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Spatio-temporal analysis of rainfall trends in Chhattisgarh State, Central India over the last 115 years

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Abstract

A quantitative and qualitative understanding of the anticipated climate-change-driven multi-scale spatio-temporal shifts in precipitation and attendant river flows is crucial to the development of water resources management approaches capable of sustaining and even improving the ecological and socioeconomic viability of rainfed agricultural regions. A set of homogeneity tests for change point detection, non-parametric trend tests, and the Sen's slope estimator were applied to long-term gridded rainfall records of 27 newly formed districts in Chhattisgarh State, India. Illustrating the impacts of climate change, an analysis of spatial variability, multitemporal (monthly, seasonal, annual) trends and inter-annual variations in rainfall over the last 115 years (1901–2015 mean 1360 $\mathrm{mm \cdot y^{-1}}$) showed an overall decline in rainfall, with 1961 being a change point year (i.e., shift from rising to declining trend) for most districts in Chhattisgarh. Spatio-temporal variations in rainfall within the state of Chhattisgarh showed a coefficient of variation of 19.77%. Strong inter-annual and seasonal variability in regional rainfall were noted. These rainfall trend analyses may help predict future climate scenarios and thereby allow planning of effective and sustainable water resources management for the region.

Key words: *change point, gridded data, modified Mann–Kendall test, rainfall variability, trend analysis*

INTRODUCTION

A complex and interwoven phenomenon, climate change has pervasive effects on all of Earth's spheres, in particular: the hydrosphere (water resources, glaciers, and oceans), biosphere (the environment, terrestrial ecosystems, and biodiversity) and lithosphere (agriculture, food security). Analysis and detection of historical changes in climatic parameters such as rainfall, temperature, etc. are the first and most important steps towards a systematic study of climate change [FANKHAUSER, TOL 1997]. The characterization and quantification of climate change and its effects on rainfall are important in helping the sustainable development of India's largely monsoon-dependent agriculture and management of its associated water resources [GADGIL 1986]. Such studies are important given that India's agricultural sector generates about 60% of jobs and 20% of the national GDP. Moreover, beyond affecting rainfall patterns or agriculture directly, the rapid retreat of glaciers triggered by climate-change-driven local warming can lead to significant soil erosion and flooding.

Widely studied around the world, the physical characteristics of rain and its multiscale (local to global – daily to yearly) spatiotemporal distribution are key elements in developing sustainable water management policies. Over recent decades, rainfall has shown an upward trend in several regions, along with a higher frequency of substantial and extraordinary precipitation events [HOUGHTON *et al.* 1979. Several widely-scattered studies have reported such trends and sought to elucidate the mechanisms of changes in pluvial patterns: in the United States [ALEXANDER *et al.* 2006; EASTERLING *et al.* 2000; GROISMAN *et al.* 2012; KARL *et al.* 1995; KUNKEL *et al.* 1999; 2013; TRENBERTH 1998]; in Australia [CHAMBERS 2003; CHOWDHURY, BEECHAM 2010; CHOWDHURY, HOSSAIN 2011; EVANS *et al.* 2009; HASAN, DUNN 2011; MURPHY, TIMBAL 2008; PLUMMER *et al.* 1999; SUPPIAH, HENNESSEY 1998]; in the Upper Blue Nile River basin [TABARI *et al.* 2015]; in Malaysia: [HUANG *et al.* 2015]; in India [JAIN, KUMAR 2012; KUMAR, JAIN 2010; LACOMBE, MCCARTNEY 2014; TAXAK *et al.* 2014]; and elsewhere around the world [RAUCH, DETOFFOL 2006; VENTURA *et al.* 2002]. Spatial and temporal trends in extreme precipitation event intensity have also been monitored in Japan [FUJIBE *et al.* 2005; IWASHIMA, YAMAMOTO 1993], India [GOSWAMI *et al.* 2006; KUMAR, JAIN 2010; SEN ROY, BALLING 2004], China [WANG, ZHOU 2005], and South Africa [ROY, ROUAULT 2013].

Having analyzed daily precipitation records for India from 1951 to 2000, GOSWAMI *et al.* [2006] found a rising occurrence and magnitude of extreme rainfall events, but a decline in the occurrence of rainfall events over central India during monsoon seasons. After an extensive analysis of the Ganges, Brahmaputra and Meghna River basins, MIRZA *et al.* [1998] reported precipitation in the Ganges River basin to be stable. SINGH *et al.* [2008] found that one of the Brahmaputra River's three sub-watersheds showed a rising rainfall pattern, while another showed a diminishing pattern. While India-wide precipitation and surface runoff showed no significant pattern, an increasing trend in precipitation, in the order of 2–19% of the 100-year annual mean, was noted for nine basins of northwestern and central India [SINHA RAY, DE 2003]. SINHA RAY and SRIVASTAVA [1999] noted a rising recurrence of extreme precipitation events in the southwest, with a downward trend in winter, pre-monsoon and post-monsoon rainfall.

Spatio-temporal changes in precipitation data which may happen gradually (following a constant trend), rapidly and unexpectedly (a stage change) or in a more complex manner [KUNDZEWICZ, ROBSON 2004], can be distinguished based on shifts in data distribution characteristics (mean, middle, variance, kurtosis, skewness, autocorrelation, etc.) over time. Sudden or continuous changes in climatic factors can occur through conventional climatic phenomenon or alternatively through changes or errors in how observations are made. Having investigated 30 Indian sub-divisions' monthly, seasonal and yearly patterns of precipitation over a 135-year period (1871–2005), KUMAR, JAIN 2010] detected rising yearly precipitation for half the sub-divisions and declining precipitation in a single sub-division (Chhattisgarh). Here, yearly and storm event precipitation declined, while pre- and post-storm rainfall and winter precipitation increased.

In view of the state of Chhattisgarh's unique climatic changes, the present study sought to investigate precipitation patterns in the state's 27 districts and thereby identify spatial patterns in these trends. Annual and seasonal trend analysis were carried out along with change point detection for all the long-term rainfall series presented in the paper.

STUDY AREA

Located in central India, the tribal-ruled and heavily-forested state of Chhattisgarh extends over 13.5 million hectares (17.78–24.12° N lat., 80.24–84.39° E long.; Fig. 1), and is presently divided into 27 districts: Balod, Balodabazar, Balrampur, Bastar, Bemetra, Bijapur, Bilaspur, Durg, Janjgir-Champa, Jashpur, Kanker, Kondagaon, Mungeli, Narayanpur, Raigarh, Rajnandgaon, Sukma, Surajpur, Raipur, Mahasamund, Koriya, Dantewada, Dhamtari, Gariabandh, Kawardha, Korba and Surguja. The state houses three unique agro-climatic zones (ACZ): the 73%, 97% and 95% rain-fed Chhattisgarh plains, Bastar plateau and northern slope regions, respectively. Subject to a variety of tropical climatic conditions, the state is – given its vicinity to the Tropic of Cancer and its reliance on storms for downpours – generally hot and humid (30–45°C in summer, 0–25°C in winter). With close to 70% of the population residing in rural areas [MHA 2011], the state's economic activities are primarily tied to horticultural crop production and the small industries which supply it. The state's other principal streams are the Hasdeo (a tributary of the Mahanadi), Rihand, Indravati, Jonk, Arpa and Seonath.

The productive fields of the upper Mahanadi River basin are situated in the central portion of the state. The state's net and gross sown areas are 4.828 and 5.788 million hectares, respectively [Bijapur… 2017]. With sandy topsoil covering roughly 55% of the arable land, and bunding (e.g. bench terraces, contour farming) of virtually all fields, only about 60% of the field area in Chhattisgarh state is cropped in any given year. The primary product, rice (*Oryza sativa* L.) is grown on roughly 77% of the net sown zone (3.7 million hectares), of which only 20% is under irrigation, the rest relying on rainfall.

Except on light upland soils, difficult rain-fed rice production conditions exist, resulting in the use of a wide variety of cultivation practices under different soil conditions. Rice cultivation is customary in the kharif season (July–October), and its extent is largely tied to farmers' financial capacities. In contrast, in the rabi season (October–March), fewer economically-viable cropping methods exist, and rice-wheat, rice-mustard or rice-winter vegetable intercropping/rotation is implemented when a partial or guaranteed

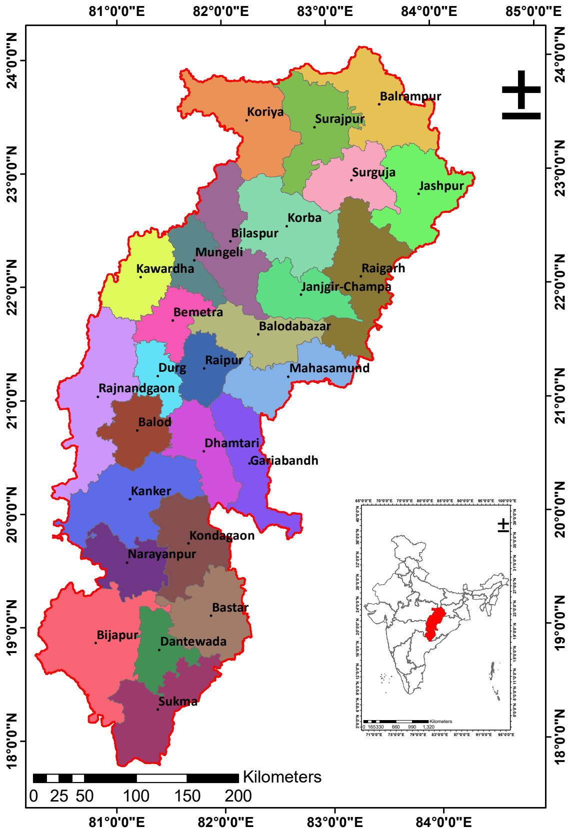

Fig. 1. The location of the Chhattisgarh State and its 27 districts in India; source: own elaboration

water supply is available, but rice-free or rice-*utera* (with *Lathyrus*, chickpea or linseed) cropping occurs under solely rain-fed conditions. Accordingly, an analysis of changing rainfall patterns in the region and its effects on water availability could play a critical role in helping water resources managers develop a sound understanding of local water supply and demand issues. However, at present, few studies have addressed precipitation patterns in India at the local or national scales [BHELAWE *et al.* 2014; DANDODIA, SASTRI 2015; MESHRAM *et al.* 2016].

DATA

Procured from the Indian Meteorological Department (IMD), monthly gridded (0.25° latitude × 0.25° longitude) rainfall data for all 27 districts of Chhattisgarh State over the period of 1901 to 2015 (115 years), served to investigate spatial and temporal changes in precipitation on both an annual and seasonal basis. The daily gridded rainfall data was first converted into weighted average rainfall for Chhattisgarh state's different districts according to their current administrative boundaries. The long-term rainfall in the state ranged between 730 and 2154 $\mathrm{mm \cdot y^{-1}}$ with an annual mean of 1360 $\mathrm{mm \cdot y^{-1}}$. Annual as well as seasonal time series were analysed. The various long-term statistical characteristics of rainfall data for the districts of Chhattisgarh State are presented in Table 1.

METHODOLOGY

Monthly precipitation data was used to generate annual, pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November), and winter (December–February) time series for investigating spatiotemporal changes in rainfall. Ideally, precipitation data employed in investigating precipitation patterns should only be influenced by climatic and atmospheric conditions; however, different elements like station location, station maintenance, monitoring practices and instruments may impact on the homogeneity of precipitation records over time [HUANG *et al.* 2015]. Accordingly, having settled the most plausible change point, further pattern investigation was performed on the pre- and post-change-point data sequences. The following tests were employed in investigating precipitation trends.

1. The standard normal homogeneity test (SNHT) tested for pattern homogeneity and assessed the overall pattern for a given area [BELLE, HUGHES 1984].
2. The Pettitt Mann–Whitney (PMW) test distinguished the most likely change year in the yearly precipitation sequence [PETTIT 1979]. The details of the PMW test are given below:

   Assume a time series $\{X_1, X_2 \ldots, X_n\}$ with a length n and with t being the time of the most likely change point. Two samples, $\{X_1, X_2, \ldots, X_t\}$ and $\{X_{t+1}, X_{t+2}, \ldots, X_n\}$, can then be derived by dividing the time series at time t. An index, U_t, is derived using the following steps:

$$U_t = \sum_{i=1}^{t} \sum_{j=1}^{T} \operatorname{sgn}\left(X_i - X_j\right) \tag{1}$$

$$\operatorname{sgn}\left(X_i - X_j\right) = \begin{cases} 1 \text{ if } \left(X_i - X_j\right) > 0 \\ 0 \text{ if } \left(X_i - X_j\right) = 0 \\ -1 \text{ if } \left(X_i - X_j\right) < 0 \end{cases} \tag{2}$$

A plot of U_t against t for a time series with no change point would result in a continually increasing value of U_t. However, if there is a change point (even a local change point) then U_t would increase up to the change point and then begin to decrease. This increase followed by a decrease may occur several times in a time series, indicating several local change points. As such, there is still the question of determining the most significant change point. We can identify the most significant change point t where the value of $|U_t|$ is maximum:

$$K_t = \max_{1 \le t \le T} \left| U_t \right|$$

The approximated significance probability $p(t)$ for a change point [PETTITT 1979] is given as:

$$p = 1 - \exp \frac{-6K_T^2}{T^3 + T^2} \tag{3}$$

The change point is statistically significant at time t with a significance level of α when probability $p\ (t)$ exceeds $(1 - \alpha)$.

Table 1. Long-term (1901–2015) statistical characteristics of rainfall data for the districts of Chhattisgarh State

District	Statistical characteristics														
	annual			pre-monsoon			monsoon			post-monsoon			winter		
	mean mm	*SD* mm	*CV* %	mean mm	*SD* mm	*CV* %	mean mm	*SD* mm	*CV* %	mean mm	*SD* mm	CV %	mean mm	*SD* mm	*CV* %
Balod	1266.0	267.9	21.2	44.8	42.5	94.9	1124.1	228.1	20.3	68.8	61.1	88.8	28.3	32.2	113.9
Balodabazar	1237.5	281.1	22.7	39.1	39.0	99.9	1113.8	245.4	22.0	53.6	48.6	90.8	31.0	32.0	103.0
Balrampur	1310.5	273.3	20.9	50.1	35.6	71.0	1130.7	232.0	20.5	74.3	60.7	81.7	55.3	45.4	82.1
Bastar	1563.5	275.3	17.6	127.8	57.1	44.7	1286.6	244.9	19.0	121.4	81.5	67.1	27.6	33.8	122.4
Bemetra	1178.6	232.5	19.7	38.0	36.5	96.1	1052.4	202.8	19.3	55.9	47.7	85.3	32.3	30.9	95.9
Bijapur	1480.3	300.3	20.3	72.9	45.6	62.5	1276.3	288.3	22.6	108.0	71.9	66.6	23.1	27.1	117.7
Bilaspur	1315.5	221.8	16.9	47.6	38.8	81.6	1159.0	199.1	17.2	62.2	52.8	84.9	46.6	38.1	81.8
Durg	1552.3	308.0	19.8	102.1	53.2	52.1	1304.8	287.7	22.0	119.8	82.2	68.6	25.6	35.7	139.4
Janjgir-Champa	1336.6	284.8	21.3	54.1	48.1	88.9	1185.1	254.4	21.5	71.2	70.8	99.5	26.3	32.0	121.6
Jashpur	1227.6	251.7	20.5	42.4	36.4	85.8	1094.7	223.8	20.4	60.6	53.8	88.7	30.0	30.6	101.9
Kanker	1305.6	254.0	19.5	58.7	47.6	81.0	1152.2	222.5	19.3	69.2	65.5	94.6	25.5	28.5	112.1
Kondagaon	1391.0	268.5	19.3	44.3	38.2	86.3	1249.8	239.3	19.1	57.7	50.0	86.7	39.2	37.3	95.2
Mungeli	1521.5	283.8	18.7	76.7	45.3	59.1	1293.7	235.1	18.2	92.5	73.2	79.2	58.6	51.5	87.8
Narayanpur	1413.9	286.4	20.3	55.3	46.0	83.1	1251.2	249.8	20.0	79.1	71.4	90.2	28.2	33.6	119.3
Raigarh	1152.4	223.2	19.4	47.0	40.9	87.1	992.6	188.4	19.0	68.4	58.1	85.0	44.5	39.5	88.7
Rajnandgaon	1420.6	262.9	18.5	86.5	52.7	60.9	1210.6	219.0	18.1	97.3	75.1	77.2	26.2	30.8	117.4
Sukma	1451.2	271.0	18.7	44.7	39.4	88.1	1296.0	241.4	18.6	64.7	53.5	82.7	45.7	44.0	96.3
Surajpur	1313.0	257.0	19.6	39.7	36.0	90.7	1162.8	226.7	19.5	59.0	53.6	90.8	51.4	43.8	85.2
Raipur	1315.2	282.5	21.5	48.5	41.6	85.8	1175.7	246.1	20.9	58.6	50.4	86.1	32.4	34.6	106.9
Mahasamund	1242.5	217.4	17.5	49.1	39.6	80.6	1084.4	190.8	17.6	63.3	54.1	85.5	45.6	36.8	80.7
Koriya	1465.7	279.8	19.1	76.1	55.9	73.5	1265.7	233.9	18.5	96.2	76.0	79.0	27.7	35.7	128.5
Dantewada	1468.7	288.3	19.6	54.6	40.0	73.2	1304.4	256.9	19.7	66.8	53.0	79.3	43.0	40.2	93.6
Dhamtari	1248.4	290.9	23.3	38.7	38.0	98.2	1124.6	263.0	23.4	57.6	56.1	97.4	27.6	29.4	106.5
Gariabandh	1251.7	244.4	19.5	43.4	37.8	87.0	1104.2	210.6	19.1	69.3	61.7	88.9	34.7	35.0	100.6
Kawardha	1448.1	256.7	17.7	103.6	48.2	46.5	1183.7	240.3	20.3	140.0	83.5	59.7	20.7	24.5	118.7
Korba	1363.1	283.5	20.8	42.6	33.3	78.1	1200.7	247.9	20.6	65.6	55.9	85.2	54.2	44.7	82.5
Surguja	1488.6	299.4	20.1	55.3	40.3	72.8	1300.0	255.6	19.7	78.9	61.9	78.5	54.4	48.4	89.0

Explanations: *SD* = standard deviation.
Source: own study.

3. The autocorrelation coefficient distinguished the nearness of serial correlation within the data series [SIEGEL, CASTELLAN 1988].
4. The Mann–Kendall (MK)/Modified Mann–Kendall (MMK) tests were applied to the non-auto correlated/auto correlated sequences to distinguish the presence of patterns in yearly and seasonal precipitation [HAMED, RAO 1998a; KENDALL 1975a].

The MK statistic, *S*, is defined as:

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

Where: x_1, x_2, x_3, …, x_n represents *n* data points where x_j represents the data point at the time *j* of data (time series); and $x_j - x_i = \theta$

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

Under the assumption that the data are independent and identically distributed, the mean and variance of the *S* statistic in Equation (2) are given by KENDALL [1975a] as:

$$E[S] = 0$$

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \tag{6}$$

Where: *m* = the number of groups of tied ranks, each with t_i tied observations.

The original MK statistic, designated by *Z* and the corresponding *p*-value (*p*) of the one-tailed test was computed as:

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

$$p = 0.5 - \varphi(|Z|)$$

$$\varphi(|Z|) = \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{-\frac{t^2}{2}} dt \tag{8}$$

In the case of the modified Mann–Kendall test, the effect of all significant autocorrelation coefficients is removed from a data set [HAMED, RAO 1998b]. For this purpose, a modified variance of *S*, designated as Var(*S*)*, was used as follows:

$$\operatorname{Var}(S)^* = V(S) \frac{n}{n^*} \tag{9}$$

Where: *n** = effective sample size.

The *n*/*n** ratio was computed directly from the equation proposed by HAMED and RAO [1998] as:

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{j=1}^{n=1} (n-1)(n-i-1)(n-i-2) ri \tag{10}$$

Where: n = actual number of observations: and ri = lag-i significant autocorrelation coefficient of rank i of time series. Once Var(S)* was computed from Equation (9), then it is substituted for Var(S) in Equation (7).

If the p-value is small enough, the trend is quite unlikely to be caused by random sampling. The Z values are approximately normally distributed, and a positive Z value larger than 1.96 (based on normal probability tables) denotes a significant increasing trend at the significance level of 0.05, whereas a negative Z value lower than –1.96 shows a significant decreasing trend.

5. Theil and Sen's slant estimator test served to estimate the magnitude of a trend [SEN 1968; THEIL 1950]. In this method, the slope estimates of N pairs of data are first calculated using the following expression as:

$$Q_i = \frac{x_j - x_k}{j-k} \quad \text{for } i = 1, 2, 3, \ldots, n \tag{11}$$

Where: x_j and x_k = data values at time j and $k(j > k)$ respectively.

The median of these N values of Q_i is Sen's estimator of slope, which is calculated as:

$$\beta = \begin{cases} Q_{[(N+1[N/2])/2]} & N \text{ is odd} \\ \frac{1}{2}(Q + Q_{(N+2)/2}) & N \text{ is even} \end{cases} \tag{12}$$

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

6. The coefficient of variation (CV) measured how different sub-datasets varied around their respective means [LANDSEA, GRAY 1992].
7. With the assistance of ArcGIS, the inverse distance weighted (IDW) method served to investigate spatially fleeting precipitation trends over a basin [LEBEL *et al.* 1987; SINGH, CHOWDHURY 1986].

RESULTS

STATISTICAL CHARACTERISTICS OF ANNUAL AND SEASONAL RAINFALL

The state's 115-year mean ± standard deviation rainfall ($\overline{P} \pm \sigma_P$) was 1360 ± 268 mm·y^{-1} and varied from a minimum of 730 mm·y^{-1} ($P_{\min}$) to a maximum of 2154 mm·y^{-1} ($P_{\max}$). Precipitation statistics were also developed for: the pre-monsoon period ($P_{\min}$ = 38 mm, $P_{\max}$ = 128 mm, σ_P = 78 mm), the monsoon period ($P_{\min}$ = 992 mm, $P_{\max}$ = 1304 mm, σ_P = 236 mm), the post-monsoon period ($P_{\min}$ = 53 mm, $P_{\max}$ = 140 mm, σ_P = 62 mm), and the winter period ($P_{\min}$ = 21 mm, $P_{\max}$ = 58 mm, σ_P = 36 mm). These statistics show the rainfall variability constraints during the study period to better understand rainfall behaviour.

MONTHLY TREND ANALYSES

The SNHT-based homogeneity tests on precipitation time series were undertaken at a significance level of 5%, where H_0 represented a homogeneous arrangement in the precipitation data sequence and H_a represented a heterogeneous arrangement, i.e., the potential presence of a change point [ALEXANDERSSON 1986; ALEXANDERSSON, MOBERG 1997]. Any change point in precipitation data (monthly, seasonally or yearly) was identified with the MWP and SNHT tests. Both tests indicated 1961 to be the most probable change point in rainfall series over the entire Chhattisgarh State. The shift change points of different districts are summarised in Table 2.

Table 2. Results of the standard normal homogeneity test and Mann–Whitney–Pettitt's (SNHT) test for Chhattisgarh State (1901–2015)

Station	Pettitt's test		SNHT test	
	t	trend	*t*	trend
Balod	1961	H_a	1961	H_a
Balodabazar	1961	H_a	1961	H_a
Balrampur	1950	H_a	1950	H_a
Bastar	1961	H_a	1936	H_a
Bemetra	1964	H_a	1964	H_a
Bijapur	1924	H_0	1913	H_a
Bilaspur	1964	H_a	1964	H_0
Durg	1961	H_a	1961	H_a
Janjgir-Champa	1964	H_a	1964	H_a
Jashpur	1953	H_a	1953	H_a
Kanker	1961	H_a	1961	H_0
Kondagaon	1961	H_a	1961	H_a
Mungeli	1964	H_a	1964	H_0
Narayanpur	1961	H_a	1961	H_a
Raigarh	1961	H_a	1961	H_a
Rajnandgaon	1961	H_a	1961	H_a
Sukma	1974	H_0	2011	H_0
Surajpur	1950	H_a	1950	H_a
Raipur	1964	H_a	1964	H_a
Mahasamund	1964	H_a	1964	H_a
Koriya	1951	H_a	1951	H_a
Dantewada	1949	H_a	1949	H_0
Dhamtari	1964	H_a	1964	H_a
Gariabandh	1961	H_a	1961	H_a
Kawardha	1964	H_0	1964	H_0
Korba	1961	H_a	1961	H_a
Surguja	1950	H_a	1961	H_a

Explanations: H_a = year at which change occurred in the time series, H_0 = Data are homogeneous.
Source: own study.

The MK, MMK and Theil–Sen incline estimator test(s) were applied at all time scales to each and all district(s). The MK and MMK test statistics (α = 0.05; Tab. 3) show increasing ($Z > 0$) and decreasing ($Z < 0$) trends, over three time scales: full series (1901–2015), pre- (1901–1961) and post-change-point (1962–2015). District-wise MK and MKK test Z-statistics for all the time steps are summarised in Table 3. For the full period, 86.73% of monthly data showed a downward

Table 3. *Z*-statistic values of monthly and seasonal rainfall using MK/MMK for Chhattisgarh State

District	*Z*-statistic values							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Years 1901–2015								
Balod	–0.17/–0.05	–2.27*/–0.82	–0.02/–0.01	–0.63/–0.36	–1.94/–1.43	–0.56/–0.56	0.11/0.11	–1.66/–2.16*
Balodabazar	–0.96/–0.32	–3.09*/–1.31	–1.50/–0.71	–1.77/–0.80	–1.17/–0.69	–1.07/–0.90	–2.51*/–2.85*	–3.67*/–3.67*
Balrampur	–2.38*/–1.49	–4.24*/–1.97*	–2.15*/–1.44	–0.39/–0.38	–1.64/–1.14	–0.37/–0.37	–2.72*/–2.72*	–4.06*/–4.06*
Bastar	0.91/0.33	–0.16/–0.04	0.49/0.38	–0.72/–0.72	1.09/1.09	0.61/1.02	–1.64/–1.28	–1.39/–1.58
Bemetra	–1.17/–0.58	–3.15*/–1.43	–1.56/–0.86	–0.81/–0.33	–1.37/–0.84	–0.69/–1.14	–0.41/–0.43	–1.81/–2.17*
Bijapur	–1.30/–0.43	–1.59/–0.44	–1.27/–0.80	–2.90*/–2.68*	–2.39*/–2.18*	1.00/1.09	1.09/1.88	3.62*/3.62*
Bilaspur	–0.11/–0.08	–3.26*/–2.06*	–1.30/–0.77	0.52/0.48	–0.09/–0.08	–0.54/–0.59	–1.36/–1.31	–1.38/–1.23
Dantewada	0.58/0.16	–0.64/–0.16	–0.82/–0.39	–2.88*/–2.44*	–2.41*/–2.63*	–0.48/–0.49	–0.82/–0.70	0.21/0.21
Dhamtari	–0.30/–0.08	–2.28*/–0.74	–0.90/–0.80	–0.37/–0.27	–1.14/–1.51	–0.13/–0.13	–0.85/–0.85	–1.59/–2.15*
Durg	–0.86/–0.27	–2.20*/–1.01	–0.96/–0.46	0.00/0.00	–1.47/–0.86	–0.46/–0.52	0.06/0.06	–1.69/–1.69
Gariabandh	–0.62/–0.15	–2.41*/–0.87	–1.23/–0.71	–1.71/–1.24	–0.80/–0.72	–0.40/–0.47	–1.34/–1.49	–2.12*/–2.17*
Janjgir-Champa	–0.79/–0.36	–3.16*/–1.33	–1.37/–0.68	–0.50/–0.42	–0.57/–0.42	–0.98/–1.02	–2.50*/–2.26*	–2.66*/–2.68*
Jashpur	–1.83/–0.93	–3.69*/–1.75	–2.26*/–1.42	–0.22/–0.23	–1.49/–1.49	0.18/0.17	–2.57*/–3.00*	–3.80*/–3.80*
Kanker	–0.40/–0.19	–3.01*/–0.96	–0.99/–0.76	–0.90/–0.76	–2.22*/–1.86	–0.77/–0.77	0.00/–0.01	0.56/0.67
Kawardha	–1.24/–0.72	–3.21*/–1.98*	–1.08/–0.63	–1.06/–0.64	–1.39/–0.94	–0.69/–0.88	0.09/0.13	–0.41/–0.41
Kondagaon	0.14/0.06	–2.11*/–0.67	–1.25/–0.63	–1.82/–1.55	–1.58/–2.85*	–0.51/–0.51	–1.74/–1.74	–0.90/–0.78
Korba	–0.86/–0.57	–3.69*/–1.88	–2.05*/–1.39	–0.56/–0.56	–1.24/–1.08	–0.48/–0.46	–2.62*/–2.62*	–2.96*/–2.48*
Koriya	–1.97*/–1.55	–3.91*/–1.91	–2.02*/–1.10	–0.78/–0.56	–2.13*/–1.39	–1.05/–0.87	–2.35*/–3.03*	–3.28*/–4.79*
Mahasamund	–0.62/–0.18	–2.38*/–1.00	–1.64/–0.81	–1.50/–0.68	–0.57/–0.55	–0.77/–0.64	–2.00*/–1.77	–2.83*/–2.63*
Mungeli	–0.26/–0.29	–2.87*/–1.75	–1.16/–0.72	0.21/0.21	–0.15/–0.12	–0.29/–0.34	–1.09/–1.09	–1.19/–1.13
Narayanpur	–0.96/–0.25	–3.28*/–0.92	–2.23*/–0.99	–3.09*/–4.41*	–3.75*/–2.94*	–1.53/–1.53	–0.94/–1.08	0.69/0.88
Raigarh	–0.94/–0.63	–2.86*/–1.15	–1.61/–0.86	0.37/0.28	0.99/0.99	0.08/0.07	–3.73*/–3.18*	–3.42*/–4.14*
Raipur	–1.30/–0.33	–2.67*/–1.18	–0.82/–0.35	–0.93/–0.49	–1.29/–0.53	–1.34/–1.15	–2.12*/–2.77*	–2.54*/–3.43*
Rajnandgaon	–0.44/–0.23	–2.60*/–1.09	–0.63/–0.43	–1.23/–0.56	–2.25*/–1.86	–0.72/–0.60	0.68/0.68	–0.18/–0.25
Sukma	–0.75/–0.19	–1.07/–0.32	–1.32/–0.69	–3.16*/–3.38*	–2.49*/–2.74*	0.58/0.58	2.75*/2.75*	2.79*/2.59*
Surajpur	–1.76/–0.86	–2.96*/–1.81	–1.30/–1.02	0.28/0.28	–1.36/–0.83	–0.66/–0.74	–2.63*/–2.45*	–4.65*/–4.65*
Surguja	–1.52/–1.00	–3.35*/–1.99*	–1.93/–1.95	0.11/0.11	–1.74/–1.16	–0.20/–0.20	–3.67*/–3.09*	–5.26*/–5.26*
Years 1901–1961, prior to change point								
Balod	0.57/0.38	–0.92/–0.53	0.08/0.04	0.42/0.42	–0.89/–0.89	0.00/0.00	1.90/1.90	0.65/0.85
Balodabazar	–0.03/–0.03	–0.92/–0.91	–0.24/–0.17	–0.80/–0.46	–0.82/–1.25	–0.33/–0.33	2.21*/2.21*	0.86/1.07
Balrampur	0.73/0.79	–1.03/–0.75	–0.32/–0.32	–0.56/–0.56	–1.18/–1.18	0.22/0.21	0.23/0.23	–0.65/–0.65
Bastar	0.09/0.03	–0.09/–0.05	1.66/1.51	–0.03/–0.03	0.80/2.15*	0.06/0.06	–0.40/–0.40	–0.78/–0.78
Bemetra	0.08/0.09	–1.28/–1.00	–0.42/–0.22	0.30/0.17	–1.43/–1.26	–0.82/–0.82	1.17/1.09	0.04/0.04
Bijapur	–1.58/–1.44	–0.46/–0.18	1.17/1.01	–0.32/–0.39	0.69/0.69	0.93/0.93	2.88*/2.38*	2.21*/2.44*
Bilaspur	1.16/1.15	–1.60/–1.33	–0.34/–0.34	0.26/0.23	–1.41/–1.41	–0.44/–0.44	2.05*/2.36*	1.02/1.02
Dantewada	–0.13/–0.05	–0.59/–0.21	1.54/1.53	–0.98/–0.80	–0.16/–0.16	–0.03/–0.03	–0.03/–0.03	–0.34/–0.44
Dhamtari	0.84/0.46	–0.73/–0.39	0.30/0.16	–0.27/–0.18	–0.90/–0.90	0.19/0.19	1.94/1.94	0.83/0.83
Durg	–0.02/–0.02	–0.89/–0.80	0.13/0.08	–0.19/–0.19	–1.68/–1.39	–0.40/–0.33	1.89/1.89	0.07/0.07
Gariabandh	–0.06/–0.03	–1.31/–0.96	–0.04/–0.03	–1.85/–1.71	–1.33/–1.33	0.11/0.09	1.28/1.28	0.01/0.01
Janjgir-Champa	0.48/0.47	–0.83/–0.71	–0.34/–0.28	–0.74/–0.51	–0.27/–0.21	–0.82/–0.51	1.75/3.68*	1.23/1.18
Jashpur	0.41/0.41	–0.92/–0.92	–0.76/–0.76	–0.19/–0.21	–1.51/–1.67	0.14/0.14	0.24/0.30	0.09/0.09
Kanker	0.26/0.16	–1.09/–0.60	0.47/0.26	1.71/1.79	0.50/0.50	0.42/0.34	2.53*/3.52*	2.13*/3.45*
Kawardha	0.56/0.56	–1.31/–1.31	–0.32/–0.32	0.70/0.57	–1.39/–1.84	–0.15/–0.15	1.80/2.08*	1.76/1.76
Kondagaon	0.36/0.28	–0.61/–0.30	1.30/1.08	0.22/0.22	0.28/0.28	0.12/0.18	0.42/0.42	0.47/0.50
Korba	0.89/0.69	–1.34/–1.34	–0.32/–0.32	–0.62/–0.62	–1.58/–1.58	–0.42/–0.42	1.21/1.21	1.03/1.03
Koriya	1.03/1.03	–1.16/–0.78	–0.26/–0.26	–0.25/–0.20	–2.02*/–1.51	–0.30/–0.30	0.10/0.13	–0.67/–0.67
Mahasamund	–0.24/–0.18	–0.72/–0.72	0.05/0.03	–1.24/–0.64	–0.80/–0.80	0.01/0.00	1.77/1.43	0.59/0.72
Mungeli	1.01/0.74	–1.18/–1.06	–0.42/–0.42	0.93/0.93	–1.08/–1.08	–0.26/–0.29	2.25*/2.25*	1.47/1.47
Narayanpur	–0.65/–0.56	–0.91/–0.44	1.38/1.38	0.65/0.65	0.22/0.25	0.14/0.14	1.40/1.32	1.62/1.62
Raigarh	0.72/0.72	–0.77/–0.62	–0.06/–0.08	–1.04/–0.83	–0.06/–0.06	0.22/0.17	0.49/0.42	0.50/0.42
Raipur	–0.35/–0.27	–0.93/–0.66	0.46/0.27	0.03/0.02	–1.66/–1.66	–0.24/–0.29	1.35/1.35	0.59/0.86
Rajnandgaon	0.51/0.45	–1.03/–1.03	0.00/0.00	0.54/0.33	–0.80/–0.80	–0.19/–0.20	2.02*/2.33*	1.89/1.89
Sukma	–0.95/–0.31	–0.95/–0.46	0.09/0.13	–2.27*/–3.00*	–1.00/–1.32	–0.04/–0.06	3.05*/3.05*	1.58/1.58
Surajpur	0.93/0.95	–0.48/–0.40	–0.22/–0.32	0.13/0.13	–1.25/–0.76	–0.78/–0.78	0.36/0.36	–0.82/–0.82
Surguja	0.69/0.69	–1.10/–1.10	–0.60/–0.69	–0.28/–0.28	–1.06/–1.06	–0.22/–0.22	–0.04/–0.06	–0.64/–0.64
Years 1962–2015, after change point								
Balod	0.34/0.18	0.35/0.31	1.36/1.06	1.16/2.49*	0.78/0.78	–0.24/–0.24	1.37/1.37	0.00/0.00
Balodabazar	0.57/0.29	–0.59/–0.59	–0.28/–0.28	0.64/0.50	0.02/0.03	0.12/0.17	–0.51/–0.88	–0.52/–0.64
Balrampur	–0.96/–1.14	–1.09/–1.25	0.44/0.36	–0.22/–0.22	0.51/0.51	0.33/0.46	–0.50/–0.50	–1.36/–1.70
Bastar	–0.01/–0.01	–0.34/–0.19	–0.58/–0.58	–0.92/–1.33	1.38/1.71	0.28/0.28	1.19/1.53	1.02/1.38
Bemetra	0.31/0.14	–0.06/–0.06	–0.14/–0.11	0.99/0.99	–0.15/–0.13	0.33/0.33	0.51/0.51	0.21/0.21
Bijapur	0.60/0.28	0.47/0.28	–0.78/–0.64	–0.47/–0.38	0.52/0.52	0.43/0.43	0.19/0.17	0.96/0.96
Bilaspur	0.80/0.57	–0.29/–0.41	–0.05/–0.05	0.89/1.16	0.30/0.34	0.10/0.13	–0.50/–0.50	–1.15/–1.15
Dantewada	0.43/0.19	0.41/0.55	–0.07/–0.07	–0.30/–0.30	1.33/1.04	0.19/0.19	0.72/0.72	1.21/1.21
Dhamtari	–0.54/–0.39	–0.45/–0.48	–1.13/–0.90	–1.35/–1.35	–0.54/–0.54	–0.34/–0.34	0.33/0.33	–0.22/–0.19
Durg	–0.17/–0.08	0.86/0.70	–0.46/–0.28	1.46/1.78	–0.76/–0.76	0.07/0.10	0.91/0.91	–0.52/–0.52
Gariabandh	–0.64/–0.34	–1.01/–0.70	–1.72/–1.17	–1.97*/–2.16*	0.18/0.18	–0.16/–0.17	0.13/0.13	0.60/0.60
Janjgir-Champa	–0.16/–0.11	–0.89/–0.89	–0.67/–0.66	0.02/0.02	–0.50/–0.44	0.01/0.00	–0.63/–0.55	–1.19/–1.19
Jashpur	–1.16/–1.03	–1.66/–1.29	0.01/0.01	–2.11*/–2.11*	–0.28/–0.42	0.46/0.48	–0.87/–0.87	–1.55/–1.55
Kanker	–0.04/–0.02	–1.19/–0.89	0.03/0.03	–0.75/–0.75	–1.63/–1.33	–0.66/–0.66	1.12/1.12	0.51/0.51
Kawardha	–0.28/–0.20	0.26/0.23	0.03/0.03	1.01/0.83	–0.56/–0.56	–0.26/–0.21	0.51/0.51	–1.17/–1.17
Kondagaon	0.20/0.12	–0.29/–0.24	–0.90/–0.54	–1.23/–1.23	–0.12/–0.12	–0.52/–0.52	–0.03/–0.03	1.04/1.04
Korba	–0.20/–0.15	–0.08/–0.11	–0.25/–0.19	–0.21/–0.29	–0.64/–0.52	–0.10/–0.10	–1.07/–1.07	–0.88/–0.88
Koriya	0.29/0.28	0.31/0.15	0.44/0.28	0.79/0.79	0.47/0.47	0.02/0.04	0.07/0.07	–0.22/–0.29
Mahasamund	0.08/0.04	–0.24/–0.24	–0.94/–0.58	–0.03/–0.03	–0.58/–0.58	0.12/0.12	–0.59/–0.59	0.40/0.36
Mungeli	0.87/0.50	–0.52/–0.57	–0.19/–0.19	1.24/1.56	0.75/0.75	0.31/0.54	–1.27/–1.27	–1.41/–1.41
Narayanpur	0.34/0.11	–0.52/–0.24	0.08/0.03	–0.75/–0.56	–1.19/–1.00	–0.24/–0.24	0.28/0.28	0.86/1.06
Raigarh	–0.40/–0.40	–0.57/–0.76	–1.01/–1.01	–0.09/–0.08	–0.07/–0.13	1.17/1.17	0.07/0.07	–0.22/–0.22
Raipur	–0.28/–0.12	0.59/0.43	–0.30/–0.23	0.66/0.56	–0.32/–0.18	0.09/0.09	0.33/0.33	–0.57/–0.57
Rajnandgaon	–0.07/–0.05	0.18/0.20	0.65/0.65	1.25/1.25	0.17/0.17	–0.22/–0.22	1.43/1.43	–0.27/–0.27
Sukma	0.15/0.06	0.57/0.36	–0.29/–0.23	0.43/0.59	1.18/1.69	0.81/0.81	0.93/1.09	1.60/1.60
Surajpur	–0.67/–0.67	0.20/0.14	0.34/0.28	0.25/0.25	0.02/0.02	–0.07/–0.09	–0.27/–0.24	–1.33/–1.33
Surguja	–0.62/–0.75	–0.61/–0.61	0.17/0.17	–0.43/–0.43	–0.80/–1.01	0.37/0.58	–0.81/–0.81	–1.70/–2.95*

Z-statistic values								
Sep	Oct	Nov	Dec	Annual	pre-monsoon	monsoon	post-monsoon	winter
Years 1901–2015								
–1.17/–1.17	–0.22/–0.22	–0.37/–0.37	0.09/0.09	–2.57*/–2.32*	–2.09*/–2.09*	–1.64/–1.45	–0.38/–0.38	–2.35*/–2.00*
–1.31/–1.42	–1.41/–1.01	–2.31*/–0.39	0.08/0.08	–4.24*/–3.96*	–2.74*/–2.74*	–3.88*/–4.00*	–1.42/–1.04	–2.76*/–1.88
–1.14/–1.14	–0.48/–0.36	–0.44/–0.13	–0.04/–0.02	–4.60*/–5.99*	–2.64*/–2.31*	–3.83*/–3.83*	–1.05/–0.77	–3.91*/–2.19*
–1.81/–1.83	–0.26/–0.35	–0.52/–0.36	0.10/0.10	–2.59*/–2.47*	–0.07/–0.09	–1.97*/–3.32*	–0.33/–0.55	–1.11/–0.88
–0.12/–0.10	–0.59/–0.62	–0.29/–0.29	0.09/0.09	–2.43*/–2.43*	–2.32*/–2.32*	–1.56/–2.03*	–0.62/–0.62	–3.07*/–2.69*
–0.54/–0.61	0.63/0.63	–1.26/–0.81	–0.67/–0.05	2.19*/2.07*	–3.40*/–4.11*	2.93*/3.19*	0.25/0.27	–2.26*/–1.89
–0.06/–0.08	–0.56/–0.39	–0.66/–0.19	–0.07/–0.01	–1.86/–2.02*	–1.09/–0.99	–1.65/–2.70*	–0.57/–0.45	–1.90/–1.90
–1.63/–1.66	–0.38/–0.38	–1.07/–0.67	–0.08/–0.08	–1.81/–1.62	–3.64*/–4.25*	–0.96/–1.15	–0.68/–0.65	–1.51/–1.09
–0.67/–0.60	–0.79/–0.52	–1.64/–0.47	–0.08/–0.08	–2.50*/–2.50*	–1.68/–1.76	–1.82/–1.82	–1.04/–0.85	–2.66*/–1.35
–0.27/–0.33	–0.39/–0.45	–0.47/–0.47	0.14/0.14	–2.15*/–2.15*	–1.91/–1.90	–1.39/–1.53	–0.65/–0.77	–2.40*/–2.40*
–0.86/–0.86	–1.05/–0.90	–2.63*/–0.82	–0.13/–0.13	–3.33*/–3.48*	–2.15*/–2.15*	–2.24*/–2.05*	–1.47/–1.09	–2.75*/–1.51
–1.41/–1.41	–1.14/–0.98	–0.98/–0.13	–0.17/–0.17	–4.20*/–4.20*	–1.58/–1.36	–3.48*/–3.48*	–1.12/–1.07	–2.30*/–1.87
–0.25/–0.30	–0.99/–0.99	–0.03/–0.01	0.42/0.04	–3.74*/–8.27*	–2.44*/–2.44*	–3.07*/–3.07*	–1.20/–1.20	–3.08*/–2.69*
–0.57/–0.53	–0.01/–0.01	–1.24/–0.46	0.13/0.13	–1.31/–1.31	–1.98*/–2.46*	–0.44/–0.44	–0.19/–0.19	–2.72*/–1.95
0.15/0.16	–0.09/–0.09	–1.32/–0.21	–1.98*/–0.18	–1.29/–1.29	–1.99*/–1.69	–0.54/–0.56	–0.36/–0.36	–2.51*/–2.59*
–0.54/–0.62	0.05/0.05	–0.99/–0.45	–0.09/–0.09	–2.55*/–2.91*	–2.25*/–2.34*	–2.04*/–2.34*	–0.03/–0.02	–2.23*/–1.20
–0.20/–0.26	–0.72/–0.46	–1.29/–0.27	–0.03/–0.03	–3.93*/–6.53*	–1.98*/–1.82	–3.38*/–5.27*	–1.12/–0.72	–2.47*/–1.87
–0.19/–0.16	–0.10/–0.06	–3.84*/–0.33	–1.65/–0.27	–4.26*/–4.26*	–2.59*/–2.29*	–3.69*/–3.69*	–0.41/–0.27	–3.18*/–2.62*
–1.49/–1.49	–1.03/–0.88	–1.06/–0.25	0.20/0.20	–3.49*/–3.00*	–2.44*/–2.59*	–2.94*/–4.93*	–1.29/–1.10	–2.26*/–1.35
0.35/0.31	–0.48/–0.48	–0.33/–0.11	–0.17/–0.17	–1.43/–1.43	–1.25/–1.25	–1.07/–1.35	–0.56/–0.64	–1.74/–1.74
–1.09/–1.37	–0.05/–0.06	–2.10*/–0.83	–0.04/–0.04	–1.91/–1.97*	–3.67*/–3.31*	–1.04/–1.04	–0.24/–0.66	–2.61*/–1.38
–0.98/–0.87	–0.61/–0.70	0.05/0.02	0.00/0.00	–4.22*/–4.50*	–0.58/–0.58	–3.97*/–3.97*	–0.70/–0.91	–2.31*/–1.69
–1.21/–1.39	–0.82/–0.75	–0.56/–0.56	0.16/0.16	–3.85*/–5.51*	–2.67*/–2.18*	–3.32*/–3.69*	–1.33/–1.46	–2.65*/–2.31*
–1.23/–1.23	–0.62/–0.49	–5.71*/–0.52	0.11/0.11	–2.19*/–2.16*	–2.81*/–2.41*	–0.96/–1.20	–0.87/–0.87	–2.63*/–1.87
–0.42/–0.42	–1.19/–1.19	–1.99*/–1.56	–1.09/–0.29	1.46/1.46	–3.59*/–4.41*	3.28*/2.91*	–1.53/–1.53	–2.63*/–1.79
–0.10/–0.10	–0.46/–0.25	–1.10/–0.20	–0.59/–0.06	–4.53*/–4.53*	–1.78/–1.78	–4.02*/–4.02*	–0.83/–0.51	–2.44*/–2.16*
–0.22/–0.31	–0.65/–0.46	–0.58/–0.18	0.02/0.02	–5.08*/–8.14*	–2.25*/–2.03*	–4.54*/–6.17*	–1.23/–0.83	–2.70*/–1.94
Years 1901–1961, prior to change point								
1.53/1.83	1.70/2.04*	–1.62/–0.59	–0.31/–0.31	1.96*/1.96*	0.03/0.04	2.11*/2.11*	1.27/1.82	–1.01/–1.01
1.17/1.17	1.62/1.62	–0.53/–0.29	–0.24/–0.24	1.82/1.82	–1.03/–1.03	2.28*/2.82*	1.39/1.75	–1.15/–1.15
1.49/1.31	1.78/1.50	–1.38/–0.66	–0.42/–0.22	0.22/0.22	–0.95/–0.81	0.23/0.23	0.95/1.11	–0.14/–0.14
–1.08/–1.08	2.63*/2.64*	–0.46/–0.53	–0.40/–0.40	–0.89/–0.89	0.62/0.62	–1.30/–1.13	1.94/1.94	–1.28/–1.28
0.96/1.10	1.47/1.49	–2.42*/–0.87	–0.21/–0.21	0.58/1.08	–0.62/–0.62	0.75/0.75	1.36/1.36	–1.20/–0.99
0.45/0.56	2.45*/3.11*	–0.21/–0.27	–2.46*/–0.54	3.59*/3.70*	0.29/0.28	3.67*/3.67*	1.98*/1.98*	–2.38*/–1.69
1.28/1.28	0.40/0.40	–1.69/–0.53	–0.56/–0.21	1.52/1.29	–1.24/–1.58	2.22*/1.75	0.50/0.62	–0.57/–0.57
–1.30/–1.17	1.91/1.85	–0.68/–0.68	–0.69/–0.69	–0.96/–0.96	–0.58/–0.44	–1.04/–0.90	1.61/2.02*	–1.83/–1.83
2.22*/2.22*	1.36/1.70	–0.74/–0.42	–0.22/–0.22	2.01*/2.01*	–0.28/–0.28	2.00*/2.00*	1.19/1.19	–1.29/–1.05
1.79/1.79	1.31/1.31	–1.08/–0.42	–0.27/–0.27	1.39/1.39	–0.54/–0.54	1.48/1.48	0.91/1.06	–1.33/–1.49
2.05*/2.05*	1.52/1.67	–1.25/–0.98	–0.50/–0.50	0.87/0.87	–1.61/–2.05*	1.50/1.50	1.21/1.30	–1.84/–1.29
1.47/1.47	1.11/1.11	–0.28/–0.11	–0.75/–0.03	1.36/1.13	–0.89/–0.89	1.95/1.95	0.95/1.15	–0.50/–0.50
2.09*/2.09*	1.51/1.51	–0.29/–0.13	–1.27/–0.32	0.62/0.62	–1.51/–1.51	0.88/0.88	0.96/0.96	–0.56/–0.56
2.45*/2.02*	1.78/1.78	–0.15/–0.08	–0.22/–0.22	3.52*/3.52*	1.41/1.64	3.34*/3.34*	1.81/1.81	–1.24/–0.90
1.21/1.56	1.70/1.70	–3.19*/–0.88	–0.81/–0.26	1.72/2.20*	–0.35/–0.35	2.04*/2.04*	1.08/1.08	–0.51/–0.40
2.22*/2.22*	2.13*/2.13*	–0.62/–0.60	–0.49/–0.49	1.56/2.48*	0.73/0.73	1.14/1.14	1.96*/1.96*	–1.11/–0.92
1.53/1.53	1.16/1.16	–1.29/–0.38	–0.61/–0.18	0.72/1.00	–1.33/–1.33	1.20/1.51	0.95/0.95	–0.58/–0.49
0.40/0.40	0.44/0.44	–1.93/–0.63	–1.32/–0.57	–0.94/–0.94	–1.61/–1.61	–0.74/–1.87	–0.14/–0.11	–0.25/–0.25
1.76/1.76	2.10*/2.10*	0.16/0.11	–0.03/–0.03	2.13*/3.13*	–1.08/–1.08	2.47*/3.99*	1.67/1.67	–1.14/–0.96
1.79/1.79	0.77/0.63	–1.85/–0.89	–0.75/–0.33	2.25*/2.25*	–0.88/–0.88	2.63*/2.63*	0.70/0.70	–0.46/–0.38
1.36/1.36	1.72/2.53*	–0.69/–0.54	–0.44/–0.44	2.73*/2.73*	1.29/1.42	2.26*/2.26*	1.97*/2.83*	–1.41/–1.41
2.48*/2.48*	1.90/1.90	–0.02/–0.02	–1.26/–0.31	1.33/1.58	–0.95/–0.95	1.48/2.12*	1.69/1.69	–0.39/–0.39
1.40/1.31	1.40/3.25*	–0.57/–0.26	–0.13/–0.13	1.41/1.41	–0.70/–0.70	1.71/1.71	1.11/1.11	–1.30/–1.30
2.08*/2.08*	1.45/1.45	–2.02*/–0.77	–9.19*/–0.38	2.08*/2.08*	0.15/0.14	2.56*/2.30*	1.10/1.18	–1.34/–1.67
–0.02/–0.03	0.40/0.40	–1.12/–1.36	–1.77/–0.67	1.57/2.36*	–1.96*/–1.96*	2.40*/2.40*	–0.02/–0.02	–2.64*/–1.94
1.85/1.85	1.64/1.64	–1.42/–0.42	–0.89/–0.41	–0.48/–0.48	–0.96/–1.40	–0.23/–0.26	0.97/0.84	0.14/0.14
2.15*/2.15*	1.77/1.43	–0.83/–0.36	–1.08/–0.29	–0.17/–0.31	–1.33/–1.33	0.18/0.18	0.77/0.77	–0.21/–0.15
Years 1962–2015, after change point								
0.36/0.47	0.51/0.44	1.08/0.30	–0.17/–0.17	0.60/1.98*	1.40/1.40	0.69/0.86	0.85/1.08	0.96/0.88
0.62/0.79	0.07/0.09	–0.06/–0.03	0.25/0.25	0.18/0.18	0.56/0.56	0.12/0.15	0.43/0.42	0.12/0.12
–1.18/–1.91	–0.25/–0.25	–1.10/–0.79	–1.07/–0.53	–1.12/–1.12	0.41/0.41	–0.95/–0.95	–0.48/–0.48	–0.85/–0.85
1.00/0.85	0.13/0.13	1.02/0.59	–0.97/–0.34	1.66/2.06*	0.37/0.57	2.20*/2.20*	0.23/0.23	–1.41/–1.55
1.19/1.64	0.57/0.59	0.82/0.39	1.30/0.12	0.81/0.81	0.12/0.15	0.87/0.87	0.79/0.79	0.09/0.10
0.47/0.77	0.00/0.00	0.49/0.37	–1.06/–0.59	1.06/1.06	0.42/0.42	1.15/1.29	–0.22/–0.19	–0.15/–0.15
0.24/0.30	0.49/0.49	–0.66/–0.51	0.01/0.00	–0.40/–0.40	0.90/0.90	–1.28/–1.96*	0.30/0.30	–0.15/–0.15
0.98/0.98	0.30/0.30	1.26/1.26	–2.03*/–0.67	1.82/2.63*	1.44/1.26	1.75/1.95	0.42/0.63	–0.81/–0.81
0.14/0.19	0.37/0.48	0.28/0.09	–0.19/–0.19	–0.51/–0.51	–1.28/–1.42	0.04/0.04	0.14/0.14	–0.76/–0.98
0.80/0.80	0.77/0.77	2.54*/0.31	–0.03/–0.03	0.63/0.63	0.18/0.18	0.43/0.43	0.82/0.96	0.66/0.66
0.88/0.88	0.49/0.49	0.05/0.02	–0.34/–0.34	0.28/0.28	–1.57/–1.57	0.85/0.85	0.04/0.04	–1.37/–2.91*
0.22/0.22	0.02/0.02	–0.07/–0.03	–0.02/–0.02	–0.45/–0.30	–0.07/–0.07	–0.56/–0.48	0.25/0.31	–0.16/–0.16
–0.13/–0.13	0.49/0.49	–0.14/–0.06	–1.32/–0.83	–0.46/–0.46	–0.68/–0.68	–0.78/–0.78	0.83/0.83	–1.25/–2.63*
0.46/0.61	0.43/0.65	0.19/0.11	–0.30/–0.30	0.30/0.30	–0.25/–0.34	0.73/0.95	0.46/0.81	–1.03/–1.14
–0.15/–0.15	0.30/0.37	0.29/0.12	–0.11/–0.03	–0.15/–0.16	0.27/0.27	–0.33/–0.28	0.61/0.66	–0.04/–0.05
0.48/0.48	1.01/0.82	0.21/0.13	–2.67*/–0.67	0.49/0.67	–0.46/–0.46	1.10/1.26	1.16/1.16	–0.75/–0.75
–0.33/–0.40	0.51/0.51	–0.91/–0.70	–0.44/–0.12	–1.00/–0.90	–0.24/–0.24	–1.40/–1.31	0.20/0.20	–0.09/–0.09
–0.28/–0.28	0.90/0.90	–0.78/–0.45	–0.32/–0.12	0.18/0.22	1.01/1.01	0.00/0.00	0.64/0.64	0.39/0.39
0.37/0.46	–0.02/–0.02	0.97/0.34	0.21/0.21	0.80/1.43	–0.51/–0.51	0.82/0.82	0.37/0.37	0.00/0.00
0.43/0.40	0.43/0.43	–0.26/–0.16	0.31/0.07	–0.51/–0.51	1.22/1.22	–1.12/–1.12	0.01/0.01	–0.17/–0.17
0.22/0.22	0.74/0.74	–0.05/–0.03	–1.82/–0.30	0.52/0.52	–0.81/–0.96	0.93/0.93	0.69/0.69	–0.64/–0.64
0.58/0.58	0.54/0.54	0.30/0.15	–0.46/–0.13	1.17/1.17	–0.39/–0.39	1.19/1.19	1.01/1.01	0.00/0.00
0.65/0.73	0.31/0.26	0.18/0.18	0.04/0.04	–0.16/–0.16	–0.54/–0.54	0.07/0.09	0.19/0.19	0.11/0.11
–0.45/–0.69	0.19/0.19	0.15/0.05	–0.11/–0.03	0.15/0.15	0.48/0.48	0.15/0.44	0.19/0.19	–0.34/–0.43
1.69/1.69	0.19/0.17	0.96/0.96	–0.81/–0.36	2.86*/3.76*	1.75/1.75	2.81*/2.81*	0.37/0.37	–0.65/–0.65
–0.87/–1.27	–0.05/–0.05	–0.60/–0.30	–0.86/–0.60	–0.87/–0.92	0.91/0.91	–0.75/–0.75	0.00/0.00	0.05/0.05
0.03/0.03	0.42/0.42	–0.20/–0.09	–0.93/–0.44	–0.78/–0.78	–0.04/–0.05	–0.83/–0.83	0.76/0.76	–0.46/–0.77

(significant or not) trend, while the remaining showed a rising trend. For all 27 districts' monthly trends (27 · 12 = 324 cases), 71 and 38 of 324 cases showed a significant negative trend based on the MK and MMK tests, respectively. Most of the significant negative trends occurred in the months of July and August. Only the Bijapur and Sukama districts showed a significant positive trend, and that was for only four months (Tab. 3).

During the pre-change-point period, roughly 52.5% of monthly data showed a declining (statistically significant or not) trend, while the remaining data showed a rising trend. Of 360 cases during this period, 7 and 1 cases showed a negative trend ($\alpha = 0.05$) based on the MK and MMK test approaches, respectively. In the same period, the monthly data showed a positive trend ($\alpha = 0.05$) in 21 and 27 cases out of 360 cases for the MK and MMK testing approaches, respectively. Declining trends were seen at all stations for the months of February, November and December all stations, whereas July, August, September and October showed the greatest number of positive trends (Tab. 3).

During the post-change-point period, about 48.80% of monthly data showed a declining (statistically significant or not) trend, while the remainder showed a rise. A positive trend ($\alpha = 0.05$) was noted in 4 and 3 of 360 cases when using the MK and MMK test approaches, respectively (Tab. 3). This period showed no clear rainfall trends at the state level.

ANNUAL AND SEASONAL TREND ANALYSIS

For the pre-change-point period, of 27 stations, 19 and 17 in the pre-monsoon season, and 14 and 16 in the monsoon season showed significant negative trends, based on MK and MMK analyses, respectively. In contrast, two districts (Bijapur, Sukma) showed significantly positive trends in monsoonal rainfall. While 26 of 27 districts showed declining rainfall in the post-monsoon season, none of the trends was statistically significant. In the winter season, all districts showed declining trends in rainfall, with 23 and 9 of 27 stations showing significant trends based on the MK and MMK testing methods, respectively. On an annual basis, 25 of 27 stations showed negative trends, though only 19 and 21 of the 27 stations showed these trends to be significant based on MK and MMK testing, respectively. These results imply that the overall annual rainfall trend is negative (Tab. 3).

For the same pre-change-point period, Table 3 shows that 23 and 27 (MK and MMK testing, respectively) out of 135 cases (27 × 5 = 135) showed an increasing trend in precipitation ($\alpha = 0.05$). On an annual basis, most districts showed a positive trend, except five districts: Bastar, Dantewara, Koriya, Surajpur and Surguja. Overall, 8 and 11 districts showed an increasing trend in precipitation ($\alpha = 0.05$) based on the MK and MMK testing methods, respectively. In the monsoon period 12 districts showed increasing trends in precipitation for both MK and MMK testing. Almost all negative trends in precipitation occurred in the pre-monsoon (20 of 27) and winter seasons (26 of 27) whereas, in the post-monsoon period, most stations (25 out of 27) showed increasing trends ($\alpha = 0.05$). In winter, many districts showed negative but non-significant trends (Tab. 3).

For the post-change-point period, 79 out of 135 cases showed a significant or non-significant increasing trend in precipitation for both MK and MMK testing (Tab. 3). On an annual basis, based on the MK and MMK tests, 1 district (Sukma) and 4 districts (Sukma, Balod, Bastar, and Dantewara) showed a positive trend, respectively. None of the districts had an increasing trend at a 5% level of significance. In the monsoon season, 10 districts showed a positive but non-significant trend, while two districts (Sukma, Bastar) showed a significant increasing trend ($\alpha = 0.05$). Almost all positive precipitation trends occurred in the post-monsoon period (24 of 27) but none was significant. There were no significant trends observed for the pre-monsoonal season. In winter, many districts (20 out of 27) showed negative trends.

Over the full rainfall series (1901–2015), most districts showed a negative trend in precipitation. Over the full series and after the change point, pre-monsoon rainfall showed a decreasing trend, while post-monsoon rainfall showed no trend. However, prior to the change point, rainfall showed a rising pre-monsoon trend. Thus, overall, prior to the change point there were increasing trends in rainfall and after the change point decreasing trends in rainfall. However, a decreasing trend was found over the complete time series. The range of annual and seasonal rainfall trend slopes are presented in box plots in Figure 2.

MAGNITUDE OF TRENDS

On evaluating, across the considerable number of districts, the rate of precipitation change over time ($\mathrm{mm \cdot y^{-1}}$) for yearly and seasonal series, two districts (Bijapur and Sukama) were found to have undergone increasing precipitation in the monsoon and post-monsoon seasons as well as over the full year. The greatest decline was found for the Surguja district ($-4.1\ \mathrm{mm \cdot y^{-1}}$), while the greatest increase occurred in the Bijapur district ($+1.93\ \mathrm{mm \cdot y^{-1}}$ for full year, and $+2.4\ \mathrm{mm \cdot y^{-1}}$ in the monsoon season), followed by the Sukma district ($+1.02\ \mathrm{mm \cdot y^{-1}}$ for full year and $+2.16\ \mathrm{mm \cdot y^{-1}}$ in the monsoon season). For the entire state the rate of decline in yearly precipitation over the 115 years was $2.02\ \mathrm{mm \cdot y^{-1}}$.

SPATIAL VARIATION OF RAINFALL TRENDS

Using the entire time series, annual and seasonal rainfall variability (*CV* %) for the 27 districts of Chhattisgarh State were determined using an inverse distance weighted (IDW) technique applied in ArcMap 10.1 (Fig. 3). Annual variability was highest in

Table 4. Magnitude of slope for monthly and seasonal rainfall series using Sen's slope method for Chhattisgarh State (1901–2015)

Districts	1901–2015					1901–1961					1961–2015				
	annual	pre-monsoon	monsoon	post-monsoon	winter	annual	pre-monsoon	monsoon	post-monsoon	winter	annual	pre-monsoon	monsoon	post-monsoon	winter
Balod	–1.85	–0.18	–1.14	–0.04	–0.13	3.26	0.01	3.21	0.54	–0.17	1.45	0.30	1.03	0.23	0.13
Balodabazar	–3.20	–0.18	–2.62	–0.18	–0.16	3.08	–0.23	3.64	0.42	–0.23	0.44	0.11	0.28	0.09	0.01
Balrampur	–3.55	–0.24	–2.44	–0.17	–0.43	0.41	–0.23	0.48	0.37	–0.03	–2.61	0.09	–2.23	–0.21	–0.21
Bastar	–1.98	–0.01	–1.33	–0.05	–0.03	–1.71	0.26	–2.54	0.95	–0.13	3.35	0.21	4.14	0.19	–0.26
Bemetra	–1.65	–0.15	–0.88	–0.06	–0.22	0.89	–0.15	1.15	0.42	–0.30	1.64	0.02	1.87	0.20	0.01
Bijapur	1.93	–0.37	2.40	0.05	–0.09	6.86	0.09	5.61	1.05	–0.33	3.21	0.14	3.00	–0.09	–0.01
Bilaspur	–1.22	–0.10	–0.84	–0.07	–0.17	2.22	–0.27	2.81	0.17	–0.15	–1.13	0.18	–1.88	0.10	–0.06
Dantewada	–1.72	–0.51	–0.75	–0.14	–0.06	–1.96	–0.26	–2.05	0.82	–0.21	4.55	0.51	4.33	0.28	–0.09
Dhamtari	–2.05	–0.14	–1.31	–0.11	–0.13	2.82	–0.07	3.75	0.44	–0.18	–1.46	–0.40	0.12	0.05	–0.09
Durg	–1.57	–0.14	–0.84	–0.06	–0.16	2.45	–0.12	2.32	0.30	–0.29	1.22	0.03	1.02	0.20	0.09
Gariabandh	–2.31	–0.21	–1.55	–0.18	–0.14	1.23	–0.51	1.96	0.44	–0.30	0.81	–0.34	1.47	0.03	–0.16
Janjgir-Champa	–2.93	–0.13	–2.42	–0.13	–0.17	2.10	–0.20	2.80	0.29	–0.14	–1.09	–0.02	–1.10	0.09	–0.03
Jashpur	–2.71	–0.30	–1.77	–0.22	–0.35	0.88	–0.53	1.64	0.55	–0.21	–0.93	–0.22	–1.18	0.29	–0.32
Kanker	–0.99	–0.20	–0.29	–0.02	–0.15	6.24	0.42	5.68	0.73	–0.21	0.63	–0.08	1.80	0.17	–0.12
Kawardha	–0.74	–0.17	–0.24	–0.04	–0.22	2.85	–0.09	2.47	0.42	–0.15	–0.34	0.07	–0.58	0.15	–0.01
Kondagaon	–1.93	–0.30	–1.27	0.00	–0.10	2.74	0.23	2.01	1.01	–0.15	1.12	–0.16	1.64	0.58	–0.07
Korba	–2.87	–0.16	–2.10	–0.14	–0.22	1.27	–0.29	1.58	0.36	–0.18	–2.47	–0.06	–2.67	0.10	–0.01
Koriya	–3.33	–0.19	–2.38	–0.04	–0.33	–1.53	–0.35	–1.19	–0.03	–0.10	0.36	0.19	0.00	0.18	0.08
Mahasamund	–2.75	–0.21	–2.04	–0.14	–0.14	3.44	–0.28	3.60	0.66	–0.25	1.70	–0.13	1.84	0.10	0.00
Mungeli	–0.91	–0.11	–0.54	–0.06	–0.16	3.66	–0.21	3.61	0.26	–0.11	–1.00	0.28	–1.88	0.00	–0.03
Narayanpur	–1.65	–0.56	–0.70	–0.04	–0.12	4.92	0.45	3.62	0.99	–0.20	1.17	–0.31	2.12	0.39	–0.05
Raigarh	–3.08	–0.06	–2.79	–0.09	–0.18	2.26	–0.20	2.12	0.70	–0.10	2.76	–0.14	2.20	0.30	0.01
Raipur	–3.22	–0.18	–2.30	–0.15	–0.15	2.42	–0.16	2.65	0.39	–0.26	–0.48	–0.10	0.13	0.06	0.01
Rajnandgaon	–1.47	–0.21	–0.52	–0.11	–0.18	3.37	0.06	3.85	0.42	–0.33	0.32	0.10	0.10	0.06	–0.03
Sukma	1.02	–0.51	2.16	–0.39	–0.10	2.84	–0.63	3.69	–0.03	–0.29	6.52	0.68	6.53	0.24	–0.05
Surajpur	–3.58	–0.14	–2.67	–0.13	–0.25	–0.92	–0.19	–0.35	0.32	0.05	–2.38	0.18	–1.95	0.00	0.01
Surguja	–4.10	–0.22	–3.15	–0.20	–0.26	–0.28	–0.36	0.26	0.41	–0.07	–1.96	–0.01	–1.68	0.23	–0.08

Source: own study.

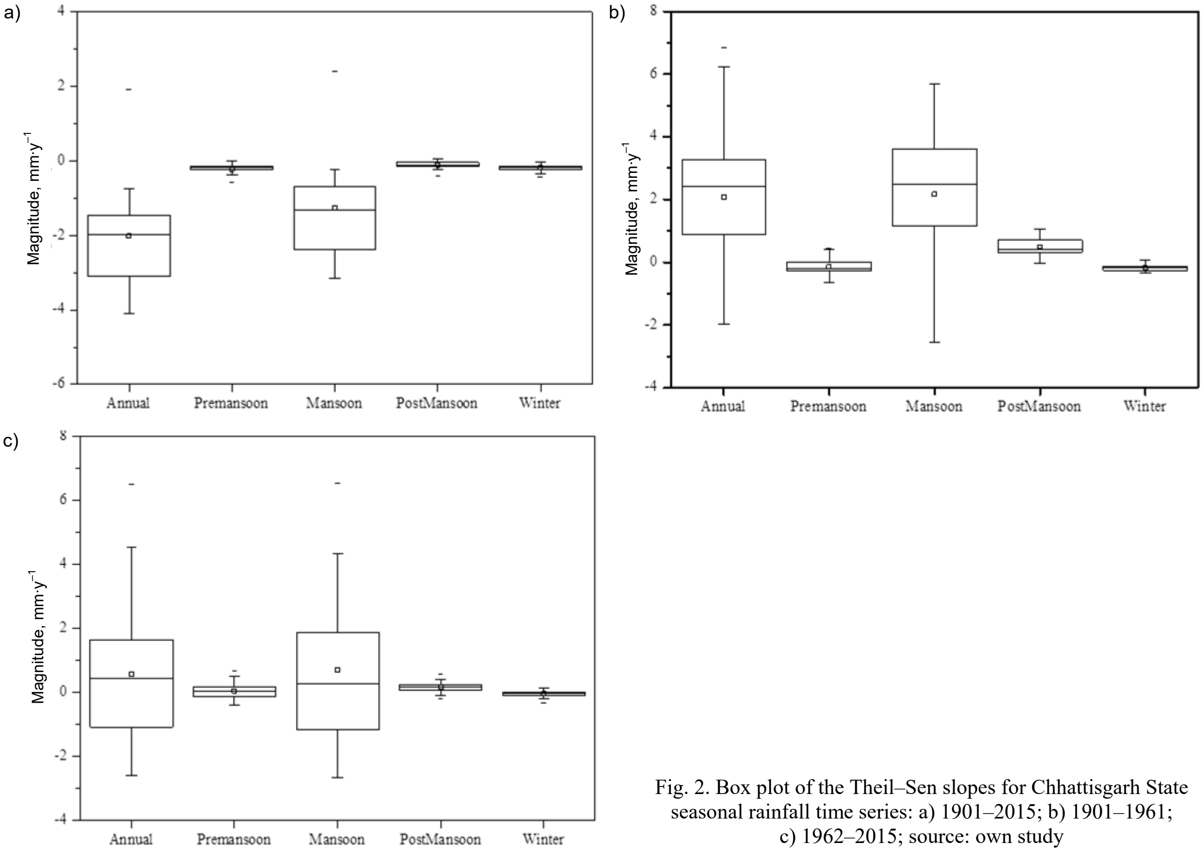

Fig. 2. Box plot of the Theil–Sen slopes for Chhattisgarh State seasonal rainfall time series: a) 1901–2015; b) 1901–1961; c) 1962–2015; source: own study

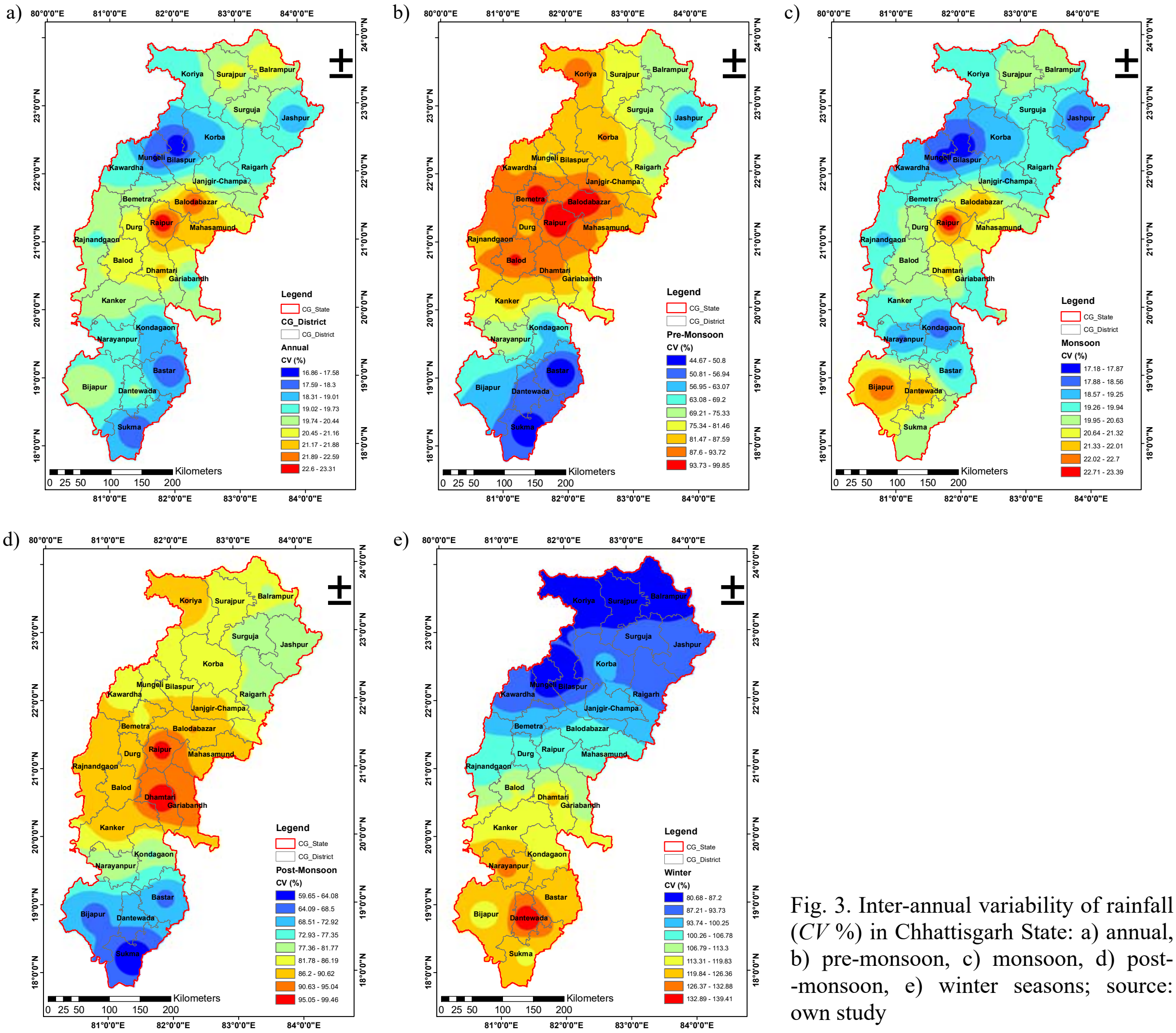

Fig. 3. Inter-annual variability of rainfall (*CV* %) in Chhattisgarh State: a) annual, b) pre-monsoon, c) monsoon, d) post-monsoon, e) winter seasons; source: own study

the central part of the state, possibly due to the urban heat island effect. Similarity in the coefficient of variability of annual and monsoon season precipitation distribution indicates a significant influence of the monsoonal rainfall on the total annual rainfall. The southern part of the state showed lesser variability in the post-monsoon season, but greater variability in the winter season. Overall, annual and inter-annual variability in rainfall exists within the state of Chhattisgarh.

CONCLUSIONS

Trends and variability in monthly, yearly and seasonal precipitation time series were explored for each of the 27 districts of Chhattisgarh State. Mann–Kendall and adjusted Mann–Kendall tests were used to explore these trends. The Sen's incline estimation tests were used for pattern recognition to situate possible shifts in precipitation patterns, while the Mann–Whitney–Pettitt test served to determine any break point. The positive and negative values of *Z* from the Mann–Kendall and Sen's incline tests demonstrated positive and negative trends in precipitation for Chhattisgarh State. Spatial variety in precipitation on yearly, seasonal and monthly scales was determined using an inverse distance weighted (*IDW*) approach applied in Arc-Map 10.1. This showed both positive and negative precipitation trend patterns to exist within the state. The entire analysis was carried out at significance level $\alpha = 0.05$. The full series (1901–2015) showed a decreasing rainfall trend with annual and pre-monsoon rainfall data, but post-monsoon rainfall showed no trend. Very similar trends were found after the change point (1946–2013) whereas converse trends were found prior to the change point (1901–1945), i.e., pre-change-points showed increasing rainfall trends, whereas post-change-point rainfall showed a decreasing trend. Over the full time series, most of the districts in Chhattisgarh State showed decreasing trends for annual and monsoon season rainfall, and decreasing rainfall trends for the winter season.

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Przestrzenna i czasowa analiza tendencji zmian opadów w stanie Chhattisgarh w środkowych Indiach w ciągu ostatnich 115 lat

STRESZCZENIE

Ilościowe i jakościowe rozpoznanie przewidywanych wielowymiarowych zmian opadów i towarzyszących im przepływów w rzekach spowodowanych zmianami klimatu jest decydujące dla rozwoju metod zarządzania zasobami wodnymi zdolnych utrzymać lub nawet usprawnić rentowność obszarów rolniczych zasilanych opadami. Zastosowano kilka testów jednorodności do wykrycia punktu zwrotnego, nieparametryczne testy trendu i estymator nachylenia Sena do analizy wieloletnich danych o opadach w 27 nowo utworzonych dystryktach stanu Chhattisgarh w Indiach. Ilustrując wpływ zmian klimatu, wyniki analizy przestrzennej zmienności, miesięcznych, sezonowych i rocznych trendów oraz zmienności między latami (1901–2015, średni opad 1360 mm·r^{-1}) wykazały ogólne zmniejszenie ilości opadów w większości dystryktów stanu Chhattisgarh. Rok 1961 był punktem zwrotnym między rosnącym a malejącym trendem opadów. Współczynnik zmienności przestrzennej i czasowej opadów w stanie Chhattisgarh wynosił 19,77%. Zanotowano znaczną zmienność opadów między poszczególnymi latami i porami roku. Takie analizy trendów mogą być przydatne w przewidywaniu przyszłych scenariuszy klimatycznych, a w związku z tym – umożliwić wydajne i zrównoważone zarządzanie zasobami wodnymi regionu.

Słowa kluczowe: *analiza trendu, dane gridowe, punkt zwrotny, zmienność opadów, zmodyfikowany test Manna–Kendalla*