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ORIGINAL PAPER

Long-term temperature trend analysis associated with agriculture crops

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Abstract

Temperature is one of the most significant elements in climate and weather forecasting. There was an increase in the earth's surface (land and ocean) temperature by 0.6 ± 0.2 °C during 1901–2000 (NOAA, Global Climate Report 2017). In evaluating the effects of climate change, the spatiotemporal variability of temperature was examined in the Chhattisgarh State, India, using monthly data at 16 stations over the period 1901–2016 with a length of 116 years. The standard normal homogeneity test was used to evaluate the homogeneity of temperature data. Linear regression analysis and four altered versions of the Mann-Kendall (MK) method were utilized to analyze the existence of trends in temperature series. These four versions of the MK tests include the conventional Mann-Kendall method (MK1), the removed influence of noteworthy lag-1 autocorrelation (MK2), the removed influence of all noteworthy autocorrelation coefficients (MK3) and the considered Hurst coefficient (MK4). The results of both parametric and non-parametric tests indicated an increase in the annual and seasonal temperature in the Chhattisgarh State over the period 1901–2016. The most likely change year in the state was 1950. There was a decreasing trend at some stations during the period 1901–1950, which reversed in the following period 1951–2016. Overall, annual and seasonal temperature time series showed increasing trends in all stations over the course of the long-term period. Our results confirmed a fact that the agriculture crop production has been decreased due to climate change.

1 Introduction

Environment variations and its effects on temperature vary across global spatiotemporal scales, which has resulted in unexpected impacts and changes in regions around the world. As many regions on the earth normally experience both short- and long-term climatic variability (Houghton 1994; Gardner et al. 1996), its understanding is so critical in exploring not only present and future climatic conditions due to climate change but also its effects on water resources to support the implementation of suitable adaptation strategies. Temperature patterns provide basic evidence when assessing claims with respect to anthropogenic environmental change (Nazeri Tahroudi et al. 2019). An important change in temperature can also impact soil quality since temperature and water are vital physical elements for plant growth. Non-ideal levels of water and temperature conditions can unequivocally hinder plant growth, particularly at the early phases of development, such as during seed germination and rise (Helms et al. 1996), which has major implications for future food production.

The Intergovernmental Panel on Climate Change (IPCC) reported that over the course of the twentieth century, there was an increase in the earth's surface temperature by 0.6 ± 0.2 °C (Obiekezie et al. 2010). Likewise, the temperature has been increasing by 0.13 ± 0.07 °C every decade in the past

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50 years. Due to increased emanations of greenhouse gases into the atmosphere, the IPCC anticipated a warming of around 0.2 °C every decade and surface air temperature is expected to rise by 1.1 °C to 6.4 °C over the course of the twenty-first century. A number of recent studies have characterized increasing global temperature over the last 100 years, and many researchers have conducted trend analysis for hydrologic and climate time series in all over the world (e.g., Chaouche et al. 2010; Mirabbasi and Dinpashoh 2010; Tabari and Hosseinzadeh Talaee 2011a, b; Dhorde and Zarenistanak 2013; Dinpashoh et al. 2014; Jhajharia et al. 2014; Zamani et al. 2017; Sanikhani et al. 2018; Ahmadi et al. 2018).

The warming rate over the course of last centurial years (1901–2007) in India was observed around 0.51 °C (Krishna Kumar 2009), and its negative effects on the yield of wheat and paddy in some parts of India have become noticeable. For each 1 °C increase in temperature, the yield of mustard, wheat, soybean, groundnut and potato is expected to decrease by 3–7% (Agrawal 2009). Similarly, the rice yield may decay by 6% for each 1 °C increase in temperature. An increase in temperature will extend the viable developing season in zones where agrarian potential is currently restricted by frosty temperature stress. In the tropics in general, rising temperatures will reduce the length of the variable growing season, especially where more than one crop is grown in each year. In semi-parched locales and other agro-biological zones where there is high diurnal temperature variation, moderately little changes in annual mean temperature could particularly build the recurrence of most shocking temperature damage.

In this study, we were concerned with the influences of climate change in terms of significant trend behaviors in temperature data in the Chhattisgarh State, India, from a wide distinctive perspective. This, in fact, will actualized first at the stage of using types/forms of analysis methodologies and second at the stage of determining time scale/period of the temperature variable. In the methodological distinction of this study, the inclusion of the long-term persistence (LTP) and short-term persistence (STP) characteristics is considered in examining temperature trends in the Chhattisgarh State, India, has yet been reviewed in the literature. Specifically speaking, our analysis approach will be comprising of four types of the Mann-Kendall (MK) test; that is to say, (i) the conventional MK method (MK1); (ii) the removed effect of noteworthy lag-1 serial correlation (MK2); (iii) the removed effects of all noteworthy serial correlation coefficients (MK3); and (iv) the MK coupled with the Hurst coefficient (MK4). In addition, our analysis approach will be adopting the linear regression analysis and finally Theil-Sen method to estimate temperature trend magnitudes. In the time period distinction of this study, we concentrate on both the annual and seasonal time scales at which some modes of the latter scale will be defined by the turning point of the long-term temperature series spanning from 1901 to 2016. Besides testing the homogeneity condition of temperature series, the standard normal homogeneity test (SNHT) will also help us find out a turning point in a time series in order to know where exactly we split it over the time axis. At last, it is expected that our results could be used as scientific bases to examine the impacts of temperature trends on agriculture and water demands.

2 Study area and data

The Chhattisgarh (CG) State is positioned between 17°46′N to 24°5′N latitude and 80°15′ E to 84°20′E longitude covering a geographical area of 135,100 km^2 or 13.5 million hectares (Fig. 1) of which rice cultivation takes up 3.7 million hectares. The temperature differs between 30 and 45 °C in the summer and 0 and 25 °C for the period of the winter. Annual mean rainfall in the study area is approximately 1400 mm in which a major portion occurs in July and September. The state has three distinct agro-climatic sectors (i.e., the Chhattisgarh Plains, Bastar Plateau and Northern Hills) and additional 16 districts.

We analyzed the temperature series in the study area for the time period 1901–2016 having a length of 116 years. Data in 16 stations were compiled by the Indian Meteorological Department (IMD), Pune, and Department of Water Resources, Raipur (Chhattisgarh), to examine the spatiotemporal trend and temperature variability. The spatial distribution of the stations, their features and data availability are presented in Fig. 1 and Table 1. According to the IMD, Pune, four main seasons are dominant in India: (1) monsoon (June–September); (2) post-monsoon (October–November); (3) winter (December–February); and (4) summer (March–May). Annual and seasonal time series were formed using monthly temperature data. After the determination of the most possible change point, trend analysis was conducted using two pieces of the series (after and before the change point). Rice production (tons/year) data has been collected from the Department of Agriculture, Raipur (Chhattisgarh), for the time period 2000–2014.

Table 2 includes information concerning station elevation and surrounding soil types. Stations with higher elevations above 600 m are located in the northern districts. Rajnandgaon with elevation 316 m is coming under hilly area and having red sandy soil; this shows that, due to dense vegetation present in the area, soils will have lower temperature among other districts. Hilly and plain land covers in Kawardha (elevation 357 m) and Korba (elevation 316 m) have black and red-yellow soil, respectively. This shows that, in Kawardha District, due to presence of clay minerals (montmorillonite), soils will have more shrinkage and swelling property due to hyderation and temperature. Plain land is observed in Bilaspur, Durg, Chapa, Koriya, Rajgarh, Raipur and Sarguja districts with elevation ranges from 232 to 755 m.

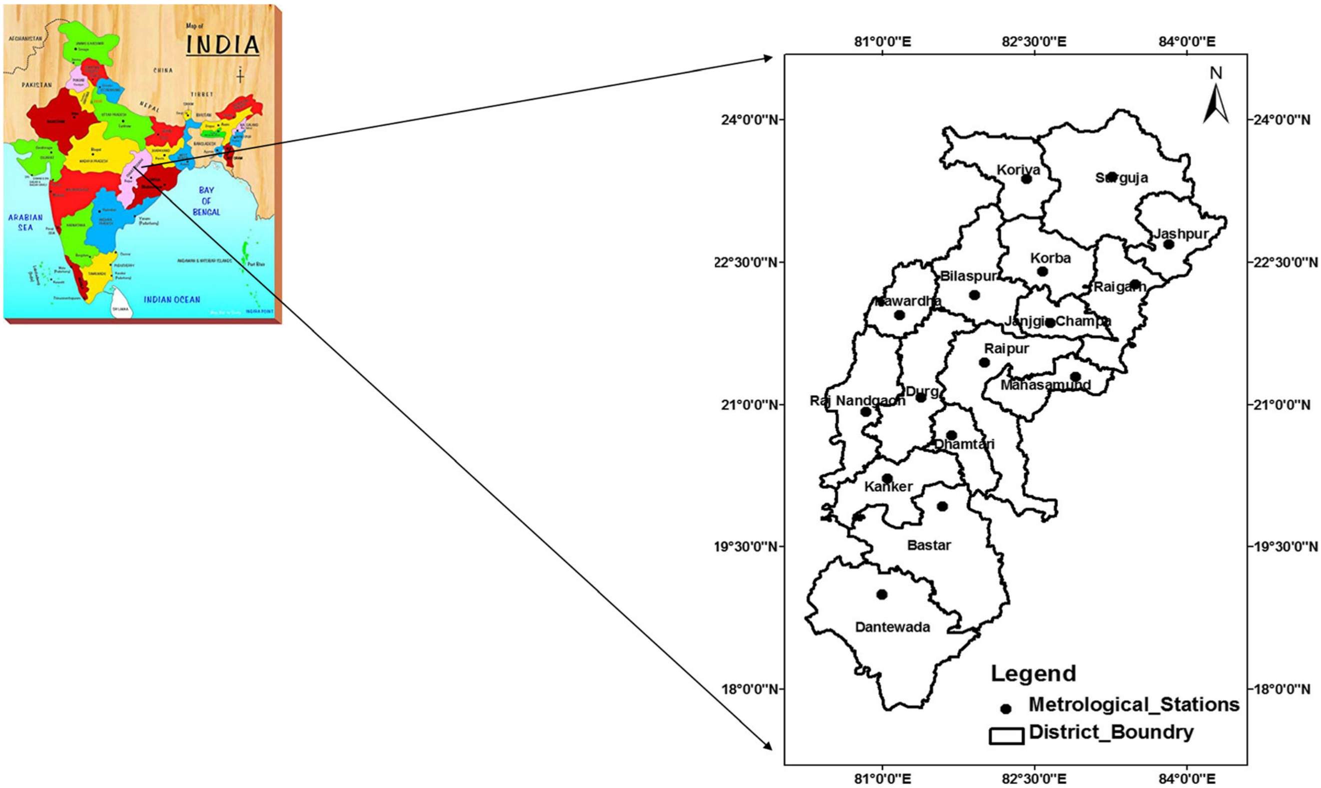


Fig. 1 Location of the study area and distribution of meteorological stations

Table 1 Descriptive statistics of air temperature in the study area

Season	Minimum	Maximum	Mean	SD	CV	Skewness	Kurtosis
1901–2016							
Annual	23.00	28.52	25.93	0.89	3.45	− 0.41	− 0.09
Monsoon	25.97	32.21	28.13	0.99	3.50	1.34	2.95
Summer	23.13	33.67	30.25	1.45	4.80	− 1.27	2.48
Winter	11.98	24.75	20.11	2.01	9.99	− 1.15	2.03
Post-monsoon	20.68	27.15	23.75	1.13	4.74	0.05	− 0.20
1901–1950							
Annual	23.00	27.84	25.72	0.87	3.39	− 0.50	− 0.24
Monsoon	26.03	32.16	28.05	1.04	3.71	1.58	3.37
Summer	23.13	33.38	30.10	1.50	4.98	− 1.50	3.14
Winter	11.98	24.05	19.79	2.04	10.32	− 1.27	2.07
Post-monsoon	20.68	26.60	23.39	1.01	4.33	0.02	− 0.08
1951–2016							
Annual	23.35	28.52	26.08	0.88	3.37	− 0.40	− 0.05
Monsoon	25.97	32.21	28.20	0.94	3.32	1.14	2.72
Summer	24.16	33.67	30.37	1.40	4.63	− 1.05	1.63
Winter	13.47	24.75	20.35	1.95	9.58	− 1.07	1.95
Post-monsoon	20.74	27.15	24.02	1.13	4.71	− 0.05	− 0.24

Kurtosis is a measure of data peakedness or flatness relative to a normal distribution. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. Positive kurtosis indicates a peaked distribution and negative kurtosis indicates a flat distribution

Table 2 Information concerning stations elevation and surrounding soil types

S.N	Stations	Physiography	Elevation (m)	Soil type
1	Bastar	The plateaus	325	Red-sandy soil
2	Bilaspur	The plain land	272	Red-yellow soil
3	Dantewada	The plateaus	351	Red-sandy soil
4	Dhamtari	The plateaus	305	Red-sandy soil
5	Durg	The plain land	288	Red-yellow soil
6	Champa	The plain land	232	Red-yellow soil
7	Jashpur	The plateaus	753	Red-yellow soil
8	Kanker	The plateaus	388	Red-sandy soil
9	Kawardha	The hilly area, plain land	357	Black soil
10	Korba	The hilly area, plain land	316	Red-yellow soil
11	Koriya	The plain land	755	Red-yellow soil
12	Mahasunmund	The plateaus	318	Red-yellow soil
13	Raigarh	The plain land	215	Red-yellow soil
14	Raipur	The plain land	287	Red-yellow soil
15	Rajnandgaon	The hilly area	316	Red-sandy soil
16	Surguja	The plain land	623	Red-yellow soil

However, the soil in these districts is red-yellow soil, which implicates the presence of iron content in the soil due to long trend of heating of soil. As studied by Wondafrash et al. (2005), because of long time heating of soil, its color changes due to formation of Fe hydrous oxide. Plateau land is observed in Baster, Jashpur, Kanker and Mahasamund districts having elevation range between 318 and 753 m. Moreover, red-yellow soil to red sandy soil is present in the area.

3 Methodology

In the present research, we first test the homogeneity of temperature series for reliable results. Later we adopt well-known parametric and non-parametric tests to identify statistically significant trends that will be associated with the influences of climate change in the CG State; at the same time, we will point out increasing and decreasing tendency in temperature behaviors. One may wonder why we use both parametric and non-parametric trend tests in the same study although they are theoretically alternative to each other. In other words, one type of method should be selected as a result of preliminary statistical testing. As in our case, if the analysis variable is temperature, which is generally known to follow a normal distribution well, one may think that a parametric approach (such as Linear Regression) is logical to implement. However, we here aim to perform detailed trend analyses that take serial dependency characteristics into consideration. This is now possible through the use of some versions of the Mann-Kendall (MK) test. For this reason, we decided to use both approaches to strength our finding as the length of our series allows us to do so (Fig. 2).

3.1 Homogeneity test

Since homogeneous time series of climate variables is fundamental in investigating climate change, we tested the homogeneity of our temperature series using the standard normal homogeneity test (SNHT) at a significant level of 0.05 (Alexandersson 1986). A temperature series is considered to be homogenous when the SNHT statistic is less than the critical value of 9.17 at the 95% confidence level for the sample size of 102 (Khaliq and Ouarda 2007).

3.2 Linear regression method

A parametric measurable method was connected to identify and investigate trend in data over time. In any case, with the typical approach of changing the regression line's log slope, focus trends may frequently be clouded by dissemination of data emerging from non-ideal hydrogeologic conditions, examining and analysis circumstances, etc. The most usually applied approach for trend identification is formulating a linear model among the time and data in the following form (Hameed et al. 1997):

$$y_t = \varphi + \mu.t + \varepsilon_t \quad (1)$$

where y_t $(t\in(1, , n))$ = practical estimate at time t, φ and μ = regression coefficients and ε_t = a random error.

Linear regression has been widely utilized to search long-term trends in annual and seasonal precipitation or temperature (Gadgil and Dhorde 2005). Its core statistical limitation indicated the mean temporal amendment in the considered component. The positive and negative slope values indicate

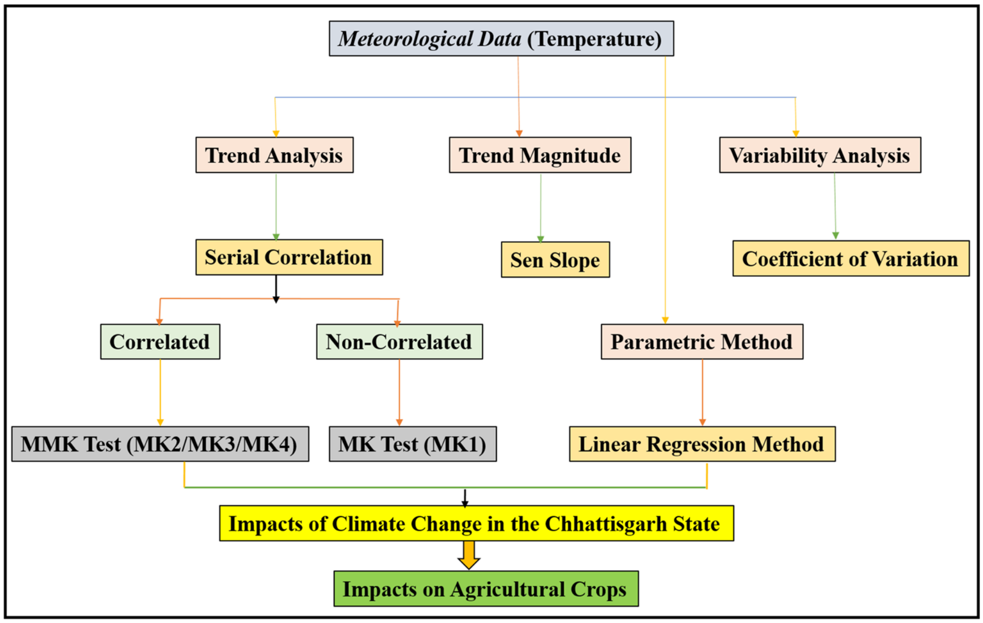


Fig. 2 Flowchart of the research methodology

increasing and decreasing trends, respectively. The total change during the detected period can be acquired by increasing the slope through the number of years (Tabari et al. 2010).

3.3 Mann-Kendall methods

The Mann-Kendall (MK) method is a non-parametric test and usually applied to identify noteworthy trends in a time series of interest because of its simplicity and robustness (Yue and Hashino 2003; Cannarozzo et al. 2006; Partal and Kahya 2006; Modarres and da Silva 2007; Tabari et al. 2011b, d; Chandniha et al. 2017; Gajbhiye et al. 2016a, b; Zamani et al. 2017; Meshram et al. 2017; Meshram et al. 2018). This test is reasonable for data that is not taken after a typical distribution (Tabari et al. 2011c), and it bolsters numerous perceptions per time arrangement (Kampata et al. 2008). In addition, the MK test fits missing values and the information involve no measurable dispersion (Libiseller and Grimval 2002; Gilbert 1987).

A majority of trend studies have adopted the conventional MK method (hereafter abbreviated as MK1) for trend detection. The existence of negative autocorrelation results in under-assessment of the noteworthy level, whereas positive autocorrelation results in over-assessment of the noteworthy level in both negative and positive trends (Zamani et al. 2017). This has motivated some investigators to use the modified MK test, when there is a noteworthy lag-1 serial correlation between observations. The presence of significant first order (lag-1) serial correlation in a time series is called short-term persistence (STP). MK2, which is a renowned adapted method, was developed to treat data against unfavorable STP effects in temperature time series (Yue and Wang 2002). In some hydro-meteorological time series (i.e., temperature), additional significant serial correlations at different lag times can be present in the series, and this case is called long-term persistence (LTP) (Tabari et al. 2015). In this type of time series, the utilization of MK1 and MK2 approaches in trend investigation could produce questionable outcomes. Hence, Hamed (2008) altered the traditional type of the MK test in order to incorporate LTP behavior (hereafter as MK3).

Another approach for trend analysis based on the MK method considering the Hurst phenomenon (hereafter as MK4) was proposed by Hamed (2008), which was distinguished as the fundamental cause of vulnerability in investigating the hydro-meteorological time series (Koutsoyiannis and Montanari 2007). The presence of LTP performance in the time series results in the under-estimation of serial correlation and thereby the over-estimation of the significance of the MK test (Koutsoyiannis 2003; Kumar et al. 2009). The mathematical expressions of these four methods are given in Appendix.

3.4 Sen's slope estimator

To distinguish the presence of a trend, the extent of the trend is assessed using a slope estimator β, previously proposed by Sen (1968) (Hirsch et al. 1982). The incline of n sets of data points is assessed utilizing the Theil–Sen's estimator (Theil 1950; Sen 1968). As indicated by Yue et al. (2002), the Theil–Sen's estimator is a hearty gauge of the size of a trend that has been generally utilized as a part of recognizing the trend line slope in hydrological time series (e.g. Mohsin and Gough 2009; Dinpashoh et al. 2011).

The magnitude of temperature trend is estimated by the Theil-Sen's estimator, which uses Eq. (2) to calculate all data sets' slope.

$$S_i = \frac{w_j - w_i}{j - i} \quad (2)$$

Where w_j and w_i are values of information at time i and j ($j > i$), respectively. The average of these n estimations of $S_\rangle$ is signifies the Theil-Sen's slope estimator, which can be calculated as $Q_{med} = \left[\frac{\mathcal{T}(n+2)}{2} + \frac{\mathrm{Tn}}{2}\right]/2$ and $Q_{med} = \mathcal{T}(n+1)/2$ for even and odd values of n, respectively. A positive (negative) estimation of S_i shows an increasing (decreasing) trend in the time series.

3.5 Spatial analysis of temperature series

The Inverse Distance Weighting (IDW) interpolation technique (Lu and Wong 2008; Achilleos 2011) was used to explore the spatial distribution of the temporal temperature trends over the study region using Arc GIS 10. To explore the spatial distribution of trends on a monthly basis, statistics value was introduced using Arc GIS and information from each station over the entire study period. Spatial interpolation method inverse distance weighting (IDW) was utilized in view of the supposition that the addition surface should be mainly impacted by neighboring points and less remote points. The electrical field $E(x, y)$ interpolated value is provided by (Azpurua and Ramos 2010):

$$E(x,y) = \sum_{j=0}^{n} w_j E\left(x_j y_j\right) \quad (3)$$

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

4 Results and discussion

A preparatory examination of the descriptive statistics (mean, coefficient of variation (CV), skewness, standard deviation and kurtosis) of the temperature series (1901–1950 and 1951–2016) have been calculated in every station (Table 1). The mean temperature in the region varies from 19.79 °C in the winter to 30.37 °C in the summer for the first and second century series, with a standard deviation of 0.87 to 2.04 °C. The CV varied from 3.32% (monsoon, 1951–2016) to 10.32% (winter, 1901–1951). This preliminary analysis indicates that the zones of higher temperatures (Dantewada) have the least variability and the zones of lowest temperatures (Bilaspur) have the highest variability. Similar results have been reported for rainfall series for which the CV values increased with decreasing rainfall in Chhattisgarh State (Meshram et al. 2017). Monsoon and post-monsoon (1901–1950 and 1951–2016) temperature data in the entire state were found to be skewed to the right, and annual/post-monsoon time series in the periods 1901–2016, 1901–1950 and 1951–2016 had a flat distribution based on the kurtosis parameter, which is a measure of data peak or flatness connected to a normal distribution.

4.1 Homogeneity and break point in temperature series

The homogeneity test was functional to the data series by standard normal homogeneity test (SNHT) at the 5% significance level (Alexandersson 1986; Alexandersson and Moberg 1997) and was considered homogeneous (Table 3). The break point in temperature series was assessed by the Mann-Whitney-Pettitt (MWP) and SNHT test where considerable temperature change is detected. Table 3 indicates that the break point occurred in 1950 as noticed at the maximum values in the MWP and SNHT tests.

4.2 Trend analysis

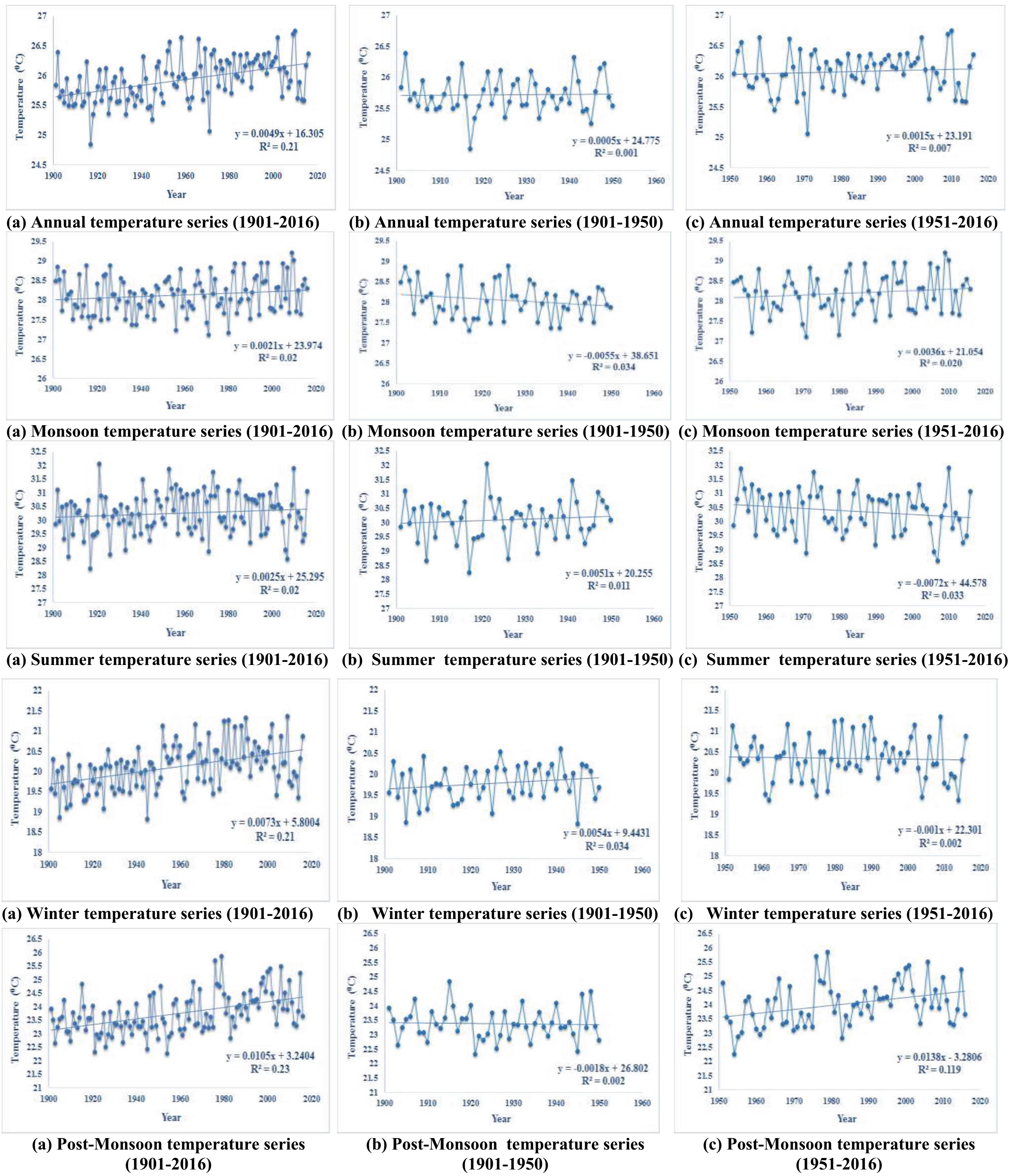
The linear regression, Sen's Slope estimator and Mann-Kendall tests were all used to examine possible temperature

Table 3 Results of the standard normal homogeneity and Mann-Whitney-Pettits tests (H_o: homogeneous series; H_a: heterogeneous series)

Stations	Pettitt's test		SNHT test	
	t	Trend	t	Trend
Bastar	1950	H_a	1981	H_a
Bilaspur	1950	H_a	1950	H_a
Dantewada	1953	H_a	1978	H_a
Dhamtari	1950	H_a	1950	H_a
Durg	1956	H_a	1978	H_o
Champa	1950	H_a	1950	H_a
Jashpur	1951	H_a	1950	H_a
Kanker	1959	H_a	1978	H_a
Kawardha	1950	H_a	1950	H_a
Korba	1950	H_a	1950	H_o
Koriya	1950	H_a	1950	H_a
Mahasunmund	1950	H_a	1950	H_a
Raigarh	1959	H_a	1956	H_a
Raipur	1950	H_a	1950	H_a
Rajnandgaon	1950	H_a	1950	H_a
Surguja	1950	H_o	1903	H_o

trends in 16 stations in the state of Chhattisgarh in India. The brief subtle elements of the outcomes are displayed in the following subsections.

Annual trends The mean annual temperature trends based on the linear regression analysis are shown in Fig. 3. As a result of an overall inspection, an increasing trend has been observed in the original long-term series (1901–2016) as well as in the



(a) Annual temperature series (1901-2016) **(b) Annual temperature series (1901-1950)** **(c) Annual temperature series (1951-2016)**

(a) Monsoon temperature series (1901-2016) **(b) Monsoon temperature series (1901-1950)** **(c) Monsoon temperature series (1951-2016)**

(a) Summer temperature series (1901-2016) **(b) Summer temperature series (1901-1950)** **(c) Summer temperature series (1951-2016)**

(a) Winter temperature series (1901-2016) **(b) Winter temperature series (1901-1950)** **(c) Winter temperature series (1951-2016)**

(a) Post-Monsoon temperature series (1901-2016) **(b) Post-Monsoon temperature series (1901-1950)** **(c) Post-Monsoon temperature series (1951-2016)**

Fig. 3 Linear regression analysis for temperature (°C) series of different period: (**a**) 1901–2016; (**b**) 1901–1950; and (**c**) 1951–2016

Table 4 Z-statistics (MK1/MK2/MK3/MK4) for the temperature time series of the Chhattisgarh State during 1901–1950

Stations	Annual				Monsoon.				Summer				Winter				Post-monsoon			
	MK1	MK2	MK3	MK4	MK1	MK2	MK3	MK4	MK1	MK2	MK3	MK4	MK1	MK2	MK3	MK4	MK1	MK2	MK3	MK4
Bastar	0.95	0.95	0.95	0.95	0.40	0.40	0.40	0.40	1.32	1.32	1.32	1.32	0.28	0.28	0.28	0.28	− 0.83	− 0.83	− 0.83	− 0.83
Bilaspur	0.68	0.68	0.68	0.68	− 0.88	− 0.88	− 0.88	− 0.88	*1.89*	*1.89*	*1.89*	*1.89*	− 0.05	− 0.05	− 0.05	− 0.05	− 0.23	− 0.23	− 0.23	− 0.23
Dantewada	0.55	0.55	0.55	0.55	0.63	0.63	0.63	0.63	1.17	1.17	1.17	1.17	− 0.01	− 0.01	− 0.01	− 0.01	− 1.12	− 1.12	− 1.12	− 1.12
Dhamtari	0.11	0.12	0.11	0.11	− 0.92	− 0.92	− 0.92	− 0.92	0.70	0.70	0.70	0.70	0.77	0.77	0.77	0.77	− 0.78	− 0.78	− 0.78	− 0.78
Durg	0.03	0.03	0.03	0.03	− 1.27	− 1.27	− 1.27	− 1.27	0.56	0.56	0.56	0.56	1.17	1.17	1.62	1.17	− 0.81	− 0.81	− 0.81	− 0.81
Champa	− 0.48	− 0.48	− 0.48	− 0.48	− 1.41	− 1.41	− 1.41	− 1.41	− 0.10	− 0.10	− 0.10	− 0.10	1.48	− 0.05	2.28	1.48	− 0.65	− 0.65	− 0.65	− 0.65
Jashpur	− 0.31	− 0.31	− 0.31	− 0.31	− 1.08	− 1.08	− 1.08	− 1.08	− 0.41	− 0.41	− 0.41	− 0.41	*1.85*	0.66	3.07	1.85	− 0.15	− 0.15	− 0.15	− 0.15
Kanker	0.75	0.75	0.75	0.75	− 0.33	− 0.33	− 0.33	− 0.33	1.28	1.28	1.28	1.28	0.71	0.71	0.71	0.71	− 0.87	− 0.87	− 0.87	− 0.87
Kawardha	0.15	0.15	0.15	0.15	− 1.47	− 1.47	− 1.47	− 1.47	0.56	0.56	0.56	0.56	1.55	− 0.23	2.28	1.55	− 0.15	− 0.15	− 0.15	− 0.15
Korba	− 0.08	− 0.08	− 0.08	− 0.08	− 1.35	− 1.35	− 1.35	− 1.35	0.19	0.19	0.19	0.19	*1.72*	− 0.46	2.72	1.72	− 0.15	− 0.15	− 0.15	− 0.15
Koriya	0.32	0.32	0.32	0.32	− 1.43	− 1.43	− 1.43	− 1.43	0.35	0.35	0.35	0.35	*2.07*[a]	*2.07*[a]	*2.07*[a]	*2.07*[a]	0.63	0.63	0.63	0.63
Mahasunmund	− 0.78	− 0.78	− 0.78	− 0.78	− 1.30	− 1.30	− 1.30	− 1.30	− 0.21	− 0.21	− 0.21	− 0.21	0.90	0.90	0.90	0.90	− 0.82	− 0.82	− 0.82	− 0.82
Raigarh	− 0.63	− 0.63	− 0.63	− 0.63	− 1.25	− 1.25	− 1.25	− 1.25	− 0.33	− 0.33	− 0.33	− 0.33	*1.66*	− 0.78	*2.60*[b]	*1.66*	− 0.58	− 0.58	− 0.58	− 0.58
Raipur	− 0.31	− 0.31	− 0.31	− 0.31	− 1.18	− 1.18	− 1.18	− 1.18	0.15	0.15	0.15	0.15	0.93	0.93	0.93	0.93	− 0.77	− 0.77	− 0.77	− 0.77
Rajnandgaon	0.28	0.28	0.28	0.28	− 1.18	− 1.18	− 1.18	− 1.18	0.87	0.87	0.87	0.87	1.30	1.30	1.30	1.30	− 0.60	− 0.60	− 0.60	− 0.60
Surguja	− 0.05	− 0.05	− 0.05	− 0.05	− 1.27	− 1.27	− 1.27	− 1.27	− 0.06	− 0.06	− 0.06	− 0.06	*1.95*	− 0.48	*2.92*[b]	*1.95*	0.40	0.40	0.40	0.40

Numbers in italics indicate significant values at the 10% level ($Z_{10\%} = \pm 1.645$)

[a] Significant at the 5% level ($Z_{5\%} = \pm 1.96$)

[b] Significant at the 1% level ($Z_{1\%} = \pm 2.58$)

Table 5 Z-statistics (MK1/MK2/MK3/MK4) for temperature time series of the Chhattisgarh State during 1951–2016

Stations	Annual				Monsoon				Summer				Winter				Post-monsoon			
	MK1	MK2	MK3	MK4	MK1	MK2	MK3	MK4	MK1	MK2	MK3	MK4	MK1	MK2	MK3	MK4	MK1	MK2	MK3	MK4
Bastar	*2.66*[b]	*2.34*[a]	*2.09*[a]	*2.66*[b]	1.42	1.42	1.42	1.42	0.49	0.49	0.49	0.49	*1.65*	1.25	1.36	*1.65*	*3.80*[b]	*3.95*[b]	*2.20*[a]	*3.12*[b]
Bilaspur	*2.80*[b]	*4.22*[b]	0.92	1.04	*−6.49*[b]	*−7.86*[b]	*−2.10*[a]	*−2.60*[b]	*3.96*[b]	*4.73*[b]	1.33	*1.80*	*4.32*[b]	*6.02*[b]	1.29	1.53	*3.23*[b]	*3.41*[b]	*2.00*[a]	*1.76*
Dantewada	−0.10	−0.60	−0.06	−0.05	−1.56	*−2.05*[a]	−1.08	−1.12	−1.48	−1.48	−1.48	−1.48	1.22	0.72	0.93	0.78	*2.29*[a]	*2.17*[a]	1.50	1.55
Dhamtari	*3.83*[b]	*3.51*[b]	*2.94*[b]	*3.83*[b]	*4.28*[b]	*3.92*[b]	*1.93*	*4.28*[b]	−0.06	−0.06	−0.06	−0.06	−0.10	−0.10	−0.10	−0.10	*4.45*[b]	*4.27*[b]	*2.53*[a]	*4.45*[b]
Durg	−1.46	*−1.97*[a]	−1.11	−1.05	1.38	1.38	1.38	1.38	*−2.98*[b]	*−3.49*[b]	*−2.43*[a]	*−2.98*[b]	*−2.51*[a]	*−3.08*[b]	−1.40	*−1.69*	*1.77*	1.60	1.23	1.35
Champa	*−2.03*[a]	*−2.46*[a]	−1.50	*−1.66*	−0.56	−0.56	−0.56	−0.56	*−3.62*[b]	*−4.00*[b]	*−2.92*[b]	*−3.62*[b]	*−2.71*[b]	*−3.28*[b]	*−2.06*[a]	*−2.22*[a]	0.91	0.61	0.63	0.58
Jashpur	1.25	1.25	1.25	1.25	1.26	1.26	1.26	1.26	−1.53	−1.53	−1.53	−1.53	−0.17	−0.17	−0.17	−0.17	*3.00*[b]	0.23	*1.96*[a]	*3.00*[b]
Kanker	0.40	−6.59	0.32	0.40	*2.15*[a]	*2.15*[a]	*2.15*[a]	*2.15*[a]	−1.46	−1.46	−1.46	−1.46	*−1.79*	*−2.25*[a]	−1.11	−1.14	*2.99*[b]	*−1.93*	*1.99*[a]	*2.29*[a]
Kawardha	−1.00	*−5.16*[b]	−0.82	−1.00	*2.08*[a]	*2.08*[a]	*2.08*[a]	*2.08*[a]	*−2.87*[b]	−0.86	*−2.42*[a]	*−2.87*[b]	*−2.56*[a]	*−3.12*[b]	*−2.03*[a]	*−2.56*[a]	*1.97*[a]	*−4.23*[b]	1.55	1.62
Korba	*−2.36*[a]	*−3.75*[b]	*−1.73*	*−1.80*	−0.48	−0.48	−0.48	−0.48	*−3.82*[b]	*−3.60*[b]	*−2.37*[a]	*−3.82*[b]	*−2.68*[b]	*−3.38*[b]	*−2.08*[a]	*−2.68*[b]	0.93	−0.56	0.65	0.59
Koriya	*3.81*[b]	*−5.25*[b]	*2.95*[b]	*3.81*[b]	*3.29*[b]	0.72	1.46	*2.36*[a]	−1.12	−1.12	−1.12	−1.12	−0.37	−0.37	−0.37	−0.37	*4.45*[b]	*−4.16*[b]	*2.71*[b]	*4.45*[b]
Mahasunmund	1.57	1.57	1.57	1.57	*2.94*[b]	−1.08	*2.15*[a]	*2.94*[b]	−1.31	−1.31	−1.31	−1.31	−1.18	−1.18	−1.02	−1.18	*3.10*[b]	*−3.09*[b]	*2.13*[a]	*3.10*[b]
Raigarh	*−2.34*[a]	*−4.44*[b]	−1.42	*−1.79*	−0.89	−0.89	−0.89	−0.89	*−3.71*[b]	*−1.38*	*−2.99*[b]	*−3.71*[b]	*−2.82*[b]	*−3.36*[b]	*−1.71*	*−2.16*[a]	0.28	*−3.03*[b]	0.18	0.17
Raipur	0.85	0.85	0.85	0.85	*2.77*[b]	*−3.29*[b]	*2.35*[a]	*2.77*[b]	*−1.84*	*−1.84*	*−1.84*	*−1.84*	−1.45	*−1.69*	−1.20	−1.45	*2.87*[b]	*−3.73*[b]	*1.96*	*2.87*[b]
Rajnandgaon	*−1.73*	*−3.92*[b]	−1.30	−1.24	−0.03	−0.03	−0.03	−0.03	*−2.82*[b]	*−2.16*[a]	*−2.39*[a]	*−2.82*[b]	*−2.36*[a]	0.27	*−1.87*	*−1.93*	*1.74*	*−1.66*	1.21	1.33
Surguja	*4.11*[b]	0.63	*3.10*[b]	*4.11*[b]	*2.94*[b]	*−2.27*[a]	1.44	*2.94*[b]	−0.44	−0.44	−0.44	−0.44	1.05	1.05	1.05	1.05	*4.51*[b]	−0.20	*2.69*[b]	*4.51*[b]

Numbers in italics indicate significant values at the 10% level ($Z_{10\%} = \pm 1.645$)

[a] Significant at the 5% level ($Z_{5\%} = \pm 1.96$)

[b] Significant at the 1% level ($Z_{1\%} = \pm 2.58$)

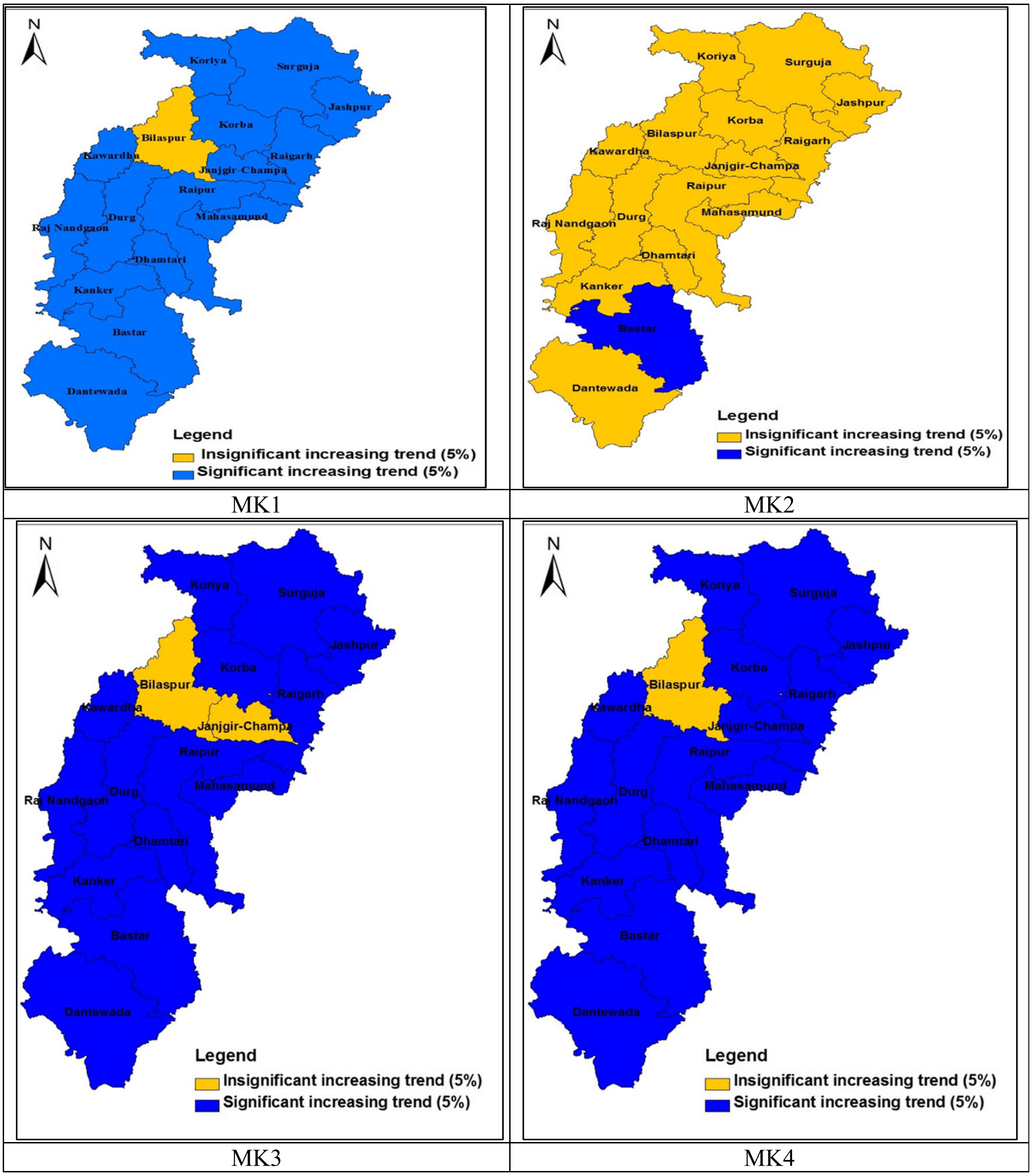


Fig. 4 Z statistics values for annual temperature time series during 1901–2016 using MK1/MK2/MK3/MK4

first and second half of the series (namely, 1901–1950 and 1951–2016).

Tables 4 and 5 and Fig. 4 show the annual temperature trends through the -statistic values for the temperature series in each 16 stations for the periods 1901–2016, 1901–1950 and 1951–2016. These results were the outcome of the four versions of the MK tests that were conducted as part of the trend analysis. In the time period between 1901 and 2016, all stations exhibited increasing trend in temperature at the annual scale. During the first half of twentieth century, all stations exhibited insignificant temperature trends (both decreasing and increasing). Seven out of the 16 stations did not reveal significant trends, but increasing tendency can be said. This was also the case for the stations during the second half of twentieth century. The number of significant trends utilizing the four versions of MK test (MK1/MK2/MK3/MK4) were found to be 5/2/3/4 (at 1% significance level), 0/1/1/0 (at 5% significance level) and 0/0/0/0 (at 10% significance level), respectively.

The trend magnitudes are shown in Table 6 and Fig. 9 in the form of Sen's slope estimator, which were positive in all stations during the whole period (1901–2016). The magnitude of the positive trends ranges from 0.002 at Champa, Korba and Raigarh districts to 0.009 at Bilaspur District (Table 6). For the

Table 6 Sen's slope of the temperature trend of Chhattisgarh State

Stations	1901–1950					1951–2016					1901–2016				
	Annual	Monsoon	Summer	Winter	Post-monsoon	Annual	Monsoon	Summer	Winter	Post-monsoon	Annual	Monsoon	Summer	Winter	Post-monsoon
Bastar	0.038	0.008	0.027	0.004	− 0.013	0.006	0.005	0.002	0.006	0.020	0.008	0.005	0.008	0.009	0.012
Bilaspur	0.042	− 0.018	0.069	− 0.002	− 0.003	0.015	− 0.044	0.044	0.046	0.019	0.009	− 0.013	0.024	0.019	0.008
Dantewada	0.016	0.011	0.025	− 0.001	− 0.013	0.000	− 0.006	− 0.007	0.004	0.010	0.006	0.002	0.006	0.008	0.008
Dhamtari	0.006	− 0.016	0.014	0.012	− 0.013	0.010	0.020	0.000	0.000	0.023	0.008	0.008	0.006	0.007	0.013
Durg	0.002	− 0.029	0.014	0.016	− 0.009	− 0.004	0.006	− 0.019	− 0.013	0.009	0.004	0.003	− 0.001	0.004	0.008
Champa	− 0.021	− 0.027	− 0.005	0.020	− 0.008	− 0.007	− 0.002	− 0.019	− 0.013	0.005	0.002	0.000	− 0.003	0.004	0.007
Jashpur	− 0.012	− 0.029	− 0.007	0.026	− 0.002	0.003	0.005	− 0.008	− 0.001	0.015	0.005	0.002	0.001	0.008	0.011
Kanker	0.027	− 0.008	0.025	0.012	− 0.011	0.001	0.008	− 0.008	− 0.008	0.016	0.006	0.006	0.004	0.005	0.010
Kawardha	0.006	− 0.033	0.014	0.024	− 0.001	− 0.003	0.009	− 0.019	− 0.013	0.011	0.004	0.004	− 0.002	0.005	0.009
Korba	− 0.004	− 0.033	0.005	0.024	− 0.001	− 0.008	− 0.002	− 0.022	− 0.013	0.006	0.002	0.000	− 0.004	0.005	0.007
Koriya	0.011	− 0.035	0.010	0.031	0.009	0.008	0.018	− 0.006	− 0.001	0.025	0.007	0.006	0.002	0.008	0.014
Mahasunmund	− 0.030	− 0.025	− 0.006	0.016	− 0.012	0.004	0.011	− 0.006	− 0.005	0.017	0.006	0.005	0.002	0.006	0.011
Raigarh	− 0.023	− 0.028	− 0.007	0.023	− 0.008	− 0.008	− 0.003	− 0.020	− 0.015	0.002	0.002	− 0.001	− 0.004	0.004	0.006
Raipur	− 0.011	− 0.020	0.005	0.015	− 0.011	0.002	0.011	− 0.009	− 0.006	0.015	0.005	0.005	0.002	0.006	0.010
Rajnandgaon	0.010	− 0.023	0.020	0.018	− 0.009	− 0.006	0.000	− 0.018	− 0.012	0.010	0.003	0.001	0.000	0.005	0.008
Surguja	− 0.003	− 0.030	− 0.001	0.031	0.005	0.010	0.014	− 0.002	0.005	0.026	0.007	0.005	0.003	0.010	0.014

first half of the twentieth century, annual temperature time series indicated both negative and positive trends. Nine out of 16 stations demonstrated a positive trend, whereas the remaining seven stations showed a negative trend. In the case of the second half of the twentieth century, six out of 16 stations demonstrated a negative trend, whereas the remaining ten stations showed a positive trend.

Seasonal trends The plot of mean temperature trend of the Chhattisgarh State for the monsoon, post-monsoon, summer and winter seasons is depicted in Fig. 3. There was an overall increasing trend pattern for all the seasons during the entire series (1901–2016). During 1901–1950 and 1951–2016, all the series showed an increasing trend. Overall, the State of Chhattisgarh showed an increasing temperature trend based on the linear regression analysis.

Tables 4 and 5 as well as Figs. 5, 6, 7 and 8 showed the Z-statistic values for seasonal temperature trends at each 16 stations during the periods 1901–1950 and 1951–2016. In the first period, there were increasing temperature trends in all stations

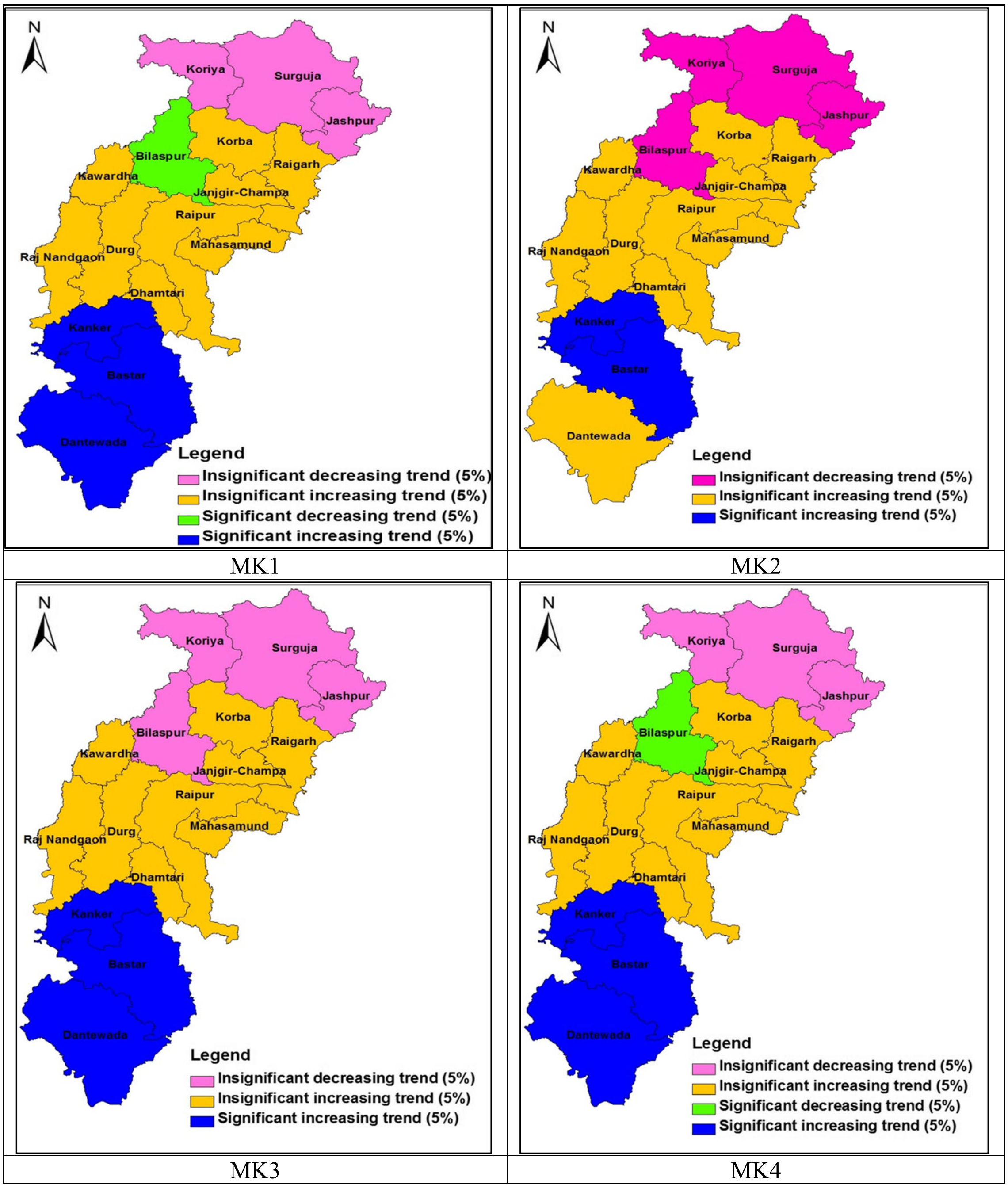


Fig. 5 Z statistics values for monsoon temperature time series during 1901–2016 using MK1/MK2/MK3/MK4

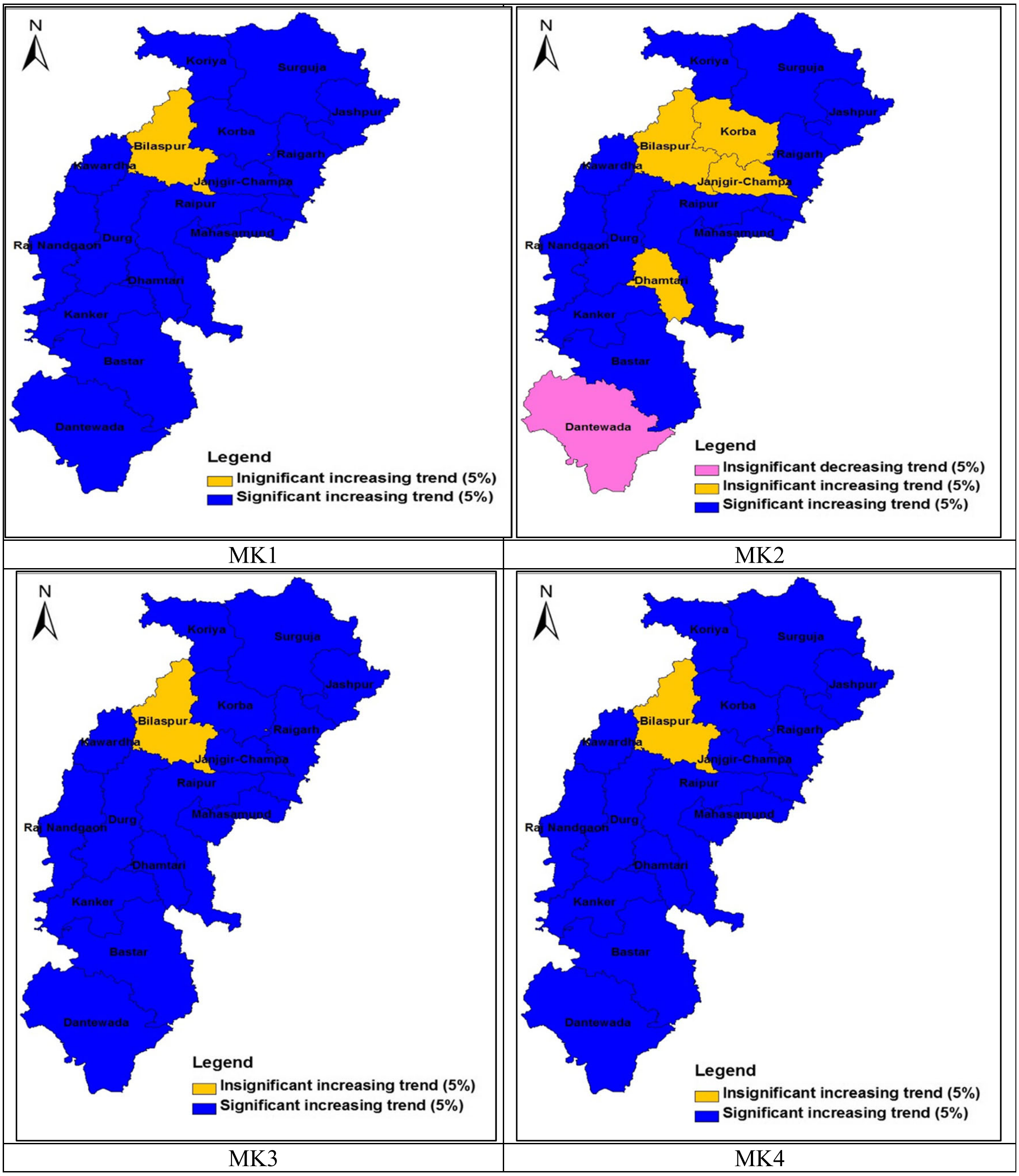


Fig. 6 Z statistics values for post-monsoon temperature time series during 1901–2016 using MK1/MK2/MK3/MK4

in all seasons (summer, winter and post-monsoon) except for the monsoon season in which four stations showed (two of them significant) decreasing tendency using the four altered versions of MK tests. In monsoon season, the quantity of significant negative trends ($p < 0.01$) were 1, 0, 0 and 1 utilizing MK1, MK2, MK3 and MK4, respectively. Only 4 out of 16 stations exhibited a significant either positive or negative trend. Hence, the quantity of statistically significant trends diminished from three to one when applying the MK2 instead of the MK1 and MK4. In summer season, eight stations demonstrated increasing significant trends with five stations at 1% significance level and three stations at 5% level according to the four versions of MK tests. In winter, the quantity of positive significant trends at the 1% significance level appeared to be 16/2/12/16 using MK1/MK2/MK3/M4, respectively. Nine stations showed insignificant positive trends; however, two stations in the state indicated a positive significant trend at the 5% significance level as well as another three stations at the 10% significance level using the MK2 test. In post-monsoon, there were significant increasing trends in all stations, except three stations: Bilaspur, according to MK1/MK3/MK4, and Dantewada and Champa, according to MK2.

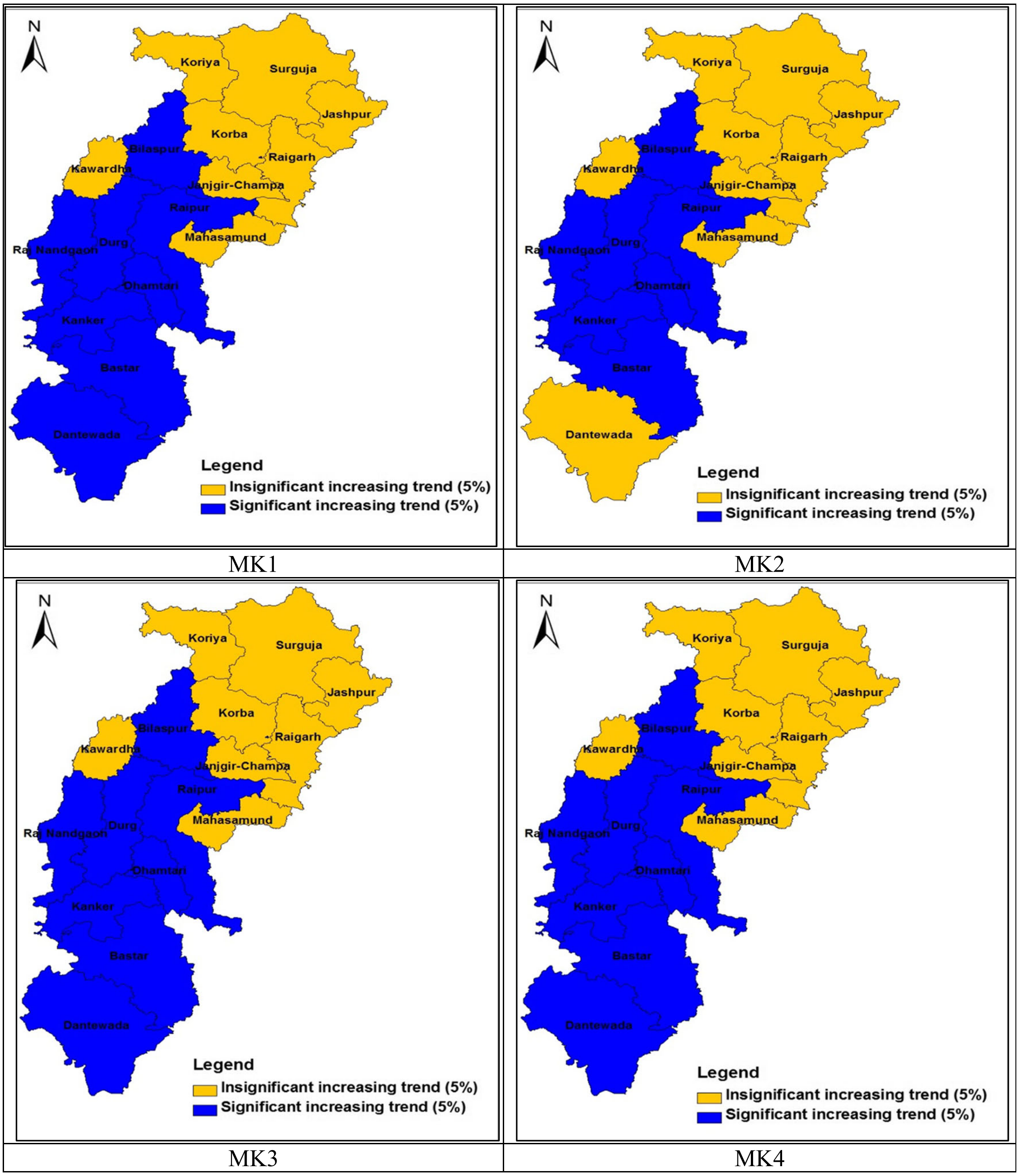


Fig. 7 Z statistics values for summer temperature time series during 1901–2016 using MK1/MK2/MK3/MK4

However, in the second half of the twentieth century, we detected significant trends depending on station/season/methods. For example, monsoon season showed strong positive trends where the quantity of significant trends at the 5% significant level utilizing MK1/MK2/MK3/MK4 was counted as 2/0/5/3, respectively. Kanker and Kawardha stations demonstrated a significant increasing trend at the 5% significant level using all four versions of MK test. Bastar and Jashpur stations showed non-significant trend (but increasing tendency) using all four versions of MK and similarly, Bilaspur, Dantewada, Champa, Korba, Raigarh and Rajnandgaon stations showed non-significant trend (but decreasing tendency) using the all four versions of MK test. In summer, there is only one station (Bilaspur) demonstrating significant trend in increasing manner at the 1% significance level utilizing MK1/MK2 tests. Nevertheless, Baster station showed non-significant increasing trend using all versions of MK. The remaining 14 stations exhibited non-significant decreasing trend using all versions of MK in the same season. In winter season, only one station (Baster) showed positive trend at the 10% significance level using MK1 and MK4. While Bilaspur station

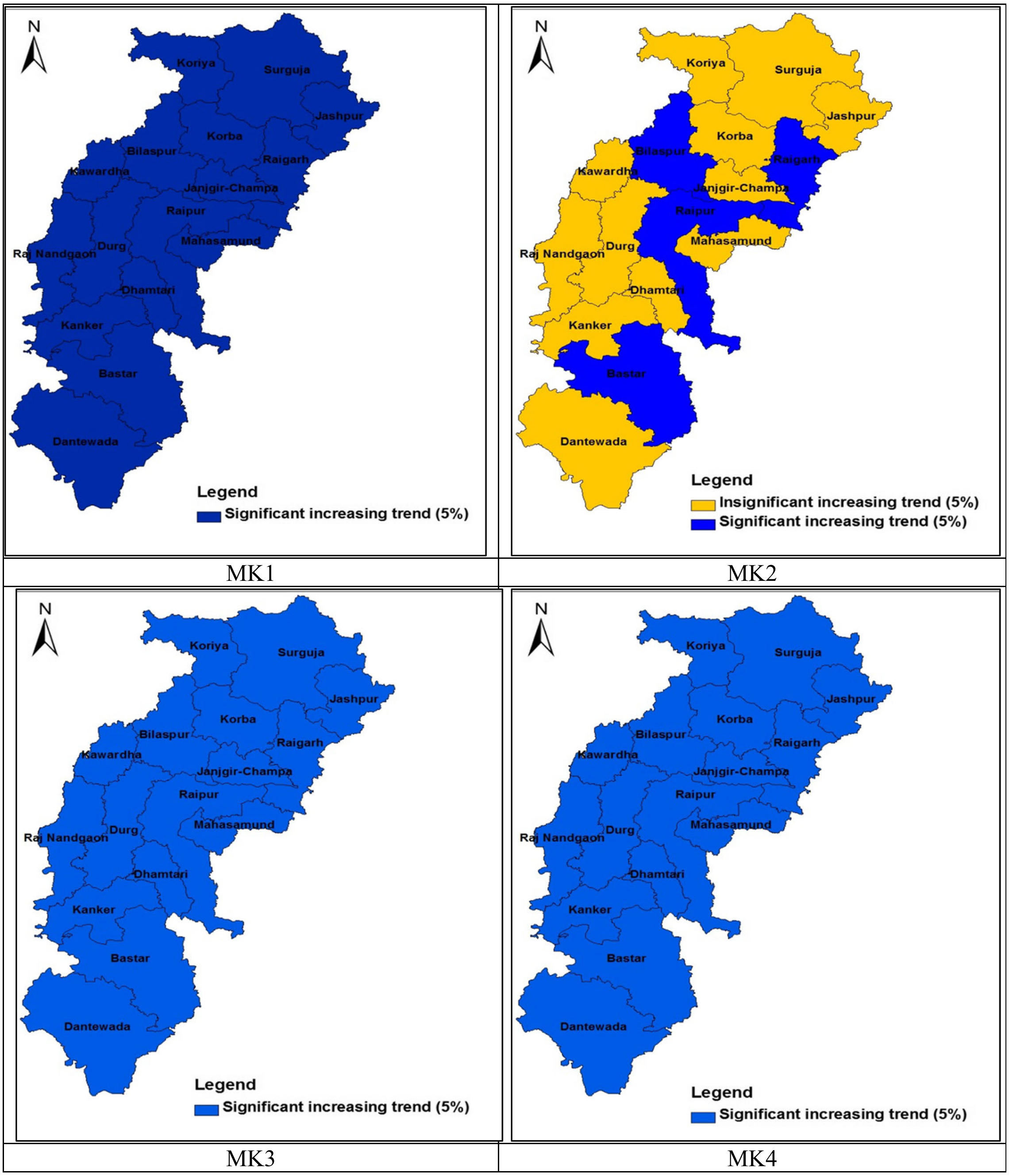


Fig. 8 Z statistics values for winter temperature time series during 1901–2016 using MK1/MK2/MK3/MK4

showed positive trend at the 1% significance level using MK1/MK2. Dantewada and Surguja station demonstrated non-significant positive trend according to all versions of MK test. The remaining 12 stations showed non-significant decreasing trend using all versions of MK in the same season. In post-monsoon and monsoon seasons, all stations exhibited increasing trends in temperature using all versions of MK except MK2. All 16 stations showed significant positive trends at the three significance levels 1, 5 and 10% using MK1, MK3 and MK4 except Dantewada, Durg, Champa, Kawardha, Korba, Raigarh and Rajnandgaon. Nine out of 16 stations showed decreasing trend using MK2. The number of positive significant trends using MK1/MK2/MK3/MK4 was 9/3/2/7 at the 1% significance level, 2/1/7/1 at the 5% significance level and 2/0/0/1 at the 10% significance level, respectively.

The trend magnitudes are presented in Table 6 and Fig. 9. During the long-term period (1901–2016), positive values of the Sen's slope estimator were computed in all stations for all the seasons except monsoon and summer, having the following ranges: (a) 0.004–0.019 between

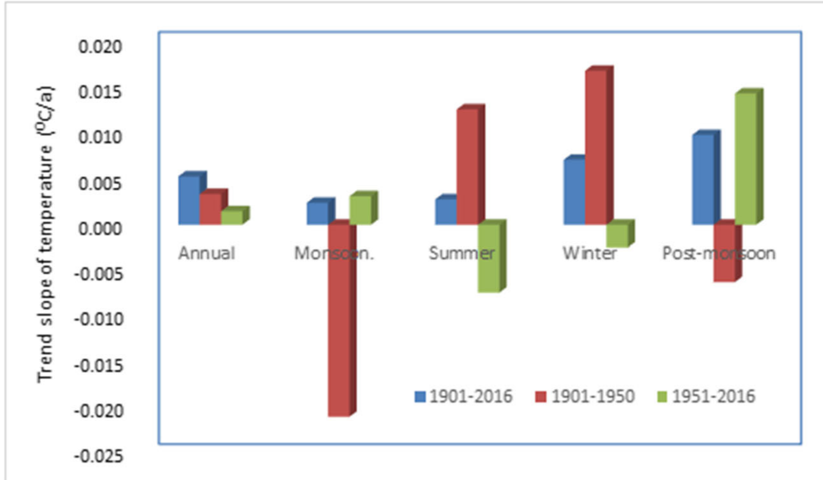


Fig. 9 Sen's slope of temperature trend for different periods: (a) 1901–2016; (b) 1901–1950; and (c) 1951–2016

Raigarh/Durg/Champa and Bilaspur; and (b) 0.006–0.014 between Raigarh and Surguja for the winter and post-monsoon seasons, respectively. In the monsoon season, only two stations and summer season, five stations showed negative trends. For the first half of the twentieth century (the monsoon season), there appeared positive trends in Baster and Dantewada stations. In the post-monsoon season, Koriya and Surguja also showed positive trends. Negative trends were found at two stations (Bilaspur and Dantewada) in the winter season and five stations in the summer season. In the case of late 1900s, all the temperature series exhibited a positive estimate of the Sen's slope estimator for the post-monsoon season. Eleven out of 16 stations indicated a positive trend in the monsoon season. In the summer season, one station indicated no trend and two stations demonstrated a positive trend. In the winter season, one station indicated no trend and four stations demonstrated a positive trend. The range of the positive trend magnitudes was 0.005–0.026 between Champa and Surguja for the post-monsoon seasons.

It is known that temperature is much less noisy field than precipitation. Because of this, we may speculate that the temperature trend distributions shown in Figs. 4, 5, 6, 7 and 8 did not show very busy patterns; that is to say, clusters indicating non-significant/significant trends reflect a harmony with elevation and district average temperature. For example, stations with higher elevations, which are located in the northern districts, behaved same as seen in Fig. 5. Although it is a good practice to strive explaining the physical reasoning's behind the trend-type behaviors in a surface climate variable, it is a difficult task as focusing on factors other than atmospheric ones because knowledge on specific local topographic and climate variability plays an important role to understand the actual reasoning's.

5 Impacts of climate change in the Chhattisgarh State

A number of noticeable impacts of climate change have been recently observed in the Chhattisgarh State in such a way that summers (April to June) nowadays become hotter and heavy rainfall in short period sometimes causes water logging and landslides as opposed to scarce rainfall in dry season does drought. The state economy has been consequently punched heavily by continuous spells of drought in many years, particularly in the Raipur, Bilaspur and Jagdalpur districts. Droughts

Table 7 Nutrient losses due to burning of residues in rice-growing areas in Chhattisgarh State

Nutrient	Nutrient losses in Chhattisgarh State (except Sarguja District)			
	Concentration in stubble (g/kg)	% lost in burn	Loss (kg/ha)	Total loss from 2.00 Mt
C	398	99	2400	786.00
N	6.1	89	35	11.80
P	2.2	22	3.3	1.09
K	16.1	21	19	7.01
S	0.69	59	2.6	0.91

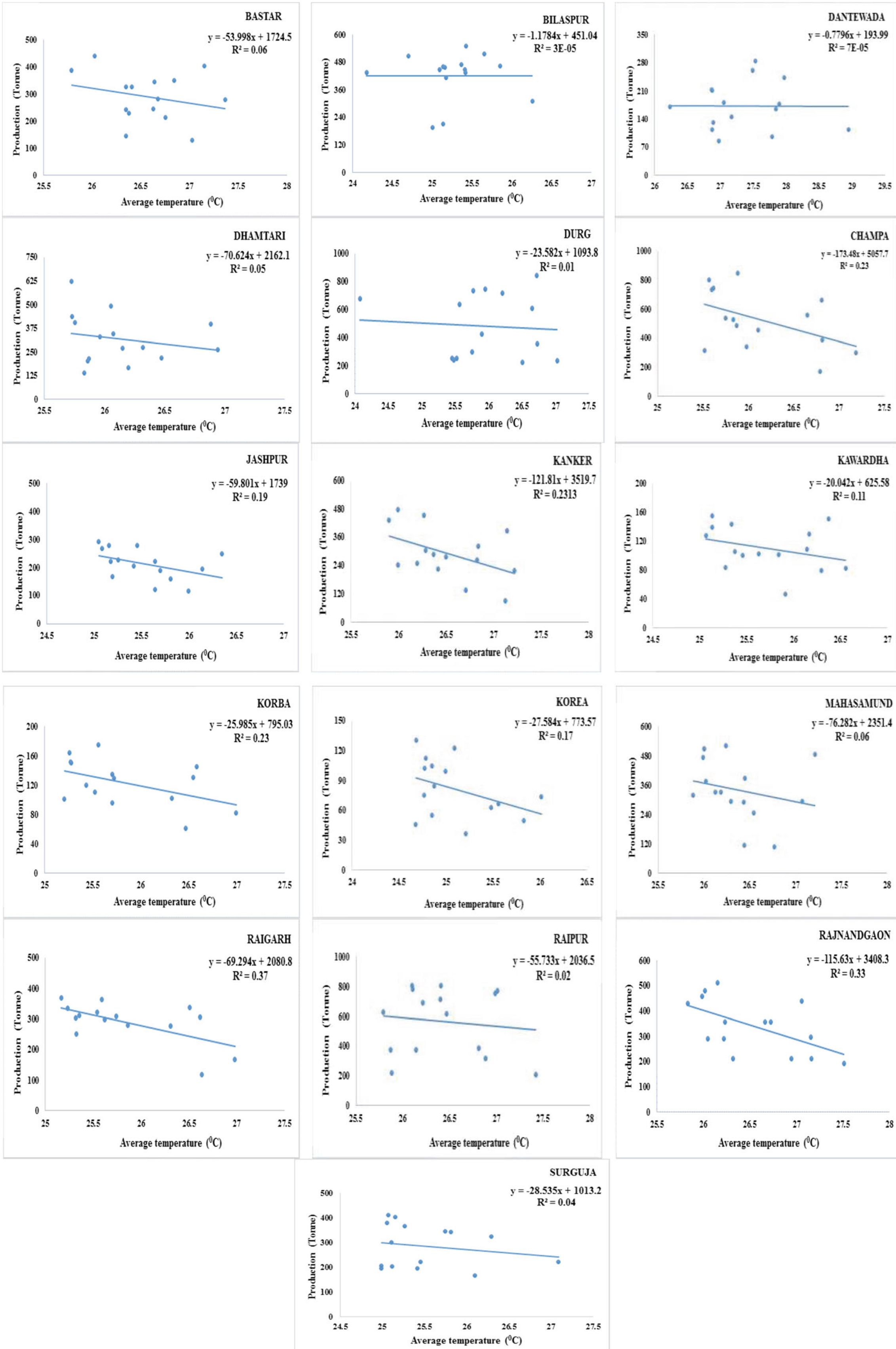


Fig. 10 Linear regression analysis between average temperature (°C) and rice production (tonne/year) during 2000–2014 period

in these districts reduced river flows and dried up irrigation canals, being an undesirable cause for the killing of fishes and other aquatic organisms. These consequences reduce both fishing and tourism. On the other hand, flooding events emerge as the most prevalent disaster along Shivnath River (the longest tributary of Mahanadi River) in Rajnandgoan District. It is a well-known fact that kids, female and elderly people are more vulnerable against such severe environmental conditions over the Chhattisgarh state. A rise in temperature at Raipur and Bilaspur regions can possibly alter original non-malarial regions to territories with regular pandemics. Thus, residents will be exposed to the infection, which is destructive to human life. Chhattisgarh is a tropical region hence impact of temperature show vastly for crop production. In the light of above, the impacts on agricultural crop (paddy) has been presented below.

5.1 Impacts on agricultural crops

Rice is one of the most common crops in the Chhattisgarh State, which is also known as "Rice Bowl of Central India." In addition to the aforementioned drought and flood consequences, higher night-time temperatures affecting pollination and invasive species, climate has great impacts on the state's agriculture in numerous ways, like changes in rainfall pattern, average temperature and deviations in new pests and weeds and disease. The agriculture impacts radiative and non-radiative forcing agents that can have direct or indirect effects on the climate (IPCC 2007). In the Jajgir Champa District, the greenhouse gas emission from agriculture areas are high because of huge number of cattle and improper manure supervision, inappropriate use of agro-chemicals and mismanagement of the farm land. Food security is a big challenge in the Jajgir Champa District. In the Chhattisgarh State, the burning of stubbles mainly occurs during summer season (April to May), resulting in significant loss of soil nutrients and fertility in both rice and winter cereal residues. The nutrient losses during the burning of rice in Chhattisgarh are described in Table 7. Burning of crop stubble (rice and wheat) releases very toxic gases to the environment. Ambade (2012) estimated that a process of burning one ton of rice and wheat stubble releases 3.5 kg of course particulate matter (PM_{10}), 2.3 ppm of CO_2 and 215 kg of most toxic ash.

The mean annual temperature and rice production trends based on the linear regression analysis are shown in Fig. 10. As a result of an overall inspection, a decreasing trend has been observed during the period 2000–2014. Our study showed that the rice can grow only within certain temperature limits. A suggested temperature limit for the germination of rice seed is between 11 °C and 35 °C; this varies for each rice species. In Chhattisgarh State, rice production is dependent on temperature as its growth is proportional to the rate of photosynthesis. While higher temperatures affect photosynthetic rate adversely, the rate of photosynthesis rises with increasing temperature from 5° to 37 °C beyond which there is a rapid fall. Between these limits, the rate of photosynthesis becomes twice for every 10 °C increase in temperature. Furthermore, rice production and the rate of respiration increases with increasing temperature up to a certain level, but the respiration rate shows marked decrease beyond the optimum limit. A rise in temperature results in huge reduction in yield of agronomic crops. Sustaining the rice production under changing climate is a key challenge. Consequently, adaptation measures are requisite to reduce the climate vulnerabilities. The adverse effect of climate change can be alleviated by developing heat tolerant cultivars and some modification in current production tools (Song et al. 2014).

At last, an independent study will be interesting somehow to relate the detected temperature trends with respect to relevant large scale atmospheric oscillations (e.g., MJO) prevailing around India. For example, Şarlak et al. (2009) showed how strongly critical drought durations of Göksu River affected by the NAO. Such efforts might help understand the trends in a physical sense.

6 Conclusions

In this study, we analyzed the temporal trend and variability in annual and seasonal temperature at 16 stations located in the Chhattisgarh State, India. A group of the Mann-Kendall tests (MK1/MK2/MK3/MK4) and the Sen's slope estimator were applied to estimate the trend significance and magnitude, respectively, while the Mann-Whitney-Pettitt test was used for the identification of possible break points in the temperature series over the long-term period of 116 years. Moreover, the spatial variations of temperature at the annual and seasonal scales were determined following the IDW technique using ArcGIS 10. Our results showed that annual and seasonal temperature increased during the period 1901–2016 in the Chhattisgarh State. The most likely year of change in temperature series was found as 1950. There were decreasing trends at some stations in early 1900s (the period 1901–1950), which reversed in late 1900s (the period 1951–2016). In conclusion, we aimed by this analysis to support the decision-making processes of agricultural and irrigation managers and to act a significant role in management of water resources in the basin.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Appendix

Trend analysis using MK (MK1/MK2/MK3/MK4) tests

Trend analysis based on MK1 test

The following procedure was followed to identify trend in the time series temperature: in the expectation that the time series will be autonomous, the Mann-Kendall value $\mathcal{S}$ will be described as

$$\mathcal{S} = \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} \text{sign}\left(y_j - y_i\right) \quad (4)$$

where y_i, y_j and m are $i^{\text{th}}$and j^{th}terms sequential data and sample size respectively and

$$\text{sign}\left(y_j - y_i\right) = \begin{cases} -1, \text{if } y_j - y_i < 1 \\ 0, \text{if } y_j - y_i = 0 \\ 1, \text{if } y_j - y_i > 1 \end{cases} \quad (5)$$

The statistic $\mathcal{S}$ is generally Gaussian when $m = 18$ with the variance Var($\mathcal{S}$) and mean $\mathcal{E}(\mathcal{S})$ of the statistic $\mathcal{S}$ expressed as

$$\mathcal{E}(\mathcal{S}) = 0, Var(\mathcal{S}) = \frac{(m-1)m(2m+5)}{18} \quad (6)$$

However, if there are ties in the data set, the adjusted articulation for Var($\mathcal{S}$) will be

$$\text{Var}(\mathcal{S}) = \frac{\left\{(m-1)m(2m+5) - \sum_{p=1}^{q} \left(t_p - 1\right) t_p \left(2t_p + 5\right)\right\}}{18} \quad (7)$$

The variables q and t_p in Eq. (7) denote the number of tied groups and data values in the p-th group, individually. The institutionalized statistic ($\mathcal{Z}$) for one- followed trial of the statistic $\mathcal{S}$ is

$$\mathcal{Z}_{mk} = \begin{cases} \frac{S+1}{\sqrt{\text{Var}(S)}}, \text{if } \mathcal{S} < 0 \\ 0, \text{if } \mathcal{S} = 0 \\ \frac{\mathcal{S}-1}{\sqrt{\text{Var}(\mathcal{S})}}, \text{if } \mathcal{S} > 0 \end{cases} \quad (8)$$

The trend is increasing for a positive value of $\mathcal{Z}_{mk}$ and decreasing for a negative value of it.

Trend analysis based on MK2 test

The effect of serial correlation on the MK test was removed by eliminating from the temperature time sequence the lag-1 serial correlation section before using the MK test for trend analysis. This is called the trend free pre-whitening (TFPW) treatment. Afterwards, trends were identified using the MK test in the remaining (or pre-whitened) sequence. Steps 1 through 4 used the MK2 to analyze trends:

1. The new time series suggested by Kumar et al. (2009) was acquired as

$$y_i' = y_i - (\beta \times i) \quad (9)$$

   where, β = magnitude of slope.

2. After calculating the r_1 for y_i' time data set, the residual series was determined as

$$x_i' = y_i' - r_1 \times y_{i-1}' \quad (10)$$

3. The estimation of $(\beta \times i)$ was added again to the remaining data set as taken after

$$x_i = x_i' + (\beta \times i) \quad (11)$$

4. MK1 was used for trend analysis of x_i series.

Trend analysis based on MK3 test

In this technique, an improved variance of $\mathcal{S}$, assigned as Var($\mathcal{S}$)*, was utilized to remove the impact of every critical coefficients of autocorrelation from a data set as follows (Hamed and Rao 1998):

$$\text{Var}(\mathcal{S})^* = \frac{m}{m^*} V(\mathcal{S}) \quad (12)$$

where $m^* =$ effective sample size. Hamed and Rao (1998) proposed the accompanying condition to directly calculate the $\frac{m}{m^*}$ ratio:

$$\frac{m}{m^*} = 1 + \frac{2}{m(m-1)(m-2)} \sum_{i=1}^{m-1} (m-i)(m-i-1)(m-i-2) r_i \quad (13)$$

where $m =$ actual number of perceptions and $r_i =$ lag$-i$ significant coefficient of autocorrelation of rank i of time series. After computing Var($\mathcal{S}$)* from Eq. (13), it is substituted for Var($\mathcal{S}$) in Eq. (12). Ultimately, the Mann-Kendall was tried for significance of trend contrasting it with limit levels 1.645 for 10%, 1.96 for 5% and 2.33 for 1% level of significance.

Trend analysis based on MK4 test

Kumar et al. (2009) explained the Mann-Kendall method's fourth version, which considers the Hurst coefficient ($\mathcal{H}$) of a series for long-term persistence. In order to apply the MK4, the calculation of the Hurst coefficient ($\mathcal{H}$) was carried out. The standard deviation and mean of ($\mathcal{H}$) are the function of m and can be calculated using the method described by Dinpashoh et al. 2014 (Hamed 2008). As suggested by Kumar et al. (2009), improved variance for the $\mathcal{S}$ static was calculated for significant ($\mathcal{H}$) values.

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