) and slope of the trend was high (>0.01).

The statistic S is defined as (Salas 1993):

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sgn}(x_j - x_i) \tag{4}$$

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

$$\text{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0, \\ 0 & \text{if } \theta = 0, \\ -1 & \text{if } \theta < 0. \end{cases} \tag{5}$$

This statistic 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 (Helsel and Hirsch 1992) with the mean and the variance as follows:

$$\text{Var}(S) = \frac{E[S] = 0}{18} \frac{N(N - 1)(2N + 5) - \sum_{k=1}^n t_k(t_k - 1)(2t_k + 5)}{\tag{6}}$$

where n is the number of tied (zero difference between compared values) groups and t_k is the number of data points in the k th tied group. The standard normal deviate (Z -statistics) is then computed as (Hirsch et al. 1993):

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0. \end{cases} \tag{7}$$

If the computed value of $|Z| > z_{\alpha/2}$, the null hypothesis H_0 is rejected at the α level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level.

Results and Discussion

For better comprehension and visual interpretation of the observed trends, first of all, seasonal and annual anomalies of rainfall for each station were computed with reference to the mean of the respective variable for the available records. Further, these anomalies were plotted against time and the trend was examined by fitting the linear regression line. The linear trend value represented by the slope of the simple least square regression provided the rate of rise/fall in the variable. Thereafter, Mann–Kendall (MK) test has been used for identification and to test the statistical significance of trend at a confidence interval of 95%. Prior to which data series of all the variables were checked for the presence of auto-correlation. The Sen’s estimator of slope (SE) was then applied to estimate the magnitude of the trend over the study period. The SE was applied to verify the outcomes of simple regression analysis. The outcomes of the analysis are shown in the form of Table and/or graph.

The anomalies of rainfall and their trends were determined for all the stations considered in the study. Anomalies in annual rainfall and their trends for the all the meteorological stations within the study area are shown in Fig. 2.

The figure shows the outcomes of the parametric approach which shows that there are a decreasing trend in almost all the stations. Further analysis using the

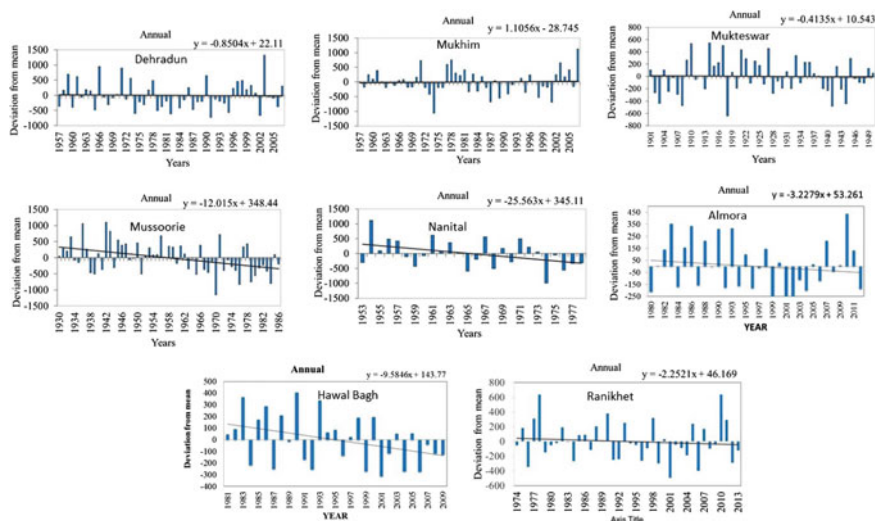


Fig. 2 Anomalies in annual rainfall (% of mean) for stations over central Himalaya

Table 2 Sen estimator of slope (mm/year) for seasonal and annual rainfall

Station	Pre monsoon		Monsoon		Post monsoon		Winter		Annual	
	Z	Sen slope	Z	Sen slope	Z	Sen slope	Z	Sen slope	Z	Sen slope
Almora	-1.41	-2.06	0.63	2.08	-0.84	-0.46	-3	-3.53*	-0.66	-2.13
Dehradun	1.77	1.35	-0.48	-2.11	-1.86	-0.543	0.17	0.122	-0.29	-1.81
HawalBagh	-1.26	-2.69	-0.77	-2.81	-0.58	-0.25	-2.85	-3.37*	-1.97	-9.96*
Mukhim	1.96	2.268	-0.25	-1.837	-2.15	0.723*	-0.25	-0.214	-0.12	-0.262
Mukteshwar	-0.89	-0.497	0.33	0.533	-0.45	-0.098	0.63	0.475	-0.18	-0.385
Mussoorie	0.93	0.68	-3.35	-12.9*	0.66	0.398	-1.85	-1.66	-2.94	-11.6*
Nainital	0.79	1.95	-0.79	-7.35	-1.99	-5.57*	-0.97	-3.66	-1.9	-24.07
Ranikhet	-0.59	-0.74	-0.9	-2.09	-0.26	0	0.22	0.28	-0.78	-2.14

*Bold indicates statistical significance at 95% confidence level as per with Mann-Kendall test (+ for increasing and - for decreasing)

parametric approach has been detailed in Table 2. It indicates that the annual rainfall at all the stations is showing decreasing trend with a maximum decrease (-24.07 mm/year) at Nainital with a minimum decrease (-0.262 mm/year) at Mukhim. However, these decreasing trends are significant at 95% confidence level only at stations Hawal Bagh and Mussoorie.

Seasonal analysis of rainfall trends shows that pre-monsoon rainfall shows negative trends for Almora, Hawal Bagh, Mukteshwar, and Ranikhet whereas stations Dehradun, Mukhim, Mussoorie, and Nainital shows increasing trend. Table 2 also indicates that none of these increasing or decreasing trends are statistically significant. Similar analysis of monsoon rainfall shows decreasing trend at all stations except Almora and Mukteshwar. However, none of these increasing/decreasing trends are significant except at Mussoorie (-12.9 mm/year) which shows a statistically significant decreasing trend. In post-monsoon rainfall, all station except Mukhim and Mussoorie are showing decreasing trend. These trends are significant at Mukhim (0.725 mm/year) and Nainital (-5.57 mm/year). The winter rainfall analysis shows decreasing trends at Almora, HawalBagh, Mukhim, Mussoorie and Nainital whereas stations Dehradun, Mukteshwar, and Ranikhet show increasing trends. Winter rainfall trends at two stations namely Almora (-3.53 mm/year) and Hawal Bagh (-3.37 mm/year) are statistically significant.

Conclusions

The mountainous basin is highly sensitive to climate change. Any change in rainfall and temperature highly influences stream flow downstream. The detection of trends and magnitude of variations due to climatic changes in hydro-climatic data, particularly temperature, precipitation and stream flow, is essential for the assessment of impacts of climate variability and change on the water resources of a region. The present study is based on the analysis of trends in rainfall data using parametric (linear regression) and nonparametric (Mann–Kendall test and Sen's estimator of slope) methods on seasonal and annual scales for the Central Himalaya.

The analysis shows that all the stations indicate a decreasing trend in the annual rainfall. These decreasing trends are found statistically significant at the 95% confidence level at two stations HawalBagh and Mussoorie. The seasonal rainfall analysis shows a mix of increasing and decreasing trends. These trends, however, are not significant for pre-monsoon rainfall. Monsoon rainfall is found to be significant at Mussoorie whereas post-monsoon rainfall is significant at two stations. The winter rainfall trends have significant decreasing trends at Almora and HawalBagh. More such analysis is required to examine the trend in other climatological variables in other Himalayan basins. Also, there is need to understand the behavior of this basin to climate change and its future impact to plan and manage the water resources.

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