Theoretical and Applied Climatology (2018) 134:1231–1243
https://doi.org/10.1007/s00704-017-2335-y

ORIGINAL PAPER

Statistical evaluation of rainfall time series in concurrence with agriculture and water resources of Ken River basin, Central India (1901–2010)

Sarita Gajbhiye Meshram[1,2] · **Sudhir Kumar Singh**[1] · **Chandrashekhar Meshram**[3] · **Ravinesh C. Deo**[4] · **Balram Ambade**[5]

Received: 25 September 2016 / Accepted: 17 November 2017 / Published online: 1 December 2017

Abstract

Trend analysis of long-term rainfall records can be used to facilitate better agriculture water management decision and climate risk studies. The main objective of this study was to identify the existing trends in the long-term rainfall time series over the period 1901–2010 utilizing 12 hydrological stations located at the Ken River basin (KRB) in Madhya Pradesh, India. To investigate the different trends, the rainfall time series data were divided into annual and seasonal (i.e., pre-monsoon, monsoon, post-monsoon, and winter season) sub-sets, and a statistical analysis of data using the non-parametric Mann–Kendall (MK) test and the Sen's slope approach was applied to identify the nature of the existing trends in rainfall series for the Ken River basin. The obtained results were further interpolated with the aid of the Quantum Geographic Information System (GIS) approach employing the inverse distance weighted approach. The results showed that the monsoon and the winter season exhibited a negative trend in rainfall changes over the period of study, and this was true for all stations, although the changes during the pre- and the post-monsoon seasons were less significant. The outcomes of this research study also suggest significant decreases in the seasonal and annual trends of rainfall amounts in the study period. These findings showing a clear signature of climate change impacts on KRB region potentially have implications in terms of climate risk management strategies to be developed during major growing and harvesting seasons and also to aid in the appropriate water resource management strategies that must be implemented in decision-making process.

1 Introduction

The agricultural sector in India is heavily reliant on sustained and reasonable amount of rainfall. The present study area Ken River basin (KRB) is very much prone to frequent drought events with meteorological, hydrological, and agricultural consequence including it impacts on edaphic and socioeconomic activities. Taken together, drought affects the primary productivity in the KRB region. Water is an essential input for the sustenance of all living entities (Gajbhiye et al. 2014; Singh et al., 2013a; Singh et al. 2015); therefore, a good knowledge of water balance over local, regional, national, and continental scales in a large nation such as India is required for various decision-making tasks. The demand for fresh water is continuously rising due to the unprecedented population growth, high rate of urbanization, unplanned industrialization, over-exploitation, and people's attitude towards water utilization and water savings (Gajbhiye et al. 2015a). Timely availability of quality water is necessary to improve food and social, and this can help avoid the migration of people from rural to urban areas during water-stressed periods (Jain and Kumar 2012).

The Intergovernmental Panel on Climate Change (IPCC 2007) revealed that the global temperature of the earth's atmosphere is rising at rate of about 0.74 ± 0.18 °C with data

---

✉ Sarita Gajbhiye Meshram
gajbhiyesarita@gmail.com

[1] K. Banerjee Centre of Atmospheric and Ocean Studies, IIDS, Nehru Science Centre, University of Allahabad, Allahabad, U.P. 211002, India

[2] Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee, Uttarakhand 247667, India

[3] Department of Mathematics and Computer Science, R D University, Jabalpur, M.P., India

[4] School of Agricultural, Computational and Environmental Sciences, International Centre for Applied Climate Sciences, Institute of Agriculture and Environment, University of Southern Queensland, Springfield, Queensland 4300, Australia

[5] Department of Chemistry, National Institute of Technology, Jamshedpur, Jharkhand 831014, India

analyzed over the period 1906–2005 (IPCC 2007). This increase can have global implications. Some researchers have also reported an increasing trend in the global rainfall during the twentieth century, but a majority of the works have found decreasing trends in rainfall (IPCC 1996). In order to better understand the overall changes in rainfall, many researchers have also performed trend analysis on yearly and seasonal precipitation data in the last few decades over global and country-specific scales (Easterling et al. 2000; Zhang et al. 2000; Zhai et al. 2005; Fathian et al. 2014; Taxak et al. 2014). In respect to the increasing number of investigations, it is therefore true that the rainfall time series analysis is essential for analyzing the effects of climate variability on water resources and the development and control of water use in a given region (Haigh 2004). A number of researchers have also applied statistical analysis on the time series of rainfall and temperature datasets to reveal the persistent trends in these variables over a sustained period of study in many parts of the world (e.gHirsch et al., 1982; Brunetti et al. 2000; Zhang et al. 2000; Piccarreta et al. 2004; Zhai et al. 2005; Haylock et al. 2006; Dhorde et al. 2009; Karpouzos et al. 2010; Shang et al. 2011; Jain and Kumar 2012; Darshana and Pandey 2013; Dhorde and Zarenistanak 2013; Villafuerte et al. 2013; Nyatuame et al. 2014; Gajbhiye et al. 2015b; Chandniha et al. 2016; Meshram et al. 2016, 2017; Zamani et al. 2017).

In some studies, researchers have linked these trends in data with geospatial techniques to develop a better understanding of their region-specific changes. In these studies, the Geographic Information System (GIS) has been demonstrated as a powerful tool used to collect, store, retrieve, analyze, and visualize large datasets (Singh et al. 2010; Thakur et al. 2013; Singh et al., 2013b; Thakur et al. 2016). An important outcome of these applications was the better ability to understand existing relationships between the patterns and trends in geospatial datasets.

In India where the present study is focused, the Ken River basin (KRB), categorized as predominant basin, has a catchment area of more than 20,000 km^2. KRB has a total of 12 such sub-basins whose total catchment area amounts to approximately 2.528 million km^2. Among several primary river systems, the Ganga–Brahmaputra–Meghna (Barak) River is the biggest river within the KRB region. Except the Brahmaputra, the Ganga and the Indus, majority of the major river basins in the KRB region is rainfall dependent, but these rivers are also fed with snow as a source of water (Jain and Kumar 2012). Another major river system, Yamuna originates from the Yamunotri glacier located in the Himalayas, and this forms a main stream of the Ganges River flowing in the alluvial plains of North India. The Yamuna River receives a significant contribution of water from the Tons, Chambal, Hindon, Betwa, and Ken rivers. Considering a myriad of river systems in the study region, this research work has focused on the application of statistical approaches on rainfall time series data in order to explore the patterns and variability in drought that affect the Ken River basin (KRB) of Central India.

This study has been divided into six primary sections. Section 1 is concerned with the introduction of the topic and the objective of this research work. A brief study area description, the source of the data, and the statistical techniques are discussed in Sections 2 and 3, respectively, and the results with discussions are presented in Section 4 whereas Section 5 deals with the impacts on agriculture and water resources and Section 6 concludes the major findings of this research work.

2 Study area

Ken River flows in two states in India, known as the Uttar Pradesh (U.P.) and the Madhya Pradesh (M.P.). Hence, the present river can be considered as an interstate river system that is of great importance to the people. The river system lies between the latitudes of 23° 20′ to 25° 20′ and the longitudes of 78° 30′ to 80° 32′. East Ken River originates near the Ahirgawab village in Jabalpur district of Madhya Pradesh that is about 550 m above mean sea level, flowing towards the north and finally joining with the major river Yamuna near the village of Chilla in the state of Uttar Pradesh.

The total length of Ken River is about 427 km, where a major portion (292 km) of this length falls in the Madhya Pradesh. A significant portion of this length (84 km) is situated in Uttar Pradesh, and about 51 km of the total length shares a common boundary with other states. The total catchment area of the Ken River measures approximately 28,058 km^2, and it is divided into 24,472 km^2 located in Madhya Pradesh and the remaining area of about 3386 km^2 located in Uttar Pradesh. The major tributaries of the Ken River are as follows: Banne, Kali, Siameri, Sonar, Bearma, Kopra, Bewas, Urmil, Mirhasan, Kutni, Gurne, Patan, and Chandrawal. In terms of the overall climate, the Ken River basin receives an average annual rainfall of about 1165 mm, and the majority of this rainfall occurs during the southwest monsoon season. The land use/land cover of the study region is characterized by thick forests and agricultural lands, and the agricultural practices near the Ken River basin show an increasing trend.

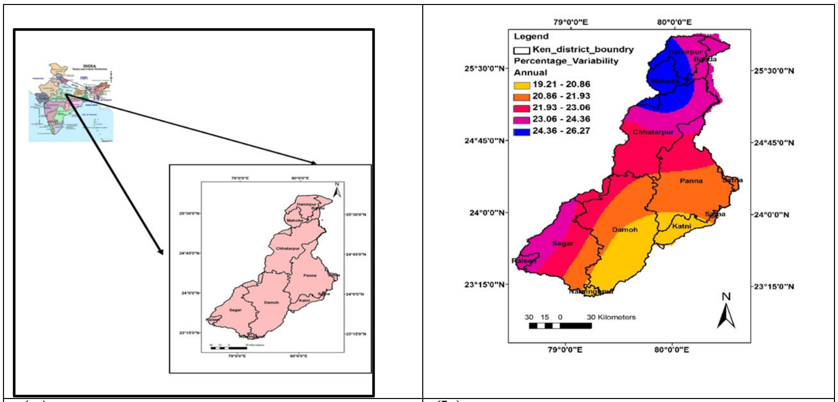
3 Methodology

3.1 Data availability

The rainfall data for a total of 12 districts within the Ken River basin, India, were acquired over a period of 1901–2010 from the web-based India Water Portal (http://www.indiawaterportal.org/metdata) in Excel format. The downloaded data were arranged and preprocessed in Excel format before any statistical analysis. The locations of the study stations have been illustrated in Fig. 1a, and the data availability and rainfall characteristics are listed in Table 1.

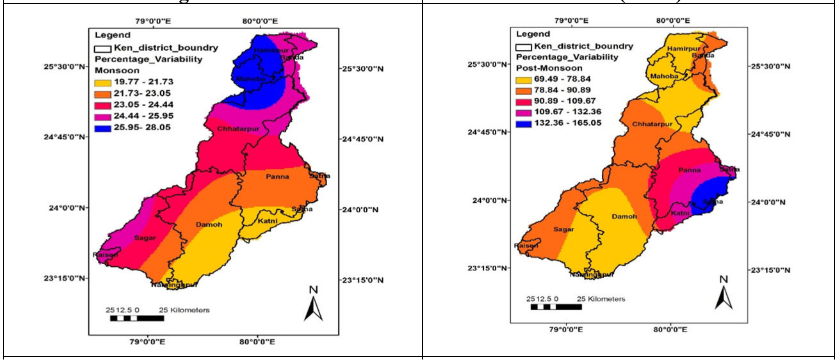
3.2 Materials and methods

To analyze and extract useful information from the data, a series of stepwise methods were applied to better understand the characteristics of the rainfall data and the trends therein. The basic descriptive statistics (i.e., mean, coefficient of variation, standard deviation, kurtosis, and skewness) were calculated for the annual and seasonal rainfall time series for each station over the 110-year period, followed by the presence of autocorrelation checked for each station (Anderson 1942). After the autocorrelation process, statistical homogeneity tests were also applied (Alexandersson 1986; Alexandersson and Moberg 1997) that aimed to check the authenticity of the data. The locally weighted scatter plot smooth (LOWESS) curve was then applied to check the general patterns in the data series over the study period and the probability plot correlation coefficient of the normality including a simple linear regression analysis. Finally, the Mann–Kendall (MK) test and the Sen's slope estimator test were applied (Sen 1968). In order to also gather some information on the direction and the magnitude of trends, spatial analysis based on the inverse distance weighted approach was applied. The following section provides a brief description of these approaches.



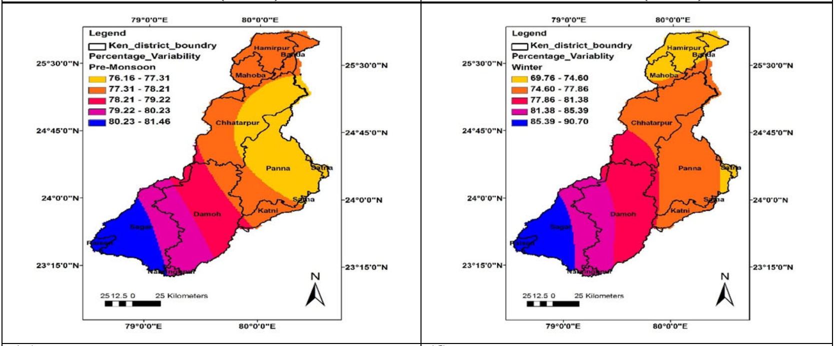
(a) Study area and distribution of meteorological stations

(b) Inter-annual variability in annual rainfall (%CV)



(c) Inter-annual variability in monsoon rainfall (%CV)

(d) Inter-annual variability in post-monsoon rainfall (%CV)



(e) Inter-annual variability in pre-monsoon rainfall (%CV)

(f) Inter-annual variability in winter rainfall (%CV)

Fig. 1 **a** Study area and distribution of meteorological stations, **b** inter-annual variability in annual rainfall (% CV), **c** inter-annual variability in monsoon rainfall (% CV), **d** inter-annual variability in post-monsoon rainfall (% CV), **e** inter-annual variability in pre-monsoon rainfall (% CV), and **f** inter-annual variability in winter rainfall (% CV)

3.2.1 Autocorrelation

A major challenge faced in respect to the time series analysis is the effect of serial dependence of the antecedent and current data points that can cause a major problem in the interpretation and testing of the trends in the given time series dataset. The presence of autocorrelation in such data marks the recognition of a notable trend (Hamed and Rao 1998; Yue et al. 2002). It is important to note that the MK test is likely to identify a significant trend in the data series if (+ ve) autocorrelation (persistence) exists in the series although there may not actually be a realistic trend. Consequently, in this study, the rainfall series were initially analyzed for serial correlation by utilizing a lag-1 autocorrelation coefficient (r) as specified in Eq. (1) at a significance p value of 5% for a two-tailed (upward or downward) test. The results, utilizing the following equation, are presented in Table 2.

$$r_1 = \frac{\sum_{i=1}^{N-1}\left(x_t-\overline{x}\right)\left(x_{t+1}-\overline{x}\right)}{\sum_{i=1}^{N}\left(x_t-\overline{x}\right)^2} \tag{1}$$

where $\overline{x} = \sum_{i=1}^{N} x_t$ is the overall mean of the N sized sample data.

3.2.2 Homogeneity test

To assess the homogeneity (as a quality assurance factor) of the rainfall time series, the standard normal homogeneity test (SNHT) (Alexandersson 1986; Alexandersson and Moberg 1997) was applied at a 5% centrality level. The data series were considered to be homogeneous if the basic estimation of the SNHT statistic T of the 111 samples at a 95% critical level was found less than 9.17 (Khaliq and Ouarda 2007). The conclusive outcomes of this test, indicating that all the data series were homogeneous, are reported in Table 2.

3.2.3 Linear regression analysis

In light of the graphical representation of the information discussed in the exploratory investigation phase, a straight line regression model was conjectured in order to portray the relationships between the measure of time (i.e., temporal dependence) and rainfall. This test was applied to characterize the expectation of any measure of rainfall $\mathcal{Y}$ (mm), given at a time t (years). The conditions relating the measure of rainfall in respect to the time were used as per the following relationship:

$$\mathcal{Y} = \mathcal{Y}_0 + \mathcal{Y}_1 t + \mathfrak{e} \tag{2}$$

where, $\mathcal{Y}$, t, and $\mathfrak{e}$ were the variables demonstrating the measure of rainfall (mm), explanatory variable, and the disturbance or the unobserved error, respectively. The objective of this approach was to evaluate the regression constraints $\mathcal{Y}_0$ (the intercept) and $\mathcal{Y}_1$ (the slope) present within the time series data.

3.2.4 Trend analysis using the Mann–Kendall test

The statistical significance of the trends in rainfall records was investigated using the Mann–Kendall test (Mann 1945; Kendall 1975). To identify the presence of any upward or downward trends in the rainfall time series, the following notion was satisfied.

Supposing the time series data were not dependent (or serially correlated), then the Mann–Kendall statistic $\mathcal{S}$ can be described as follows:

$$\mathcal{S} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sign}\left(x_j - x_\mathrm{i}\right) \tag{3}$$

where x_j and x_i were consecutive information for the jth and ith terms; n was the sample size; and

$$sign\left(x_j - x_i\right) = \begin{cases} -1, if\ x_j - x_i < 1 \\ 0, if\ x_j - x_i = 0 \\ +1, if\ x_j - x_i > 1 \end{cases} \tag{4}$$

The statistic $\mathcal{S}$ can be considered to be Gaussian when n = 18 with the variance $Var\,\mathcal{S}$ and the mean E (s) of the statistic $\mathcal{S}$ are given by the expressions:

$$E(s) = 0, Var(\mathcal{S}) = \frac{n(n-1)(2n+5)}{18} \tag{5}$$

In any case, if ties exist in the dataset, then the expression for $Var\,\mathcal{S}$ must be balanced. This is likely to lead to:

$$Var(\mathcal{S}) = \frac{\left\{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right\}}{18} \tag{6}$$

The variables t_p and q in Eq. (4) are the number of datum points in the pth group and the number of tied groups, respectively. The standardized statistic (Z) that provides final conclusions of the Mann–Kendall test is given as follows:

$$Z_\mathrm{mk} = \begin{cases} \frac{\mathcal{S}-1}{\sqrt{Var(\mathcal{S})}}, if\ \mathcal{S} > 0 \\ 0, if\ \mathcal{S} = 0 \\ \frac{\mathcal{S}+1}{\sqrt{Var(\mathcal{S})}}, if\ \mathcal{S} < 0 \end{cases} \tag{7}$$

Note that if Z_mk is + ve, then the trend in rainfall data can be considered to be an increasing trend and if this statistic is − ve, then the trend is considered to be a decreasing nature.

Table 1 General statistics of the Ken River basin

Station	Annual					Post-monsoon					Monsoon				
	Mean (mm)	SD (mm)	CV (%)	Skewness	Kurtosis	Mean (mm)	SD (mm)	CV (%)	Skewness	Kurtosis	Mean (mm)	SD (mm)	CV (%)	Skewness	Kurtosis
Banda	87.89	20.41	23.22	− 0.09	− 0.61	15.35	12.17	79.27	0.98	0.84	238.89	60.36	25.27	− 0.18	− 0.48
Hamirpur	80.57	19.25	23.89	− 0.28	− 0.70	14.59	11.36	77.85	0.99	0.79	220.08	56.49	25.67	− 0.36	− 0.74
Mahoba	85.27	22.83	26.77	− 0.71	0.45	15.23	12.30	80.76	1.15	1.26	232.52	65.30	28.09	− 0.71	0.29
Chhatarpur	93.31	20.93	22.43	− 0.06	− 0.67	17.42	14.66	84.16	1.41	2.35	253.50	60.74	23.96	− 0.15	− 0.55
Damoh	99.19	20.80	20.97	0.19	− 0.41	19.21	15.41	80.21	1.14	1.17	268.95	59.24	22.03	0.25	− 0.07
Jabalpur	103.15	18.47	17.91	0.49	0.02	22.62	16.26	71.88	0.73	− 0.08	272.85	50.38	18.46	0.53	0.17
Katni	101.77	21.93	21.55	0.04	0.67	19.36	13.64	70.42	0.67	0.00	270.20	59.45	22.00	0.24	1.67
Narsinghpur	98.02	19.96	20.37	0.52	− 0.35	21.14	17.62	83.36	1.20	1.65	263.27	54.93	20.86	0.68	− 0.04
Panna	97.11	21.98	22.63	− 0.35	− 0.23	17.95	16.36	22.63	2.77	13.88	262.00	63.33	24.17	− 0.32	− 0.40
Raisen	100.40	24.87	24.77	0.66	0.29	18.46	20.53	111.23	3.02	13.88	277.92	71.78	25.83	0.82	0.58
Sagar	98.20	24.36	24.81	0.44	− 0.12	18.29	17.65	96.54	1.73	3.33	269.74	69.80	25.88	0.56	0.18
Satna	95.58	20.36	21.30	− 0.07	− 0.54	17.20	14.55	84.59	1.95	6.47	255.36	58.31	22.83	− 0.12	− 0.44
	Pre-monsoon					Winter									
Station	Mean (mm)	SD (mm)	CV (%)	Skewness	Kurtosis	Mean (mm)	SD (mm)	CV (%)	Skewness	Kurtosis					
Banda	6.90	5.76	83.43	1.07	0.70	16.20	12.33	76.11	0.86	0.21					
Hamirpur	5.08	3.78	74.55	0.95	0.73	13.73	9.42	68.56	0.71	− 0.02					
Mahoba	5.86	4.25	72.64	1.08	1.48	14.97	11.18	74.72	0.88	0.45					
Chhatarpur	6.75	5.66	83.88	1.92	5.66	16.60	12.79	77.05	1.07	0.99					
Damoh	7.96	5.65	70.98	1.20	1.83	16.49	13.47	81.70	1.14	0.69					
Jabalpur	12.54	8.69	69.26	1.29	2.86	20.48	15.50	75.67	1.00	0.48					
Katni	13.19	24.37	184.75	8.69	82.19	21.39	15.85	74.10	0.97	0.40					
Narsinghpur	10.49	7.32	69.72	1.06	1.36	14.14	11.96	84.62	1.02	0.21					
Panna	8.31	6.50	78.21	1.15	1.38	19.25	14.79	76.84	1.04	0.60					
Raisen	6.50	4.61	70.89	0.72	0.01	9.15	8.84	96.58	1.46	1.85					
Sagar	6.40	5.40	84.28	2.25	8.86	12.66	11.14	88.02	1.32	1.54					
Satna	10.00	8.10	80.95	1.33	1.76	21.93	15.85	72.27	0.89	0.18					

Table 2 Autocorrelation/homogeneity and PPCC of the precipitation data of Ken River basin

Stations	Autocorrelation					Homogeneity					PPCC for normality				
	Annual	Post-monsoon	Monsoon	Pre-monsoon	Winter	Annual	Post-monsoon	Monsoon	Pre-monsoon	Winter	Annual	Post-monsoon	Monsoon	Pre-monsoon	Winter
Banda	0.0422	0.0012	0.0481	0.0013	0.0010	Ha	Ha	Ha	Ho	Ho	0.996	0.960	0.995	0.949	0.963
Hamirpur	0.0471	0.0049	0.0549	0.0025	0.0000	Ha	Ho	Ha	Ho	Ho	0.990	0.961	0.988	0.964	0.974
Mahoba	0.0862	0.0003	0.0927	0.0056	0.0032	Ha	Ho	Ha	Ho	Ho	0.983	0.952	0.982	0.959	0.967
Chhatarpur	0.0380	0.0032	0.0495	0.0135	0.0006	Ha	Ho	Ha	Ho	Ho	0.996	0.939	0.995	0.916	0.956
Damoh	0.0129	0.0008	0.0117	0.0036	0.0003	Ha	Ho	Ha	Ho	Ho	0.996	0.952	0.996	0.958	0.947
Jabalpur	0.0049	0.0025	0.0027	0.0045	0.0007	Ha	Ho	Ha	Ho	Ho	0.988	0.972	0.988	0.957	0.959
Katni	0.0245	0.0070	0.0287	0.0056	0.0085	Ha	Ho	Ha	Ho	Ho	0.992	0.978	0.984	0.536	0.960
Narsinghpur	0.0072	0.0097	0.0048	0.0013	0.0019	Ha	Ho	Ha	Ho	Ho	0.984	0.948	0.979	0.964	0.948
Panna	0.0488	0.0103	0.0588	0.0075	0.0000	Ha	Ho	Ha	Ho	Ho	0.994	0.884	0.993	0.955	0.955
Raisen	0.0146	0.0077	0.0217	0.0012	0.0051	Ha	Ho	Ha	Ho	Ho	0.985	0.847	0.978	0.974	0.919
Sagar	0.0086	0.0008	0.0130	0.0224	0.0014	Ha	Ho	Ha	Ho	Ho	0.991	0.907	0.988	0.903	0.935
Satna	0.0370	0.0058	0.0456	0.0000	0.0005	Ha	Ho	Ha	Ho	Ho	0.995	0.919	0.996	0.938	0.963

Ho homogeneous, *Ha* heterogeneous

3.2.5 Theil–Sen's estimator

The magnitude of the trend determined by the Mann–Kendall test can be further investigated using the Theil–Sen's estimator as follows:

$$\beta = Median\left(\frac{\mathcal{X}_j - \mathcal{X}_i}{j - i}\right) for \text{ all } i < j \tag{8}$$

In Eq. (8), $1 < j < i < n$ and β are the robust approximation of the trend magnitude. A + ve estimation of β is likely to show an upward trend, while a negative value is likely to demonstrate a downward trend.

3.2.6 Spatial analysis of the rainfall data series

To investigate the spatial distribution of the trends on a monthly basis, the *Z*-statistics was added utilizing Quantum GIS and data from every station over the entire study period. Inverse distance weighted (IDW) interpolation method was used to generate spatial surface ought to be affected largely by nearby points and less by far distant points (Gemmer et al. 2004). The interpolated value of the electric field $E(x, y)$ is given by Azpurua and Ramos (2010):

$$E(x,y) = \sum_{j=0}^{n} w_j E\left(x_j y_j\right) \tag{9}$$

where $(x_j y_j)$ are the coordinates of each dispersion point; (x, y) are the coordinates of the interpolation point and w_j is the weight function.

4 Results and discussion

4.1 Statistical characteristics

The basic statistical parameters of annual and seasonal rainfall datasets for the whole period of 110 years (1901–2010) of KRB are shown in Table 1. The mean and standard deviation (SD) of the annual and seasonal rainfall time series are significantly different for different seasons, ranging from approximately 80.57 to 103.15 mm and 5.08 (pre-monsoon) to 277.92 (monsoon) mm and 18.47 to 24.87 mm and 3.78 (pre-monsoon) to 71.78 (monsoon), respectively. The analysis of annual and seasonal rainfall records showed that the maximum coefficient of variation (CV) was approximately 184.75 mm found for the Katni station in the pre-monsoon and minimum CV and approximately 18.46 mm at the Jabalpur station in the monsoon season.

Skewness is a measure of the symmetry in any given dataset. In accordance with the results, the skewness factor (aligned towards the right side) was found in the post-monsoon, pre-monsoon, and winter season time series of rainfall at all stations. However, the annual and the monsoon time series revealed a skewness aligned towards the left at Banda, Hamirpur, Mahoba, Chattarpur, Narsinghpur, and Satna meteorological stations. The flatness of data as also measured by kurtosis factor appeared to attain a positive value for the pre-monsoon season for all stations, whereas the post-monsoon and winter data also had a positive kurtosis for all stations, except at Hamirpur in the winter and Jabalpur in the post-monsoon season.

4.2 Long-term pattern in mean annual and seasonal precipitation

4.2.1 Locally weighted scatter plot smooth curve

The standardized yearly or annual and seasonal (i.e., pre-monsoon, monsoon, post-monsoon, and winter) precipitation data of the 110-year period have been used to assess the long-term weather/climate patterns notable in the precipitation series. The running mean value is just not resistant to the regional changes. Thus, to decrease the nearby variances, these data or information were fitted with the LOWESS test (Cleveland 1979, 1984; Helsel and Hirsch 2002; Duhan and Pandey 2013) (Fig. 2) in order to recognize the normal patterns over the passage of time over annual and seasonal scales.

Annual precipitation LOWESS curve (as shown in Fig. 2) indicates a continuous increase up to 1941 and appeared to reach the highest value in 1941. From the year 1941 onwards, this curve exhibited a decreasing trend up to the year 2010 and then reached the lowest value in the year 2010. The LOWESS curve of the monsoon rainfall also showed a continuous increase up to the year 1941 and reached the highest value in the year 1941. From the year 1941 onwards, the data exhibited a decreasing trend up to the year 2010. Figure 2c shows the LOWESS curve of post-monsoon rainfall, which firstly increased up to the year 1941 and then marginally reduced up to the year 1948. Later, this trend showed an upward pattern up to the year 1970 and then achieved the highest value in the year 1970. From 1970 onwards, the data showed a decline in the rest of the periods and then dipped to a lowest value in the 2010. The LOWESS curve of the pre-monsoon precipitation (Fig. 2d) showed a continuous increase up to the year 2010. Figure 2e shows the LOWESS curve of the winter rainfall, which primarily exhibited an increasing trend up to the 1946 and, thereafter, showed a decrease that was evident in the rest of the decade.

4.2.2 Probability plot correlation coefficient for the normality

The probability plot correlation coefficient (PPCC) plot that is also called a typical Q-Q plot has been utilized to determine how well a variable fitted the ordinary distribution. To test for normality, this linearity test was also tried by computing the

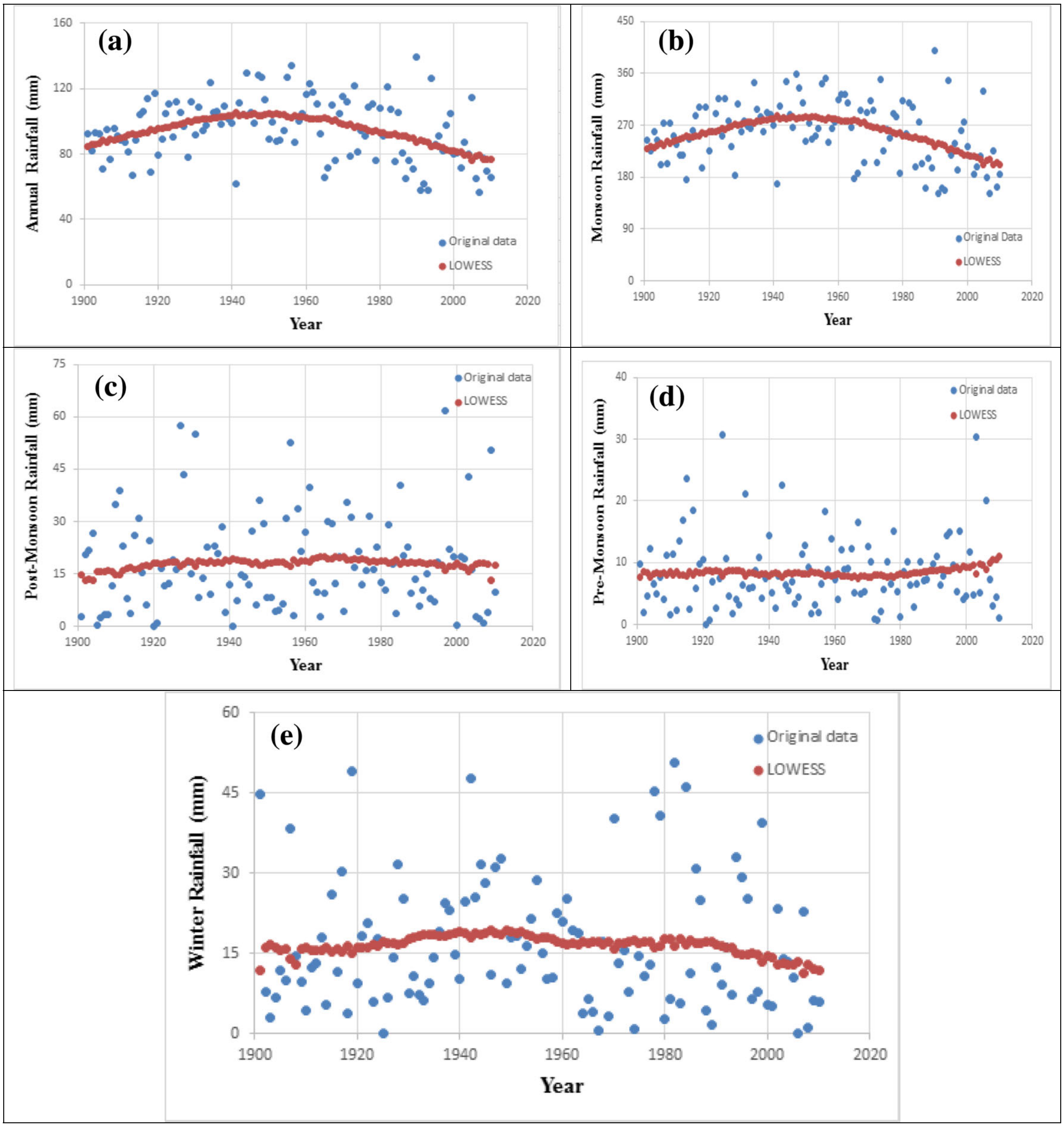


Fig. 2 Standardized rainfall (mm) and LOWESS trend lines during 1901–2010 at Ken River basin. **a** Annual, **b** monsoon, **c** post-monsoon, **d** pre-monsoon, and **e** winter

linear correlation coefficient among the data and their typical quantiles. Samples from a normal distribution are likely to have a correlation coefficient (*r*) near to a value of 1. As the data departs from the normality, their correlation coefficient is likely to reduce below 1.

Table 2 shows that PPCC-based *r* value attained the maximum for the case of Banda, Chhatarpur, and Damoh of about 0.996 and minimum of about 0.983 for Mahoba in an annual series, whereas a maximum PPCC-based *r* value was obtained of about 0.978 (Katni) and minimum of about 0.847 for Raisen in post-monsoon season.

In monsoon season, PPCC-based *r* value was the highest for Damoh (0.996) and the lowest for Mahob (0.982) whereas in the pre-monsoon season, the maximum PPCC-based *r* value was obtained for the case of Raisen (0.974) and a minimum for the case of Katni (0.536). In the winter season, the PPCC-based *r* maximum (0.974) was found for Hamirpur and a minimum for Sagar (0.963). The higher PPCC-based *r* values suggest that the datasets have some degree of normality and they do not deviate from the mean value. It is important to note that when the PPCC-derived *r* has had low value as compared to critical *r* value, the null hypothesis is then rejected and data are normal.

4.3 Trend analysis

Linear regression analysis, Mann–Kendall (MK), and Sen's slope estimator have been used to determine the trends.

4.3.1 Result of linear regression analysis

The results of the linear regression trend analysis are presented in Table 3. The linear trend lines of the annual and monsoon rainfall showed a downward trend for all study stations. In addition, the *R*-square statistic showed a poor relationship between the rainfall and respective year. Table 3 shows a downward trend in the post-monsoon rainfall for the stations of Damoh, Jabalpur, Katni, and Narsinghpur, and the rest of the stations recorded upward trend in the rainfall data. In the pre-monsoon season, five stations showed a downward trend and the rest of the stations showed an upward trend, whereas in winter season, only three stations (Narsinghpur, Raisen, and Sagar) showed upward trend and remaining stations showed a downward trend.

Jain et al. (2013) performed trend analysis of rainfall data series for 1871–2008 and did not show any clear trend for the north eastern region of India as a whole, although there are seasonal trends for some seasons and for some hydro-meteorological subdivisions. Subash and Sikka (2014) investigated the trend meteorological subdivisions of India of rainfall and temperature and the possibility of any rational relationship between the trends over the homogeneous regions over India. They found that there is no direct relationship between temperature and rainfall and concluded that trends of rainfall and temperature have large scale spatial and temporal dependence. Addisu et al. (2015) have analyzed time series of temperature and rainfall using Mann–Kendell trend analysis in the highlands of Ethiopia and Lake Tana Sub-basin (LTSB) in particular to address the issue of national and local climate change. They found that rainfall amount showed a general decreasing trend in Lake Tana Sub-basin. Jain and Kumar (2012) have comprehensively reviewed many articles related to trends in rainfall, rainy days, and temperature over India. They studied 15 basins and reported decreasing trend in annual rainfall, whereas only one basin showed a significant decreasing trend at 95% confidence level. Same direction of trend in rainfall and rainy days at the annual and seasonal scale was also reported for most of the basin. Parthasarathy and Dhar (1974) found that the annual rainfall for the period 1901–1960 had a positive trend over Central India and the adjoining parts of the peninsula and a decreasing trend over some parts of eastern India. Pant and Hingane, 1988found an increased trend in mean annual and SW monsoon rainfall over meteorological sub-divisions of Punjab, Haryana, west Rajasthan, east Rajasthan, and west Madhya Pradesh during the period 1901–1982. Rupa Kumar et al. (1992) reported that northeast peninsula, northeast India, and northwest peninsula experienced a decreasing trend (ranged between − 6 and − 8% of the normal per 100 years) in the monsoon rainfall. But the west coast, central peninsula, and northwest India experienced an increasing trend (about 10–12% of the normal per 100 year) in monsoon rainfall.

The present study basin depends on rain-fed agriculture and that the rainfall is likely to adversely affect the crop yield in the rain-fed agriculture. The rainfall is reduced gradually due to the increase in temperature. It was revealed that an increase in temperature may adversely affect the wheat and paddy crop yield. The main reason of increasing temperature is more of industrialization. It has been observed that the quantity of rainfall decreased due to delay in monsoon. It is well known that all the soil processes with respect to changes in precipitation pattern and increased air temperature can influence available soil water content, runoff, and erosion. The long-term, low intensity of rainfall affects the water balance of the basin. Due to this decrease in surface runoff and less percolation and finally low water yield will be visible in the system. The effect of declining in rainfall on the agricultural production is not certain due to possibility of shifting of spatial monsoon or use of water stress tolerant varieties of crops. Therefore, changes in sowing dates may be an alternate option for enhancing the crop yield under future climate change (Turner 2004).

4.3.2 Mann–Kendall test

Table 3 shows the values of the *Z*-statistics of annual and seasonal time scale rainfall derived from the MK test. The annual, monsoon, and winter seasons have a negative (either a statistically significant or an insignificant) trend at all study stations. However, the pre-monsoon and post-monsoon seasons in eight and seven stations, respectively, out of the 12 stations, have a non-significant increasing trend. In the annual time scale, it was found that three out of 12 stations had a decreasing trend at the 10% significance level, and only one station (i.e., Mahoba, U.P.) had a negative trend at the 5% level. In a monsoon case, a total of seven out of 12 stations showed a declining trend at the 10% significance level, and only one station (i.e., Mahoba, in U.P.) showed a statistically decreasing trend at the 5% significance level.

4.3.3 Magnitude of precipitation series

Figure 1 and Table 3 show the Theil–Sen's slope deduced from the rainfall time series data on the annual and seasonal time scales over the KRB region in India. Table 3 also shows that all the stations exhibited a declining trend in annual, monsoon, and winter season rainfall amounts. In fact, the post-monsoon season showed downward trends in rainfall only at the Damoh, Jabalpur, Katni, Narsinghpur, and Sagar study stations, and the rainfall in the pre-monsoon has a negative trend at the Jabalpur, Katni, Narsinghpur, and Panna stations located in Madhya Pradesh, India.

Table 3 Linear regression analysis, *Z*-statistics, and Sen's slope of the precipitation data of Ken River basin

Stations	Annual Linear regression		Z value	Sen's slope (mm/year)	Post-monsoon Linear regression		Z value	Sen's slope (mm/year)	Monsoon Linear Regression		Z value	Sen's slope (mm/year)
		R^2				R^2				R^2		
Banda	$y=-0.125x+332.6$	0.038	-1.8199^{b}	−0.134	$y=0.019x-23.44$	0.003	0.8222	0.0281	$y=-0.393x+1007.8$	0.043	-1.7937^{b}	−0.3623
Hamirpur	$y=-0.122x+320.8$	0.041	-1.7727^{b}	−0.114	$y=0.030x-45.14$	0.007	1.1941	0.0338	$y=-0.389x+980.9$	0.048	-1.6890^{b}	−0.3485
Mahoba	$y=-0.203x+482.0$	0.081	-2.0556^{a}	−0.16	$y=5E{-}05x+15.02$	0.000	0.0210	0.0002	$y=-0.600x+1405.9$	0.086	-2.0451^{a}	−0.4623
Chhatarpur	$y=-0.123x+334.6$	0.035	-1.7623^{b}	−0.122	$y=0.032x-46.63$	0.005	0.3352	0.0129	$y=-0.408x+1051.1$	0.046	-1.8304^{b}	−0.3907
Damoh	$y=-0.072x+240.6$	0.012	−1.1652	−0.075	$y=-0.005x+29.1$	0.001	−0.5368	−0.0218	$y=-0.195x+650.34$	0.011	−0.982	−0.1866
Jabalpur	$y=-0.038x+178.2$	0.004	−0.9872	−0.049	$y=-0.015x+53.3$	0.001	−0.5761	−0.0285	$y=-0.075x+420.06$	0.002	−0.9767	−0.1416
Katni	$y=-0.104x+305.9$	0.023	−1.5161	−0.102	$y=-0.027x+72.1$	0.004	−0.8222	−0.037	$y=-0.303x+863.76$	0.026	-1.8146^{b}	−0.2893
Narsinghpur	$y=-0.052x+201.2$	0.007	−1.0396	−0.061	$y=-0.044x+108.8$	0.006	−1.4323	−0.0601	$y=-0.118x+494.73$	0.004	−1.0553	−0.1674
Panna	$y=-0.148x+388.1$	0.047	−1.6366	−0.126	$y=0.059x-97.58$	0.013	0.5080	0.0206	$y=-0.468x+1177.1$	0.056	-1.7570^{b}	−0.3885
Raisen	$y=-0.094x+285.0$	0.014	−1.2595	−0.094	$y=0.062x-103.6$	0.009	0.0812	0.0014	$y=-0.330x+925.14$	0.029	-1.6628^{b}	−0.3441
Sagar	$y=-0.069x+234.8$	0.008	−0.9191	−0.076	$y=0.022x-24.98$	0.002	−0.1702	−0.0061	$y=-0.245x+750.23$	0.013	−1.2648	−0.2784
Satna	$y=-0.119x+328.5$	0.035	−1.6156	−0.118	$y=0.041x-64.89$	0.008	0.3326	0.0138	$y=-0.374x+987.37$	0.042	-1.8565^{b}	−0.3577
Stations	Pre-monsoon Linear regression		Z value	Sen's slope (mm/y)	Winter Linear regression		Z value	Sen's slope (mm/y)				
		R^2				R^2						
Banda	$y=0.007x-7.15$	0.0016	1.3066	0.02	$y=-0.0048x+25.968$	0.0001	−0.110	−0.0038				
Hamirpur	$y=0.006x-7.70$	0.0031	1.1364	0.01	$y=-0.0145x+42.304$	0.0023	−0.225	−0.006				
Mahoba	$y=0.010x-14.36$	0.0061	1.469	0.02	$y=-0.033x+79.793$	0.0085	−1.074	−0.0332				
Chhatarpur	$y=0.020x-33.12$	0.0133	1.4454	0.02	$y=-0.0044x+25.482$	0.0001	−0.233	−0.0069				
Damoh	$y=-0.011x+30.7$	0.0044	0.0419	0.00	$y=-0.0188x+53.541$	0.0019	−0.754	−0.026				
Jabalpur	$y=-0.28x+1959.1$	0.006	−0.5263	−0.01	$y=-0.103x+1957.6$	0.0025	−0.422	−0.018				
Katni	$y=0.055x-94.46$	0.0052	−1.3199	−0.03	$y=-0.0612x+141.45$	0.0147	−1.173	−0.0506				
Narsinghpur	$y=-0.011x+32.7$	0.0025	−0.1702	0.00	$y=0.0044x+5.7655$	0.0001	−0.031	−0.0006				
Panna	$y=-0.017x+42.9$	0.0076	−0.4347	−0.01	$y=-0.0191x+56.849$	0.0016	−0.503	−0.0172				
Raisen	$y=-0.005x+18.0$	0.0017	0.2619	0.00	$y=0.0107x-11.681$	0.0015	−0.126	−0.0028				
Sagar	$y=0.024x-41.41$	0.0211	1.5947	0.02	$y=0.0024x+8.0676$	0.0001	−0.280	−0.006				
Satna	$y=0.001x+7.09$	0.0000	0.375	0.01	$y=-0.0313x+83.458$	0.0038	−0.526	−0.0229				

[a] Indicate a 5% level of significance

[b] Indicate a 10% level of significance

4.4 Analysis of rainfall variability pattern

The study of rainfall variability patterns, in respect to the coefficient of variation (CV) over the 110 years of data, indicated that the inter-annual variability was the highest for KRB. It is noteworthy that the high CV clearly indicated that the rainfall was highly variable and in fact, not dependable or reliable due to its stochastic nature over the period of study. The lower CV values in any given season were consistent with lower variability and greater dependability. A closer look at the data showed minimum CV values as approximately 17.91% (Jabalpur) for the annual rainfall case, while the maximum seasonal CV value was found in the pre-monsoon season for the Katni study site (184.75%). Further, the CV value revealed that the annual and the monsoon rainfall variability was relatively low, and the annual CV showed a minimum variation compared to the other seasons.

5 Impacts on agriculture and water resource

The knowledge about the precipitation and its trends over long-term periods is very important for an agrarian economy such as India, since this variable together with other meteorological variables such as temperature is required for an appraisal of the water resources for various applications. The occurrence and inconsistency in rainfall amounts received control the activities within an area under different current cropping and future agricultural scenarios (Kumar et al. 2010). In the present era, precision agriculture is gaining significant popularity under increasing climate stress, and much of the variation in precipitation regimes is notable at a variety of spatial and temporal scale. A better understanding of rainfall features and availability of soil moisture is seriously important for the sustained growth of farming systems (Gajbhiye et al. 2015a). Agriculture is heavily reliant on rainfall, and it has a direct influence on the production of food grains, hydropower, and economy. It also influences the supply of water in urban and industrial sectors (Gajbhiye et al. 2015a). Therefore, declining trends in rainfall at agricultural stations is likely to lead to drought, reduced soil moisture, decline in the groundwater table, lower agricultural yield, and the migration of rural people to urban area in search of food and employment. While the annual trends of rainfall for most studied stations showed a decreasing pattern, some stations showed an upward trend, indicating reasonably good conditions for agricultural activities. However, the present study showed that a few stations during the pre-monsoon and the post-monsoon seasons exhibited an upward trend in rainfall. Therefore, alternative water resource measures such as regular checks at dams, identification of the new recharging sites, rainwater harvesting, and water stress tolerant crops are required to adapt to the changing climate in the present study region.

6 Conclusion

In this paper, a statistical evaluation of trends in rainfall for the Ken River basin, Central India (1901–2010) was investigated. The results showed that the seasonal and annual rainfall data analyzed with linear regression approaches revealed that all the study stations exhibited a downward trend, whereas the *Z* values obtained from the non-parametric Mann–Kendall test represented both positive as well as negative trends. Statistically significant negative trends in data series were evident for in study stations in terms of the annual, monsoon, and winter seasons. The time series analysis of the post and pre-monsoonal season, however, showed a non-significant increasing and decreasing trend. In particular, the negative trend found at the 5% significance level was observed for both the annual and monsoon seasons for the Mahoba rain gauge station. At the 10% significance level, a total of three study stations revealed a decreasing trend in annual time series data, whereas, a total of 7 study stations revealed a decreasing trend in the monsoon season. From the statistical test of the present results, it was evident that there was a clear signature of the changes in precipitation trend in the KRB region. Annual as well as seasonal data indicated decreasing tendency in rainfall amounts during the last part of the century. The approaches and conclusive results presented in this research study can have useful implications for the water resource planning and local policy making in respect to sustainable water utilization in the current and future changing climate in the Ken River basin, Central India.

Acknowledgments The authors are thankful to the University Grants Commission (UGC), New Delhi, India, for providing financial support during the study period. We are also thankful to the anonymous reviewers for their continuous constructive comments and suggestions on the manuscript.

References

Addisu S, Selassie YG, Fissha G, Gedif B (2015) Time series trend analysis of temperature and rainfall in lake Tana Sub-basin, Ethiopia. Environ Syst Res 4–25(1):1–12. https://doi.org/10.1186/s40068-015-0051-0

Alexandersson H (1986) A homogeneity test applied to precipitation data. J Climatol 6(6):661–675. https://doi.org/10.1002/joc.3370060607

Alexandersson H, Moberg A (1997) Homogenization of Swedish temperature data. Part I: a homogeneity test for linear trends. Int J Climatol 17(1):25–34. https://doi.org/10.1002/(SICI)1097-0088(199701)17:1<25::AID-JOC103>3.0.CO;2-J

Anderson RL (1942) Distribution of the serial correlation coefficient. Ann Math Stat 13(1):1–13. https://doi.org/10.1214/aoms/1177731638

Azpurua M, Ramos KD (2010) A comparison of spatial interpolation methods for estimation of average electromagnetic field magnitude. Progress in Electromagnetics Research M 14:135–145. https://doi.org/10.2528/PIERM10083103

Brunetti M, Buffoni L, Maugeri M, Nanni T (2000) Precipitation intensity trends in Northern Italy. Int J Climatol 20(9):1017–1031. https://doi.org/10.1002/1097-0088(200007)20:9<1017::AID-JOC515>3.0.CO;2-S

Chandniha SK, Meshram SG, Adamowski JF, Meshram C (2016) Trend analysis of precipitation in Jharkhand State, India. Theor Appl Climatol 130(1–2):261–274. https://doi.org/10.1007/s00704-016-1875-x

Cleveland WS (1979) Robust locally weighted regression and smoothing scatter plots. J Am Stat Assoc 74(368):829–836. https://doi.org/10.1080/01621459.1979.10481038

Cleveland WS (1984) Graphs in scientific publications. Am Stat 38(4):261–269

Darshana D, Pandey A (2013) Statistical analysis of long term spatial and temporal trends of precipitation during 1901–2002 at Madhya Pradesh, India. Atmos Res 122:136–149

Dhorde AG, Zarenistanak M (2013) Three-way approach to test data homogeneity: an analysis of temperature and precipitation series over southwestern Islamic Republic of Iran. J Ind Geophys Union 17(3):233–242

Dhorde A, Dhorde A, Gadgil AS (2009) Long-term temperature trends at four largest cities of India during the twentieth century. J Ind Geophys Union 13(2):85–97

Easterling DR, Evans JL, Groisman PV, Karl TR, Kunkel KE, Ambenje P (2000) Observed variability and trends in extreme climate events: a brief review. B Am Meteor Soc 81(3):417–425. https://doi.org/10.1175/1520-0477(2000)081<0417:OVATIE>2.3.CO;2

Fathian F, Dehghan Z, Bazrkar MH, Eslamian S (2014) Trends in hydrologic and climatic variables affected by four variations of Mann-Kendall approach in Urmia Lake basin, Iran. Hydrol Sci J 61(5):892–904. https://doi.org/10.1080/02626667.2014.932911

Gajbhiye S, Awasthi MK, Sharma SK (2014) Assessment of ground water quality. LAMBERT Academic Publishing, Germany ISBN 978-3-659-53985-5

Gajbhiye S, Meshram C, Mirabbasi R, Sharma SK (2015a) Trend analysis of rainfall time series for Sindh River basin in India. Theor Appl Climatol 125(3):593–608

Gajbhiye S, Meshram C, Singh SK, Srivastava PK, Islam T (2015b) Precipitation trend analysis of Sindh River basin, India from long term 102 years of record (1901–2002). Atmos Sci Lett 17(1):71–77

Gemmer M, Becker S, Jiang T (2004) Observed monthly precipitation trends in China 1951−2002. Theor. Appl Climatol 77(1–2):39–45. https://doi.org/10.1007/s00704-003-0018-3

Haigh MJ (2004) Sustainable management of headwater resources: the Nairobi headwater declaration (2002) and beyond. Asian J Water Environ Pollut 1(1–2):17–28

Hamed KH, Rao AR (1998) A modified Mann-Kendall trend test for auto correlated data. J Hydrol 204:182–196

Haylock MR, Peterson TC, Alves LM, Ambrizzi T, Anunciação YMT, Baez J, Barros VR, Berlato MA, Bidegain M, Coronel G, Corradi V, Garcia VJ, Grimm AM, Karoly D, Marengo JA, Marino MB, Moncunill DF, Nechet D, Quintana J, Rebello E, Rusticucci M, Santos JL, Trebejo I, Vincent LA (2006) Trends in total and extreme South American rainfall in 1960–2000 and links with sea surface temperature. J Clim 19:1490–1512. https://doi.org/10.1175/JCLI3695.1

Helsel DR, Hirsch RM (2002) Statistical methods in water resources (Techniques of water resources investigations of the United States geological survey, Book 4 hydrologic analysis and interpretation, chapter A3). U.S. Geological Survey, Reston, p. 522

Hirsch RM, Slack JS, Smith RA (1982) Technique of trend analysis for monthly water quality data. Water Resour Res 18(1):107–121. https://doi.org/10.1029/WR018i001p00107

IPCC (1996) Climate change. In: Houghton JT, MeiraFilho LG, Callander BA, Harris N, Kattenberg A, Maskell K (eds) The IPCC second assessment report. Cambridge University Press, New York, NY

IPCC (2007) Climate change 2007: Impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ and Hanson CE (eds) Contribution of working group II to the fourth assessment report of the IPCC. Cambridge University Press, Cambridge, p. 976

Jain SK, Kumar V (2012) Trend analysis of rainfall and temperature data for India. Curr Sci 102(1):37–49

Jain SK, Kumar V, Sharia M (2013) Analysis of rainfall and temperature trends in northeast India. Int J Climatol 33(4):968–978. https://doi.org/10.1002/joc.3483

Karpouzos DK, Kavalieratou S, Babajimopoulos C (2010) Trend analysis of precipitation data in Pieria Region (Greece). European Water 30:31–40

Kendall MG (1975) Rank correlation methods. Charles Griffin, London

Khaliq MN, Ouarda TBMJ (2007) Short communication on the critical values of the standard normal homogeneity test (SNHT). Int J Climatol 27(5):681–687. https://doi.org/10.1002/joc.1438

Kumar V, Jain SK, Singh Y (2010) Analysis of long-term rainfall trends in India. Hydrol Sci J 55(4):484–496. https://doi.org/10.1080/02626667.2010.481373

Mann HB (1945) Nonparametric tests against trend. Econometrica 13(3):245–259. https://doi.org/10.2307/1907187

Meshram SG, Singh VP, Meshram C (2016) Long-term trend and variability of precipitation in Chhattisgarh State, India. Theor Appl Climatol 129:729–744

Meshram SG, Gautam R, Kahya E (2017) Drought analysis in the Tons River Basin, India during 1969–2008. Theor Appl Climatol. https://doi.org/10.1007/s00704-017-2129-2

Nyatuame M, Owusu-Gyimah V, Ampiaw F (2014) Statistical analysis of rainfall trend for Volta Region in Ghana. Int J Atmos Sci 2014:11. https://doi.org/10.1155/2014/203245

Pant GB, Hingane LS (1988) Climatic changes in and around the Rajasthan desert during the 20th century. Int J Climatol 8(4):391–401. https://doi.org/10.1002/joc.3370080406

Parthasarathy B, Dhar ON (1974) Secular variations of regional rainfall over India. Quat J Royal Meteorol Soc 100:245–257

Rupa Kumar K, Pant GB, Parthasarathy B, Sontakke NA (1992) Spatial and sub-seasonal patterns of the long term trends of Indian summer monsoon rainfall. Int J Climatol 12(3):257–268. https://doi.org/10.1002/joc.3370120303

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 63(324):1379–1389. https://doi.org/10.1080/01621459.1968.10480934

Shang H, Yan J, Gebremichael M, Ayalew SM (2011) Trend analysis of extreme precipitation in the Northwestern Highlands of Ethiopia with a case study of Debre Markos. Hydrol Earth Syst Sci 15(6):1937–1944. https://doi.org/10.5194/hess-15-1937-2011

Singh SK, Singh CK, Mukherjee S (2010) Impact of land-use and land-cover change on groundwater quality in the Lower Shiwalik hills: a remote sensing and GIS based approach. Cent Eur J Geosci 2:124–131

Singh SK, Srivastava PK, Pandey AC, Gautam SK (2013a) Integrated assessment of groundwater influenced by a confluence river system: concurrence with Remote Sensing and Geochemical Modelling. Water Resour Manag 27(12):4291–4313. https://doi.org/10.1007/s11269-013-0408-y

Singh SK, Srivastava PK, Pandey AC (2013b) Fluoride contamination mapping of groundwater in Northern India integrated with geochemical indicators and GIS. Water Sci Technol Water Supply 13(6):1513–1523. https://doi.org/10.2166/ws.2013.160

Singh SK, Srivastava PK, Singh D, Han D, Gautam SK, Pandey AC (2015) Modeling groundwater quality over a humid subtropical region using numerical indices, earth observation datasets, and X-ray diffraction technique: a case study of Allahabad district, India. Environ Geochem Health 37(1):157–180. https://doi.org/10.1007/s10653-014-9638-z

Subash N, Sikka AK (2014) Trend analysis of rainfall and temperature and its relationship over India. Theor Appl Climatol 117(3–4):449–462. https://doi.org/10.1007/s00704-013-1015-9

Taxak AK, Murumkar AR, Arya DS (2014) Long term spatial and temporal rainfall trends and homogeneity analysis in Wainganga Basin, Central India. Weather and Climate Extremes 4:50–61. https://doi.org/10.1016/j.wace.2014.04.005

Thakur J, Singh P, Singh SK, Baghel B (2013) Geochemical modelling of fluoride concentration in hard rock terrain of Madhya Pradesh, India. Acta Geol Sin (English Ed) 87(5):1421–1433. https://doi.org/10.1111/1755-6724.12139

Thakur JK, Singh SK., Ekanthalu VS (2016) Integrating remote sensing, geographic information systems and global positioning system techniques with hydrological modeling. Appl Water Sci 7(4):1595–1608

Turner NC (2004) Agronomic options for improving rainfall-use efficiency of crops in dryland farming systems. J Exp Bot 55:2413–2425

Villafuerte MQ, Matsumoto J, Akasaka I, Takahashi HG, Kubotac H, Cinco TA (2013) Long-term trends and variability of rainfall extremes in the Philippines. Atmos Res 137:1–13

Yue S, Pilon P, Phinney B, Cavadias G (2002) The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrol Process 16(9):1807–1829. https://doi.org/10.1002/hyp.1095

Zamani R, Mirabbasi R, Nazeri M, Meshram SG, Ahmadi F (2017) Spatio-temporal analysis of daily, seasonal and annual precipitation concentration in Jharkhand State, India. Stochastic Environ Res Risk Assess. https://doi.org/10.1007/s00477-017-1447-3

Zhai P, Zhang X, Wan H, Pan X (2005) Trends in total precipitation and frequency of daily precipitation extremes over China. J Clim 18:1097–1108

Zhang X, Vincent LA, Hogg WD, Niitsoo A (2000) Temperature and precipitation trends in Canada during the 20th century. Atmosphere-Ocean 38(3):395–429. https://doi.org/10.1080/07055900.2000.9649654