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ORIGINAL PAPER

Spatio-temporal trend and change detection of rainfall for Kosi River basin, Uttarakhand using long-term (115 years) gridded data

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Abstract
The paper analyzed the spatial-temporal variability of rainfall and detection of potential trend change point over Kosi River basin, Kumaon Lesser Himalaya, India, using long-term gridded data and historical metrological records in hilly river basin of Uttarakhand. The Mann-Kendall (MK) test was used to determine the spatio-temporal trend using IMD (0.25° × 0.25°) gridded rainfall data during 1901–2015. The Theil-Sen slope was used to determine the magnitude of change in rainfall during the study period. Additionally, the sequential Mann-Kendal (SQ-MK) test and Pettitt's test has been used to find the abrupt change point in historical time series (1980–2019). Results of the study show that northeastern and southwestern parts of the Kosi River basin exhibit a statistically significant decreasing trend in both June and July months at 5% significance level. Northeastern and southwestern parts of the basin exhibit a statistically significant decreasing trend for monthly and annual rainfall. The range of Sen's slope values varies from −0.6 to −6.6 mm/year. Based on the analysis of SQ-MK and Pettitt's test, the change points for Almora, Mukteshwar, and Hawalbagh were 1991, 2004, and 1998 respectively. Therefore, this paper attempts to provide actionable knowledge for irrigation water planning, water management, and soil and water conservation for Uttarakhand.

Keywords Mann-Kendall · Sen's slope · Rainfall · Kosi River basin · North-Western Himalayas

Introduction

The mountain ecosystem hosts about one-third of biodiversity despite it covering approximately 25% of land surface area of the earth (Barthlott et al. 1996). However, these mountain ecosystems are most fragile and vulnerable to the adverse impact of climate change (Palombo et al. 2013). The climate parameters, especially rainfall, temperature, humidity, and light, are widely considered as the most important parameters, as they determine local site condition and biotic niches (Trindade et al. 2020). Owing to impact of climate change, the Himalayan region is warming faster than the rest of the world and it is the origin of many important river basins that support more than one billion of people (IPCC 2013). The Great Himalaya is known as the Water Tower of Asia (Qiu 2008; Xu 2008). In hydrological cycle, rainfall is one of the dynamic parameters and has a diverse range of impact on livelihood, namely, agricultural operations (Bhatt et al. 2014), hydropower generation (Gaddam et al. 2018), and sustainability of different ecosystems (Chakraborty et al. 2018). High hilly regions are potential localities for assessing climate change and its associated impacts because it is

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less exposed to anthropogenic activities. Therefore, understanding spatial-temporal variation and detection of abrupt change in rainfall of hilly river basin is extremely important for water resource management.

In the recent decade, there has been growing concern for understanding the spatial-temporal variation of rainfall, temperature, rainy days, and time series data using parametric and non-parametric tests all over the world. Kumar et al. (2021a) explored the long-term temporal variation in rainfall for Hawalbagh and Almora stations in Uttarakhand using Mann-Kendall and Sen's slope estimator test. Pingale et al. (2014) analyzed the spatial-temporal variation of rainfall and temperature for 33 urban centers of Rajasthan, India, using the Mann-Kendall test at 10% significance level and found mix type of trend in rainfall for the study period. Trend and variability of rainfall for Chhattisgarh state of India were studied by Meshram et al. (2017). To quantify the magnitude of change using Sen's slope and to know the trend, an MK test was applied. Bhagwati et al. (2018) reported no clear trend in rainy and rainfall in Basar (Arunanchal Pradesh) during 1975–2015 using the linear regression method. Bera (2017) explored the rainfall trend in Ganga Basin of India using the Mann-Kendall and Sen's slope estimator test. Salehi et al. (2020) detected trends and identified change point of seasonal and annual rainfall for Iran based on the Mann-Kendall test. Rajeevan et al. (2008) examined the long-term trend of extreme rainfall events for central India using 104 years of a gridded dataset in line with Goswami et al. (2006). Various studies in context of rainfall variability and trends in extreme events were analyzed across the globe (Wan Zin et al., 2010; Kumar et al., 2021a; Patakamuri et al. 2020; Zin et al., 2010; Tabari and Talaee, 2011; Gocic and Trajkovic, 2013; Cinco et al., 2014; Kamruzzaman et al., 2016). Impact of climate change on variability of rainfall and extreme rainfall events in India have been studied by several researchers (Jain and Kumar, 2012; Patra et al., 2012; Jena et al. 2014; Pingale et al., 2014). For example, Sharma et al. (2000) reported positive trend for Kosi basin in Nepal and Kumar et al. (2005) reported positive trend of Himachal Pradesh in India. The negative rainfall trends are reported by others, such as Singh and Sen-Roy (2002) for Beas basin and Kumar and Jain (2010) for Qazigund and Kukarnag of Kashmir. Orographic convection due to the diurnal heating and cooling is thought to be responsible for the precipitation over Himalayas which seldom gives rise to flash floods (Chow et al. 2013). To be precise about rainfall trends in the Kumaon region, most of the previous studies did not identify any distinct results about rainfall trend over Kosi River basin (Jain and Kumar, 2012; Shrestha et al., 2000). The reason behind limited studies in IHR is lack of information available on long-term rainfall data particularly to higher altitudes (Singh et al., 1995; Pant, 2003). The rationale behind the study was no study in context with spatial-temporal trend has been made with fine resolution (0.25° × 0.25°) long-term (1901–2015) India metrological gridded (IMD) gridded data to capture the impact of climate change on seasonal, monthly, and annual rainfall variability for Kosi basin, called lifeline of Kumaon region, Uttarakhand. Therefore, the present study was undertaken to analyze spatial-temporal variation of rainfall along elevation gradient in Kosi River basin of North-Western Himalayas. Understanding the spatio-temporal variation of rainfall along elevation gradient in mountain ecosystem will enable us to better understand the response of the mountain ecosystem to global climate change impact. The objectives of the work were to (i) evaluate spatial-temporal trends and magnitude of annual and monthly rainfall during long-term (1901–2015) (ii) detection of abrupt change point of annual rainfall for Hawalbagh, Almora, and Mukteshwar stations located at different altitudes using long-term (1980–2019) rainfall data.

Physiographic and climatological characteristics of the study area

The Kosi River basin is located in the mid-hill zones of the northwestern Himalayas in India (29° 18′ N–79° 02′ E and 29° 51′ N–79° 51′ E), elevation range of 1250 m above mean sea level (A.M.S.L), having undulating and hilly terrain elevation and depressions, gentle slopes, and southeastern aspect (Fig. 1). The area comes under the sub-tropical belt, but slightly skewed towards the temperate climate, with temperatures ranging from 1 °C in winter to 37 °C during the summer, with a mean annual temperature of 19.8 °C. The hottest months are May and June, while the coldest months are December and January. The area receives 850–1100 mm of rain per year, with most of the rain falling during the monsoon season (July and September). The soil texture of the study area falls under the loamy to clay categories. The major agriculture crops in the watershed are wheat, paddy, barley, pulses, and vegetables. The study area is also rich for temperate horticulture fruit crops.

Materials and method

Observed data

In this study, observed monthly rainfall data of 3 meteorological stations were obtained from the central organization (India Meteorological Department and ICAR-VPKAS, Almora). The details of observatory are given in Table 1 for the duration

Fig. 1 Location of the study area

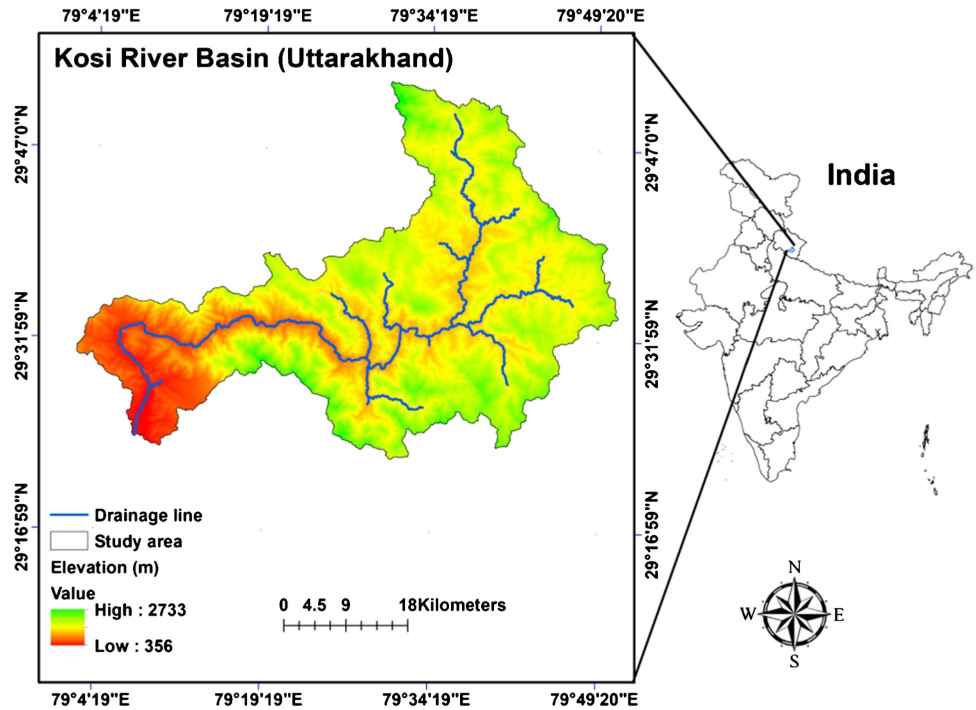

Table 1 Data used for calculation of change point analysis in the Kosi River basin

Station	Location		Period	Elevation (m)
	Latitude	Longitude		
Hawalabgh (ICAR-VPKAS)	29°37′11.4″N	79°37′48.1″E	1980–2019	1250 m
Mukteswar (IMD)	29°27′25.4″N	79°39′16.2″E	1980–2019	2286 m
Almora (ICAR-VPKAS)	29°23′41.15″N	79°7′ 35″E	1980–2019	1672m

1980–2019. The monthly time series data were summed up for calculating annual rainfall for change point analysis.

Gridded data

Since the study area is poorly gauged, daily precipitation data for the period 1901–2015 were collected from 0.25° × 0.25° grid points from the India Meteorological Department (IMD), Government of India (Pai et al. 2014). The daily gauge-based gridded precipitation data were generated at 0.25° resolution by IMD using 6955 rain gauges across India (Bharti et al. 2016; Pai et al. 2014, 2015). Pai et al. (2015) used IMD (0.25° × 0.25°) data to analyze daily rainfall events in India. IMD (0.25° × 0.25°) gridded rainfall data was freely downloaded from Climate Data Service Portal Pune (https://www.imdpune.gov.in/). Readers are encouraged to go through the literature Pai et al. (2014) for more information on IMD (0.25° × 0.25°) gridded data. The rain gauges are evenly distributed all over the country except for some areas over the northern India (Jammu and Kashmir state).

Trend analysis

In this study, annual and monthly rainfall trend analysis was evaluated using non-parametric approaches, namely Mann-Kendall (Mann 1945; Kendall 1975 Sharif et al., 2013) and Sen's slope estimator (magnitude of change) (Zhang and Lu 2009; Gautam et al., 2012). It is a non-parametric test, which is owing to the efficacy of handling any distribution of time series. This test required an independent data pattern. The MK test is a robust and widely accepted method in different hydro-climatic studies. Serial correlation in the time series was checked before applying the MK test to a dataset (Yue et al., 2002). According to Salas et al. (1980), if lag-1 correlation coefficient ($r1$) is within the range $\left(-1 \pm 1.645\sqrt{(n-2)}\right)/(n-1)$, then there is no serial correlation, and if it is outside of the range, it is considered that there is a serial correlation effect. In cases where there is no serial correlation effect, the original time series is used. In the case of serial correlation, the "pre-whitened" series is obtained by applying the "pre-whitening" (von Storch and Navarra, 1995) procedure to the time series and the MK test is applied to these new time series.

Mann-Kendall (MK) test

The MK test (Mann, 1945; Kendall, 1975) computes statistics as Eq. (1)

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \tag{1}$$

where S is the normal distribution with the mean, n is the number of observations (≥ 10), and x_j is the jth observation and sgn () is the sign function defined as sgn (α) = 1 if $\alpha >$ 0; sgn (α) = 0; if α = 0 and sgn (α)=−1 if α<0.

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i\left(t_i - 1\right)\left(2t_i + 7\right)}{18} \tag{2}$$

where n is the number of tied groups having similar value for a data group and t_i is the number of data in the ith tied group. The actual MK statistics is given as Eqs. (3, 4).

$$Z = \frac{S+1}{\sqrt{V(S)}}, ifS < 0 \tag{3}$$

$$Z = 0, \text{if} S \tag{4}$$

$$Z = \frac{S+1}{\sqrt{V(S)}}, \text{if} S < 0 \tag{5}$$

Two hypotheses are made, i.e. H_o (null hypothesis) and H_1 (alternative hypothesis). H_o indicates no statistically significant trend, while H_1 indicates a statistically significant trend.

Sen's slope

It is a non-parametric procedure for estimating the slope of trend in the sample of N pairs of data (Theil, 1950; Sen, 1968). This is a simple linear regression method, which can estimate the slope of the median of two different variables (dependent and independent). It can be estimated using Eq. (6).

$$d_{ijk} = \frac{X_{ij} - x_{ik}}{j-k} \tag{6}$$

where X_{ij} and x_{ik} are data value, j and k ($j > k$), respectively. If there is only one datum point in each period, the $N = \frac{n(n-1)}{2}$ where n is the number of time periods. If there are multiple observations in one or more time periods, then $< \frac{n(n-1)}{2}$, where n is the total number of observations. The N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as:

$$Q_{\text{med}} = \begin{cases} Q_{\left[\frac{(N+1)}{2}\right]}, & \text{if } N \text{ is odd} \\ \frac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2}, & \text{if } N \text{ is even} \end{cases} \tag{7}$$

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q_{med} at specific probability. Sen's slope estimator has been widely used in hydro-meteorological time series.

Abrupt change point analysis

Sequential Mann-Kendall (SQ-MK) test

This test is applied to assess change point in the rainfall time series data by observing the fluctuations during the study period. In this test, the null hypothesis H_o was assumed that the rainfall time series data under study period show no abrupt point. This method is calculated based on rank values of y_i of original values in the analysis ($x_1, x_2, x_3 \ldots x_n$). Magnitude of rank based forward and backward series are computed and the points where $x_j > x_k$ are noted as n_j in each comparison. Null hypothesis is rejected or accepted based on the following condition:

(i) Calculation of test statistics: the test statistics S_j is computed as follows

$$S_j = \sum_{j=1}^{n} n_j \tag{8}$$

where n_j indicated the condition where $x_j > x_k$ with j = 1,2 … ,n and k = 1,2, … j−1

The test statistic follows normal asymptotically normal distributions with mean $E(S_j) = (j(j-1))/4$ and variance $\operatorname{Var}(S_j) = j(j-1)(2j+5)/72$

(ii) Calculation of reduced variable: the reduced variable or forward sequential test statistic is calculated for each of the variable S_j as follows:

$$U(S) = \frac{|S_j - E(S_j)|}{\sqrt{\mathrm{Var}(S_j)}} \tag{9}$$

(iii) Determination of turning point: the backward sequential statistics $U^{'}(S)$ is calculated in similar ways as forward sequential statistics but starting from end of time series. The turning point is the meeting point of forward sequential statistics $U(S)$ and sequential statistics $U^{'}(S)$. The null hypothesis H_0 is expected to accept when at least one variable is larger than considered significance level of normal distribution.

Pettitt's test

This test, developed by Pettitt (1979) is a non-parametric test, which is useful for evaluating the occurrence of abrupt changes in climatic records. One of the reasons for using this test is that it is more sensitive to break in the middle of the time series (Wijngaard et al. 2003). The statistics used for the Pettitt's test has been explained by Kang and Yusof (2012), Dhorde and Zarenistanak (2013), and many others. It is computed as follows: the first step is to compute U_k statistic using the following formula:

$$U_k = 2\sum_{i=0}^{n} m_i - k(n+1) \tag{10}$$

where m_i is the rank of the ith observation when the values $x_1, x_2, ..., x_n$ in the series are arranged in ascending order and k takes values from 1, 2, ..., n. The next step is to define the statistical change point (SCP) test as follows:

$$K_\alpha = \left[-\ln\alpha\left(n^3 + n^2\right)/6\right]^{1/2} \tag{11}$$

when U_k attains maximum value of K in a series, then a change point will occur in the series. The critical value is obtained by:

$$K_\alpha = \left[-\ln\alpha\left(n^3 + n^2\right)/6\right]^{1/2} \tag{12}$$

where n is the number of observations and α is the level of significance which determines the critical value.

Inverse distance weighted (IDW)

To show the spatial trend map over the study area, MK test statistics were calculated at each grid. The inverse distance weighted (IDW) interpolation technique was applied to generate the spatial map of rainfall trend in QGIS (Kumar et al. 2021b, c). It is an important technique which assumes that the points which are nearer to each other are like than that is further apart.

Linear regression

For identifying the trend in the rainfall data, the statistical analysis of linear regression was used. Linear regression is one of the simplest methods to calculate the trend of data in the time series. The equation of the linear regression line is written by

$$Y = bX + a \tag{13}$$

where Y is the dependent variable. X is the independent variable. The slope line is b and a is the intercept (value of Y when $X = 0$).

Results and discussion

Variation of rainfall

Descriptive statistics, namely, mean, coefficient of variation, and standard deviation for rain gauges located in the study area, is presented in Table 2.

The box plot of annual rainfall (mm) for each station is presented in Fig. 2. The mean annual rainfall varies from 925.01 mm for Hawalbagh to 1323.18 mm for Mukteshwar. The standard deviation (SD) varies from 189.25 for Hawalbagh to 242.67 for Mukteshwar, while coefficient of variation (CV) 0.18 for Mukteshwar to 0.23 for Almora.

It is evident from Fig. 2 that Mukteshwar receives highest rainfall followed by Almora while, least rainfall occurs in Hawalbagh.

Spatio-temporal trend of monthly and annual rainfall (1901–2015)

In this study, the IDW method in the GIS environment was used to generate the spatially continuous distribution of raster data based on interpolation of known magnitude of significance level and Sen's slope value of different gridded point data within the study area based on the non-parametric MK test. The spatial distribution of the significance level value is presented in Fig. 3 for each month. Northeast and southwest parts exhibit a statistically significant decreasing trend for both June and July months at 5% significance level (Fig. 3). The spatial distribution

Table 2 Descriptive statistics of meteorological stations in the study area

Station	Mean (mm)	SD (mm)	Min. (mm)	Max. (mm)	CV
Hawalbagh	925.01	189.25	667.90	1369.50	0.20
Almora	959.35	221.11	541.30	1434.00	0.23
Mukteshwar	1323.18	242.67	915.70	1650.80	0.18

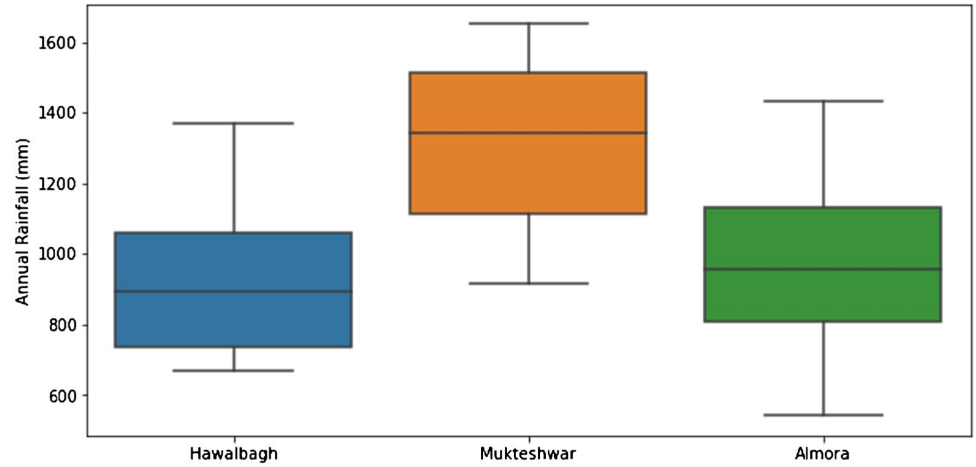

Fig. 2 Box plot of annual rainfall for different meteorological stations

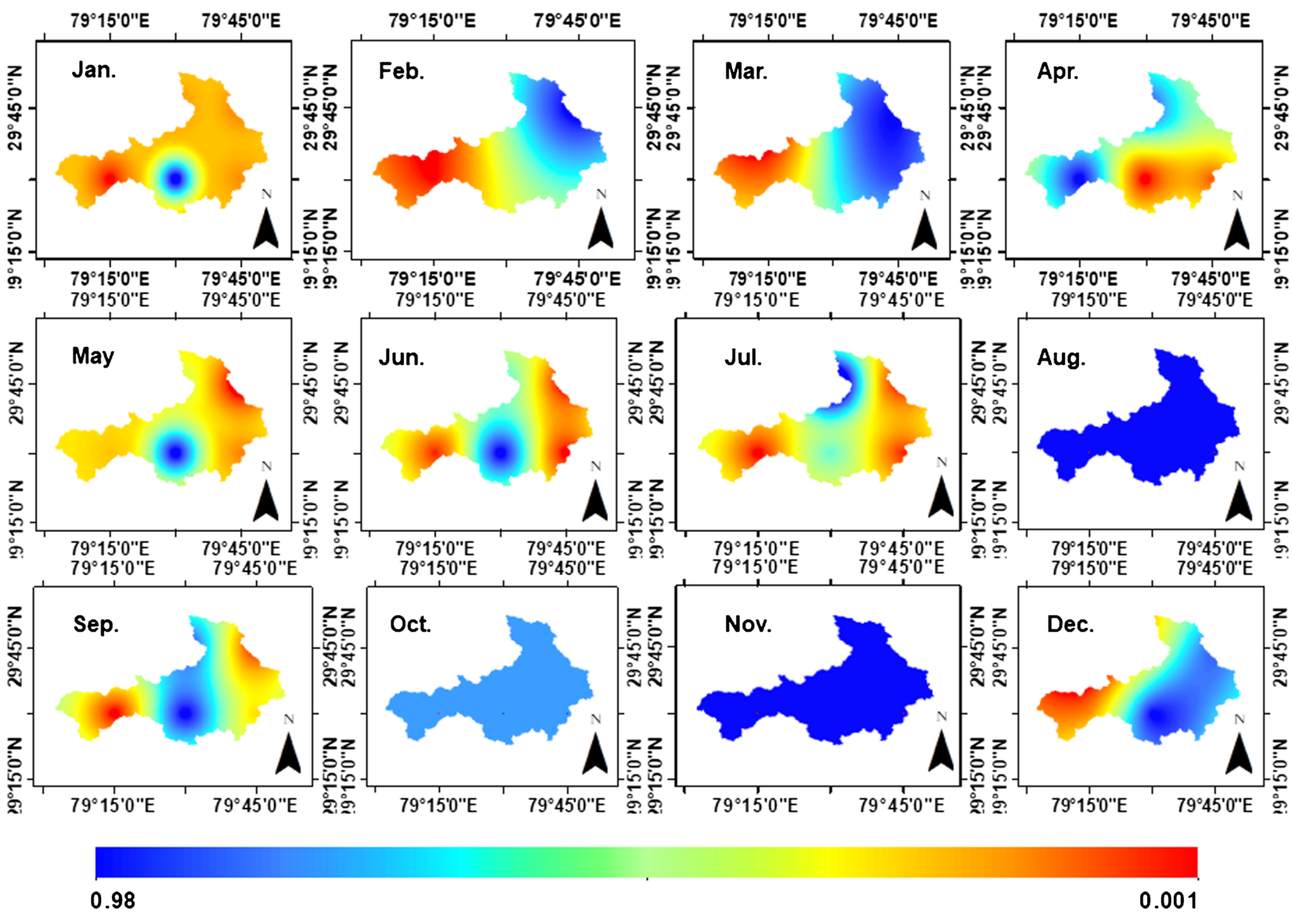

Fig. 3 Spatial distribution of significance level (*p* value) for monthly rainfall, during 1901–2015

of Sen's slope (magnitude of change) over the basin is shown in Fig. 4. Spatial variation of significance level and Sen's slope (magnitude of change) of annual rainfall for the basin is shown in Fig. 5a, b. The spatial distribution of the annual rainfall was similar to the monthly rainfall during 1901–2015, showing a spatial trend of decreasing rainfall gradient from north to south, and the highest precipitation was mainly concentrated in the southeast region. As per Fig. 5b, the Sen's slope values vary from −0.6 to −6.6 mm/year. The finding agrees with the results of previous studies conducted in the Indian Himalayas by Basistha et al. (2009), central Himalayas by Shrestha et al.

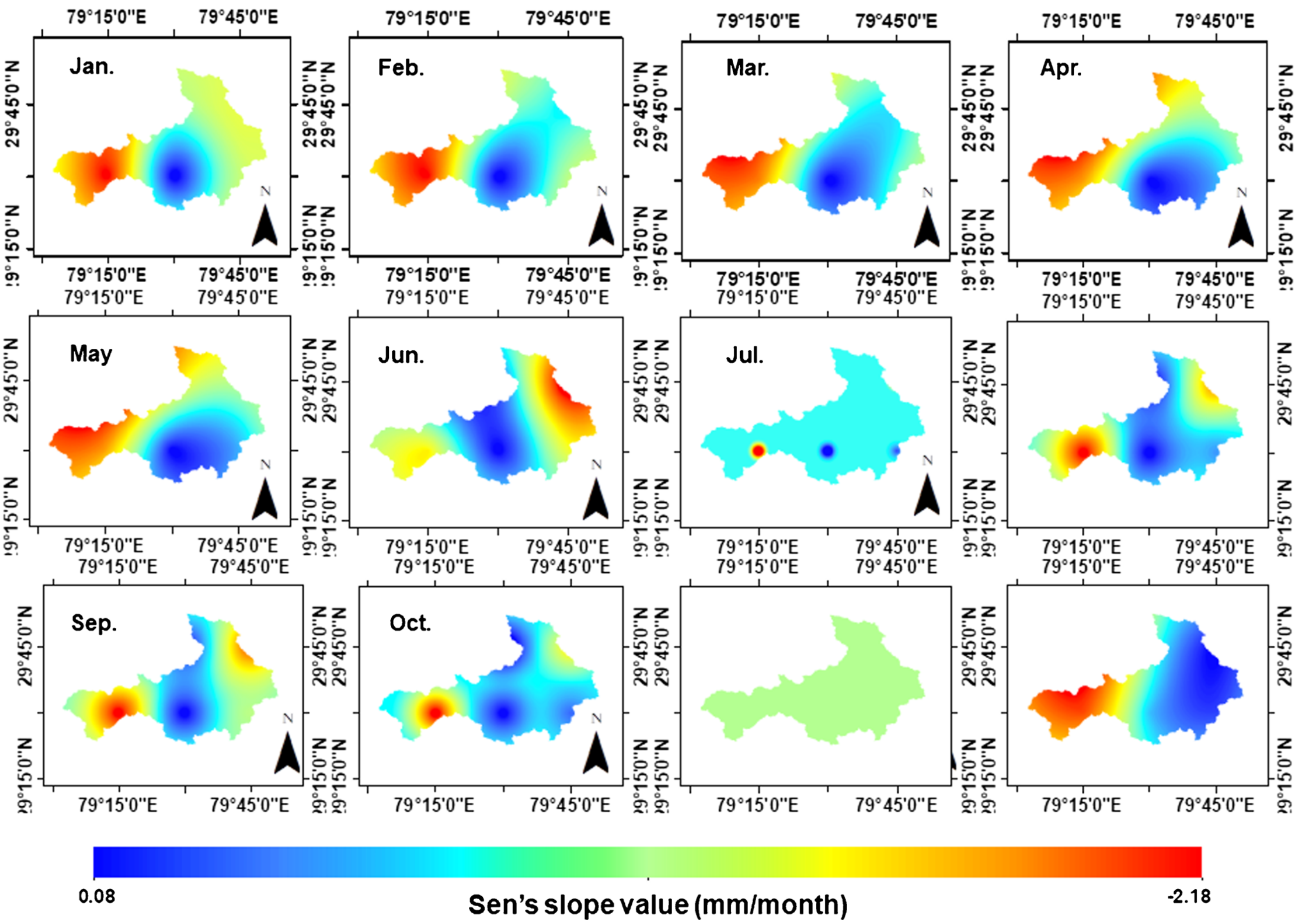

Fig. 4 Spatial distribution of magnitude of trend (Sen's slope value) for monthly rainfall, during 1901–2015

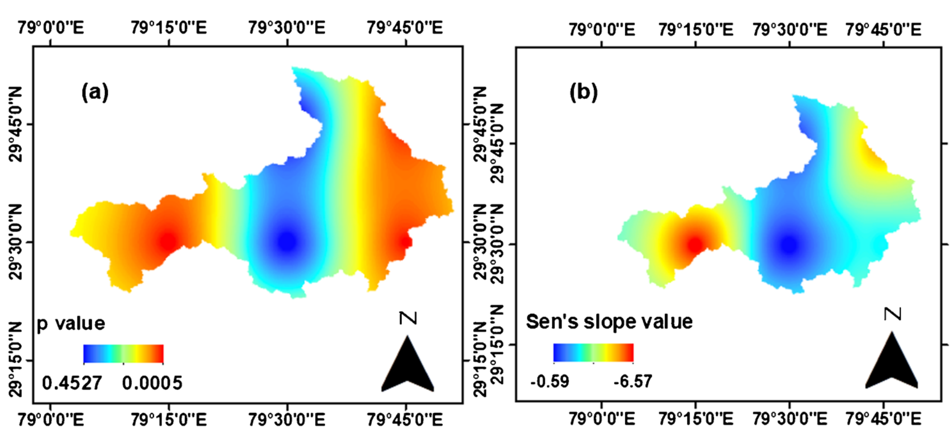

Fig. 5 Spatial variation of **a** statistical significance level (*p* value) and **b** magnitude of trend (Sen's slope value) for annual rainfall, during 1901–2015

(2019), Uttarakhand Himalaya by Banerjee et al. (2020) Alaknanda valley Srinagar Garhwal of Uttarakhand by Negi et al. (2018). Ghosh et al. (2009) revealed in their study that a micro-scale study might be different from macro-scale study for the same region. Population growth and urbanization were the most important reasons for the decreasing trend as it is evident from Table 3. The State registered highest growth of urban population during 1971–1981 (56.38%); however, decadal urban population growth declined slightly during 1981–1991 (42.20%) and 1991–2001 (32.81%) (Tiwari et al. 2018).

Table 3 Trends of urban growth in Uttarakhand (1901–2011)

Census years	Total population	Urban population	Urban content (%)	Urban growth (%)
1901	19,79,866	1,54,424	7.8	—
1911	21,42,258	1,79,332	8.37	16.13
1921	21,15,984	1,91,660	9.06	6.87
1931	23,01,019	1,95,797	8.51	2.16
1941	26,14,540	2,70,503	10.35	38.15
1951	29,45,929	4,00,631	13.6	48
1961	36,10,938	4,95,995	13.74	23.8
1971	44,92,724	7,34,856	16.36	48.16
1981	57,25,972	11,49,136	20.07	56.38
1991	71,13,483	16,34,084	22.97	42.2
2001	84,79,562	21,70,245	25.59	32.81
2011	1,01,16,752	30,91,169	30.55	42.43

Change point analysis

Pettitt's test and the SQ-MK test were applied to detect annual trends in rainfall series for Hawalbagh, Mukteshwar, and Almora. Besides indicating tendencies, the Pettitt's test and SQ-MK test also reveal the year when the trend begins (mutation point). Outputs of these two statistical techniques for annual rainfall time series are almost similar. Graphical representations of the results obtained by applying the SQ-MK test and Pettitt's test to annual rainfall series are shown in Figs. 6, 7, and 8. The intersection point of the curves of UF and BF values is the mutation point that indicates the year when the trend begins.

Early transition trends dominated the stations which are rapidly urbanizing or have already urbanized in the study area such as Almora and Hawalbagh. The population density in these cities is very high. The cities are able to absorb more solar radiation because of high-rise buildings. Besides these factors, local topography and atmospheric circulation features increase the possibility of influencing nature and magnitude of rainfall in hilly regions.

Based on the analysis of SQ-MK and Pettitt's test, the change points for Almora, Mukteshwar, and Hawalbagh were 1991, 2004, and 1998, respectively. The result indicated that stations located at lower elevation had a higher frequency of abrupt change than that of station located at higher elevation for annual precipitation. The trend of annual rainfall in the high hilly region showed less variability than the lower hilly region in the Kumaon region.

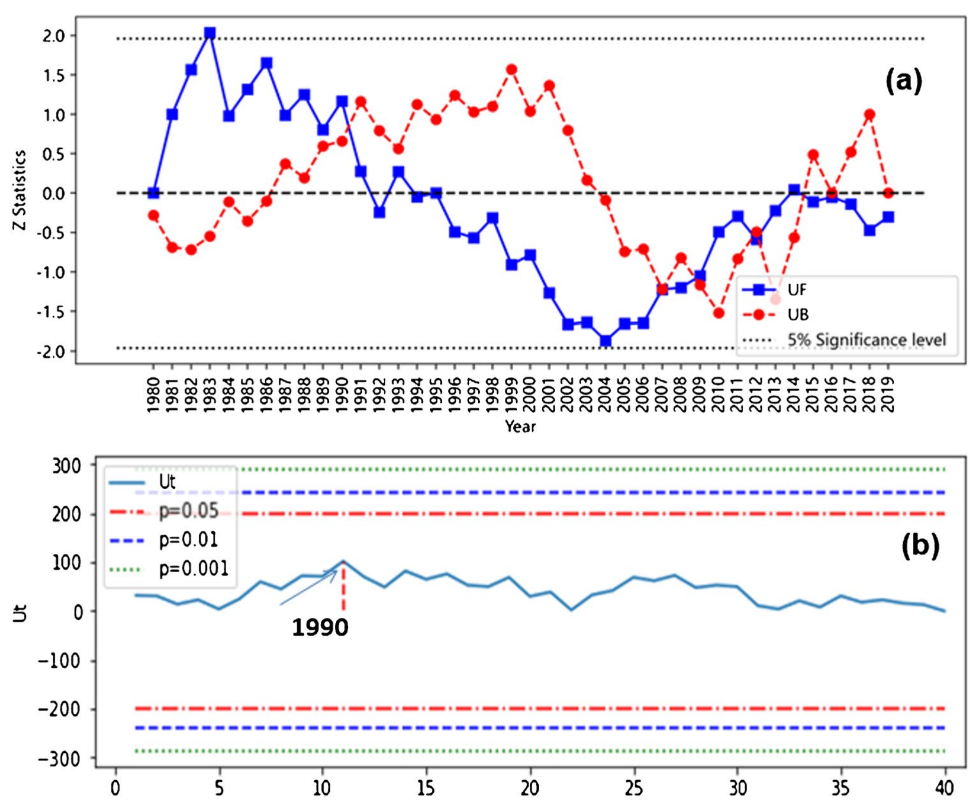

Fig. 6 Graphical representation of **a**) SQ-MK test and **b**) Pettitt's test used for detecting a change point for annual rainfall for Almora

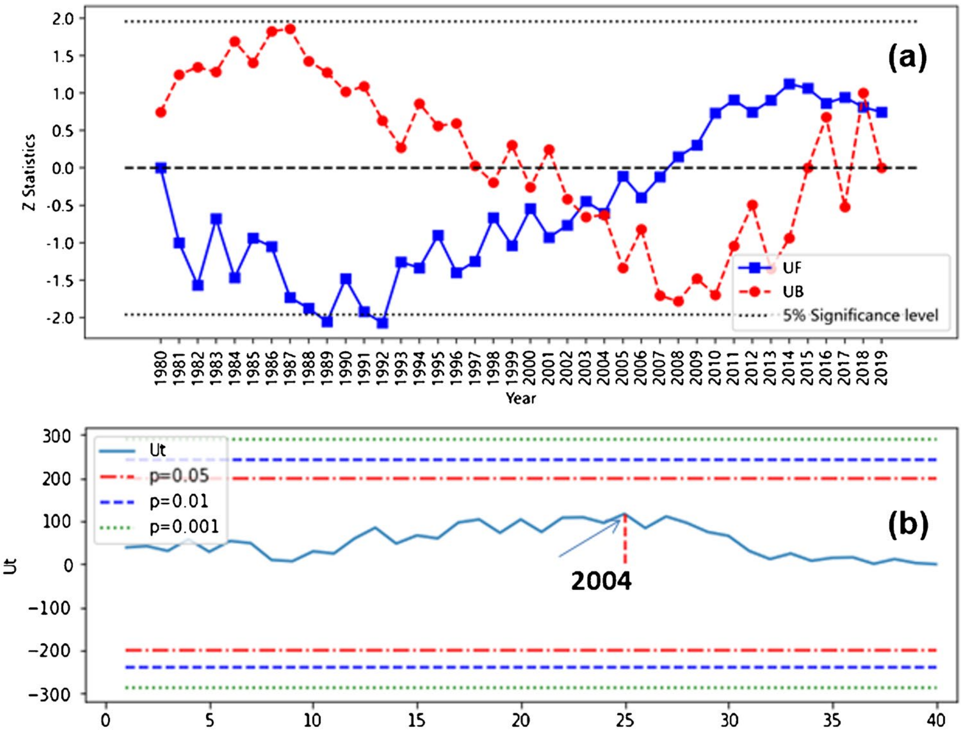

Fig. 7 Graphical representation of **a**) SQ-MK test and **b**) Pettitt's test used for detecting a change point for annual rainfall for Mukteshwar

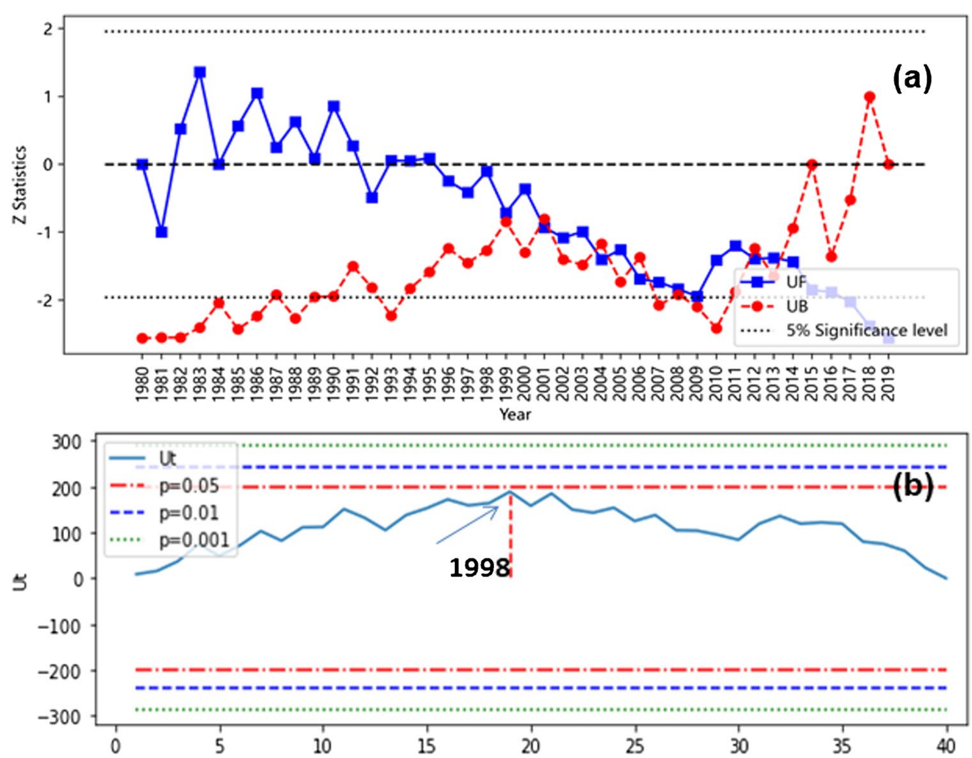

Fig. 8 Graphical representation of **a**) SQ-MK test and **b**) Pettitt's test used for detecting a change point for annual rainfall for Hawalbagh

Annual trend using linear regression (1980–2019)

Using a linear regression model (Fig. 9), the rate of change is defined by the slope of regression line which in this case about −7.28, −1.13, and 1.31 mm/year for Hawalbagh, Almora, and Mukteshwar, respectively. The declining trend rainfall was found to be highest at the Hawalbagh station while Mukteshwar showed an increasing trend which was statistically insignificant as seen from r^2 value.

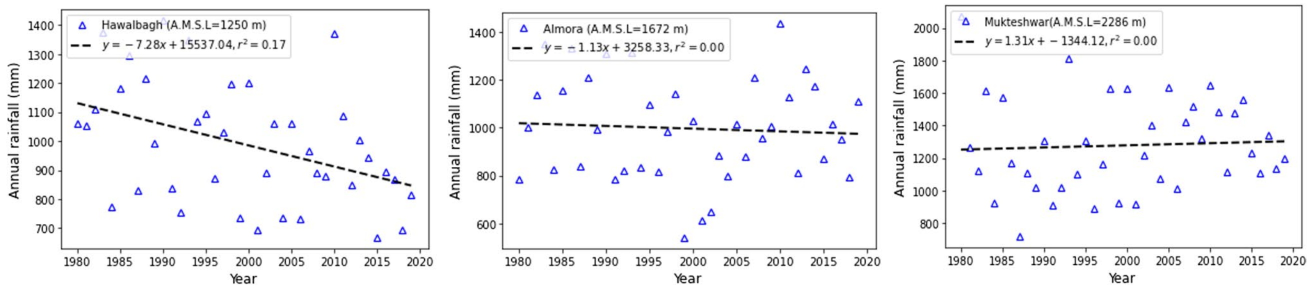

Fig. 9 Linear regression trends of annual rainfall for 40 years (1980 to 2019)

Conclusion

In this study, an effort has been made to analyze spatial-temporal trend of rainfall in Kosi basin, which is located in Kumaon Lesser Himalaya. Long-term IMD gridded data (1901–2015) was used for this analysis to understand the rainfall trend in the basin for effective water resource management. The rainfall trend was analyzed using the MK test at 5% significance level. In addition to this, change point analysis for three meteorological stations during 1980–2019 located in basin was analyzed using SQ-MK and Pettitt's test. The results of trend analysis and change point detection in precipitation series are important for policy makers, water resources management, and agriculture. There have been increasing extreme events, flash floods, and frequent drought in recent decade in Uttarakhand state of India. The extreme event refers to the high-intensity short-duration events occurring frequently in the past 20 years such as Kedarnath disaster and flash flood during 2010 monsoon in Almora. Flash flood and cloudburst are an annual occurrence in Uttarakhand especially during the Monsoon season. The results of this study show that there were more number of changing point in annual rainfall for the station having low altitude which indirectly indicates that the impact of urbanization population growth and industrialization on climate change in the lower hilly region in more as compared to the high hilly region which exhibit less number of changing point. The salient findings of the study are as follows:

(a) The northeastern and southwestern parts of the basin show a significant decreasing trend for June and July months as well as for annual rainfall
(b) The range of Sen's slope values for annual rainfall varies from −0.6 to −6.6 mm/year
(c) The station lying in high altitude of the basin showed less number of changing point whereas the station lying in low altitude showed more number of changing point

The spatial distribution of the trend map might be useful for local farmers, water managers, and policy makers to keep eye on vulnerability and susceptibility of climate change in the study area. Site-specific mitigation strategies such as rain water harvesting during monsoon season, construction of contour bund, and vegetative cum mechanical measure for surface runoff harvesting may lead to increasing water availability during lean season for use in irrigation and domestic purpose. The results of this study will be useful in the domain of rain water harvesting, soil and water conservation measure, and water availability in the region.

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Declarations

Conflict of interest The authors declare no competing interests.

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