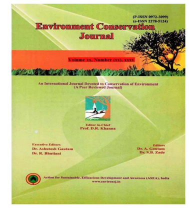
Environment Conservation Journal 23 (1&2): 131-142, 2022

Journal homepage: https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)



Statistical and temporal trends analysis of rainfall in Bundelkhand region, Central India

Liansangpuii Fanai ✉
Department of Agricultural Engineering, Institute of Agricultural Sciences, BHU, Varanasi, Uttar Pradesh, India.

K. N. Singh
Department of Soil and Water Engineering, IGKV, Raipur, Chhattisgarh, India.

R. Singh
ICRISAT Development Centre, International crops Research Institute for the Semi-Arid Tropics, Patancheru, Hyderabad, Telangana, India.

R. M. Singh
Department of Agricultural Engineering, Institute of Agricultural Sciences, BHU, Varanasi, Uttar Pradesh, India.

D. Khalkho
Department of Soil and Water Engineering, IGKV, Raipur, Chhattisgarh, India.

ARTICLE INFO

Received : 11 August 2021
Revised : 14 October 2021
Accepted : 08 November 2021

Available online: 11 February 2022

Key Words:
Central India
Rainfall
Nonparametric Mann-Kendall test
Sen's slope.

ABSTRACT

Three timescale i.e. monthly, seasonal and annual rainfall data of Bundelkhand region, Central India, was analyzed for 40 years (1981-2020). The annual mean average rainfall for the region ranges between 657.7 mm and 1146.4 mm for the studied period with the month August receiving the highest amount of rainfall. The region receives about 90 % of its annual rainfall during South West Monsoon period i.e. from June to September. Temporal trend of rainfall for different timescale was analysed using nonparametric Mann-Kendall test and Sen's slope estimator. Increasing and decreasing trend were found for the three timescale in which the study was carried out. Annual rainfall trend of Bundelkhand region is found to follow decreasing trend except for Sagar district. A decreasing South West Monsoon rainfall trend was also observed in 11 districts of Bundelkhand region.

Introduction

Producing enough food for growing population is a great challenge for mankind due to persistently growing pressure on finite freshwater and soil resources. According to 2011 census 54.6 % of Indian citizens are dependent on agriculture and its allied sectors to it. Agriculture contributes about 17 % to India's Gross Value added and hence it is very vital for the economic growth in India (GoI, 2016-17). Availability of the required water at the correct time is one of the main factors which affect agricultural production and power consumption in agricultural sector in the country. Irrigated land, covering 40% of India's agricultural land has contributed extensively to meeting 55% of the country's demand for food (GOI,2012). But on the other hand, there is a limited room for further expansion of the irrigation area as it uses nearly 70% of fresh water resources (CWC,2005) .Therefore, development of rainfed agriculture will help in achieving national food security in the future (Wani *et al.,* 2009, 2012).

According to Intergovernmental Panel on Climate Change **(**IPCC), by 2020, India will be negatively affected by greater climate variability, higher temperatures, and significant reductions in summer rains in some areas, as well as water stress (Cruz *et al.,* 2007). Once in every eight years, Bundelkhand region is affected by severe drought (Alam *et al.,* 2012 and 2014). This reveals the inevitable impact of changing climate in Bundelkhand region. Lack of water availability is the main factor which limits production of crop in this region (Alam *et al.,*2016). Agricultural failure has become a repeated trend in this region (Jain, 2009). Analysing the prevailing

Corresponding author E-mail: *fanaisangpuii@gmail.com*
https://doi.org/10.36953/ECJ.021812-2119

trend of Indian summer monsoon rainfall is a necessity (Guhathakurta and Rajeevan,2008). Precipitation trends have been analysed in several countries at different scales in the last century. Many studies were conducted to find outrainfall trends in India at different spatial scales, but it was found that rainfall trends are different for each regional level (Krishnakumar *et al.,* 2009). Therefore, the current study was conducted to identify the different characteristic of rainfall and its monthly, seasonal and annual trends to present reliable scientific knowledge for the effective preparation, planning, design and managing the limited water resources for the improvement of agricultural production under current climate change scenarios.

Material and Methods

General Features of the Study Area

Bundelkhand region is located in the transitional

Figure 1: Map of study area

zone between peninsular plateau and northern plain and comprises of 7 districts of Uttar Pradesh and 6 districts of Madhya Pradesh. It is located between 23° 8’– 26° 30’ N and 78° 11’- 81° 30’ E covering a total geographical area of 7.085 million ha and a forest cover of 17.63% (FSI, 2005). The region is located at 230 to 280 m above mean sea level (MSL).The agro-climate is characterized in three distinct seasons, viz. summer, rainy and winter. The mean temperature of region varies from 3 °C to 49 °C. During summer the temperature is about 34 °C and can go up to 46 °C to 49 °C.During winter the area have a mean temperature of 16 °C and it can decrease up to 3 °C to 5 °C during December and January. The relative humidity in Bundelkhand ranges from 40 to 60 %.

Bundelkhand region is receiving an annual rainfall of 800 to 1300 mm. Hard rocks such as Archaen granite, gneiss, metamorphic and igneous rocks are found in its geomorphology. The aquifers are either perched or unconfined with low water storage capacity. In this poorly permeable hard rock aquifer, shallow wells are the main resource of water for different activities. Agricultural productivity is about 0.5-1.5 t/ha which is a result of undulating terrain, low groundwater potential, high temperatures, low and unreliable rainfall. Depending on rain and temperature, different crops in Bundelkhand region have 90 and 150 days growing period. Figure 1 is showing the map of the study area.

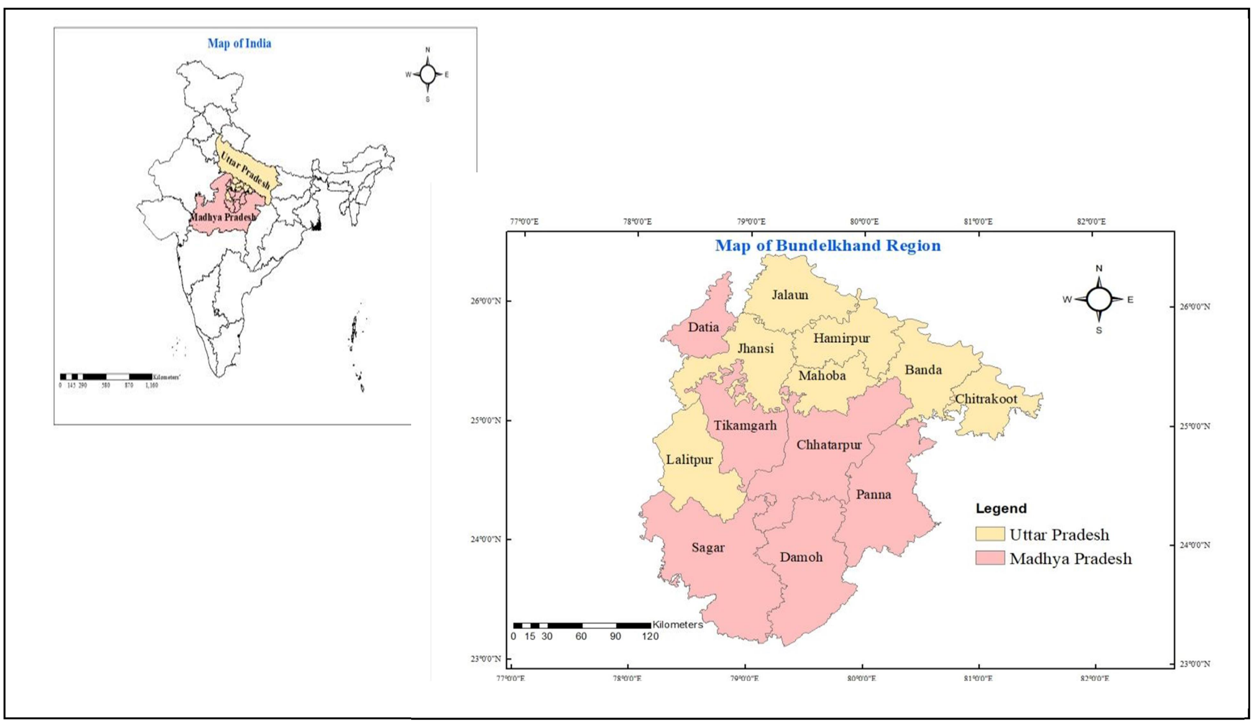


Figure 1 : Map of study area

Data Collection and Methodology

Daily gridded rainfall data of 0.25X0.25 degree spatial resolution covering all the district of Bundelkhand region was obtain from India Meteorological Department (IMD), Pune, India for the period of 1981 to 2020 (Pai *et al.,* 2014) . Monthly, annual and seasonal rainfalls were constructed using the daily rainfall data. The entire year was divided into four seasons viz., Pre monsoon (March-May), South West monsoon (June-September), Post monsoon (October to November) and Winter (December to February) in order to analyze the seasonal rainfall pattern. The mean, standard deviation and coefficient of variations of the rainfall data were analysed.75% dependable rainfall was also calculated for different timescale using Weibull's plotting position method (Weibull, 1939). An attempt was also made to detect rainfall trend using the nonparametric Mann-Kendall test (Mann, 1945; Kendall, 1975: Bayazit and Onoz, 2007). The nonparametric Sen's method (Gilbert, 1987) was used to determined the slope of a linear trend. Figure 2 represents the methods used during trend analysis.

Results and Discussion

Rainfall Characteristics

Statistical parameters of rainfall for 13 districts of Bundelkhand region of Central India are shown in Table 1. The results of average monthly analysis shows that for all the studied districts January, February, March, April, May, November and December received less than 20 mm rainfall for the studied period i.e. 1981 to 2020. A rainfall depth of 66.8 mm to 153.8 mm was received in the month of June. Minimum rainfall depth of 199.2 mm was observed in Jalaun district while Sagar district received a maximum rainfall depth of 348.2 mm for the month of July. The rainfall depth varies between 188.7 mm to 366.6 mm and 125.1 mm to 189.4 mm for the month of August and September respectively. The rainfall depth varies between 22.7 mm in Sagar district to 36.6 mm in Chitrakoot district for the month of October. The average annual rainfall ranges between 657.7 mm in Jalaun district to 1146.4 mm in Sagar district. Figure 3 shows the annual variations of rainfall for different districts of Bundelkhand region from 1981 to 2020. The highest average annual rainfall was 1548.4 mm for Chhatarpur district in the year 2016 while the lowest average annual rainfall was found at Jalaun district with rainfall depth of 205.1 mm in the year 2012. During Pre Monsoon period the region received a rainfall depth of 13.6 mm in Lalitpur district to 25.1 mm in Banda district.

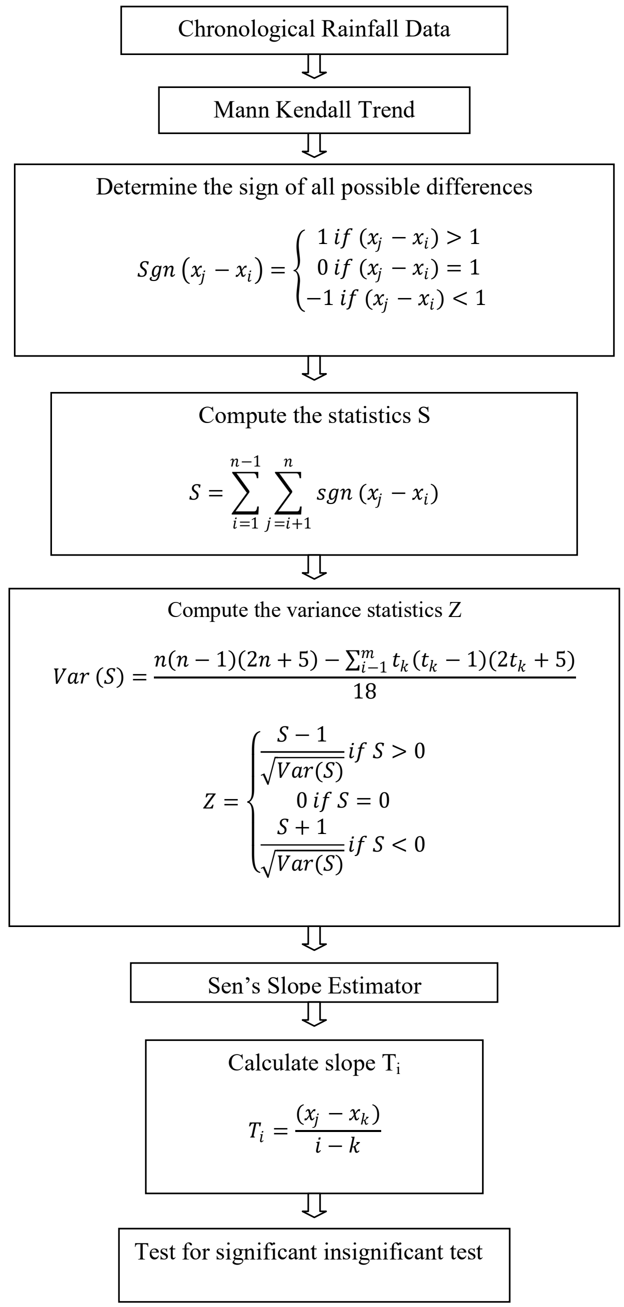


Figure 2: Methodology for calculating trend and slope of rainfall.

Table 1: Statistical parameters of rainfall over Bundelkhand region from 1981 to 2020 for characterization of rainfall.

Districts		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Pre	Swm	Post	WIn
Jalaun	Mean	12.3	11.2	5.0	3.9	8.3	66.8	199.2	188.7	125.1	30.0	2.7	4.5	657.7	17.2	579.7	32.7	28.0
	S.D	18.4	19.2	9.9	8.2	9.3	54.0	81.7	100.4	105.3	44.0	8.6	7.2	225.5	18.5	203.2	43.9	30.3
	C.V	149.5	171.3	197.1	209.6	112.7	80.8	41.0	53.2	84.2	146.7	316.1	161.6	34.3	107.8	35.1	134.1	108.2
	75%	-1.2	-2.7	-1.9	-1.4	1.3	26.0	139.5	113.6	45.0	-3.0	-2.5	-0.9	496.6	3.5	436.5	-0.5	5.2
	% Con	1.9	1.7	0.8	0.6	1.3	10.2	30.3	28.7	19.0	4.6	0.4	0.7	100.0	2.6	88.2	5.0	4.3
Jhansi	Mean	10.2	12.8	6.3	5.5	9.4	85.4	224.9	243.0	139.8	29.9	2.8	5.0	775.0	21.1	693.1	32.7	28.0
	S.D	14.4	19.7	11.1	11.0	8.5	73.6	77.6	114.7	125.2	48.7	6.8	10.9	232.6	20.1	207.8	48.9	31.4
	C.V	141.5	154.1	178.3	200.4	90.6	86.1	34.5	47.2	89.5	162.9	241.5	217.5	30.0	95.1	30.0	149.5	112.0
	75%	-0.6	-1.8	-1.8	-1.9	2.9	29.7	170.4	156.2	44.7	-6.0	-1.8	-2.4	600.1	5.9	541.6	-3.7	4.2
	% Con	1.3	1.7	0.8	0.7	1.2	11.0	29.0	31.4	18.0	3.9	0.4	0.6	100.0	2.7	89.4	4.2	3.6
Hamirpur	Mean	13.4	12.7	6.9	4.6	11.0	84.9	217.3	231.8	142.2	28.9	2.1	4.5	760.3	22.5	676.2	31.1	30.6
	S.D	16.0	20.2	13.2	8.1	10.8	73.9	92.0	95.6	107.4	41.9	4.8	6.7	201.5	20.1	193.4	41.8	30.0
	C.V	119.8	159.5	191.6	177.8	97.7	87.0	42.3	41.2	75.5	144.7	222.8	147.4	26.5	89.6	28.6	134.5	98.2
	75%	1.2	-2.1	-2.2	-1.0	2.8	28.5	149.7	162.5	60.5	-2.3	-1.1	-0.5	613.9	7.2	535.4	-0.3	7.6
	% Con	1.8	1.7	0.9	0.6	1.4	11.2	28.6	30.5	18.7	3.8	0.3	0.6	100.0	3.0	88.9	4.1	4.0
Mahoba	Mean	12.8	14.8	6.3	4.3	11.5	91.9	240.5	258.3	151.8	27.8	3.5	5.1	828.4	22.0	742.5	31.2	32.7
	S.D	15.5	21.0	10.9	6.7	13.1	84.3	88.1	112.8	123.8	40.5	9.0	12.1	235.7	20.0	239.0	43.3	30.7
	C.V	121.2	141.8	173.7	157.7	113.8	91.8	36.6	43.7	81.6	146.1	260.1	237.1	28.5	91.0	32.2	138.5	93.8
	75%	1.0	-1.0	-1.7	-0.7	1.8	28.4	178.3	175.4	58.5	-2.4	-2.4	-2.9	656.8	7.0	569.0	-1.3	9.3
	% Con	1.5	1.8	0.8	0.5	1.4	11.1	29.0	31.2	18.3	3.4	0.4	0.6	100.0	2.7	89.6	3.8	3.9
Banda	Mean	14.8	14.4	6.7	5.1	13.2	100.8	225.3	247.7	155.6	29.9	2.1	5.8	821.5	25.1	729.4	32.0	35.0
	S.D	18.8	21.0	13.8	8.8	14.8	97.6	101.4	96.5	112.6	44.3	5.0	8.9	200.0	26.1	191.2	44.0	35.6
	C.V	127.0	146.1	205.1	172.8	112.0	96.8	45.0	39.0	72.4	148.2	235.1	153.8	24.4	103.9	26.2	137.4	101.7
	75%	0.6	-1.1	-2.6	-1.1	2.0	27.5	149.5	175.2	69.6	-3.3	-1.3	-0.8	673.0	5.9	590.0	-1.1	8.2
	% Con	1.8	1.8	0.8	0.6	1.6	12.3	27.4	30.2	18.9	3.6	0.3	0.7	100.0	3.1	88.8	3.9	4.3
Chhitrakoot	Mean	12.9	17.2	6.4	4.3	10.7	101.5	247.3	252.5	184.2	36.6	2.6	6.4	882.7	21.4	785.5	39.2	36.6
	S.D	16.6	25.6	13.0	7.9	14.5	90.9	89.7	85.2	109.8	46.2	6.5	8.3	189.1	27.7	168.0	45.7	35.6
	C.V	128.3	148.7	203.0	184.4	136.1	89.6	36.3	33.7	59.6	126.2	249.5	129.7	21.4	129.7	21.4	116.4	97.4
	75%	0.6	-1.5	-2.5	-1.0	-0.2	32.1	183.0	190.0	102.7	1.8	-1.7	0.1	784.6	1.6	667.6	4.8	9.5
	% Con	1.5	1.9	0.7	0.5	1.2	11.5	28.0	28.6	20.9	4.1	0.3	0.7	100.0	2.4	89.0	4.4	4.1

Lalitpur	Mean	10.5	11.9	5.4	2.1	6.0	111.8	278.0	296.5	145.5	25.2	4.2	5.1	902.3	13.6	831.8	29.4	27.5
	S.D	15.2	18.9	10.4	5.1	7.3	124.7	115.7	139.4	143.5	46.6	11.9	12.0	252.6	15.0	236.9	51.0	34.2
	C.V	144.6	159.0	191.7	240.2	121.7	111.5	41.6	47.0	98.6	184.7	282.1	235.8	28.0	110.4	28.5	173.4	124.1
	75%	-0.9	-2.1	-2.0	-1.2	0.5	22.7	192.6	193.1	37.3	-7.7	-3.3	-2.6	714.9	2.3	657.1	-7.4	2.6
	% Con	1.2	1.3	0.6	0.2	0.7	12.4	30.8	32.9	16.1	2.8	0.5	0.6	100.0	1.5	92.2	3.3	3.0
Datia	Mean	9.7	11.6	4.2	4.0	9.6	75.0	209.6	218.3	129.2	27.0	3.3	6.1	707.8	17.9	632.2	30.3	27.4
	S.D	16.1	17.9	8.0	8.0	12.2	59.5	76.6	97.0	111.5	41.8	10.4	16.4	193.8	18.4	172.7	42.2	29.7
	C.V	165.6	153.7	190.3	197.2	126.8	79.3	36.5	44.4	86.3	154.9	313.7	270.5	27.4	103.0	27.3	139.1	108.3
	75%	-1.8	-1.7	-1.4	-1.2	0.5	30.7	153.5	147.2	45.2	-4.2	-2.9	-3.7	562.0	4.1	505.3	-1.5	4.9
	% Con	1.4	1.6	0.6	0.6	1.4	10.6	29.6	30.8	18.3	3.8	0.5	0.9	100.0	2.5	89.3	4.3	3.9
Tikamgarh	Mean	11.4	14.1	7.2	4.4	8.8	98.5	261.1	299.4	158.5	29.0	3.5	5.5	901.4	20.4	817.5	32.5	31.0
	S.D	16.9	19.9	13.6	6.7	10.4	98.6	92.0	137.6	152.0	55.2	7.7	12.2	259.6	21.4	246.9	56.9	36.4
	C.V	148.3	141.8	188.8	152.3	118.6	100.2	35.2	46.0	95.9	190.4	222.9	221.5	28.8	104.8	30.2	175.2	117.5
	75%	-1.2	-0.9	-2.5	-0.6	1.1	25.0	197.7	196.2	45.0	-9.3	-1.9	-2.8	709.6	4.3	639.4	-7.8	3.8
	% Con	1.3	1.6	0.8	0.5	1.0	10.9	29.0	33.2	17.6	3.2	0.4	0.6	100.0	2.3	90.7	3.6	3.4
Chhatarpur	Mean	13.6	15.7	7.0	4.8	9.6	121.3	290.6	334.0	177.4	30.1	4.2	5.4	1013.7	21.3	923.3	34.3	34.8
	S.D	17.4	19.7	11.8	7.9	9.9	103.1	106.2	139.2	140.1	45.4	11.9	12.7	256.1	21.9	253.1	49.4	32.3
	C.V	127.3	125.6	169.5	164.6	103.1	85.0	36.5	41.7	79.0	150.9	280.4	234.4	25.3	102.6	27.4	144.0	92.8
	75%	0.5	0.8	-1.7	-1.0	2.0	43.0	214.9	228.0	71.7	-3.4	-3.3	-2.8	825.5	4.7	738.9	-2.6	10.2
	% Con	1.3	1.6	0.7	0.5	0.9	12.0	28.7	32.9	17.5	3.0	0.4	0.5	100.0	2.1	91.1	3.4	3.4
Panna	Mean	15.7	16.6	7.0	2.8	6.6	128.1	307.2	337.6	185.5	27.6	4.2	4.1	1043.0	16.4	958.4	31.8	36.4
	S.D	22.4	22.0	12.9	4.3	9.0	103.6	139.3	134.1	158.3	37.2	13.1	9.1	278.6	20.5	277.6	44.0	38.3
	C.V	142.5	132.8	184.1	153.8	137.2	80.9	45.3	39.7	85.3	134.8	312.3	220.3	26.7	125.1	29.0	138.4	105.1
	75%	-1.2	0.0	-2.2	-0.4	-0.2	49.0	204.0	236.1	66.9	-0.2	-3.6	-2.1	832.6	1.1	749.2	-0.7	7.7
	% Con	1.5	1.6	0.7	0.3	0.6	12.3	29.5	32.4	17.8	2.6	0.4	0.4	100.0	1.6	91.9	3.0	3.5
Damoh	Mean	14.1	16.9	7.4	4.0	8.0	144.3	328.6	350.8	170.1	24.1	5.9	5.1	1079.5	19.4	993.8	30.0	36.2
	S.D	19.9	24.6	12.4	8.3	10.2	125.2	150.6	136.8	134.4	29.4	17.6	11.4	267.5	21.4	268.7	40.5	36.2
	C.V	140.4	145.5	166.6	209.1	126.8	86.7	45.8	39.0	79.0	121.7	299.6	221.1	24.8	110.2	27.0	134.9	100.1
	75%	-0.8	-1.6	-1.7	-1.6	0.3	50.3	215.8	250.0	68.2	2.2	-4.7	-2.6	879.0	3.3	793.3	0.0	8.6
	% Con	1.3	1.6	0.7	0.4	0.7	13.4	30.4	32.5	15.8	2.2	0.5	0.5	100.0	1.8	92.1	2.8	3.4
Sagar	Mean	12.3	16.4	8.8	3.3	9.6	153.8	348.2	366.6	189.4	22.7	7.9	7.4	1146.4	21.7	1058	30.6	36.1
	S.D	22.7	26.1	14.3	5.7	13.2	135.1	143.1	150.3	160.4	31.2	22.6	16.8	298.9	21.7	292.4	47.2	38.6
	C.V	184.5	158.7	163.5	170.0	137.1	87.9	41.1	41.0	84.7	137.7	287.2	226.5	26.1	99.8	27.6	154.5	106.8
	75%	-3.7	-2.6	-1.8	-0.8	-0.2	53.1	241.1	255.2	68.5	-0.6	-6.2	-3.5	923.1	5.2	839.4	-3.8	7.1
	% Con	1.1	1.4	0.8	0.3	0.8	13.4	30.4	32.0	16.5	2.0	0.7	0.6	100.0	1.9	92.3	2.7	3.2

Sagar district received rainfall depth of 1058 mm during South West Monsoon Period while Jalaun district received only 579.7 mm rainfall depth. The Post Monsoon rainfall varies from 29.4 mm in Lalitpur district to 39.2 mm in Chitrakoot district. A rainfall depth of 27.4 mm to 36.6 mm was received during winter season. Figure 3, 4, 5, 6 and 7 represent the seasonal variations of rainfall respectively over the studied period. Jhansi district in the year 1984, Lalitpur district in the year 2003 and 2012, Tikamgarh district in 1984 and Damoh district in 2003 did not received rainfall during Pre Monsoon season.

Chitrakoot district received the highest Pre Monsoon rainfall of 122.7 mm in 2020. Sagar district in the year 2013 received the highest south west monsoon of 1730 mm while the lowest 186.8 mm was received in 2012 at Jalaun district The Post Monsoon season showed the highest amount of rainfall Tikamgarh district in the year 1985. There was no winter season rainfall received in the year 2006 for all the districts and Lalitpur district have the highest winter season rainfall of 183.6 mm in the year 2014.

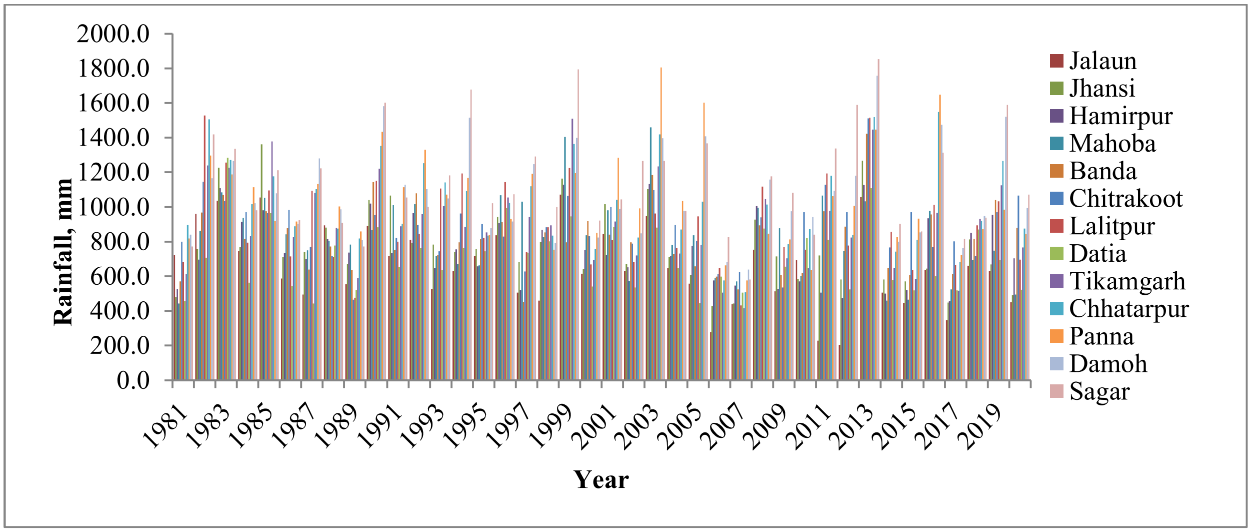


Figure 3: Annual variations of rainfall over Bundelkhand from 1981 to 2020

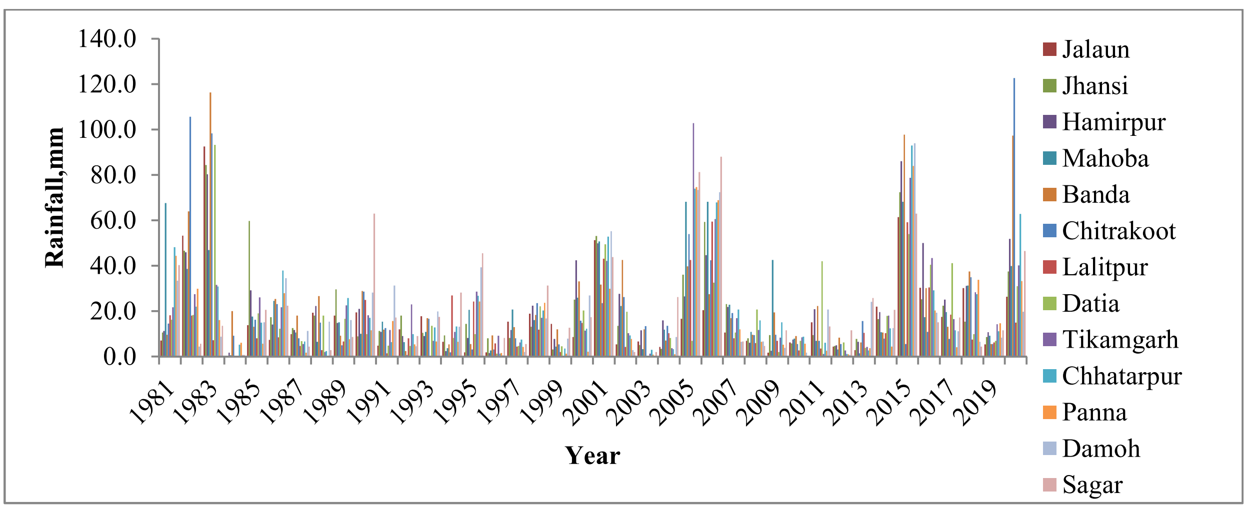
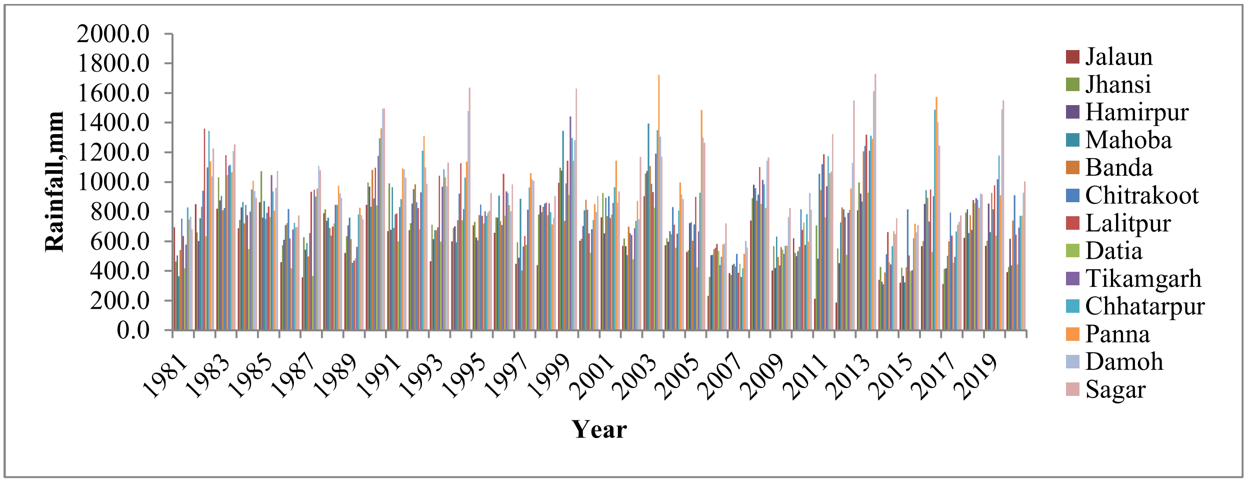


Figure 4: Pre Monsoon (March-May) variations of rainfall of Bundelkhand from 1981 to 2020



.**Figure 5: South West monsoon (June-September) variations of rainfall over Bundelkhand from 1981 to 2020**

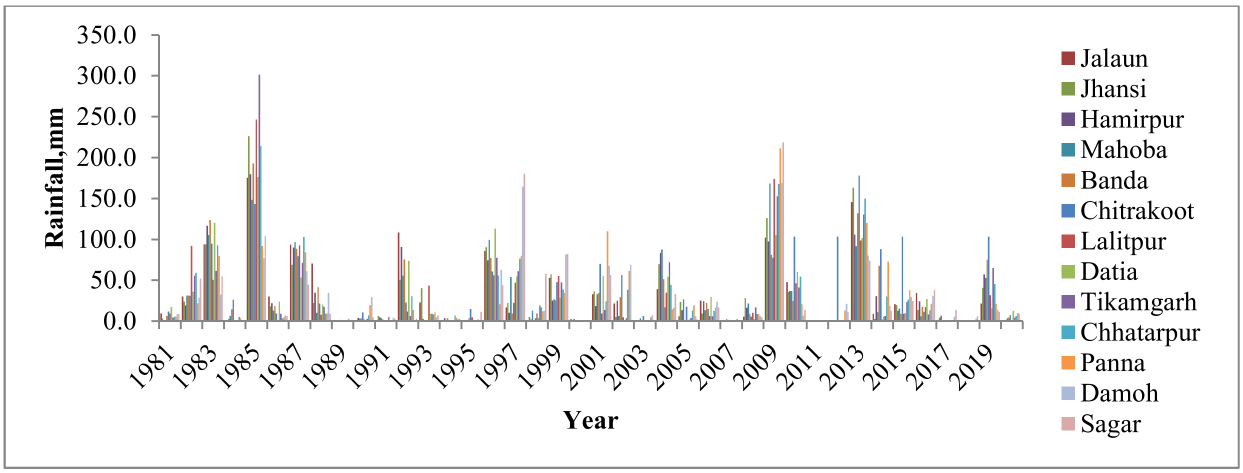


Figure 6: Post Monsoon (Oct- Nov) variations of rainfall over Bundelkhand from 1981 to 2020

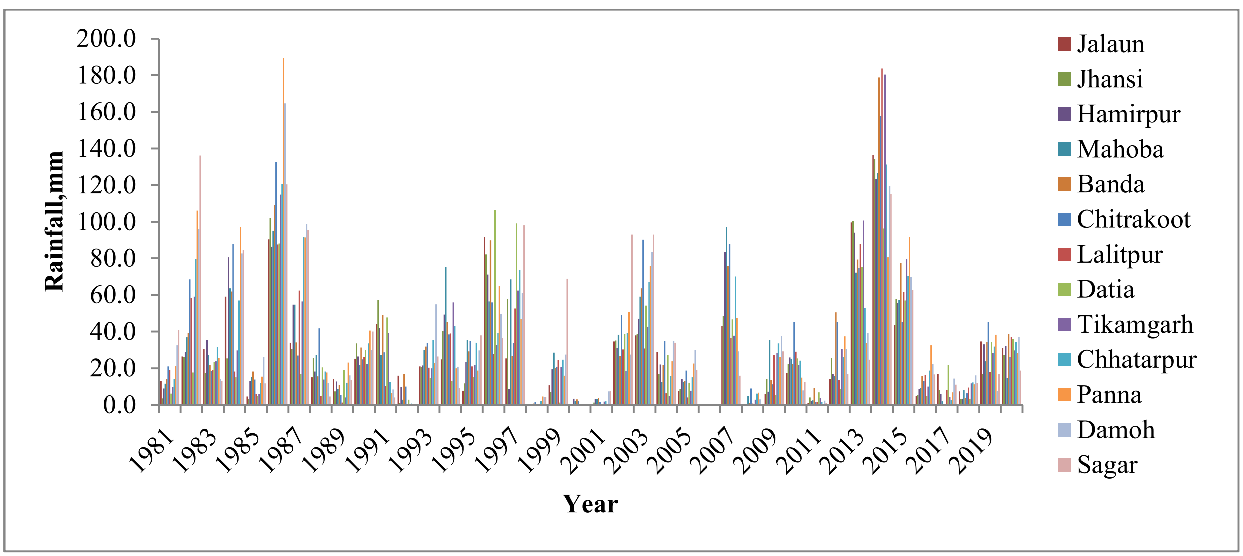


Figure 7: Rainfall variations in Winter Season (Dec- Feb) over Bundelkhand from 1981 to 2020

The monthly standard deviations values show that except for Damoh district, all the remaining district of Bundelkhand region, the month of September have the highest standard deviation. The annual standard deviation ranges from 189.1 mm in Chitrakoot district to 298.9 mm in Sagar district. Minimum 15 mm and maximum 27.7 mm value of standard deviation for Pre Monsoon season was observed in the district of Lalitpur and Chitrakoot respectively. The standard deviation of South West Monsoon season varies from 168 mm in Chitrakoot district and 292.4 mm in Sagar district. The standard deviation of Post Monsoon season and Winter Season were found to be in the range of 40.5 mm to 56.9 mm and 29.7 mm to 38.6 mm respectively.

The coefficient of variation value of the monthly rainfall showed that November has the highest value in the entire district ranging from 222.8 % for Hamirpur district to 316.1 % for Jalaun district. The annual coefficient of variation ranges from 24.4 % in Banda district to 28.8 % in Tikamgarh district. From the seasonal coefficient of variation analysis Tikamgarh district have the highest value of 175.2 % during Post Monsoon Season and lowest value of 21.4 % in Chitrakoot district during South West Monsoon Period.

The annual 75 % dependable rainfall varies from 496.6 mm to 923.1 mm in Jalaun and Sagar districts respectively. Jaluan district have the lowest 75 % dependable rainfall of 436.5 mm for South West Monsoon Period while Sagar district have the highest value of 839.4 mm. Except Chhatarpur district during the winter season, the Pre Monsoon, Post Monsoon and Winter season have less than 10 mm 75 % dependable rainfall. 10.2 mm of 75 % dependable rainfall was observed in Chhatarpur district during the winter season.

Seasonal evaluation showed that South-West monsoon contributes about 90% of the total annual rainfall which is also given by Singh *et al.*(2002). The Post Monsoon and Winter Season contribution to annual rainfall is about 4 % each. About 2 % of the annual rainfall comes from Pre Monsoon rainfall in Bundelkhand region.

Rainfall Trend

The Mann-Kendall trend, its statistical significance and Sen's slope magnitude of rainfall for the period of 1981 to 2020 are shown in Table 2.

Monthly Rainfall Trend

A decreasing rainfall trend was observed for the month of January but only Hamirpur district show a significant trend at 0.1 level of significance. 6 districts viz. Jalaun, Jhansi, Chitrakoot, Panna, Damoh and Sagar show a non-significant decreasing trend while the remaining 7 districts show a non-significant increasing trend for the month of Febuary. All 13 districts show a non-significant increasing trend for the month of March. Sagar district shows an increasing trend for the month of April significant at 0.01 level of significance. No significant increasing or decreasing trend was observed for the month of May, June and July in all the districts. A decreasing trend was observed for the month of August in all the district. Among them Jalaun and Datia show a decreasing trend at 0.1 level of significance while Jhansi district shows a decreasing trend at 0.05 level of significance. Damoh and Sagar districts show an increasing trend for September. Jalaun and Hamirpur districts show a significant decreasing trend at 0.01 level of significance while Jhansi and Mahoba districts show a decreasing trend at 0.05 level of significance. The month of October, November and December show a non-significant increasing and decreasing trend.

Annual Rainfall Trend

Except Sagar district, the other 12 districts show a decreasing annual rainfall trend for the period of 1981 to 2020. Jalaun and Jhansi districts show an annual rainfall decreasing trend significant at 0.01 level of significance. Hamirpur and Mahoba districts show a decreasing annual rainfall trend at 0.1 level of significance.

Seasonal Rainfall Trend

Jhansi, Chritrakoot, Chhatarpur, Panna and Damoh show a non-significant decreasing Pre Monsoon rainfall trend but the remaining districts show a non-significant increasing trend. Banda and Sagar districts show an increasing South West Monsoon rainfall trend but these trends are insignificant. A decreasing South West Monsoon rainfall trend was observed in the remaining 11 districts. Among them two districts i.e. Jalaun and Jhansi show a significant decreasing trend at 0.01 level of significance and 0.05 level of significance respectively. Panna and Chitrakoot districts show a non-significant increasing Post Monsoon trend while the remaining districts show a non-significant decreasing trend.

Table 2: Mann Kendall (Z) values, Significance (α) and Sen's slope (Q) values over Bundelkhand region from 1981 to 2020

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Pre	Swm	Post	Win
Jalaun	Z	-0.40	-0.64	0.32	0.19	0.03	-0.47	-1.19	-1.89	-3.05	-1.21	0.40	-1.04	-2.84	0.23	-3.03	-1.20	-0.42
	α								+	**				**		**		
	Q	-0.03	-0.02	0.00	0.00	0.00	-0.40	-1.48	-2.62	-3.00	-0.02	0.00	0.00	-9.05	0.06	-7.76	-0.13	-0.09
Jhansi	Z	-0.70	-0.11	0.60	1.43	-0.37	-0.48	-0.34	-1.99	-1.99	-0.79	0.08	-0.53	-2.64	-0.43	-2.48	-0.77	-0.07
	α								*	*				**		*		
	Q	-0.03	0.00	0.00	0.04	-0.04	-0.41	-0.34	-3.31	-2.02	-0.02	0.00	0.00	-6.62	-0.07	-6.71	-0.05	0.00
Hamirpur	Z	-1.75	0.07	0.73	0.49	-0.08	0.36	0.10	-1.11	-2.62	-0.47	0.68	-0.69	-1.71	0.62	-1.50	-0.55	-0.85
	α	+								**				+				
	Q	-0.23	0.00	0.01	0.01	-0.01	0.17	0.10	-2.17	-2.45	-0.01	0.00	0.00	-5.81	0.14	-5.12	-0.06	-0.26
Jalaun	Z	-1.45	0.16	0.72	1.23	-0.28	-0.17	-0.29	-1.08	-2.20	-0.44	1.28	0.27	-1.83	0.15	-1.50	-0.64	-0.89
	α									*				+				
	Q	-0.19	0.00	0.00	0.03	-0.03	-0.17	-0.35	-2.12	-2.15	-0.02	0.00	0.00	-6.19	0.02	-5.04	-0.10	-0.24
Banda	Z	-1.29	0.61	0.14	-0.29	0.20	-0.71	0.97	-0.22	-1.41	-1.12	0.05	-1.03	-0.24	0.00	0.00	-1.33	-0.45
	α																	
	Q	-0.25	0.04	0.00	-0.01	0.02	-0.57	1.10	-0.34	-1.76	-0.10	0.00	0.00	-1.05	0.00	0.00	-0.15	-0.21
Chitrakoot	Z	-1.49	-0.06	0.72	0.49	0.30	-0.80	0.76	-0.41	-0.71	0.17	-0.36	0.12	-0.01	-0.57	-0.08	0.10	-0.45
	α																	
	Q	-0.14	0.00	0.02	0.00	0.01	-0.79	0.77	-0.40	-0.69	0.00	0.00	0.00	0.00	-0.09	-0.04	0.00	-0.17
Lalitpur	Z	-0.57	0.73	0.72	1.48	-0.02	1.06	-0.62	-1.01	-0.73	-0.98	0.03	0.02	-0.87	0.68	-0.80	-1.32	0.28
	α																	
	Q	0.00	0.01	0.00	0.00	0.00	0.80	-0.96	-1.44	-0.87	-0.02	0.00	0.00	-2.59	0.10	-3.46	-0.06	0.07
Datia	Z	-0.52	0.26	0.01	1.04	1.12	0.73	1.39	-1.83	-1.34	-1.41	0.71	-0.21	-0.66	0.64	-0.45	-0.98	0.19
	α								+									
	Q	0.00	0.00	0.00	0.02	0.10	0.43	1.35	-3.41	-1.23	-0.02	0.00	0.00	-1.29	0.10	-1.40	-0.04	0.06
Tikamgarh	Z	-1.01	0.28	0.26	0.78	0.16	0.22	-0.57	-1.13	-1.25	-0.46	0.33	-0.06	-1.62	0.13	-1.57	-0.45	-0.07
	α																	
	Q	-0.05	0.00	0.00	0.01	0.01	0.18	-1.18	-2.52	-1.56	0.00	0.00	0.00	-7.00	0.06	-6.36	-0.02	-0.02
Chhatarpur	Z	-0.99	0.08	0.16	0.09	0.22	-0.24	-0.20	-0.87	-1.15	-0.72	0.49	-0.52	-1.53	-0.03	-1.20	-0.80	-0.48
	α																	
	Q	-0.09	0.00	0.00	0.00	0.01	-0.27	-0.16	-1.88	-1.37	-0.05	0.00	0.00	-4.89	-0.02	-4.52	-0.08	-0.18
Panna	Z	-0.55	-0.29	0.71	0.64	-0.16	-0.17	0.41	-1.27	-0.94	0.44	0.00	-0.64	-1.29	-0.17	-1.01	0.13	-0.58
	α																	
	Q	-0.01	0.00	0.00	0.00	0.00	-0.26	0.78	-2.20	-0.94	0.04	0.00	0.00	-4.62	-0.02	-3.93	0.02	-0.28
Damoh	Z	-0.52	-0.71	0.13	1.44	-1.15	0.48	0.87	-1.22	0.24	0.00	0.37	-0.93	-0.34	-0.10	-0.20	-0.05	-0.86
	α																	
	Q	0.00	-0.03	0.00	0.02	-0.07	0.42	1.15	-2.48	0.37	0.00	0.00	0.00	-1.71	-0.01	-0.60	-0.01	-0.31
Sagar	Z	-1.47	-0.51	0.27	3.17	-1.08	0.76	0.99	-1.13	0.10	0.09	0.37	-0.60	0.00	0.50	0.03	-0.29	-1.12
	α				**													
	Q	-0.03	-0.01	0.00	0.07	-0.05	0.80	1.36	-2.62	0.09	0.00	0.00	0.00	0.00	0.12	0.37	-0.04	-0.43

***** if trend at α = 0.001 level of significance, ** if trend at α = 0.01 level of significance, * if trend at α = 0.05 level of significance and + if trend at α = 0.1 level of significance.**

For winter season rainfall, Lalitpur and Datia districts show a non-significant increasing trend while the remaining 11 districts show a non-significant decreasing trend.

The decreasing trends in rainfall are supported by other researcher. Jana *et. al,*(2017),reported that rainfall pattern over Bundelkhand region is depicting a declining trends, and that the region is heading in the direction of drier time with more erratic rainfall behaviour. A declining annual rainfall trend was also observed in the studies conducted by Rai *et al.,* (2012), Thomas *et al.,* (2014) Deo *et al.,* (2015), Jain *et al.* ,(2017) and Ahmed *et al.,* (2019) which comply with the current findings of the studies.The decreasing trend of rainfall can be due to Chaurasia *et al.,* (2021) reported that the deviation in rainfall correlates with forest cover. Thus increasing forest cover which is far below the average recommended by Nation's Forest Policy can be one of the solution to reduce water woes in the region. Saharwardi *et al.,* (2021), stated that the decrease in rainfall over Bundelkhand region is due warmer sea surface temperature in the eastern Pacific. It was also reported that the increase occurrence of El-Nino events in recent years has led to a drought years in Bundelkhand region.

Gupta *et al.* ,(2014) noted that frequency of drought occurrence is increasing in Bundelkhand region and has become a recurring annual phenomenon since 2004.Thomas *et al.,*(2015) detailed an increase severity of meteorological drought in the region. Dubey *et al.,* (2017) has found a growing trend of drought event in Bundelkhand region. Saharwardi *et al.,* (2021) reported an increase in drought frequency in the since the starting of the 21st century.

Bhusan *et al.,* (1997) revealed that occurrence of dry spell during South West Monsoon season leads to crop failure in Bundelkhand region. Chand *et al.,*(2011) stated that rainfall plays a vital role for agriculture production in the region and reported that the crop production which is lower than the national average is mainly due to decrease trend in rainfall which prevails in the region. Dubey *et al.,*(2011) reported that the declining rainfall have contributed to the yield reduction of pulse crops. Gupta *et. al.*, (2021) reported that cultivated area for *Kharif* crops like paddy, peas and soybean cultivated areas have been declining in Bundelkhand region and that changing rainfall and climate trend corroborated to declining crop production. Ahmed *et al.,* (2019) reported that decreasing South West Monsoon rainfall have negative impact on the production of groundnut. Production of *Rab*i crops like wheat, berseem etc are likely to be affected in the coming era due to water shortages caused by declining rainfall.

Conclusion

The work presents an analysis of rainfall characteristics and its trend of Bundelkhand region in India. Rainfall was characterized using different statistical parameters. Monthly, annual and seasonal rainfall trend was studied using Man-Kendall Test and change in rainfall magnitude was detected using Sen's slope estimator. From the study it was found that the average yearly rainfall over Bundelkhand ranges from 657.7 mm to 1146.4 mm. The rainfall in the region is mainly concentrated in the four South West Monsoon months which are June, July, August and September. An alarming finding of the study is that the annual and south west monsoon is following a declining trend. From the study we suggested that rainfall received during south west monsoon months should be harnessed and conserved through soil and water conservation practices for year round water availability.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Ahmed, A., Deb, D., & Mondal, S. (2019). Assessment of rainfall variability and its impact on groundnut yield in Bundelkhand region of India. *Current Science*, 117 (5), 794-803.

Alam, N. M., Adhikary, P. P., Jana, C., Kaushal, R., Sharma, N. K., Avasthe, R. K., & Mishra, P. K. (2012). Application of Markov Model and Standardized Precipitation Index for Analysis of Droughts in Bundelkhand Region of India. *Journal of Tree Sciences*, 31(1 & 2), 46-53.

Alam, N. M., Mishra, P. K., Jana, C., & Adhikary, P. P. (2014). Stochastic model for drought forecasting for Bundelkhand region in Central India.*Indian Journal of Agricultural Science*, 84(1), 79–84.

Alam, N. M., Ranjan, R., Adhikary, P. P., Kumar, A., Mishra, P. K., & Sharma, N. K. (2016). Statistical modeling of weekly rainfall data for crop planning in Bundelkhand region of Central India. *Indian Journal of Soil Conservation*, 44(3), 336–342.

Bayazit, M., & Onoz, B. (2007). To prewhiten or not to prewhiten in trend analysis? *Hydrological Sciences Journal,* 52 (4), 611–624.

Bhusan, L.S., Sharma, A.K., Tiwari, A.K., Singh, B.L., & Yadav, R.C. (1997). Management of Ravine watershed. Bulletin NoT-37/A1.CSWCRTI, Research Centre, Agra (UP).

Central Water Commission. (2005). Ministry of Water Resources, Government of India. Hand book of water resources statistics.

Chand, M., Kumar, D., Singh, D., Roy, N., & Singh, D.K. (2011). Analysis of rainfall for crop planning in Jhansi district of Bundelkhand zone of Uttar Pradesh. *Indian Journal of Soil Conservation*, 39(1), 20-26.

Chaurasia, P. R., & Chandra, S. (2021). Bundelkhand Water Woes: Paradigm Shift is Needed in the Strategy. *Journal of the Institution of Engineers (India): Series A*, 102(1), 335-345.

Cruz, R.V., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., Honda, Y., Jafari, M., Li, C., & Huu Ninh, N. (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. Edited by Parry, M.L., et al., Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 469-506.

Deo, K., Tripathi, P., Kumar, A., Singh, K., Mishra, S., Mishra, A., & Singh, A. (2015). Trend of rainfall in different sectors of Uttar Pradesh under present scenario of climate change. *International Journal of Environmental Sciences*, 6, 303–310.

Dubey, S. K., Sah, U., & Singh, S. K. (2011). Impact of climate change on pulse productivity and adaptation strategies as practiced by the pulse growers of Bundelkhand region of Uttar Pradesh. *Journal of Food Legumes*, 24(3), 230-234.

Dubey, R. K., Singh, R. K., & Dubey, S. K. (2017). Long-term rainfall trend and drought analysis for Bundelkhand region of India. *Climate Change and Environmental Sustainability*, 5(1), 42-49.

F. S. I. (2005). State of Forest Report, Forest Survey of India, Dehradun.

Gilbert, R.O. (1987). Statistical methods for environmental pollution monitoring, Van Nostrand Reinhold , New York.

Government of India. (2016-17). Annual report, Department of Agriculture, Cooperation & Farmers Welfare Ministry of Agriculture & Farmers Welfare, Government of India.

Government of India. (2012). Final report of minor irrigation and watershed management for the twelfth five year plan (2012-2017), Planning commission, Government of India, New Delhi.

Guhathakurta, P., & Rajeevan, M. (2008). Trends in the rainfall pattern over India. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 28(11), 1453-1469.

Gupta, A. K., Nair, S. S., Ghosh, O., Singh, A., & Dey, S. (2014). Bundelkhand drought: Retrospective analysis and way ahead. National Institute of Disaster Management, New Delhi, 148.

Gupta, A., Sawant, C. P., Rao, K. V. R., & Sarangi, A. (2021). Results of century analysis of rainfall and temperature trends and its impact on agriculture production in Bundelkhand region of Central India. *Mausam*, 72(2), 473-488.

Jain, S. K. (2009). Change in Climate in Bundelkhand and Challenges for Life. Available from:www.indiaenvironmentportal.org.in/content/265039/change-in-climate-in-bundelkhand-andchallenges- for-life/ (accessed 29 April 2016).

Jain, V. K., Pandey, R. P., Jain, M. K., & Byun, H. R. (2017). Spatiotemporal rainfall trends in the twentieth century for Bundelkhand region, India. *Journal of Water and Climate Change*, 8, 441–455.

Jana, C., Alam, N. M., Mandal, D., Shamim, M., & Kaushal, R. (2017). Spatio-temporal rainfall trends in the twentieth century for Bundelkhand region, India. *Journal of Water and Climate Change*, 8(3), 441-455.

Kendall, M.G. (1975). Rank correlation Method, Griffin, London.

Krishnakumar, K. N., Rao, G. P., & Gopakumar, C. S. (2009). Rainfall trends in twentieth century over Kerala, India. *Atmospheric environment*, 43(11), 1940-1944

Mann, H.B. (1945). Nonparametric tests against trend. *Econometrics*, 13, 245–259.

Pai, D.S., Sridhar, L., Rajeevan, M., Sreejith, O.P., Satbhai, N.S., & Mukhopadhyay, B. (2014). Development of a new high spatial resolution (0.25° X 0.25°) Long period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. *Mausam*, 65 (1), 1-18.

Parry, M., Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (2007). Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC (Vol. 4), Cambridge University Press.

Rai, S. K., Behari, P., Satyapriya, A., Rai, K., & Agrawal, R. K. (2012). Long term trends in rainfall and its probability for crop planning in two districts of Bundelkhand region. *Journal of Agrometeorology*, 14, 74–78.

Saharwardi, M. S., Mahadeo, A. S., & Kumar, P. (2021). Understanding drought dynamics and variability over Bundelkhand region. *Journal of Earth System Science*, *130*(3), 1-16.

Singh, R., Rizvi, R. H., Kareemulla, K., Dadhwal, K. S., & Solanki, K. R. (2002). Rainfall analysis for investigation of drought at Jhansi in Bundelkhand region. *Indian Journal Soil Conservation*, 30(2), 117-121.

Thomas, T., Nayak, P. C., & Ghosh, N. C. (2014). Irrigation planning for sustainable rain-fed agriculture in the drought-prone Bundelkhand region of Madhya Pradesh, India. *Journal of Water and Climate Change*, 5(3), 408-426.

Thomas, T., Jaiswal, R. K., Nayak, P. C., & Ghosh, N. C. (2015). Comprehensive evaluation of the changing drought characteristics in Bundelkhand region of Central India. *Meteorology and Atmospheric Physics*, 127(2), 163-182.

Wani, S.P., Sreedevi, T.K., Rockström, J., & Ramakrishna, Y.S. (2009). Rainfed agriculture–Past trends and future prospects. Rainfed agriculture: unlocking the potential*,* 1-35.

Wani, S.P., Garg, K.K., Singh, A.K. & Rockstrom, J. (2012). Sustainable management of scarce water resource in tropical rainfed agriculture. *Soil Water and Agronomic Productivity*, 347–408.

Weibull, W. (1939). A statistical theory of strength of materials. Ing. Vetensk. Akad. Handl., 151, 1-4.