MAUSAM, **72**, 2 (April 2021), 473-489

631 : 551.577.3 : 551.581.22 (540.27)

Results of century analysis of rainfall and temperature trends and its impact on agriculture production in Bundelkhand region of Central India

A. GUPTA, C. P. SAWANT, K. V. R. RAO and A. SARANGI*

ICAR-Central Institute of Agricultural Engineering, Bhopal – 462 038, India

**ICAR-Indian Agricultural Research Institute, New Delhi – 110 012, India*

(*Received 5 June 2020, Accepted 18 November 2020*)

e mail : ajitagupta2012@gmail.com

सार – इस अध्ययन में भारत के बुंदेलखंड क्षेत्र की दीर्घकालिक वर्षा और तापमान के रुझान की जांच की गई है। वार्षिक, ऋतुनिष्ठ और मासिक वर्षा की प्रवृत्ति के साथ-साथ ऋतुनिष्ठ और वार्षिक न्यूनतम, अधिकतम और औसत तापमान की प्रवृत्ति का विश्लेषण 102 वर्ष (1901-2002) की मासिक डेटा श्रृंखला का उपयोग करके किया गया। प्रवृत्ति का पता लगाने और प्रवृत्ति परिमाण का निर्धारण करने के लिए मान-केंडल (MK) परीक्षण और सेन स्लोप पद्धति का अनुप्रयोग किया गया। मॉनसून के दौरान 1.049 मिमी / वर्ष से लेकर 0.497 मिमी / वर्ष तक के परिमाण के साथ महत्वपूर्ण रूप से कमी की प्रवृत्ति देखी गई। वार्षिक वर्षा में वृद्धि और कमी की प्रवृत्ति देखी गई। तापमान की प्रवृत्ति में बहुत उतार-चढ़ाव देखा गया। इस क्षेत्र की वर्षा और तापमान परिवर्तनशीलता के परिणामों के आधार पर वर्षा आधारित कृषि के लिए उपयुक्तता वर्गों का परिसीमन किया गया। 1991-2010 के दौरान धान, मटर और सोयाबीन की खेती, उत्पादन और उत्पादकता में नकारात्मक वृद्धि दर देखी गई। मॉनसून के दौरान वर्षा और तापमान की कमी की प्रवृत्ति और मॉनसूनोत्तर में वर्षा और तापमान में वृद्धि की प्रवृत्ति से क्षेत्र का कृषि उत्पादन प्रभावित हुआ है।

ABSTRACT. Long-term rainfall and temperature trends of Bundelkhand region of India were investigated in this study. The annual, seasonal and monthly rainfall trends as well as seasonal and annual minimum, maximum and mean temperature trends were analysed using monthly data series of 102 years (1901-2002). Mann-Kendall (MK) test and Sen's slope method were applied for trend detection and trend magnitudes determination. Significantly decreasing trends during monsoon were found with magnitude ranging from 1.049 mm/year to 0.497 mm/year. Both increasing and decreasing trends were found in the annual rainfall. Large fluctuations in temperature trends were observed. Based on the results of rainfall and temperature variability of the region, suitability classes for rain-fed agriculture were delineated. The negative growth rate was found in the cultivated area, production and productivity of paddy, peas and soybean during 1991-2010. Decreasing trends of rainfall and temperature during monsoon and increasing trends of rainfall and temperature in post-monsoon have been affected agricultural production of the region.

Key words – Bundelkhand, Mann-Kendall test, Sen's slope estimator, Rainfall, Temperature, Trend analysis.

1. Introduction

The visible impressions of climate change on our environment have led the scientific community to pay constant attention to analysing trends of climatic parameters and their possible repercussions. Climate change and its variability may badly disturb the agriculture economy of an agrarian country like India (Sinha *et al*., 1998; Goswami *et al*., 2006; Mall *et al*., 2007). Various variables such as rainfall, temperature, wind conditions, atmospheric pressure, relative humidity, etc. establish weather and climate of a place. The rainfall and temperatures are considered to be the two most important climatic parameters (Singh *et al.*, 2013) among all as these parameters play a crucial role in determining the environmental conditions of a specific location which alternatively affects agricultural productivity (Samdi, 2006; Kumar and Gautam, 2014). These two variables are also critical in hydrological studies for appropriate planning of conservation practices.

Rainfall of any region plays a significant role in the planning and management of irrigation projects and any quantitative and temporal changes in rainfall distribution will affect crop yield, productivity and cropping pattern (Kumar *et al*., 2010). Various studies have been performed in India to estimate the effect of climate change on the water resources of country (Lal, 2001; Gosain *et al*., 2006; Mall *et al*., 2007) as well as on crop yield (Kalra *et al*., 2008; Prasanna *et al*., 2014).

Nicholls *et al*., 1996 have been reported that global average precipitation has increased about 1% during 20th century. However, regional variations at different spatial and temporal can be much more and that need to be evaluated (Brekke *et al*., 2009; Vallebona *et al*., 2015).

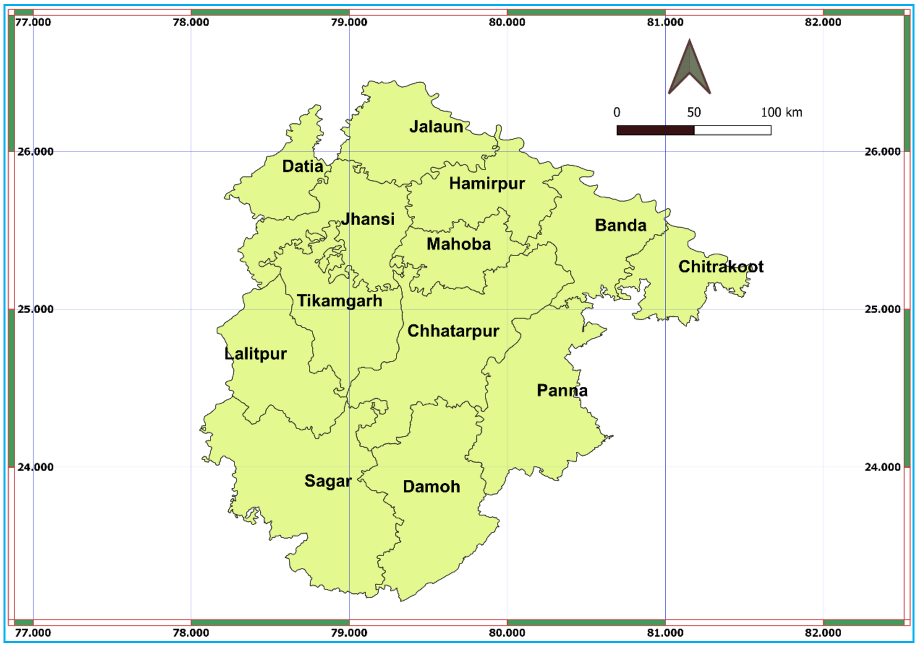


Fig. 1. Map of Bundelkhand region of Central India

India receives about 80% of the rainfall during the four months (June-September) of monsoon season with the high amount of Spatio-temporal variations in rainfall magnitude and its intensity over the country (Kumar *et al*., 2010). Rainfall concentration over these four months results in creating water scarcity in the country during the non-monsoon period. Various work has been done in the past to determine rainfall trends at regional as well as country scales (Jagannathan and Parthasarathy, 1973; Kripalani *et al.*, 2003; Guhathakurta and Rajeevan, 2008; Kumar *et al*., 2010) in India. Although no specific trend in the annual and monsoon rainfall is reported at the national scale, however, significant rainfall trends have been reported on a regional scale (Rupa Kumar *et al*., 1992; Dash *et al*., 2007). Temperature impact several climatic factors including rainfall and as a result of this, other climatic variables get affected (Jain and Kumar, 2012). The average global temperature has augmented about 0.85 °C from 1880 to 2012 as reported in the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2014). Thus, decreasing precipitation amount with increasing temperatures have contributed to frequent drought occurrence in many regions (Mondal *et al*., 2014). An increase in temperature over India at national and regional scale has been reported by several authors (Arora *et al*., 2005; Dash *et al*., 2007; Sonali and Nagesh, 2013).

All the above-cited studies deal with the individual analysis long-term trend of rainfall and temperature parameters for a region or entire India. However, information and analysis of seasonal and annual trends of rainfall and temperature together for entire India at the regional scale are very few and limited.

Bundelkhand region has always accepted as one of the most drought vulnerable regions of the country but the frequency of drought occurrence and its intensity has increased over some past decades. This region experiences acute scarcity of water for crop production and frequently faces drought and deficit rainfall (Rai, 2007; Sharma, 2008; Thomas *et al*., 2015; TERI, 2018). Several researchers have made attempts to analyse rainfall trends over Bundelkhand region using long term rainfall data (Rai *et al*., 2012; Jana *et al*., 2017; Ahmed *et al*., 2019). But some of these studies are based on the rainfall data analysis of a few stations with very low temporal resolution. However, no detailed analysis of rainfall along with temperature data and its trend over Bundelkhand region has been made so far. A detailed analysis of rainfall and temperature data of Bundelkhand region would facilitate decision making on agriculture and water resources planning and management at regional level. Hence, the present study aimed to provide a comprehensive investigation to detect the trends in the annual, seasonal and monthly time series of rainfall as well as annual and seasonal mean, minimum and maximum temperature of all districts of Bundelkhand during the last century. Simultaneously, to assess the impact of climate change on agriculture production of the region were also studied in this work.

TABLE 1

List of station name, latitude, longitude, elevation and total area

Station	Latitude	Longitude	Elevation (m)	Total Area (ha)
Jhansi	25.4484° N	78.5685° E	285	5,01,329
Hamirpur	25.7913° N	80.0088° E	80	3,90,178
Mahoba	25.2921° N	79.8724° E	214	3,27,429
Banda	25.4926° N	80.3380° E	123	4,38,767
Chitrakoot	25.1788° N	80.8655° E	137	3,38,897
Jalaun	26.1459° N	79.3297° E	144	4,54,434
Lalitpur	24.6879° N	79.5810° E	428	5,07,500
Datia	25.6653° N	78.4609° E	420	2,95,874
Chhatarpur	24.9164° N	78.5812° E	305	8,63,036
Sagar	23.8348° N	78.7378° E	427	10,22,759
Damoh	23.8381° N	79.4422° E	595	7,02,924
Panna	24.7180° N	80.1819° E	410	7,02,924
Tikamgarh	24.7456° N	78.8321° E	349	5,04,002

2. Materials and method

2.1. *Study area*

The Bundelkhand region situated in the north-central part of India, the Indo-Gangetic plain at the northern side and undulating Vindhyan mountain range at the northwest to the southern side of the region forms its boundary. The region stretches across thirteen districts: seven in Uttar Pradesh - Banda, Chitrakoot, Hamirpur, Jalaun, Jhansi, Lalitpur and, Mahoba and six in Madhya Pradesh - Damoh, Datia, Chattarpur, Tikamgarh, Panna and Sagar. It covers a total geographical area of 7.08 million hectares (mha) of the country. Bundelkhand region stretches between 24° 11' and 26° 27' N latitude and 78° 17' and 81° 34' E longitudes with an average altitude of 250-300 m above mean sea level (Fig. 1). Details of all the stations studied are provided in Table 1. The soil of the region is black and red-yellow mix soils that are poor in water holding capacity and organic nutrients. The climate of the region is hot and sub-humid (dry) type. This region has semi-arid geography, which is significantly sensitive to climate change due to its internal weak conditions. Around 60% of manpower of this region are involved in agricultural activities as farmers or labourers, this shows a higher dependence on agricultural work compared to other region of rural India. The average normal rainfall of Bundelkhand is about 850 mm. About 70% of rainfall is received during south-west monsoon between July to September month. Almost entire crop production is under rain-fed condition. Managing the agriculture sustainability is one of the major task, due to change in climatic pattern, increasing cost of production, loss of soil fertility owing to the largely rain-fed nature of agriculture in this region.

2.2. *Data used*

Monthly rainfall and temperature data from 1901-2002 (one hundred and two years) of selected stations were downloaded from India Water Portal. (http://www.indiawaterportal.org/met_data/) for all 13 districts of Bundelkhand region. These climatic data are provided and uploaded by India Meteorological Department (IMD). Before uploading the data set, the IMD carries out quality and error checks works. Thus, these climatic series are considered one of the most reliable long term climatic data set of the country. To investigate the seasonal changes in the rainfall and temperature series, the whole year was bifurcated into four seasons as follow: winter (December-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November). Rainfall and temperature analysis was made on seasonal and annual basis. However, monthly rainfall analysis was also done to see the behaviour of rainfall. While applying different tests, the same lengths of data set for each station were taken into the study.

2.3. *Rainfall and temperature characteristics*

The average, standard deviation and variability for monthly, seasonal and annual rainfall as well as for seasonal and annual temperatures were calculated for each district. Basic statistical properties such as mean values, coefficient of variation (CV) and standard deviation of rainfall and temperature data sets are given in Tables 2&3.

2.4. *Trend analysis*

The non-parametric Mann-Kendall test is used to assess any potential trend present in the time series (Mann, 1945; Kendall, 1975). This method has been widely used by many authors for various hydro-meteorological parameters (Douglas *et al*., 2000; Burn *et al*., 2004; Arora *et al*., 2005; Jhajharia and Singh, 2010). Unlike parametric tests, this method identifies the presence of a trend in the data series without making any assumption about distribution properties of data series, therefore less subjective to the presence of outliers. The null hypothesis of the test assumes as no trend is present in the time series, whereas the alternative hypothesis defines that a trend is present in the underlying data series.

The test statistic, S, is presented as follow (Eqn. 1):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}\left(y_j - y_i\right) \qquad (1)$$

where, y_i and y_j are the data value at time i and j, respectively, n is data set length.

where,

$$\text{sign}(y_j - y_i) = 1 \ \text{if} \ (y_j - y_i) > 0;$$

$$\text{sign}(y_j - y_i) = 0 \ \text{if} \ (y_j - y_i) = 0;$$

$$\text{sign}(y_j - y_i) = -1 \ \text{if} \ (y_j - y_i) < 0;$$

The S statistic is normally distributed when data set length $n \geq 8$, mean equals to zero and variance as (Eqn. 2).

$$\sigma^2 = n(n-1)(2n+5)/18 \quad (2)$$

If the number of values for a time series is greater than or equal to 10, then Mann-Kendall test is performed using the Z statistic (normal approximation). Thus, the standardized test statistic ZMK is computed by (Eqn. 3).

$$\text{ZMK} = \frac{S-1}{\sigma} \ \text{if} \ S > 0 \quad (3)$$

$$\text{ZMK} = 0 \ \text{if} \ S = 0$$

$$\text{ZMK} = \frac{S+1}{\sigma} \ \text{if} \ S < 0$$

which follows a standard normal distribution. Positive values of ZMK suggest increasing trend while negative values of ZMK indicate downward trend.

2.5. *Sen's slope estimator*

The Sen's slope test is used for determine the trend magnitude (Sen, 1968). This method is also a nonparametric technique. A linear model is used to calculate the slope change in the test statistics and variance of the residuals must be constant in time. The Sen's model is given as (Eqn. 4):

$$f(t) = \text{Q}t + \text{B} \quad (4)$$

where, Q indicates the slope and B indicates constant of function.

For calculating model parameters B and Q, the slope between two observations is calculated as (Eqn. 5):

$$Q_i = \frac{x_j - x_k}{j-k}, \text{ where } j > k \quad (5)$$

where, x_j and x_k represent data values at time j and k ($j > k$) respectively. Therefore, the total number of slopes, N, for n number of data point is estimated as:

$$N = \frac{n(n-1)}{2} \quad (6)$$

The slope (Q) of Sen's test is the median of Q_i slopes.

$$Q = \text{median}[Q_i]_{i=1}^{N} \quad (7)$$

The intersect B is the median of n values of difference x_i - Q_{ti} is

$$\text{B} = \text{median}[x_i - Q_{ti}]_{i=1}^{n} \quad (8)$$

2.6. *Cluster analysis of annual rainfall and temperature series*

k - means cluster analysis (Hartigan, 1975) was done on annual rainfall and temperature series by making the group of 13 rainfall stations into clusters based on similar rainfall region so that variation of the data within the group can be minimized and between-group can be maximized. This is non-hierarchical clustering technique, more robust and flexible then the other clustering algorithms. In this method, whole dataset is divided into k mutually exclusive cluster classes and each station allotted to that cluster having closest centre. The clusters have been achieved by decreasing the squared error differences (ϕ) between the selected variables and corresponding centroid of cluster (IMSL, 1997).

2.7. *Impact of climate variability on crop production of the region*

To assess the impact of climate variability on agriculture production of the region, annual data of some major *kharif* crop of each district were collected from the state (http://updes.up.nic.in) and central agriculture departments (www.agricoop.nic.in). The compound annual growth rate (CAGR) of *Kharif* crop area, yield & productivity of Bundelkhand region of Uttar Pradesh was calculated using the data from 1990-2010. Based on the results of rainfall and temperature variability of the region, suitability class for rain-fed agriculture was delineated for the region.

3. Results and discussion

3.1. *Statistical analysis of rainfall and temperature*

The standardised annual and seasonal series were prepared using 102 years of rainfall and temperature data.

TABLE 2

Statistical analysis of annual and seasonal rainfall (mm)

Station		Winter	Pre-monsoon	monsoon	Post-monsoon	Annual Average
Jhansi	Mean	11.31	16.09	906.88	33.91	989.55
	SD	8.33	11.01	213.63	33.10	219.58
	CV (%)	73.65	68.43	23.56	97.61	22.19
Hamirpur	Mean	36.57	15.34	904.60	35.79	992.29
	SD	21.37	11.18	207.80	33.34	212.37
	CV (%)	58.44	72.88	22.97	93.15	21.40
Mahoba	Mean	40.84	17.28	969.79	38.57	1066.49
	SD	24.92	12.25	215.88	36.75	223.24
	CV (%)	61.02	70.89	22.26	95.28	20.93
Banda	Mean	42.57	20.29	973.12	37.38	1073.36
	SD	27.22	17.18	232.51	36.19	237.27
	CV (%)	63.94	84.67	23.89	96.82	22.11
Chitrakoot	Mean	50.05	24.79	975.13	21.53	1088.21
	SD	34.07	22.34	248.78	27.41	253.93
	CV (%)	68.07	90.12	25.51	127.31	23.33
Jalaun	Mean	30.55	15.69	824.96	30.88	902.08
	SD	17.30	11.00	198.36	29.07	202.15
	CV (%)	56.63	70.11	24.04	94.14	22.41
Chhatarpur	Mean	44.19	19.08	1036.27	42.50	1142.04
	SD	29.18	14.51	231.60	41.16	242.24
	CV (%)	66.03	76.05	22.35	96.85	21.21
Datia	Mean	25.46	16.11	854.21	30.37	926.15
	SD	15.38	10.96	214.19	30.13	218.93
	CV (%)	60.41	68.03	25.07	99.21	23.64
Lalitpur	Mean	34.19	16.31	1004.58	40.24	1095.31
	SD	24.16	11.55	247.55	42.97	258.66
	CV (%)	70.66	70.82	24.64	106.78	23.62
Sagar	Mean	36.72	17.86	1091.19	44.89	1190.65
	SD	29.14	12.81	274.80	48.70	288.73
	CV (%)	79.36	71.72	25.18	108.49	24.25
Damoh	Mean	45.24	24.39	1081.28	48.67	1199.59
	SD	31.86	16.83	228.98	45.10	244.33
	CV (%)	70.42	69.00	21.18	92.66	20.37
Panna	Mean	51.46	25.68	1070.24	40.35	1187.73
	SD	34.14	19.03	229.52	36.91	239.90
	CV (%)	66.34	74.10	21.45	91.47	20.20
Tikamgarh	Mean	37.08	16.39	984.85	39.97	1078.29
	SD	24.12	11.76	232.20	40.47	241.92
	CV (%)	65.05	71.75	23.58	101.25	22.44

TABLE 3

Statistical analysis of mean annual, mean annual maximum and mean annual minimum temperature (°C)

Statistic	Average			Maximum			Minimum		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
Banda	25.13	0.41	1.63	31.98	0.42	1.31	18.32	0.41	2.24
Chhatarpur	25.14	0.41	1.63	31.77	0.42	1.32	18.54	0.41	2.21
Chitrkoot	24.97	0.4	1.60	31.62	0.42	1.33	18.36	0.41	2.23
Damoh	25.29	0.4	1.58	31.64	0.41	1.30	18.98	0.41	2.16
Datia	25.3	0.43	1.70	32.04	0.44	1.37	18.59	0.43	2.31
Hamirpur	25.3	0.41	1.62	32.29	0.42	1.30	18.34	0.41	2.24
Jalaun	25.42	0.41	1.61	32.35	0.43	1.33	18.52	0.42	2.27
Jhansi	25.25	0.42	1.66	32.01	0.43	1.34	18.52	0.42	2.27
Lalitpur	25.28	0.44	1.74	31.78	0.44	1.38	18.83	0.44	2.34
Mahoba	25.03	0.41	1.64	31.88	0.42	1.32	18.21	0.41	2.25
Panna	25.11	0.41	1.63	31.71	0.42	1.32	18.54	0.41	2.21
Sagar	25.27	0.44	1.74	31.61	0.44	1.39	18.96	0.44	2.32
Tikamgarh	25.27	0.42	1.66	31.87	0.43	1.35	18.71	0.42	2.24

The statistical analysis of rainfall and temperature data of all thirteen districts is presented in Tables 2&3. From these tables, it is observed that Damoh received the highest annual average rainfall whereas Sagar received the highest monsoon season rainfall. Jalaun district received the lowest annual average and seasonal rainfall followed by Datia. The annual average rainfall varies from 1199.59 mm for Damoh to 902.08 mm for Jalaun. Looking at the rainfall quantity in respective seasons (Table 2), it is obvious that all the stations receive the maximum rainfall in monsoon season and minimum rainfall in pre-monsoon season followed by post-monsoon season. The highest coefficient of variation (CV) for annual rainfall (24.25%) was obtained for Sagar district while the lowest coefficient of variation (20.20%) was obtained for Panna district. CV values were quite high for pre-monsoon, post-monsoon and winter rainfall. There is less variation in the annual average mean, maximum and minimum temperature of all stations. However, the highest mean (25.42 °C) and maximum (32.35 °C) temperature were observed for Jalaun district, whereas, highest minimum temperature (18.98 °C) for Damoh district. However, the lowest mean (24.97 °C), Maximum (31.61 °C) and Minimum (18.21 °C) temperature were observed in Chitrakoot, Sagar and Mahoba districts, respectively.

3.2. *Rainfall trends and its magnitude*

3.2.1. *Monthly rainfall trend*

To inspect whether trends are showing increasing, decreasing pattern, or otherwise no trend, The MK test was applied to the rainfall series of different months and also the trend magnitude determined by Sen Estimator (Tables 4).

For January month, all stations have shown an increasing trend, but the significantly increasing trend was found at Chitrikoot station with a magnitude of 0.094 mm/year.

For February, a consistent result with a decreasing trend was also observed with all stations except Lalitpur station, where no trend was observed. In the rainfall analysis of March month, three stations namely Damoh, Chitrakoot and Panna exhibited a downward trend. Whereas other stations show upward trend, however the magnitude of trends was insignificant. Similarly, for April month, an increasing trend was discovered at all stations except for Panna and Damoh station. However, the magnitude of trends was found to be insignificant. A remarkable result was found for the May month rainfall series. MK test revealed a significant increasing trend for all stations with the magnitude varying from 0.015 mm/year (Chitrakoot) to 0.037 mm/year (Datia). Similarly, for June month increasing rainfall trend was found in all stations. However, a significantly increasing trend was reported in the rainfall time series of Banda (0.280 mm/year) and Chitrakoot (0.354 mm/year) stations.

In the rainfall time series of July month, an agriculturally important month of this region. Decreasing trends were found at all stations with magnitude ranging from 1.049 mm/year to 0.497 mm/year. It was also shown

TABLE 4

Sen estimator of slope (mm/year) for monthly rainfall

Months	January	February	March	April	May	June	July	August	September	October	November	December
Jhansi	0.005	-0.003	0.003	0.000	**0.032***	0.242	**-0.819**$^{+}$	0.333	-0.094	0.038	0.00	0.00
Hamirpur	0.030	-0.004	0.000	0.003	**0.028***	0.270	-0.620	-0.188	0.039	0.042	0.00	0.00
Mahoba	0.032	-0.005	0.000	0.000	**0.028***	0.312	**-0.842**$^{+}$	-0.127	-0.115	0.039	0.00	0.00
Banda	0.072	-0.005	0.000	0.002	**0.021***	**0.280**$^{+}$	-0.765	-0.603	0.076	0.033	0.00	0.00
Chitrakoot	**0.094**$^{+}$	-0.011	0.000	0.005	**0.015**$^{+}$	**0.354**$^{+}$	-0.823	-0.804	0.085	0.028	0.00	0.00
Jalaun	0.004	-0.003	0.000	0.002	**0.034***	0.202	-0.497	0.114	0.115	0.039	0.00	0.00
Chhatarpur	0.040	-0.007	0.001	0.000	**0.027***	0.319	**-1.030***	-0.113	-0.221	0.047	0.00	0.00
Datia	0.000	0.000	0.005	0.002	**0.037***	0.170	-0.670	0.518	-0.049	**0.035**$^{+}$	0.00	0.00
Lalitpur	0.011	0.000	0.006	0.000	**0.030**$^{+}$	0.207	**-0.984**$^{+}$	0.582	-0.347	0.039	0.00	0.00
Sagar	0.017	-0.003	0.002	0.000	**0.025**$^{+}$	0.133	**-0.941**$^{+}$	0.600	-0.443	0.044	0.00	0.00
Damoh	0.028	-0.006	0.000	-0.001	**0.026***	0.220	**-1.014***	0.207	-0.331	0.065	0.00	0.00
Panna	0.053	-0.009	0.000	0.000	**0.027**$^{+}$	0.331	**-1.049***	-0.340	-0.178	0.054	0.00	0.00
Tikamgarh	0.011	-0.003	0.001	0.000	**0.032***	0.261	**-1.005**$^{+}$	0.393	-0.209	0.041	0.00	0.00

*indicates trend at 0.05 level of significance and + indicates trend at 0.1 level of significance as per the Mann-Kendall test (+ for increasing and - for decreasing)

TABLE 5

Sen estimator of slope (mm/year) for annual and seasonal rainfall

Months	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Jhansi	0.006	**0.072***	0.134	0.079	0.317
Hamirpur	0.025	0.059	0.094	0.131	0.074
Mahoba	0.055	0.055	0.033	0.102	0.102
Banda	0.068	0.046	-0.404	0.101	-0.445
Chitrakoot	0.092	0.034	-0.928	0.003	-0.836
Jalaun	-0.003	**0.080***	0.200	**0.113**$^{+}$	0.268
Chhatarpur	0.090	0.041	-0.193	0.083	-0.215
Datia	0.005	**0.028***	0.057	0.033	0.034
Lalitpur	0.060	0.062	-0.194	0.050	0.012
Sagar	0.074	0.035	-0.421	0.048	-0.218
Damoh	0.077	0.020	-0.398	0.058	-0.352
Panna	0.091	0.027	-0.470	0.083	-0.487
Tikamgarh	0.047	0.055	0.043	0.070	0.080

*indicates trend at 0.05 level of significance and $^{+}$ indicates trend at 0.1 level of significance as per the Mann-Kendall test (+ for increasing and - for decreasing).

that most of the stations have significantly decreasing trends in this month except Hamirpur, Banda, Chitrakoot, Jalaun and Datia. In the monthly rainfall time series of August month, six stations (Hamirpur, Banda, Chitrakoot, Mahoba, Chhatarpur and Panna) show a decreasing trend whereas other stations exhibit an increasing trend. However, both trends were non-significant. Similarly, in September month, all most all stations show a non-significant decreasing trend except Hamirpur Chitrakoot, Banda and Jalaun stations, where the positive trend was observed. In October month all stations show increasing rainfall trend, but significant trend was found in Datia station with the magnitude of 0.035 mm/year. In November month all most all months show a decreasing

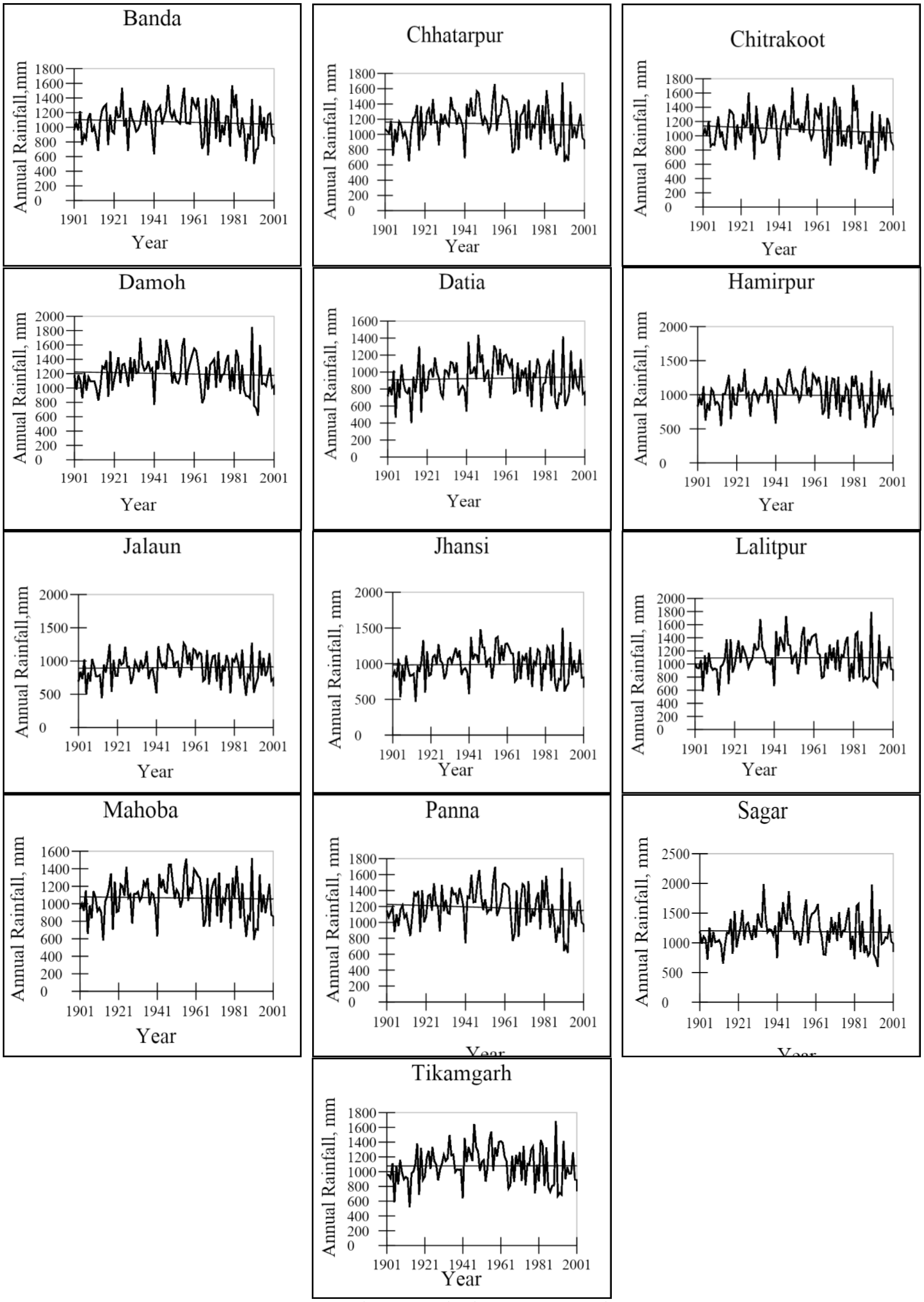


Fig. 2. Temporal variation of annual rainfall for all 13 districts of Bundelkhand Region

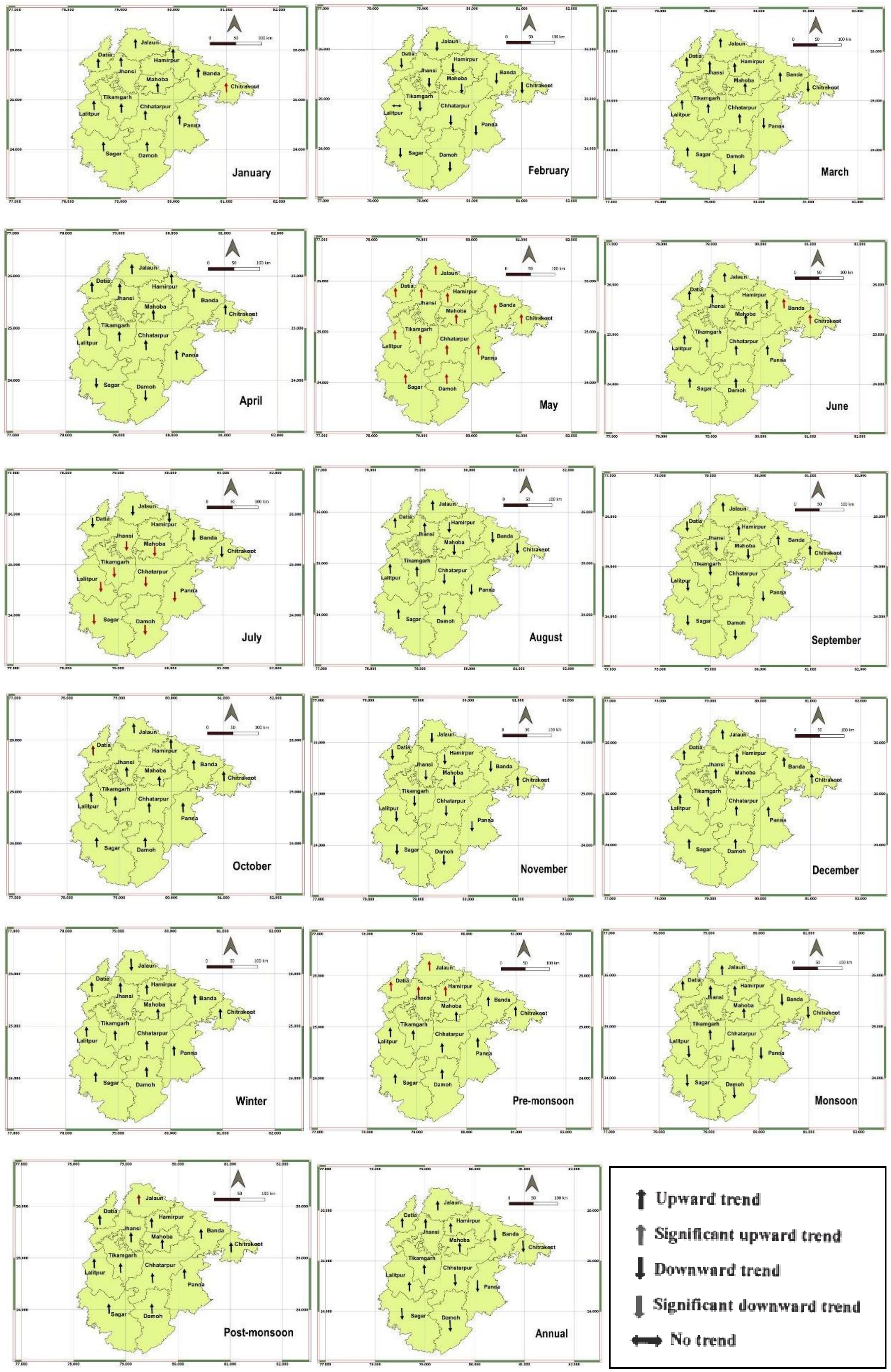


Fig. 3. Observed trends for respective monthly, seasonal and annual rainfall of Bundelkhand region

trend whereas in December month an increasing trend was observed for all stations, however, the results were non-significant.

On the month basis, all stations have shown only increasing trends in January, May, June, October and December. However, in February, July and November months all most all stations show a decreasing trend. September and October show the moderate number of stations (six and nine stations, respectively) with a decreasing trend; while March and April have only two and three stations, respectively with a decreasing trend of rainfall.

In terms of station basis, Damoh and Panna stations show the maximum months (8) with varying trends of rainfall throughout the year. Whereas, least decreasing trend (4 months) is found in Jhansi, Hamirpur, Jalaun, Datia, Lalitpur and Tikamgarh stations. The other stations show the moderate number of months in the range of 5-7 months with a decreasing trend.

3.2.2. *Seasonal rainfall trend*

To examine the rainfall changes for different seasons, rainfall analysis of four seasons: winter (December-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November) was done. Seasonal trends of rainfall and their magnitude (mm/year) achieved by the Mann-Kendall test and Sen's slope estimator are given in Table 5 and Fig. 3. For winter season results of MK test have shown a non-significant increasing trend of rainfall. During the pre-monsoon season MK test showed an increasing trend in rainfall. However, significant increase was observed in Jhansi (0.072 mm/year), Hamirpur (0.059 mm/year), Jalaun (0.080 mm/year) and Datia (0.028 mm/year) stations. During monsoon season Jhansi, Hamirpur, Mahoba, Jalaun and Datia stations have shown an increasing trend, rest other stations exhibited decreasing rainfall trend. However, results were non- significant. In post-monsoon seasons all stations exhibited positive rainfall trends, however, result was significant in Jalaun district only.

It can be seen from the results that the monsoon season rainfall amount is reducing while it is increasing during the post-monsoon season. So, a shift of rainfall was observed, which is causing delayed in agricultural practices of the region during Kharif (monsoon) season. Thus, farmers of the region get a very short window between the harvesting of Kharif crop and sowing of Rabi season crop. Which makes them unable to manage crop residues after harvesting of Kharif crop and this ends up with residues burning as a solution.

3.2.3. *Annual rainfall trend*

The magnitude of annual rainfall trend for all stations, obtained by Sen's slope estimator is given in Table 5. The increasing as well as decreasing trends were found by the M-K tests in annual rainfall data (Figs. 2&3). However, all trends were non-significant at 95% and 99% confidence levels. An increasing trend was observed in seven stations (Jhansi, Hamirpur, Mahoba, Jalaun, Datia, Lalitpur and Tikamgarh), while the other six stations exibited a decreasing trend in the amount of annual rainfall. Similar results in the annual rainfall trend of Bundelkhand region have been reported by Jana *et al*., 2017.

The results of the rainfall analysis of Bundelkhand matches the results of the rainfall study of the same region as reported by several authors at different spatial and temporal scales.

3.3. *Seasonal and annual temperature trend of Bundelkhand*

The trend magnitudes with their significance are given in Fig. 5 and Table 6 for annual as well as seasonal temperature series (minimum, mean and maximum). Temporal variation of minimum, mean and maximum temperature for annual and seasonal time series is presented in Fig. 4 for all districts of study area.

3.3.1. *Trend of minimum temperature*

As observed in Table 6, increasing trends were found in all stations of Bundelkhand in the minimum average temperature. On the annual basis minimum average temperature illustrates an increase in the temperature everywhere at the rate of 0.004 to 0.006 °C/year. However, the changes were non-significant. Increase in minimum temperature throughout the study area was observed during Winter (0.007 to 0.011 °C/year), pre-monsoon (0.004 to 0.006 °C/year) and post-monsoon season (0.010 to 0.015 °C/year) except for Jhansi district, which showed decreasing trend (0.006 °C/year) during post-monsoon season, although results were non-significant. Monsoon season showed a significant decrease in minimum average temperature in Jhansi (0.005 °C/year), Hamirpur (0.005 °C/year) and Datia (0.005 °C/year) station of Bundelkhand and non-significant negative changes were observed in other stations (0.001 to 0.006 °C/year). A rise in the minimum temperature was observed during the pre-monsoon, post-monsoon, winter seasons as well as annually. However, the rates of increase were a non-significant, but maybe a concern which shows gradual increase in temperature of the areas. Mondal *et al*., 2014 also reported non-significant decreasing minimum temperature trend in monsoon season for central India.

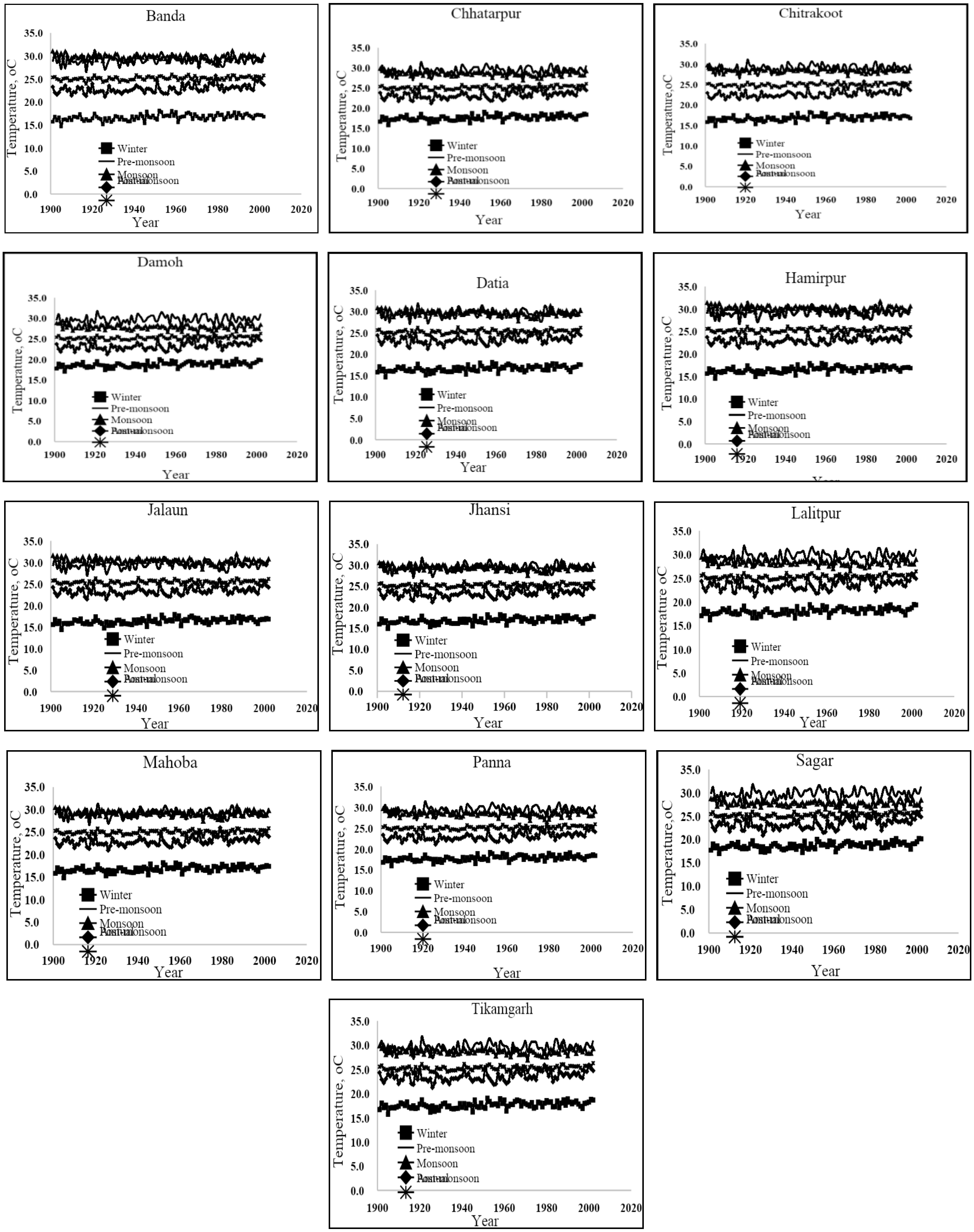


Fig. 4. Temporal variation in annual and seasonal mean temperature for all 13 districts of Bundelkhand Region

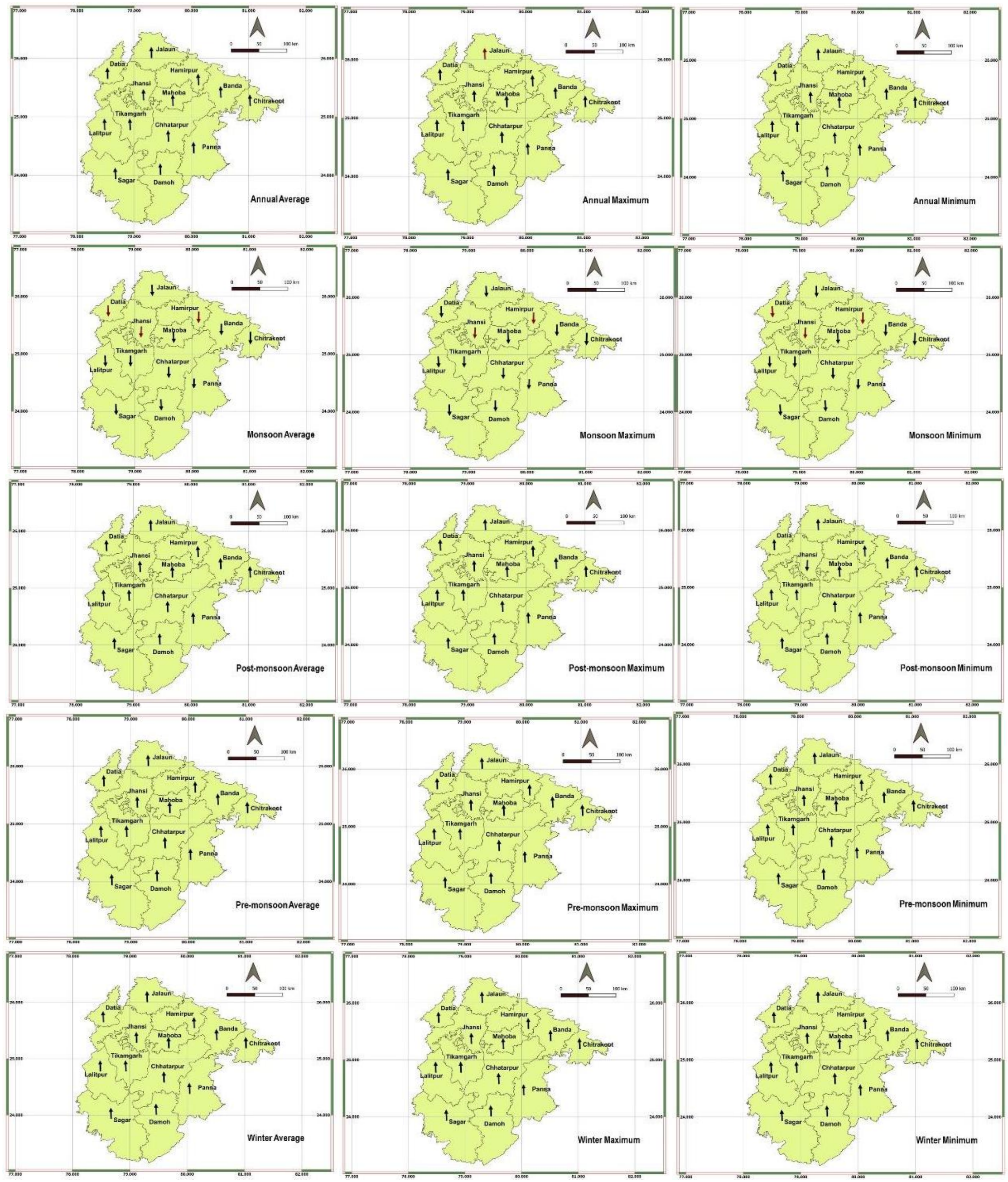


Fig. 5. Observed trends for annual and seasonal average, minimum and maximum temperature for Bundelkhand region (Notation of sign as describe in Fig. 3)

3.3.2. *Trend of mean temperature*

An increasing trend in mean temperature was observed all over the Bundelkhand region. Rise in the temperature trend was found during pre-monsoon (0.003-0.005 °C/year), post-monsoon (0.010-0.015 °C/year) and winter (0.009-0.010 °C/year) seasons. Annual mean temperature also showed an increase in temperature (0.004-0.006 °C/year) for all regions. In the monsoon season, a non-significant decrease in temperature (0.001 to 0.006 °C/year) was observed in most of the stations, whereas, significant decrease in mean temperature was found in the Jhansi (0.005 °C/year), Hamirpur (0.005 °C/year) and Datia (0.005 °C/year). Thus, the overall results show a rise in the mean temperature of Bundelkhand, except during the monsoon season.

TABLE 6

Sen estimator of slope (°C/year) for annual and seasonal temperature

Seasons	Average temperature					Maximum temperature					Minimum temperature				
	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Jhansi	0.010	0.005	**-0.005**	0.011	0.004	0.010	0.005	**-0.005**	0.011	0.004	0.010	0.005	**-0.005**	-0.006	0.005
Hamirpur	0.009	0.005	**-0.005**	0.012	0.004	0.009	0.005	**-0.005**	0.013	0.004	0.010	0.005	**-0.005**	0.012	0.005
Mahoba	0.010	0.005	-0.004	0.013	0.005	0.009	0.005	-0.004	0.014	0.005	0.010	0.005	-0.004	0.013	0.005
Banda	0.009	0.004	-0.004	0.014	0.005	0.009	0.004	-0.004	0.014	0.005	0.010	0.004	-0.004	0.013	0.005
Chitrakoot	0.010	0.003	-0.001	0.014	0.005	0.009	0.003	-0.002	0.014	0.005	0.007	0.004	-0.003	0.014	0.005
Jalaun	0.010	0.005	-0.006	0.010	0.004	0.009	0.004	-0.006	0.011	**0.003**	0.010	0.005	-0.006	0.010	0.004
Chhatarpur	0.010	0.005	-0.002	0.013	0.005	0.010	0.004	-0.003	0.014	0.005	0.010	0.005	-0.003	0.013	0.006
Datia	0.010	0.005	**-0.005**	0.010	0.004	0.010	0.005	-0.005	0.010	0.004	0.010	0.005	**-0.005**	0.010	0.004
Lalitpur	0.010	0.006	-0.002	0.013	0.006	0.010	0.006	-0.002	0.013	0.006	0.011	0.006	-0.002	0.013	0.006
Sagar	0.010	0.005	-0.001	0.014	0.006	0.010	0.005	-0.001	0.014	0.006	0.011	0.005	-0.001	0.014	0.006
Damoh	0.010	0.005	-0.001	0.014	0.006	0.009	0.005	-0.001	0.014	0.006	0.010	0.005	-0.001	0.014	0.006
Panna	0.010	0.004	-0.002	0.015	0.006	0.009	0.004	-0.002	0.015	0.006	0.010	0.005	-0.002	0.015	0.006
Tikamgarh	0.010	0.005	-0.003	0.013	0.005	0.010	0.005	-0.003	0.013	0.005	0.010	0.005	-0.003	0.012	0.005

*Bold letter indicates significant value

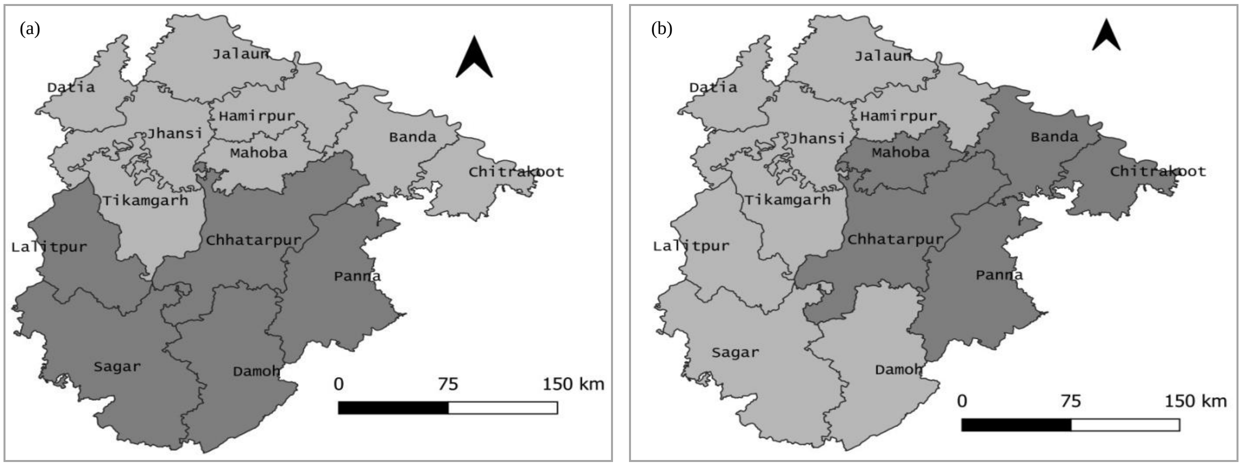
3.3.3. *Trend of maximum temperature*

The increasing trend of the maximum temperature is extremely notable as explained in Table 6. Increasing magnitude of maximum temperature was observed during winter (0.010 to 0.009 °C/year), pre-monsoon (0.003 to 0.006 °C/year), post-monsoon (0.011 to 0.015 °C/year) season and annually (0.003 to 0.006 °C/year) for all the stations of Bundelkhand. However, the only significant result was faound in annual maximum temperature (0.003 °C/year) for Jalaun station. This increasing trend is more prominent in the winter and post-monsoon season. Monsoon season indicated a decreasing trend (0.001 to 0.005 °C/year) for all stations of Bundelkhand, while significant decreasing trend was found only in Jhansi (0.005 °C/year) and Hamirpur (0.005 °C/year) stations.

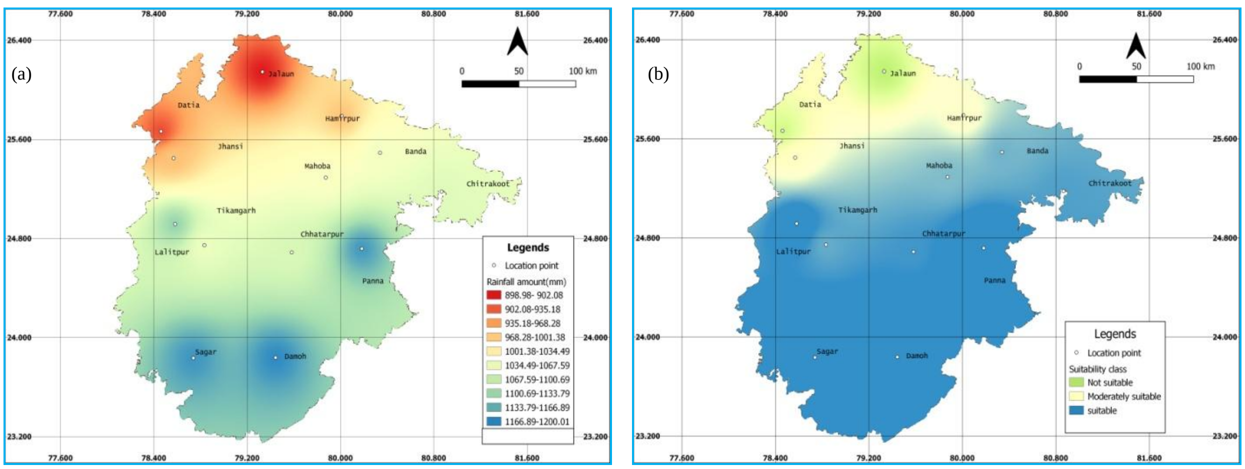
An increasing trend in temperature series was found in almost all the regions in case of minimum, maximum and average temperatures for pre-monsoon, post-monsoon, winter season and annually. However, the increasing rate in minimum temperature was slightly higher than the maximum and average temperature. A significant decrease of minimum, maximum and mean temperature was found during monsoon season in Jhansi, Hamirpur and Datia station the on (0.005 °C/year for each station), while other stations also indicated decreasing temperature trend. The rising magnitude of maximum, minimum and average temperature also conforms to the study of Arora *et al*., 2005. The similar seasonal and annual trends for north-central (NC) India has been reported by Sonali and Kumar (2013) and Mondal *et al*. (2014).

3.4. *Cluster analysis*

This technique grouped all 13 stations into two cluster classes based on calculated MSE (minimum squared error) difference among the rainfall and temperature of the centroids of the clusters and corresponding stations. Maps of clustered classes of rainfall and temperature are shown in Fig. 6(a&b) for the annual rainfall and annual average temperature series of study area. It may observe from Fig. 6(a&b) that both cluster classes showed a defined spatial distribution based on the geographical location of the stations of study area. Stations situated in the northern part of Bundelkhand were grouped in cluster-I class, while the stations situated at the southern side of Bundelkhand were grouped in Cluster-II in annual rainfall series. However, stations situated in the eastern part of the region were grouped in cluster-I class, while stations at the western part were grouped in the cluster-II in annual temperature series. Based on rainfall, cluster-I includes eight stations namely. Jhansi, Hamirpur, Mahoba, Banda, Chitrakoot, Jalaun, Datia, Tikamgarh. Whereas, Chhatarpur, Lalitpur, Sagar, Damoh and Panna stations grouped in cluster-II. Hence, it can be observed that Cluster-II represents stations received more rainfall as compared to the cluster-I station. However, based on temperature, cluster-I include five stations namely, Banda, Chhatarpur, Chitrkoot, Mahoba and Panna. Whereas, Damoh, Datia, Hamirpur, Jalaun,



Figs. 6(a&b). Cluster classes of Bundelkhand region based on rainfall (a) and based on temperature (b)



Figs. 7(a&b). (a) Rainfall spatial variability map and (b) Suitability class map for rain-fed agriculture of Bundelkhand region

Jhansi, Lalitpur, Sagar and Tikamgarh stations were grouped into cluster class-II.

3.5. *Impact of climate variability on agriculture production of the region*

Table 7 shows the compound annual growth rate (CAGR) in the area, production and yield of major cereal, pulse and oilseed crops cultivated during monsoon (*Kharif*) in Bundelkhand region of Uttar Pradesh. The region has recorded a negative growth rate in the cultivated areas of paddy, peas and soybean in the whole period (1991-2010) of study. Similarly, the production and productivity of paddy, pigeon peas, peas and groundnut of the region have recorded a negative rate. Only in case of maize, the region has registered the positive growth rate of area, production and productivity during study period. In case of the yield of soybean this region has observed a very small positive growth rate of 0.5 per cent per annum in the whole study period (1991-2010). From the table, it can be corroborated that the reduction in yield and production of *Kharif* crop might be attributed to change in rainfall pattern and climatic variability of the region.

Thus, based on the long-term rainfall and temperature data of the region, the area suitable for rain-fed cultivation was delineated [Figs. 7(a&b)] in QGIS 3.10.2 (http://qgis.org) environment. The whole region was divided into 3 suitability class namely, not suitable, moderately suitable and suitable. The weightage to rainfall and temperature was given 80:20 for the development of suitability classes because less temperature variation was observed across the region during the study period. The area belongs to Datia and Jalaun districts come under the 'not suitable class'. In these area, irrigation facilities need to be developed for obtaining better crop yield. Whereas, Jhansi, Hamirpur, Mahoba, Lalitpur, Banda and Chhatarpur districts belong to 'moderately suitable class'.

TABLE 7

Region-wise CAGR of gross cropped area, total production and yield of different major cereal, pulse and oilseeds in Uttar Pradesh (in percent per year)

Crop	Area			Production			Productivity		
	1991-2001	2001-2010	1991-2010	1991-2001	2001-2010	1991-2010	1991-2001	2001-2010	1991-2010
Paddy	1	-2.4	-0.5	51.8	-5.5	11	4.5	-4.8	-0.6
Maize	37.3	1.8	6.7	72.4	15.2	14	14.4	10	6
Pigeon Peas	-2.8	8.1	0.8	-15.7	-1.6	-9.2	1.3	-8.9	-4
Peas	2.5	-7.9	-2.2	4.2	-13.3	-3.4	-3.1	-5.9	-2.4
Groundnut	22.3	-1.2	5.2	4.6	-5.1	-4	-4.6	-5.1	-5.1
Soybean	-0.4	-1.4	-19.4	7.7	9.2	-17	0.2	12.7	0.5

In these area rain-fed agriculture can be adopted along with other soil moisture conservation practices. However, Sagar, Tikamgarh, Panna, Damoh and Chitrakoot districts are suitable for rain-fed agriculture, provided there should be proper rain-water management.

4. Conclusions

The rainfall variability on monthly, seasonal and annual basis as well as seasonal and annual minimum, maximum and mean temperature trends were analysed for thirteen representative meteorological stations of the Bundelkhand region of India using long term rainfall and temperature data from 1901 to 2002. Data have been analysed using nonparametric Mann-Kendall test with a significance level of 0.05 and in a case also with a significance level of 0.1. The trends magnitudes were calculated using Sen's method. A decreasing trend was observed in the monsoon rainfall series. However, significantly decreasing trends were found in most of the stations with magnitude ranging from 1.049 mm/year to 0.497 mm/year for the rainfall time series of July month which is an agriculturally most important month of this region. Increasing trends were observed for pre-monsoon and post-monsoon season rainfall. However, a significant increase was observed in Jhansi, Hamirpur, Jalaun and Datia stations for pre-monsoon rainfall series and only Jalaun district showed significant results during the post-monsoon season. Both increasing and decreasing trends were found in annual rainfall data. However, all trends were non-significant at 95% and 99% confidence levels. Three variables of temperature, *i.e.*, mean, minimum and maximum were studied for different seasons as well as for the year as a whole. The increasing trend in minimum, maximum and mean temperature series was found in almost all the stations for pre-monsoon, post-monsoon, winter season and annually. Whereas, decreasing trend in minimum, maximum and mean temperature was found during monsoon season. However, results were significant for Jhansi, Hamirpur and Datia stations with a magnitude of 0.005 °C/year for each station. From the study, it is concluded that monsoon rainfall and temperature in most of the stations showed a negative trend, while pre- and post-monsoon rainfall and temperature were found increasing in most of the stations of the study area. This indicates the shifting of the rainfall pattern from the normal occurrence coupled with abnormal temperature deviation. If this decreasing trend in monsoon rainfall and shifting of rainfall pattern continues, it will negatively impact the economy of the region. This study would be useful for planning and management of water resources of the region, for developing crop cultivation practices, drought mitigation strategies and crop contingency plans for the region under changing climate scenario. The cause of these changes would require further investigations.

Acknowledgement

Software like QGIS and XLSTAT used for making figures and for performing statistical analysis in the research article must be highly acknowledged for their free downloading facilities and availability of free tutorials. The contents and views expressed in this research article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Ahmed, A., Deb, D. and Mondal, S., 2019, "Assessment of Rainfall Variability and its Impact on Groundnut Yield in Bundelkhand Region of India", *Curr. Sci.*, **117**, 5,794-799.

Arora, M., Goel, N. K. and Singh, P., 2005, "Evaluation of temperature trends over India / Evaluation de tendances de température en Inde", *Hydrol. Sci. J.*, **50**, 1-93.

Brekke, L. D., Kiang, J. E., Olsen, J. R., Pulwarty, R. S. Raff, D. A., Turnipseed, D. P., Webb, R. S. and White, K. D., 2009, "Climate change and water resources management - A federal perspective", *U.S. Geological Survey Circular*, **1331,** p65.

Burn, D. H., Cunderlik, J. M. and Pietroniro, A., 2004, "Hydrological trends and variability in the Liard River basin / Tendances hydrologiques et variabilité dans le basin de la rivière Liard", *Hydrol. Sci. J.*, **49**, 1, 53-67.

Das, S. K., Jenamani, R. K., Kalsi, S. R. and Panda, S. K., 2007, "Some evidence of climate change in twentieth-century India", *Clim. Chang.*, **85**, 299-321.

Douglas, E. M., Vogel, R. M. and Kroll, C. N., 2000, "Trends in floods and low flows in the United States : Impact of spatial correlation", *J. Hydrol*., **240**, 1-2, 90-105.

Gosain, A. K., Rao, S. and Basuray, D., 2006, Climate change impact assessment on hydrology of Indian river basins. *Curr. Sci.,* **90,** 346-353.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S. and Xavier, P. K., 2006, "Increasing Trend of Extreme Rain Events Over India in a Warming Environment", *Science*, **314,** 5804, 1442-1445. doi: 10.1126/science.1132027.

Guhathakurta, P. and Rajeevan, M., 2008, "Trends in the rainfall pattern over India", *Int. J. Climatol.*, **28**, 11, 1453-1469.

International Mathematical and Statistical Libraries (IMSL), 1997, "Computational technology toolkit. Library. Visual Numerics", Houston, TX: IMSL **Vol. II**, 823.

IPCC Climate Change, 2014, "Mitigation of Climate Change", 5 Working Group III Contributions to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. https://doi.org/10.1017/CBO9781107415416.

Jagannathan, P. and Parthasarathy, B., 1973, "Trends and periodicities of rainfall over India" *Monthly Weather Review*, **101**, 4, 371-375.

Jain, S. K. and Kumar, V., 2012, "Trend analysis of rainfall and temperature data for India", *Curr. Sci.*, **102,** 37-49.

Jana, C., Alam, N. M., Mandal, D., Shamim. and Kaushal, R., 2017, "Spatio-temporal rainfall trends in the twentieth century for Bundelkhand region, India", *J Wat Clim Chang*, **8**, 3, 441-455.

Jhajharia, D. and Singh, V. P., 2010, "Trends in temperature, diurnal temperature ranges and sunshine duration in Northeast India", *Int. J. Climatol.*, **31**, 9, 1353-1367.

Kalra, N., Chakraborty, D., Sharma, A., Rai, H.K., Jolly, M., Chander, S., Kumar, P. R., Bhadraray, S., Barman, D., Mittal, R. B., Lal, M. and Sehgal, M., 2008, "Effect of increasing temperature on yield of some winter crops in northwest India", *Curr Sci*., **94,** 1, 82-88.

Kendall, M. G., 1975, "Rank Correlation Methods", 4th edition. Charles Griffin, London, UK.

Kripalani, R. H., Kulkarni, A. and Sabade, S. S., 2003, "Indian Monsoon variability in a global warming scenario", *Nat. Hazards,* **29**, 189-206.

Kumar, K. R., Pant, G. B., Parthasarathy, B. and Sontakke, N. A., 1992, "Spatial and sub seasonal patterns of the long-term trends of Indian summer monsoon rainfall", *Int. J. Climatol.*, **12**, 3, 257-268.

Kumar, R. and Raj Gautam, H., 2014, "Climate Change and its Impact on Agricultural Productivity in India", *J. Climatol. Weather. Fore,*, **2,** 109, doi: 10.4172/2332-2594.1000109.

Kumar, V., Jain, S. K. and Singh, Y., 2010, "Analysis of long-term rainfall trends in India", *Hydrol. Sci. J.*, **55**, 4, 484-496.

Lal, M., 2001, "Climatic change - implications for India's water resources", *J. Indian. Wat. Res. Soc.*, **21,** 101-119.

Mall, R. K., Singh, R., Gupta, A., Srinivasan, G. and Rathore, L. S., 2007, "Impact of climate change on Indian agriculture: A review", *Clim. Chang.*, **82**, 1-2, 2, 25-231.

Mann, H. B., 1945, "Nonparametric Tests against Trend", *Econometrica,* **13**, 3, p245.

Mondal, A., Khare, D., Kundu, S., 2014, "Spatial and temporal analysis of rainfall and temperature trend of India", *Theor. Appl. Climatol.*, **122,** 1-2, 143-158.

Nicholls, N., Gruza, G. V., Jouzel, J., Karl, T. R., Ogallo, L. A. and Parker, D. E., 1996, "Observed climate variability and change", in Houghton, J. T., Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A., Maskell, K. (eds), Climate Change, 1995: The Science of Climate Change, Cambridge University Press, UK 572.

Prasanna, V., 2014, "Impact of monsoon rainfall on the total food grain yield over India", *J. Ear. Sys. Sci.*, **123**, 5, 1129-1145.

Rai, S. K., Behari, P., Satyapriya, A., Rai, K. and Agrawal, R. K., 2012, "Long term trends in rainfall and its probability for crop planning in two districts of Bundelkhand region", *J. Agrometeorol*., **14**, 74-78.

Sen, P. K., 1968, "Estimates of the Regression Coefficient Based on Kendall's Tau", *J. Am. Stat. Asso.*, **63**, 324, 1379-1389.

Sharma, J. S., 2008, "Report on Drought Mitigation Strategy for Bundelkhand Region of Uttar Pradesh and Madhya Pradesh", Inter-ministerial Team, New Delhi.

Singh, O., Arya, P. and Chaudhary, B. S., 2013, "On rising temperature trends at Dehradun in Doon valley of Uttarakhand, India", *J. Ear. Sys. Sci*., **122**, 3, 613-622.

Sinha, S. K., Singh, G. B. and Rai, M., 1998, "Decline in crop productivity in Haryana and Punjab : Myth or reality", *Indian Council of Agricultural Research*, New Delhi, India, p89.

Smadi, M. M., 2006, "Observed Abrupt Changes in Minimum and Maximum Temperatures in Jordan in the 20th Century", *Am. J. Environ. Sci.,* **2,** 3,114-120.

Sonali, P. and Nagesh Kumar, D., 2013, "Review of trend detection methods and their application to detect temperature changes in India", *J. Hydrol.*, **476**, 212-227.

TERI, 2018, "Study of Impact of Special Package for Drought Mitigation Implemented in *Bundelkhand* Region New Delhi", The Energy and Resources Institute. [Project Report No. 2017HE02].

Thomas, T., Nayak, P. C. and Ghosh, N. C., 2015, "Spatiotemporal Analysis of Drought Characteristics in the *Bundelkhand* Region of Central India using the Standardized Precipitation Index", *J. Hydrol. Engg.*, **20**, 11, 05015004.

Vallebona, C., Pellegrino, E., Frumento, P. and Bonari, E., 2014, "Temporal trends in extreme rainfall intensity and erosivity in the Mediterranean region: A case study in southern Tuscany, Italy", *Clim, Chang*., **128**, 1-2, 139-151.