ORIGINAL ARTICLE

Analysis of seasonal and annual rainfall trends for Ranchi district, Jharkhand, India

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Abstract

The aim of this study was to investigate temporal variation in seasonal and annual rainfall trend over Ranchi district of Jharkhand, India for the period (1901–2014: 113 years). Mean monthly rainfall data series were used to determine the significance and magnitude of the trend using non-parametric Mann–Kendall and Sen's slope estimator. The analysis showed a significant decreased in rainfall during annual, winter and southwest monsoon rainfall while increased in pre-monsoon and post-monsoon rainfall over the Ranchi district. A positive trend is detected in pre-monsoon and post-monsoon rainfall data series while annual, winter and southwest monsoon rainfall showed a negative trend. The maximum decrease in rainfall was found for monsoon ($-$ 1.348 mm year^{-1}) and minimum ($-$ 0.098 mm year^{-1}) during winter rainfall. The trend of post-monsoon rainfall was found upward (0.068 mm year^{-1}). The positive and negative trends of annual and seasonal rainfall were found statistically non-significant except monsoon rainfall at 5% level of significance. Rainfall variability pattern was calculated using coefficient of variation CV, %. Post-monsoon rainfall showed the maximum value of CV (70.80%), whereas annual rainfall exhibited the minimum value of CV (17.09%), respectively. In general, high variation of CV was found which showed that the entire region is very vulnerable to droughts and floods.

Keywords Trend analysis · Temporal series · Non-parametric test

Introduction

Rainfall is an important physical phenomenon that transports water from the atmosphere back to the earth's surface and connects the weather, climate and hydrological cycle throughout the globe. A precise concept of rainfall characteristics and soil variability is of great significance to get maximum farm production in a sustainable manner (Gajbhiye et al. 2016; Meshram et al. 2017). Agriculture, food security, energy security and economy of India directly or indirectly vary on the timely accessibility of adequate quantity of rainfall and suitable climate (Jain et al. 2012). The severer change in rainfall trend and its variability resulted in the events such as flood and drought (Srivastava et al. 2015). The aquifer recharge and moisture of the soil for the agriculture crop production is determined by the amount of rainfall (Gupta et al. 2014).

The extreme changes in the amount of rainfall and frequency are the important factor affecting the runoff distribution pattern of groundwater reserve, stream flow pattern and soil moisture (Srivastava et al. 2014). Rainfall trend analysis at different spatial and temporal time scales becomes an important concern as it is directly connected to global climate change. The global surface warming is occurring at the rate of 0.74 ± 0.18 °C during the period 1906–2005 (IPCC 2007) and future climate variability is likely to affect the agriculture, freshwater availability, livelihood security and rapid melting of the glacier. Agriculture is the most vulnerable sector to climate change as climate change affects both rainfall and temperature (Philip et al. 2014) which are the determining factors of agricultural productivity. Any insignificant changes in the intensity of rainfall or amount impose an intense challenge to the economy of rural people since its main livelihood depends on agriculture which mostly relies on southwest monsoon (Kumar et al. 2010). Southwest (SW) monsoon carried about 80% of the total rainfall over India and it is crucial for the accessibility of water for

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the drinking purpose, hydropower production, and agriculture sector. Rainfall is an important variable that shapes the spatial and temporal pattern of climatic variability over a region and also provides significant information about the management of water resource in the agricultural production system (Khavse et al. 2015; Lyra et al. 2017; Sobral et al. 2018). Due to the change in the rainfall distribution driven to water scarcity around the world and the large gap between the demand and availability of water sophisticated water storage reservoir needed to deploy the natural flow of water to fulfill the requirements of specific regions (IPCC 2007).

Several studies have been conducted by the researchers to study the climate trends variability in various regions of the world (e.g. Frei and Schar 1998; Serrano et al. 1999; Smith 2004; Gallant et al. 2007; Philandras et al. 2011; Ayalew et al. 2012; Zhang et al. 2015; Almeida et al. 2017; Brito et al. 2017; Lyra et al. 2017; Sobral et al. 2018). India is a country whose economy, agriculture and food security directly or indirectly depended on the timely availability of rainfall (Kumar et al. 2010). There have been several attempts made by the investigators to study the magnitude and trends in annual and seasonal rainfall over India. Long-term rainfall trend in Indian monsoon as well as for small subdivisions was studied and identified there is no any clear trend of increase or decrease in average rainfall over the country (Mooley and Parthasarathy 1984; Kumar et al. 2010). Kumar et al. (2010) studied long-term rainfall changes in small spatial scale over some parts of India and reported spatial and temporal variation in rainfall trend. There is a significant increasing trend in monsoon rainfall over the west coast, North West India, and central peninsula, while areas of northeast India, Madhya Pradesh and parts of North West peninsula show a significant decreasing trend in summer monsoon rainfall (Kumar et al. 1992). Studies involving rainfall trend analysis over Kerala showed an insignificant negative trend of 9.8% during 1999–2005 and decrease of 72.4 mm of rainfall was observed against the normal of 2817 mm during the observation period of 135 years (Krishnakumar et al. 2009).

Guhathakurta and Rajeevan (2008) observed rainfall trend over western and southwestern parts of the country and found increasing trend for June rainfall, whereas central and peninsular India depicted decreasing trend. Rainfall in most part of central and peninsular India has decreased in the month of the July, whereas northeast India showed a significant increase in the rainfall trend.

Dash et al. (2007) inferred that over the Lakshadweep, Andaman and Nicobar Islands and some parts of central and northwest India, the occurrence of intense rainfall was found to be increased during the monsoon season, whereas there is a decline in intense rainfall over some parts of the country during post-monsoon pre-monsoon and winter. Basistha et al. (2009) noted decreased and sudden shift of rainfall trend in the Indian Himalayas during the last century. Kumar and Jain (2011) found decreasing trend in the annual rainfall and rainy days in 15 basins out of 22 basins in India. Kothawale and Kulkarni (2012) observed that during the period 1971–2010 there is a negative trend in monsoon rainfall over north India while south India showed the positive trend.

The present study is aimed to assess seasonal and annual rainfall trend variation over Ranchi district of Jharkhand state (India) during a long time period 1901–2014 using non-parametric methods. The whole manuscript is divided into five sections: (1) presents the relevance of the study, (3) introduce the study area and the available observed datasets, (4) describes the different statistical method adopted for the data interpolation in this study, (4) presents and discusses with analyses' results and (5) summarized the key points and final conclusion of the study.

Study area and data availability

Ranchi district shown in (Fig. 1) lies in the southern part of Jharkhand state in eastern India. It lies between 22°52′–23°45′ North latitude and 84°45′–85°50′ East longitude with altitude varying from 500 to 700 m above the mean sea level. Ranchi district is bounded by Saraikela Kharsawan and Purulia district of West Bengal in the East, Gumla district in the West, Latehar, Lohardaga, Ramgarh and Hazaribagh district in the North, and Khunti and Saraikela Kharsawan districts in the south. Ranchi district (5097 km^2) is parts of Chota Nagpur plateau. The weather of the Ranchi district is very pleasant and characterized by subtropical climate; during summer from March to May, the maximum mean temperature is 36 °C and the winter season starts from November to February, and the coldest month is January with mean daily temperature 7 °C. During southwest monsoon from June to October, 90% of the total annual rainfall occurs. The annual average rainfall is around 1394 mm.

The monthly rainfall data for the period 1901–2014 of Ranchi district were obtained from the website http://www.indiawaterportal.org/met-data/, India metrological Division (IMD), Pune and Department of Agro-Meteorology, and Environmental Science, Birsa Agricultural University, Kanke, Ranchi to evaluate the annual and seasonal trend in rainfall data series. According to Kumar et al. (2009), a year was divided into four prominent seasons, namely monsoon (June–September), post-monsoon (October–November), pre-monsoon (March–May) and winter (December–February). The computed value of statistics such as mean, standard deviation (σ) and coefficient of variation CV, % of annual and seasonal rainfall data series are presented in Table 1.
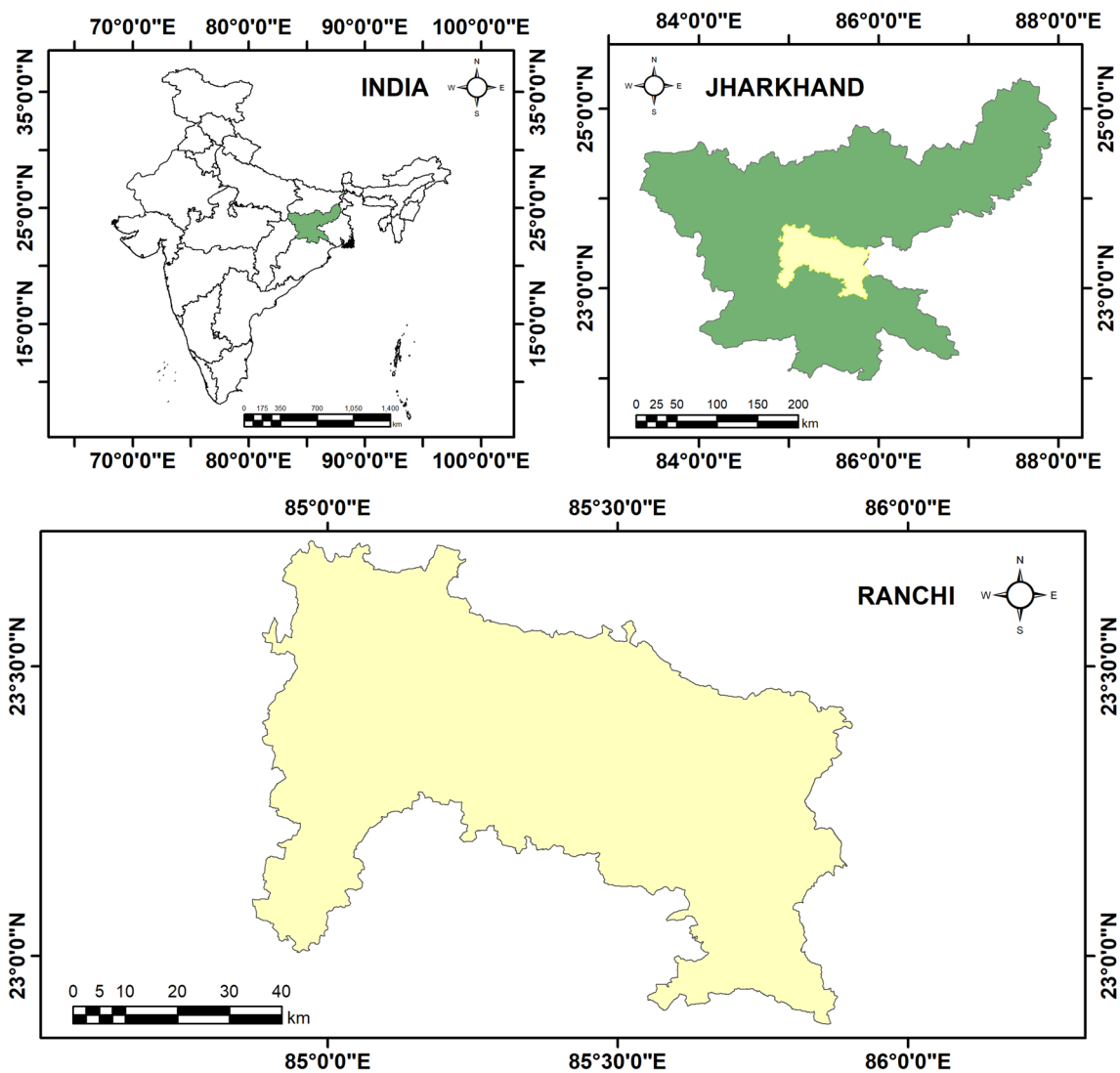
Fig. 1 Location map of the study area

Table 1 Statistical summary of seasonal and annual rainfall of Ranchi district (1901–2014)

Seasonal/annual	Mean	(σ)	(CV, %)	% Contribution to rainfall
Winter	53.77	34.51	64.18	4.16
Pre-monsoon	82.43	46.48	56.39	6.37
Monsoon	1073.91	201.85	18.80	83.00
Post-monsoon	83.69	59.25	70.80	6.47
Annual	1295.14	221.12	17.07	100.00

Methodology

The mean monthly rainfall data series (1901–2002) of Ranchi district were obtained from Indian water portal site. This monthly rainfall data series has been used in other several studies (Duhan and Panday 2013; Chandniha et al. 2017). Remaining rainfall data from (2003–2014) were collected from India Meteorological Department, Pune and Department of Agro-Meteorology and Environmental Science, Birsa Agricultural University, Kanke, Ranchi. The outliers within the rainfall data series were identified and the normal ratio method is used to calculate the detected values (Kundu et al. 2017), and after that, the data were used to calculate the annual and seasonal rainfall trend separately. The parametric and non-parametric methods are widely used to analyze the trend in the dataset. In this study, Sen's estimator (Sen 1968) was used to determine the magnitude of the trend in the time series while Mann–Kendall (MK) test (Mann 1945; Kendall 1975) was used to analyze the statistical significance of the trend in the rainfall data series. All the statistical

analyses of rainfall data were done using excel spreadsheet and XLSTAT software.

Statistical test for trend analysis

Trend analysis is an important tool helps in the effective planning and management of water resource. Trend analysis of hydrological variables such as rainfall, direct runoff and discharges provides information on the possibility of the change tendency of the variables in the future (Dinpashoh et al. 2013). In the present study, two non-parametric methods (Mann–Kendall and Sen's slope estimator) were used to detect the trends in meteorological variables.

The advantage of the non-parametric test (Scheff 2016).

- These statistics are designed to work with data that have greater variances.
- Can be applied to nominal, interval, ordinal or ratio data.
- The test is not affected if the deviation of the data is extreme.
- Can be applied to skewed data.

Magnitude of trend

Whether the magnitude of the trend is present in the hydro-metrological time series is computed by slope estimator (β), elaborated by Hirsch et al. (1982), which was expressed by Sen (1968). If the calculated value of β is positive it represents an 'upward trend' while a negative value depicted 'downward trend' (Xu et al. 2007; Karpouzos et al. 2010). For all the data pairs, the slope (T_i) was calculated as follows:

$$Ti = \frac{xj - xk}{j - k} \quad \text{for } i = 1, 2, \ldots, N, \tag{1}$$

where (xj, xk) represent the data values at time j and k ($j > k$) consequently. The median of this N value of Ti is Sen's slope estimator which is computed as. $Q_{median} = [T_{(N/2)} + T_{(N+2)/2}]/2\ldots$ if N is even and $Q_{\text{median}} = T_{(N+1)/2}\ldots$ if N is odd then the calculated value of Q_{median} is examined by two-sided test at the 100 $(1 - \alpha)$ % confidence interval. If the value Q_{median} is positive then it shows an upward trend and a negative value shows a downward trend.

Significance of the trend

Mann–Kendall (MK) test is a non-parametric test (Mann 1945; Kendall 1975) which has been one of the excellent methods to find monotonic trend in climatic variables, the MK test, tests the significance of the monotonic (upward or downward) trends in hydrological and climatic variables and is commonly used for investigating trend in time series

data (Sahu and khare 2015). It is one of the best and suitable ways to assess rainfall trend and goodness of this test is that it is a non-parametric test and does not require normally distributed data (Libiseller and Grimval 2002; Gilbert 1987). The Mann–Kendall statistical test is based on the signs of plus or minus (+ or −) instead of the value of the random variable, hence, the trend is minimally affected. (Helsel and Hirsch 1992; Birsan et al. 2005). The MK statistics (S) is defined as follows:

$$s = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sign}\,(-Xk)\,, \tag{2}$$

where n denotes the sample size, Xj and Xk are the consecutive data for the kth and jth terms; and

$$\text{Sign}\,(Xj - Xk) = \begin{cases} +1, & \text{if } xj - xk > 1 \\ 0, & \text{if } xj - xk = 0 \\ -1, & \text{if } xj - xk < 1 \end{cases} \tag{3}$$

The statistics S is considered normally distributed when $n \geq 18$ with zero mean and variance var(S) is given by

$$\text{Var}\,(S) = \frac{n\,(n-1)(2n+5)}{18}. \tag{4}$$

When there are ties in the dataset, then the Var (S) is computed as

$$\text{var}\,(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{k=1}^{n} tk\,(tk-1)(2tk+5)\right], \tag{5}$$

where n denotes the number of tied group and $\sum tk$ represent the sum of all data in the kth tied group having similar value. The standardized Z-statistics is computed as:

$$Z_{\text{mk}} = \begin{cases} \frac{s-1}{\sqrt{\text{var}\,(s)}} \ldots & \text{if } s > 0 \\ 0 \ldots & \text{if } s = 0 \\ \frac{s+1}{\sqrt{\text{var}\,(s)}} \ldots & \text{if } s < 0 \end{cases} \tag{6}$$

Positive value of Z_{mk} showed increasing trend and negative value Z_{mk} showed decreasing trend.

Rainfall variability test

Coefficient of variation

The coefficient of variation CV, % is an important statistical tool to calculate the variability of each data point with respect to the value of mean or the amount of variability to the mean. In the present study, seasonal and annual rainfall variability in the statistical datasets has been examined for

this study region using CV (Landsea and Gray 1992). The larger value of CV shows great spatial variability in the dataset and vice versa which is calculated as:

$$CV = \frac{\sigma}{\mu}(100),\tag{7}$$

where CV denotes the coefficient of variation; σ represents the standard deviation and μ represents the mean rainfall.

Results and discussion

Basic statistical characteristics of annual and seasonal rainfall data

Statistical rainfall characteristics of Ranchi district for the period of 1901–2014 such as mean were analyzed and presented in Table 1. Figure 2 presents the temporal variation of seasonal and annual rainfall of Ranchi district for the study period. It can be seen and observed from Fig. 2c, e that the trend of monsoon rainfall series has followed a similar trend as annual rainfall series. The pre-monsoon and post-monsoon rainfall series showed a slightly increasing trend which was presented in Fig. 2b, d. Figure 2a showed a declined trend in winter rainfall series. The mean of the annual
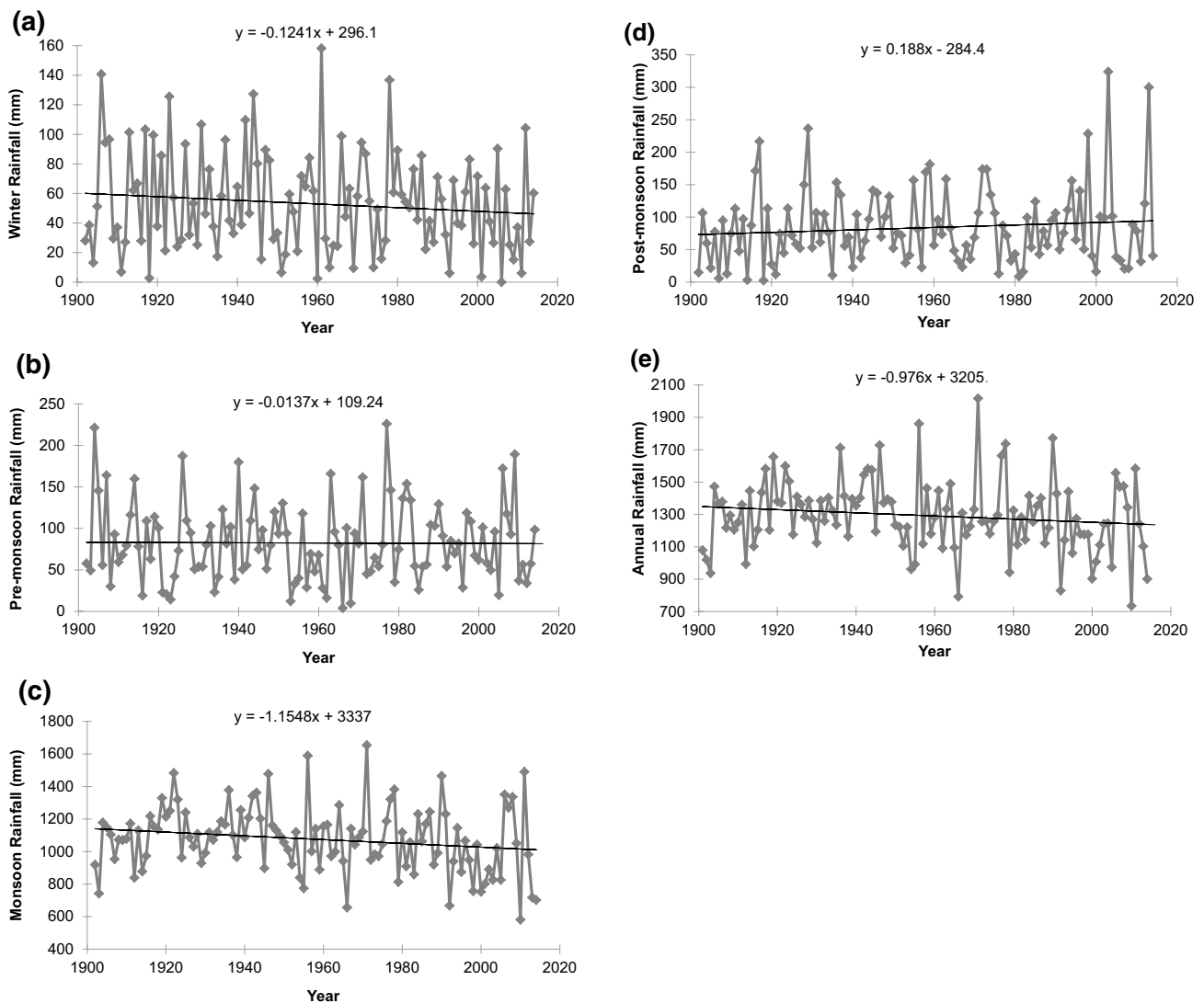

Fig. 2 Temporal variation of rainfall **a** winter, **b** pre-monsoon, **c** monsoon, **d** post-monsoon, and **e** annual of Ranchi district for the study period of 113 years (1901–2014)

rainfall of Ranchi district was 1295.14 mm and the corresponding values for seasonal rainfall were 53.77 mm for winter, 82.43 mm for pre-monsoon, 1073 mm for monsoon and 83.69 mm for post-monsoon, respectively. The result of computed statistical datasets indicates that the season with high rainfall has less variability than the season with comparatively lower rainfall. The analysis of the rainfall data record revealed that the highest rainfall of 2017.21 mm was observed in the year 1971 and lowest rainfall of 734.6 mm was recorded in the year 2010 in Ranchi district. The variation in the frequency of the cyclonic storm and the intensity of the jet stream (narrow band of fast flowing air currents in the upper atmosphere) over the Indian Ocean which are the driving factor for the monsoon depression during the Southwest monsoon season may be the possible cause for the highest rainfall in the year 1971 and lowest rainfall in the year 2010 (Sharma and Singh 2017). Monsoon season contributes 83% of the total annual rainfall in Ranchi; whereas winter has the least (4.16%) rainfall.

Trend analysis

For the identification of a trend in the time series data, Sen's slope estimator and Mann–Kendall test have been used in this study. Trend analysis was carried out for the Ranchi district pertaining to a period of 1901–2014 using average annual and seasonal rainfall data. The details of the result are illustrated in the subsection.

Seasonal and annual rainfall trend

The results of the Z-statistics, Sen's slope estimator and p value were obtained from the analyzing rainfall dataset for seasonal and annual rainfall of Ranchi District which has been presented in Table 2. The results of the MK test and Z-statistics showed both positive and negative trends for the seasonal and annual rainfall time series and at 5% level of significance, the entire test was carried out. Monsoon rainfall presented statistically significant negative trend ($P < 0.05$), while winter and annual rainfall indicated the statistically insignificant negative trend ($P < 0.05$), a statistically

Table 2 Result of trend analysis for seasonal and annual rainfall (at 5% significance level) of Ranchi district (1901–2014)

Seasonal/annual	Z-statistics	Sen's slope (mm/year)	p value	Trend
Winter	− 0.069	− 0.098	0.283	Decreasing
Pre-monsoon	0.006	0.009	0.923	Increasing
Monsoon	− 0.138	− 1.348	0.030	Decreasing
Post-monsoon	0.032	0.068	0.621	Increasing
Annual	− 0.11	− 1.104	0.084	Decreasing

insignificant positive trend was observed in pre-monsoon and post-monsoon rainfall records.

Estimation of Mann–Kendall test of rainfall series

Mann–Kendall (Z-statistics) results for seasonal and annual rainfall series for 1901–2014 are presented in Table 2. The positive and negative values of Z-statistics indicated increasing and decreasing trends, respectively. Only monsoon rainfall showed significant negative trend while winter and annual rainfall indicated insignificant negative trends. The rest of the seasons exhibited insignificant positive trend. In seasonal rainfall series, the values of Z-statistics were − 0.069, 0.006, − 0.0138 and 0.032, for winter, pre-monsoon, monsoon and post-monsoon rainfall, respectively, while the value of Z-statistics for annual rainfall is − 0.11. Annual rainfall showed the highest negative value for the Z-statistics whereas winter rainfall showed the least negative value of Z-statistics. This result agrees with the finding of Chandniha et al. (2017), who identified negative Z-statistics value for winter, monsoon and annual rainfall time series and positive Z-statistics value for pre-monsoon and post-monsoon rainfall time series over the region of Ranchi district for the period of 1901–2014. Sharma and Singh (2017), also found an increasing trend over the state of Jharkhand in pre-monsoon and post-monsoon rainfall while winter, monsoon and annual rainfall series showed decreasing rainfall trends during the time period of 102 years.

Estimation of the magnitude of the trend slope

The magnitude of the rainfall trends for the study period was calculated from Sen's slope estimator and presented in Table 2. Winter, monsoon and annual rainfall clearly showed a decreased rate of rainfall, while pre-monsoon and post-monsoon indicated rising rate of rainfall. The maximum decreased in the magnitude of rainfall was observed for monsoon rainfall (− 1.348 mm year⁻¹) and winter rainfall showed least (−0.098 mm year⁻¹) decreased in rainfall, while the magnitude of annual rainfall was found (− 1.104 mm year⁻¹). Pre-monsoon and post-monsoon rainfall showed an increased rate of rainfall (0.009 mm year⁻¹ and 0.068 mm year⁻¹), respectively. This finding is consistent with the results by Chandniha et al. (2017), for 111 years (1901–2011) over Jharkhand state and concluded an increased rate of rainfall for pre-monsoon and post-monsoon while winter, monsoon and annual rainfall showed a decreased rate of rainfall. Figure 3 illustrates the magnitude of the trend (Sen's slope %) for the annual and seasonal rainfall time series. The slope values of Ranchi district were found negative for winter, monsoon and annual rainfall. Pre-monsoon and post-monsoon showed positive slope value for the period 1901–2014. Sharma and Singh (2017) found a
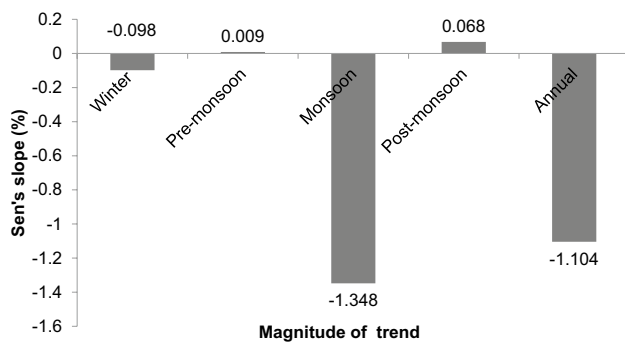
Fig. 3 Magnitude of the trend (Sen's slope, %) for the seasonal and annual rainfall time series

negative slope value for the winter, monsoon and annual rainfall over Ranchi district and positive slope value for pre-monsoon and post-monsoon rainfall over Ranchi district for the time period of 102 years. In this study, monsoon rainfall reflects a significant negative trend of rainfall. This result is in agreement with the finding with those of (Duhan and Pandey 2013; Jain et al. 2017 and; Warwade et al. 2018). The observed decrease in annual and monsoon rainfall may cause difficulties in the proper management of agricultural practices, industrial needs and domestic water supply.

Rainfall variability patterns

Study of rainfall variability pattern is an important aspect for agriculture sectors and essential to understand seasonal and annual variations for the estimation of precise water requirement. The result of rainfall variability pattern is calculated using CV for the study period for Ranchi district shows high inter-annual variation. Post-monsoon rainfall showed the maximum value of CV (70.80%), whereas annual rainfall exhibited the minimum value of CV (17.09%) during monsoon, pre-monsoon and winter rainfall the value of CV were 18.80%, 64.18%, and 56.39%, respectively, and presented in Table 1. The CV (70.80%) is higher than that of winter rainfall (64.18%), pre-monsoon rainfall (56.39%) and monsoon rainfall (18.80%) which shows the more inter-annual variability of post-monsoon rainfall than other seasonal rainfall. The variability results agree with the finding of (Chandniha et al. 2017; Warwade et al. 2018). The degree of rainfall variability was found high during winter rainfall, pre-monsoon rainfall and post-monsoon rainfall, whereas monsoon rainfall and annual rainfall showed the low degree of rainfall variability. Overall, the entire seasons except monsoon season reflect high rainfall variation. In general, high inter-annual variation was found which showed that the entire region is very vulnerable to droughts and floods (Pandey and Ramasastri 2001; Turkes 1996).

Conclusion

The aim of the present study was to analyze the rainfall trend over Ranchi district, Jharkhand state, India, using non-parametric statistical Mann–Kendall (MK) and Sen's slope test and results showed positive as well as negative trends. Pre-monsoon and post-monsoon rainfall exhibited a statistically insignificantly positive trend; winter and annual rainfall indicated statistically insignificantly negative trend only monsoon rainfall exhibited statistically significant negative trend. Winter season, monsoon season and annual rainfall showed decreasing slope magnitude and the remaining seasons showed increasing slope magnitude. The highest negative trend slope line was observed to be ($-$ 1.348 mm year^{-1}) in monsoon rainfall and the positive trend line was observed in pre-monsoon (0.009 mm year^{-1}) and post-monsoon (0.068 mm year^{-1}). Overall, it can be concluded from both non-parametric statistical assessments that there has been a significant variation in rainfall trend during the time period of the past 113 years. The rainfall variability analysis (CV) indicated high inter-annual variation. Post-monsoon rainfall shows the maximum variation in rainfall (70.80%), whereas annual rainfall exhibited minimum rainfall variation (17.09%). In general, high inter-annual variation in rainfall showed that the entire region is vulnerable to droughts and floods. Srinivasa Rao et al. (2004) analyzed NCEP/NCAR data and found that a decrease in intensity of tropical easterly jet stream over Bay of Bengal, which causes monsoon depression during the season of southwest monsoon, and play an important role in bearing rain during southwest monsoon over India. Ray and Srivastava (2000) reported that there is a decline in the frequency of the cyclonic storm over the Indian Ocean during (1981–1997). The reduction in intensity of jet stream and reduction of the cyclonic storm over the Indian Ocean may cause the decline in rainfall over the study area. The results and outcomes of the rainfall data analysis could play an important role in managing agriculture practices, hydropower generation, water resources management and weather forecast more effectively in the district.

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