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Assessment of rainfall erosivity for Bundelkhand region of central India using long-term rainfall data

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सार – मृदा अपरदन की रोकथाम के लिए क्षेत्र में अपरदनकारी वर्षा और अन्य संबंधित चरों के दीर्घकालिक मूल्यांकन की आवश्यकता होती है। वर्तमान अध्ययन में, अपरदनकारी वर्षा से संबंधित चार चरों यथा संशोधित फोरनियर इंडेक्स (एमएफआई), अपरदनकारी वर्षा (आर) कारक, कटाव घनत्व (ईडी) और वर्षा एकाग्रता सूचकांक (पीसीआई) की गणना की गई। विश्लेषण में बुन्देलखण्ड क्षेत्र (मध्य भारत) के दीर्घकालिक (1901-2021) दैनिक वर्षा डेटा का उपयोग किया गया। उपरोक्त चर का मूल्यांकन वार्षिक और मौसमी पैमाने पर स्थानिक और अस्थायी परिवर्तनशीलता के लिए किया गया था। आर-फैक्टर मान 3010.61 एमजे.एमएम हेक्टेयर$^{-1}$ एच$^{-1}$ से 5346.53 एमजे.एमएम एचए$^{-1}$ एच$^{-1}$ तक होता है जो दर्शाता है कि यह क्षेत्र मध्यम से गंभीर अपरदन वर्ग से संबंधित है। बुंदेलखंड क्षेत्र के लिए औसत वार्षिक आर-फैक्टर, एमएफआई, ईडी और पीसीआई मूल्यों की गणना क्रमशः 4072.86 एमजे.एमएम एचए$^{-1}$ एच$^{-1}$, 270.55 मिमी, 19.13 एमजे एचए$^{-1}$ एच$^{-1}$ और 28.88 के रूप में की गई थी। यह अध्ययन बुन्देलखण्ड क्षेत्र की मृदा अपरदन की समस्याओं की जानकारी प्रदान की गई है और इसके निवारक उपायों और वाटरशेड विकास गतिविधियों को अपनाने में मदद मिलेगी।

ABSTRACT. Prevention of soil erosion requires long term assessment of rainfall erosivity and other related variables of the region. In the present study, four variables related to rainfall erosivity *i.e*. modified Fournier index (MFI), rainfall erosivity (R) factor, erosivity density (ED) and precipitation concentration index (PCI) were calculated. Long-term (1901-2021) daily rainfall data of Bundelkhand region (Central India) were used in the analysis. The above variables were assessed for spatial and temporal variability on annual and seasonal scale. The R-factor values range from 3010.61 MJ.mm ha^{-1} h^{-1} to 5346.53 MJ.mm ha^{-1} h^{-1}, showing the region belongs to moderate to severe erosivity class. The mean annual R-factor, MFI, ED and PCI values for the Bundelkhand region were calculated as 4072.86 MJ.mm ha^{-1} h^{-1}, 270.55 mm, 19.13 MJ ha^{-1} h^{-1} and 28.88, respectively. This study provides the insights of soil erosion problems of Bundelkhand region and would help in adopting the preventive measures and watershed development activities.

Key words – Bundelkhand, Erosivity density, Modified fournier index, Precipitation concentration index, Rainfall erosivity factor.

1. Introduction

Soil erosion due to water is considered to be the major form of land degradation problem in India. About 120.7 million hectare (mha) geographical area of the country faces different forms of land degradation issues, of which water erosion contributes a major part of about 83 mha (68.4%) (NAAS, 2010). Every year a layer of productive soil is washed away with runoff water, which gets deposited to streams and reservoirs. Annual average soil loss quantum of the country is about 1535 t km^{-2} yr^{-1} (Sharda and Ojasvi 2016). This in turn resulted in loss of 5.37 to 8.4 million tonnes (mt) of soil nutrients per year, reduction in soil fertility and crop production, reduction in reservoirs and channel capacity (1% to 2% annually), occurrence of floods, and damage biodiversity. Rainfall characteristics of a region are of paramount importance for runoff and soil erosion studies. Soil loss due to erosion is directly proportional to the rainfall intensity, amount and duration (Pandey *et al*., 2009; Tiwari *et al*., 2016).

Various models have been developed and tested for soil loss estimation under different locations and conditions. One of the most widely-used soil erosion models is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1961, 1965). USLE is a simple empirical model compared to complex process-based models, comprising all the factors affecting the soil erosion process. USLE estimates annual average soil loss of an area by multiplying five factors, *viz*., rainfall erosivity factor (R), soil erodibility factor (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice (P) factor. This model has gone through several revisions to make it more robust and accurate and named as revised universal soil loss equation (RUSLE) with latest version codes.

Rainfall erosivity factor (R) of USLE equation shows the potential of rainfall to cause erosion (Wischmeier, 1959; Wischmeier and Smith, 1958; Lal, 2001) and was derived from research data of various experiments. Based on the experiments, it is reported that when all factors other than rainfall are held constant, soil loss from the cultivated field is directly proportional to rainstorm parameters: the total storm energy (E) multiplied by the maximum 30-min rainfall intensity (I_{30}) (Renard *et al*., 1997).

In computing the R factor, the maximum 30-min rainfall intensities data for each storm and rain events need very high-resolution pluviographic rainfall data for a very long period (about 15-20 years). For this purpose, self-recording rain gauges are required, which are usually very expensive, and even when sufficient pluviographic data are available, the computational procedure of the R factor is challenging and complicated. Thus, rainfall erosivity factor is typically known only at a few locations. In developing country like India, it is very difficult to get such long-term high-resolution precipitation data of any location especially, for the remote stations. To overcome this problem, different researchers have proposed indirect models for estimating R factor using readily available precipitation data at longer time scales (Renard and Freimund, 1994). Among such models, annual precipitation data are widely used, since long-term annual precipitation data series are available in most regions of the world and are fairly reliable. Furthermore, various authors have reported that a good correlation exists between the annual rainfall erosivity and the annual precipitation amount at many locations around the world (Stocking and Elwell 1976; Bergsma *et al*., 1996; Xin *et al*., 2010). In India, many researchers made attempt to develop the rainfall erosivity prediction models by correlating the R factor values with average annual precipitation (Singh, 1981; Ram babu*et al*., 1978). However, Modified Fournier Index has been most widely used for calculating rainfall erosivity factor using monthly rainfall data series (Tiwari *et al*., 2016; Ghosh, 2013; Karami *et al*., 2012) Moreover, various indices and factors have been developed to describe the potential of rainfall in relation to erosion, *viz*., Erosivity index (Wischmeier and Smith, 1958), Fournier Index (Fournier 1960), Modified Fournier Index (Arnoldus, 1980), Precipitation Concentration Index (Oliver 1980) and Erosion Density (Kinnell, 2010). The proper knowledge of these rainfall derived indices such as PCI and ED are of great importance in detecting erosive potential of rainfall, which may contribute to soil erosion process. The PCI is widely used for extreme rain event analysis, erosion estimation, and warning tool regarding flooding and erosion (Coscarelli and Caloiero 2012; Duan *et al*., 2014).

The *Bundlekhand* region having mixed red-black soil, undulating topography and sparse vegetation, make it the most susceptible to soil erosion (Gupta *et al.*, 2021). All districts come under severe to very severe land degradation category. The *Bundelkhand* region in India is known for its arid climate, with a semi-arid to arid tropical climate. Vegetation in this region is mainly dominated by scrubland, with scattered trees and shrubs. The region has a mix of natural vegetation and human-made forests. The natural vegetation in the region includes grasses, small shrubs, and trees such as Acacia, Prosopis and Butea. The region also has a number of rare and endangered plant species like the Beri, Kachnar, and Dhak. The human-made forests in the region are mainly located in the Vindhyan and Satpura ranges. These forests are mainly composed of teak, sal and other deciduous trees. Soil erosion, deforestation, encroachment on lands, bush fires, shifting cultivation, mining and improper land uses are major issues requiring thorough understanding when talking about climate change and its effects on the natural resources, as these elements compound land degradation which is a major challenge for agriculture and food security in India. In such circumstances, the total amount of precipitation as well as its distribution and concentration are prerequisite for the quantification of R factor, since it is the main component that provides energy for soil erosion. Overall, the vegetation and tree cover canopy in the *Bundelkhand* region have been under pressure due to human activities like agriculture, grazing, and logging. The degradation of natural vegetation has also contributed to soil erosion and land degradation in the region. However, there have been efforts to protect and restore the vegetation cover in the region, including afforestation programs and conservation initiatives. The main objective of this work is to analyse the spatial and temporal variability of rainfall erosivity and other rainfall associated factors for *Bundelkhand* region based on mean monthly rainfall data of each district of the study area. Five factors were calculated using long-term (120 years) monthly rainfall data for the *Bundelkhand* region: total annual rainfall (P), modified Fournier index (MFI),

TABLE 1

Details of the different districts of study area

District	Latitude	Longitude	Elevation(m)	Total Area(ha)	Average annual rainfall (mm)	Length ofdata (year)
Jhansi	25° 44′ N	78° 56′ E	285	5,01,329	840.86	1901-2021
Hamirpur	25° 79′ N	80° 00′ E	80	3,90,178	811.20	1901-2002
Mahoba	25° 29′ N	79° 87′ E	214	3,27,429	866.10	1901-2021
Banda	25° 49′ N	80° 33′ E	123	4,38,767	864.57	1901-2021
Chitrakoot	25° 17′ N	80° 86′ E	137	3,38,897	910.36	1901-2021
Jalaun	26° 14′ N	79° 32′ E	144	4,54,434	764.79	1901-2021
Lalitpur	24° 68′ N	79° 58′ E	428	5,07,500	958.82	1901-2021
Datia	25° 66′ N	78° 46′ E	420	2,95,874	763.81	1901-2021
Chhatarpur	24° 91′ N	78° 58′ E	305	8,63,036	1035.13	1901-2021
Sagar	23° 83′ N	78° 73′ E	427	10,22,759	1164.08	1901-2021
Damoh	23° 83′ N	79° 44′ E	595	7,02,924	1150.93	1901-2021
Panna	24° 71′ N	80.1819°E	410	7,02,924	1112.92	1901-2021
Tikamgarh	24° 74′ N	78.8321°E	349	5,04,002	914.16	1901-2021

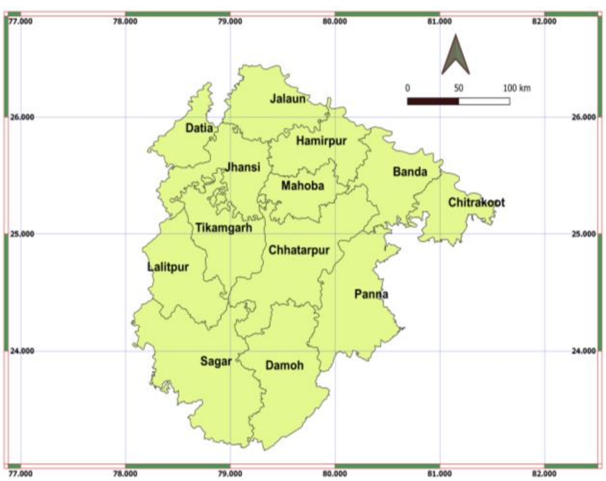


Fig. 1. Location map of study area

Rainfall erosivity (R) factor, Oliver's precipitation concentration index (PCI) and erosivity density (ED) at seasonal as well as annual scale for proper assessment of variability of the region.

2. Material and methods

2.1. *Study area*

The Bundelkhand region situated at the central part of India (Fig. 1). This region covers a total geographical area of 7.08 million hectares and comprises thirteen districts: seven in Uttar Pradesh - Jhansi, Jalaun, Lalitpur, Hamirpur, Mahoba, Banda and Chitrakoot, and six in Madhya Pradesh -Datia, Tikamgarh, Chattarpur, Damoh, Sagar and Panna. Bundelkhandregion is located 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 MSL. Details of each district of the study area have been provided in Table 1.

2.2. *Data used*

To study the rainfall erosivity of Bundelkhandregion of India, we used the high-resolution IMD gridded data of 0.25° × 0.25° resolution from 1901 to 2021. The daily gridded precipitation data for Bundelkhand region wasdownloaded in Binary format at 0.25° × 0.25° resolution from India Meteorological Department (https://www.imdpune.gov.in/cmpg/Griddata/Rainfall25Bin.html). The Binary files of each year were extracted using IMDLIB package. IMDLIB is a python package to download and handle binary gridded data from the India Meteorological Department (IMD). The Bundelkhand region is covered by a total of 100 grids. The data series are quite accurate and highly reliable for meta-analysis. The gridded data were extracted in the form of daily rainfall and then from daily rainfall data, monthly, annual and seasonal rainfall are prepared for each grid point over the region corresponding to analysis period. To investigate the seasonal changes in the rainfall erosivity variables, the whole year was bifurcated into four seasons such as winter

(December-February), pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October-November).

2.3. *Statistical analysis*

Basic statistics, *viz*., mean, Standard deviation (SD) and coefficient of variation (CV) have been estimated for each rainfall erosivity parameter.

2.4. *Modified Fournier Index*

In 1960 Fournier highlighted an index to describe aggressiveness of rainfall causing erosion when the hourly precipitation data is not available, named as Fournier Index (FI) (Fournier 1960). This index was calculated by dividing the square of wettest month rainfall to the total annual rainfall and can be found in Equation below.

$$I_F = \frac{P_m^2}{P}$$

where, P_m is the maximum monthly rainfall (mm) and P is the annual rainfall (mm).

Since, Fournier's index had some shortcomings, which were subsequently modified by Arnolds (1980), known as modified Fournier Index (MFI) (Equation).

$$\text{MFI} = \frac{\sum_{i=1}^{12} P_i^2}{P}$$

where, P_i is the rainfall amount in the, *i* month (mm); and *P* is the annual rainfall (mm).

CEC (1992), classified the MFI values in the different erosivity classes. Values of MFIs above than 160 are belong to ‘very severe erosivity class’. The values between 120 to 160 belong to ‘severe erosivity class’; values between 90 to 120 comes under ‘moderate erosivity class’; 60 to 90 considered in ‘low erosivity class’, and values less than 60 belong to ‘very low erosivity class’.

2.5. *Rainfall erosivity*

Arnoldus (1980) has shown a good relationship between annual rainfall and rainfall erosivity for the regions where no high-resolution precipitation data are available. The approximation equation is described as follows:

$$R = 1.735 \times 10^{\left(1.5 \times \log_{10} \sum_{i=1}^{12} \frac{p_i^2}{p} - 0.8188\right)}$$

where, P_i is the rainfall amount in the *i* month (mm); and *P* is the annual rainfall (mm).

Further Carvalho (2008) classified severity of erosion based on the R-factor value. According to Carvalho (2008), R-factor values (MJ mm ha^{-1} h^{-1}) less than or equal to 2452 belong to low erosivity class, values between 2542-4905 belong to moderate erosivity class, between 4905-7357 values represent moderate to severe erosivity class, values between 7357-9810 represent severe erosivity class and values more than 9810 show very severe erosivity class.

2.6. *Precipitation concentration Index*

Oliver (1980) proposed a rainfall-based index which was further developed by De Luis *et al*., (2010) to estimate the monthly rainfall heterogeneity, known as precipitation concentration index (PCI). High PCI values show highly erosive nature of rainfall and vice versa. Thus, PCI can be considered as an important index affecting erosivity of storm (Apaydin *et al.* 2006; De Luís *et al*., 2010; Elagib, 2011), Calculated as follows (Equation):

$$\text{PCI} = 100 \, \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i^2\right)^2}$$

where, P_i is the monthly rainfall amount for the *i* month and *P* is the total annual rainfall.

Oliver classified the PCI values as follow: PCI < 10 indicates uniform precipitation distribution; PCI values between 11-15 indicates moderate precipitation distribution; PCI values between 16 to 20 indicates irregular precipitation distribution, PCI > 20 indicates a highly irregular precipitation distribution.

2.7. *Erosivity density*

The erosivity density (ED) is the ratio of rainfall erosivity (R) factor to precipitation amount, calculated on monthly or yearly scale (Kinnell, 2010). Practically, it measures the erosivity per unit rainfall amount, expressed as MJ·$ha^{-1}h^{-1}$. For any station, the ED is calculated as (Equation):

$$ED_i = \frac{R_i}{P_i}$$

where, ED_i is the Erosivity Density value for *i* month, *R* is rainfall erosivity value for *i* month and *P* is rainfall amount for *i* month.

TABLE 2

Statistical analysis of annual and seasonal rainfall (mm)

District		Annual Average	Winter	Pre-monsoon	monsoon	Post-monsoon
Jhansi	Mean	840.86	35.50	18.39	753.07	33.90
	SD	237.96	74.96	18.57	211.88	48.45
	CV (%)	28.30	211.16	101.00	28.13	142.93
Hamirpur	Mean	811.20	36.70	18.53	724.00	31.96
	SD	218.80	68.02	18.17	199.09	43.35
	CV (%)	26.97	185.33	98.05	27.50	135.62
Mahoba	Mean	866.10	37.31	17.98	778.78	32.03
	SD	261.96	72.10	19.05	243.91	42.38
	CV (%)	30.25	193.25	105.96	31.32	132.29
Banda	Mean	864.57	38.15	20.70	772.30	33.50
	SD	228.70	61.90	22.90	217.70	45.00
	CV (%)	26.45	162.25	110.63	28.19	134.33
Chitrakoot	Mean	910.36	41.71	21.41	811.82	35.43
	SD	231.88	68.32	25.07	216.26	42.82
	CV (%)	25.47	163.82	117.10	26.64	120.86
Jalaun	Mean	764.79	36.17	18.11	676.75	33.77
	SD	243.19	74.28	19.07	219.24	46.84
	CV (%)	31.80	205.38	105.34	32.40	138.72
Chhatarpur	Mean	1035.13	41.65	19.89	934.13	39.47
	SD	245.17	70.77	20.73	233.48	48.77
	CV (%)	23.68	169.93	104.19	24.99	123.59
Datia	Mean	763.81	31.26	16.73	685.21	30.61
	SD	225.72	66.33	19.36	206.38	47.11
	CV (%)	29.55	212.21	115.70	30.12	153.88
Lalitpur	Mean	958.82	38.28	14.36	870.53	35.65
	SD	269.86	86.38	15.57	237.36	48.60
	CV (%)	28.14	225.66	108.40	27.27	136.33
Sagar	Mean	1164.08	45.19	21.84	1055.91	41.14
	SD	282.47	104.37	21.94	250.16	48.69
	CV (%)	230.95	230.95	100.44	23.69	118.35
Damoh	Mean	1150.93	45.90	22.61	1041.21	41.21
	SD	255.98	91.77	23.21	231.14	46.55
	CV (%)	22.24	199.94	102.67	22.20	112.97
Panna	Mean	1112.92	47.23	21.83	1002.90	40.96
	SD	276.92	79.72	23.94	261.81	46.93
	CV (%)	24.88	168.79	109.70	26.11	114.56
Tikamgarh	Mean	914.16	38.27	17.59	822.60	35.69
	SD	253.64	84.56	19.92	225.15	50.20
	CV (%)	27.75	220.95	113.22	27.37	140.64

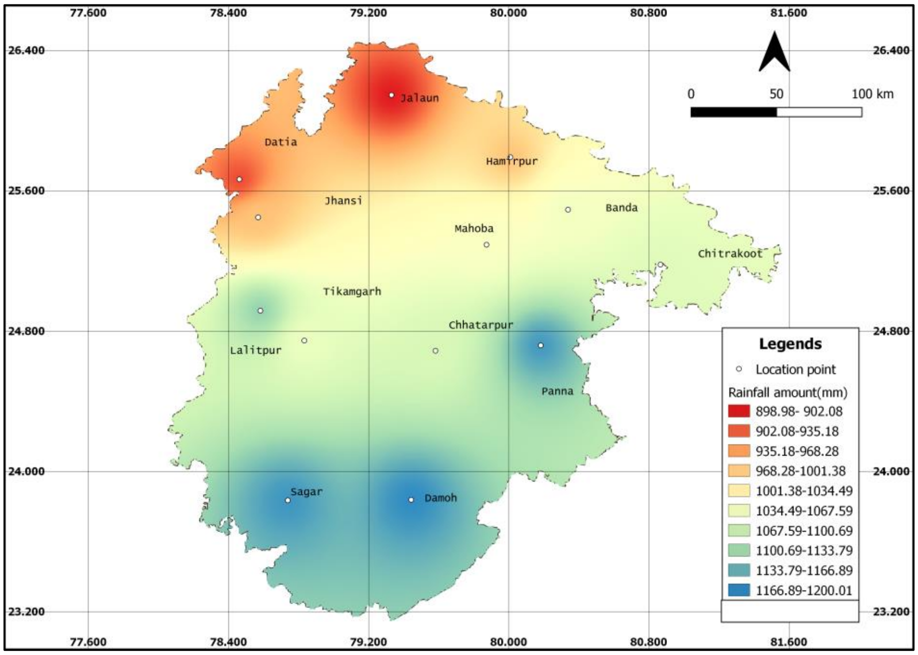


Fig. 2. Spatial variability map of rainfall of *Bundelkhand* region

The ED values are highly dependent on rainfall intensity, and impact the event sediment loss (*i.e*., amount of soil loss per unit amount of water). Higher ED values (>3 $MJ \cdot ha^{-1}h^{-1}$) indicate high-intensity rainfall for particular month or year; which may generate high runoff or high amount of soil loss (Dabney *et al*., 2011). ED values on seasonal and annual basis were calculated using monthly rainfall data.

2.8. *Spatial interpolation scheme*

The spatial variability or spatial interpolation of R factor, PCI, ED, MFI and annual rainfall were performed in QGIS using platform using inverse distance weight (IDW) interpolation method. In IDW method, the attribute value of unknown location point is calculated with weighted average values of known location point from local neighbouring region surrounding the unobserved location.

2.9. *Determination and correlation coefficients and development of linear regression model between rainfall and R and MFI values*

Pearson's coefficient of correlation, the degree of correlation between rainfall and erosivity indices was established from the equation given below:

$$r = \frac{\sum uv}{N_{\sigma u\ \sigma v}}$$

where r = correlation coefficient between the two variables; $u = (U - U_{\text{mean}})$, $v = (V\text{-}V_{\text{mean}})$; σu and σv = standard deviationsof variable U and V respectively; N = total observations of UV variables.

Also, a linear regression model was adopted to develop a linear equation among the rainfall and erosivity parameters in the study.

3. Results and discussion

3.1. *Rainfall characteristics of the region*

The standardised annual and seasonal series were prepared using 121 years of rainfall data. The statistical analysis of rainfall data of all thirteen districts has been presented in Table 2. From the Table, it is observed that Sagardistrict received the highest annual average as well as highest monsoon season rainfall. Datia district received the lowest annual average and seasonal rainfall followed by Jalaun district. The annual average rainfall varies from 1164.08 mm for Sagar to 763.81 mm for Datia district. The highest coefficient of variation (CV) for annual rainfall (31.80 %) was obtained for Jalaun district while the lowest coefficient of variation (22.24 %) was obtained for Damoh district. Rainfall spatial variability map of the study area is provided in Fig. 2; it is evident that northern part received less average annual rainfall than the southern part of Bundelkhand region.

TABLE 3

Statistical Analysis of Modified Fournier Index and R- Factor

District	Statistics	MFI (mm)					R- Factor (MJ.mm/ha.h)				
		Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon
Jhansi	Mean	245.69	4.58	0.54	237.48	3.09	3542.21	91.13	0.94	3434.32	90.12
	SD	88.66	36.81	1.05	84.34	6.95	2232.32	970.23	2.73	2070.45	970.37
	CV	36.09	803.12	193.73	35.51	224.99	63.02	1064.71	291.14	60.29	1076.75
Hamirpur	Mean	230.68	4.38	0.55	222.97	2.78	3147.97	78.86	1.06	3055.08	76.86
	SD	76.04	33.16	1.29	72.96	6.00	1862.61	829.45	4.81	1732.44	829.64
	CV	32.97	757.62	233.21	32.72	215.74	59.17	1051.87	456.02	56.71	1079.36
Mahoba	Mean	257.28	4.46	0.71	249.63	2.48	3886.72	84.49	1.88	3790.37	83.39
	SD	100.60	34.89	1.87	98.49	4.71	2652.20	895.44	7.35	2561.90	895.55
	CV	39.10	782.09	264.12	39.45	189.81	68.24	1059.77	391.90	67.59	1073.97
Banda	Mean	248.40	4.10	0.70	240.80	2.90	3561.10	65.70	1.40	3480.20	63.40
	SD	83.80	29.20	1.60	84.40	6.50	2113.00	683.60	5.70	2072.50	683.80
	CV	33.74	712.20	228.57	35.05	224.14	59.34	1040.49	407.14	59.55	1078.55
Chitrakoot	Mean	252.24	4.56	0.68	244.28	2.72	3503.29	75.85	1.39	3415.26	72.31
	SD	79.37	31.96	1.63	78.62	4.81	1936.86	784.46	4.98	1855.30	784.73
	CV	31.46	700.31	238.62	32.18	176.66	55.29	1034.20	359.64	54.32	1085.26
Jalaun	Mean	220.03	4.96	0.57	211.13	3.37	3010.61	91.16	1.08	2904.16	87.65
	SD	88.26	36.23	1.27	83.40	7.71	2157.82	945.73	4.36	1963.99	949.96
	CV	40.11	729.75	225.49	39.50	228.90	71.67	1037.43	402.59	67.63	1083.81
Chhatarpur	Mean	299.77	4.37	0.51	291.94	2.96	4698.21	79.38	0.85	4604.49	79.33
	SD	93.97	33.45	1.07	94.01	6.13	2586.66	841.14	2.81	2545.66	841.18
	CV	31.35	765.89	212.48	32.20	207.02	55.06	1059.65	330.59	55.29	1060.39
Datia	Mean	226.67	4.20	0.60	218.62	3.24	3150.65	75.87	1.35	3054.38	73.71
	SD	82.98	32.25	1.48	81.68	8.25	1946.28	794.16	5.37	1857.26	794.30
	CV	36.61	767.26	246.18	37.36	254.69	61.77	1046.69	396.68	60.81	1077.62
Lalitpur	Mean	293.74	4.92	0.33	285.62	2.87	4781.12	109.49	0.49	4644.40	110.59
	SD	101.23	41.66	0.73	97.50	7.30	2885.11	1173.17	1.52	2736.46	1173.14
	CV	34.46	846.90	222.39	34.13	254.55	60.34	1071.44	310.86	58.92	1060.76
Sagar	Mean	331.09	5.94	0.58	322.11	2.46	5346.53	147.62	1.09	5188.83	149.45
	SD	100.11	51.18	1.17	91.97	4.47	2945.75	1591.11	3.39	2579.92	1591.00
	CV	30.24	862.34	201.37	28.55	181.59	55.10	1077.87	312.05	49.72	1064.55
Damoh	Mean	322.20	5.41	0.62	313.78	2.39	5068.43	118.08	1.25	4940.86	117.58
	SD	92.53	43.83	1.36	88.77	3.98	2619.53	1260.92	4.17	2427.84	1260.98
	CV	28.72	810.62	218.94	28.29	166.68	51.68	1067.81	332.62	49.14	1072.47
Panna	Mean	316.79	4.97	0.62	308.52	2.69	5064.18	93.78	1.34	4958.70	92.44
	SD	108.08	37.27	1.47	108.35	4.83	3030.10	988.66	5.35	2979.52	988.80
	CV	34.12	750.69	237.64	35.12	179.82	59.83	1054.25	398.81	60.09	1069.68
Tikamgarh	Mean	272.53	4.91	0.54	264.00	3.09	4186.15	106.47	1.07	4061.93	106.74
	SD	93.68	41.07	1.31	89.34	7.83	2468.18	1143.39	3.77	2282.66	1143.42
	CV	34.37	836.25	244.86	33.84	253.45	58.96	1073.92	351.31	56.20	1071.26
Bundelkand	Mean	270.55	4.75	0.58	262.37	2.85	4072.86	93.68	1.17	3964.08	92.58
	SD	91.49	37.15	1.33	88.75	6.11	2418.18	992.42	4.33	2281.99	992.84
	CV	34.10	778.85	228.28	34.15	212.16	59.96	1056.93	364.72	58.17	1073.42

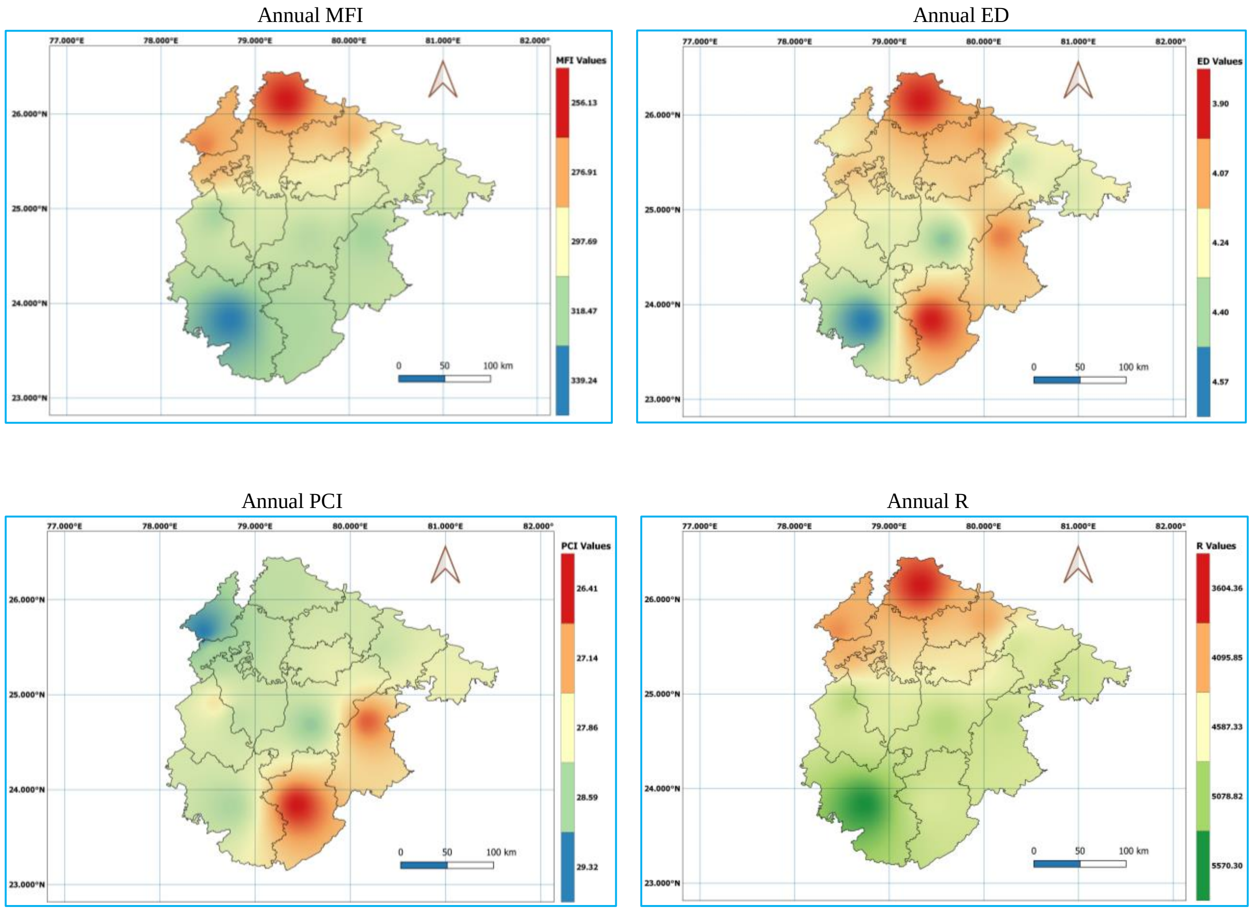


Fig. 3. Spatial variability of annual MFI, R, PCI and ED values for *Bundelkhand* region

3.2. *Spatial and temporal variations of annual and seasonal Modified Fournier Index (MFI) values*

The statistical analysis for seasonal and annual MFI for all 13 districts of Bundelkhand region is presented in Table 3. The mean annual MFI value was found as 270.55 mm for the study area. The highest annual MFI value was calculated for Sagar (331.09 mm) district followed by Damoh (322.20 mm) district. However, the lowest MFI value was observed for Jalaun (220.03 mm) district. MFI values of other districts vary between 230-330 mm. The mean SD for the region was estimated as 91.49 mm with highest value for Panna (108.08 mm) district and lowest value for Hamirpur (76.04 mm) district. The mean CV value for study area was found as 34.10%, with highest value obtained in Jalaun (40.11 %) district and lowest value (28.72 %) for Damoh district.

On seasonal basis, monsoon season is the most erosive season with mean MFI value of 262.37 mm, which is approximately 98% of annual MFI value. The mean highest value of monsoon MFI was found for Sagar (322.11 mm) district and lowest value for Jalaun (211.13 mm) district. Moreover, similar trend was observed in the SD of monsoon MFI, with mean value of 88.75 mm. MFI value of all meteorological districts of study area varies between 250-350 mm, reflecting the region comes under severe erosivity class.

The spatial variability maps of annual and monsoon MFI value of study area have been provided in Figs. 3&4. It was observed from the figure that the MFI value increases as one moves from north to south. Districts located at the southeast side show high MFI values compared to other part of study area. The spatial pattern of annual MFI and annual rainfall variation of the study area is the same. Temporal variation of MFI for each districtare presented in Fig. 5. There is much year-to-year variation in the MFI values for whole study period (1901-2021), these fluctuations happened in response to variation in rainfall pattern in the respective districts (Fig. 5). High MFI value results into high rainfall erosivity factor and may cause high soil erosion problem.

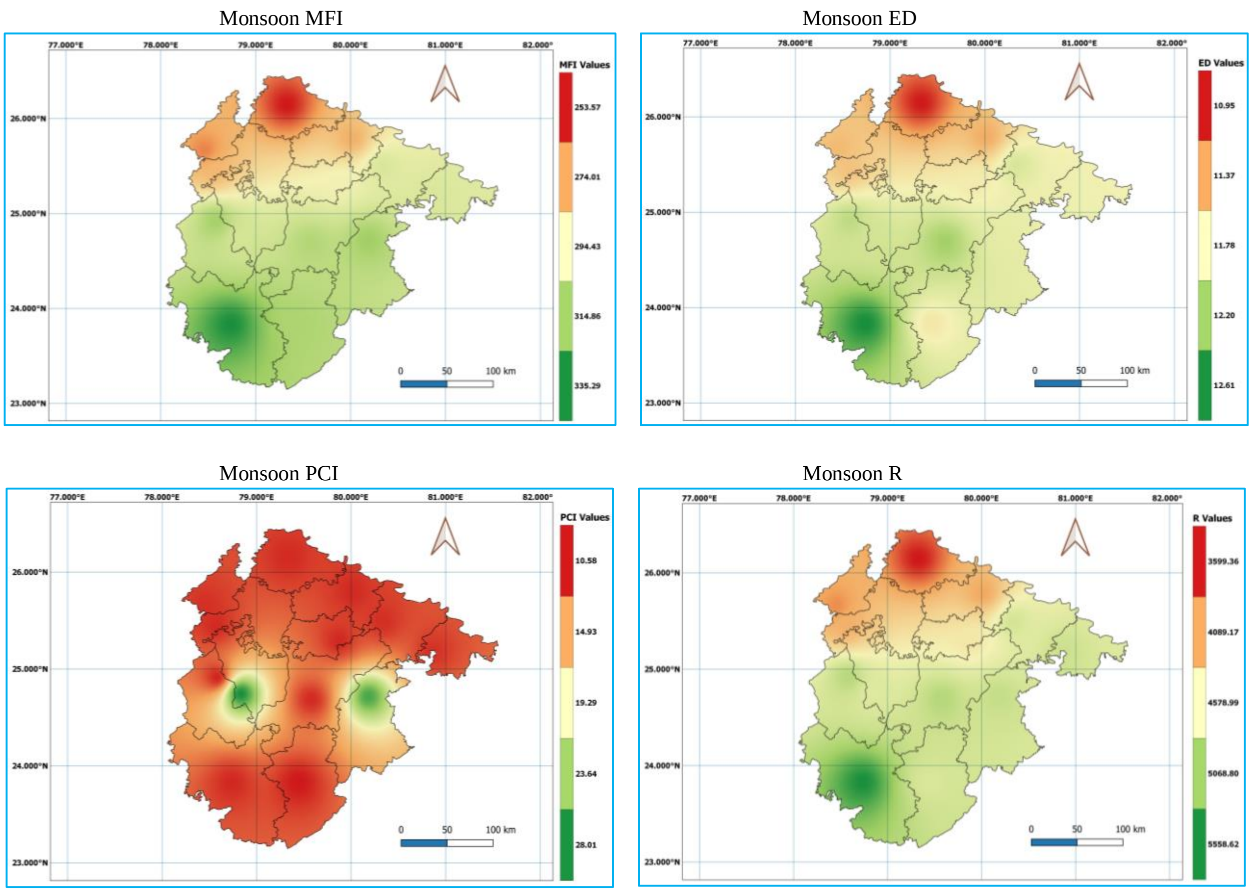
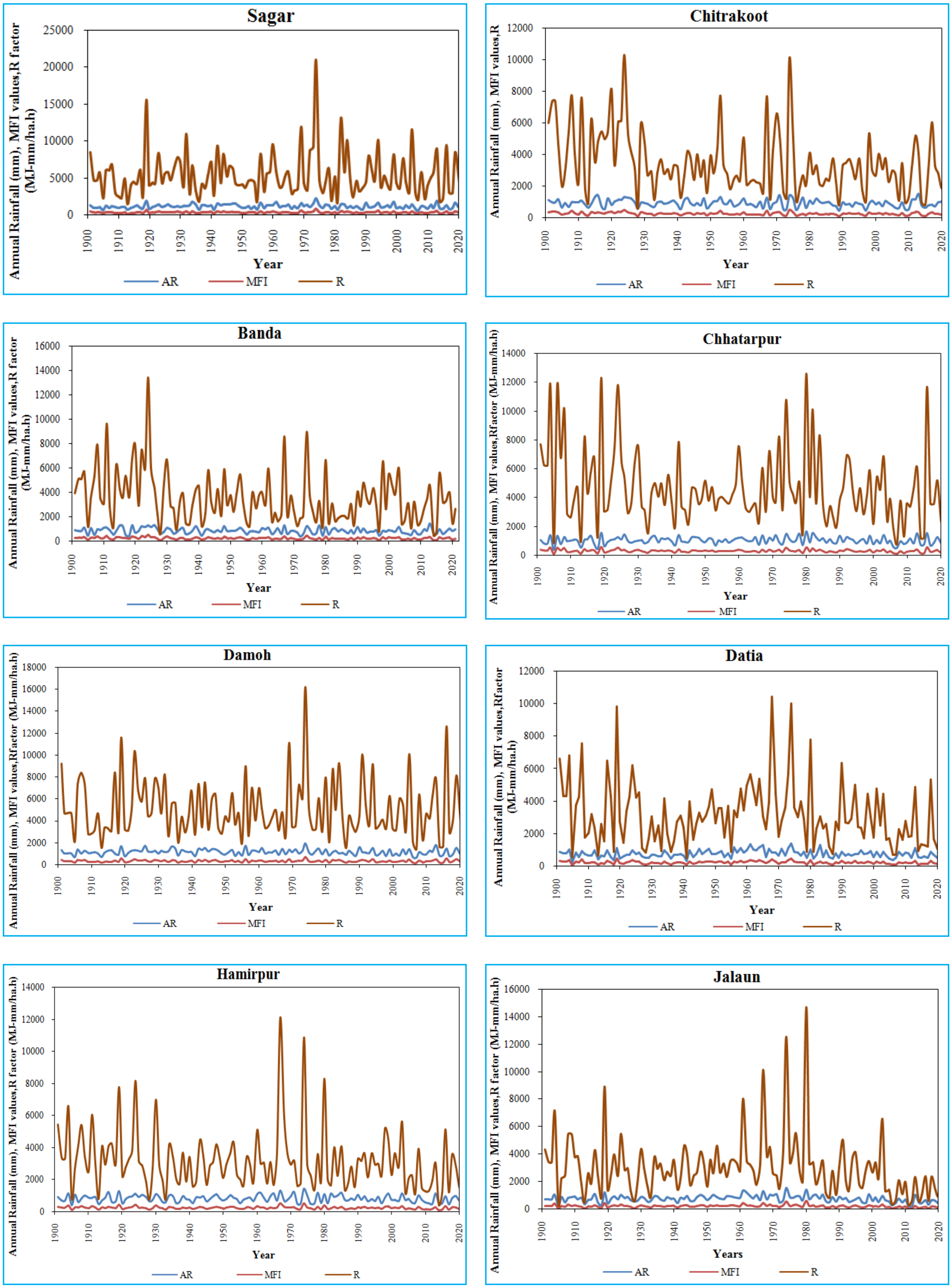


Fig. 4. Spatial variability of monsoon MFI, R, PCI and ED value for *Bundelkhand* region

3.3. *Spatial and temporal variations of annual and seasonal rainfall erosivity (R) factor*

The basic statistical analysis for seasonal and annual R factor of each 13 districts of Bundelkhand region is presented in Table 3. The mean annual value of R-factor for the whole study area is calculated as 4072.86 MJ.mm ha^{-1} h^{-1}. The highest annual mean value of R-factor was calculated for Sagar (5346.53 MJ.mm ha^{-1} h^{-1}) district followed by Damoh (5068.43 MJ.mm ha^{-1} h^{-1}) district. The lowest R-factor (3010.61 MJ.mm ha^{-1} h^{-1}) value was calculated for Jalaun district, since this district receives less amount of rainfall with few rain events in the monsoon season. Value of R- factor for rest of the districts varied between 3000-5000 MJ.mm ha^{-1} h^{-1}. The mean SD was found as 2418.18 MJ.mm ha^{-1} h^{-1} for the study area with highest SD value for Sagar (2945.75 MJ.mm ha^{-1} h^{-1}) district and lowest value for Hamirpur (1862.61 MJ.mm ha^{-1} h^{-1}) district. Similarly, mean CV value for whole region was found as 59.96%, with highest value for Jalaun (71.67%) district and lowest value (51.68%) for Damoh district. The variability of R-factor was found more than the mean annual rainfall variability of the region. The mean calculated CV for R factor was greater than the CV of MFI and rainfall. As per the classification given by Carvalho, 2008, Damoh, Panna and Sagar districts come under the moderate to severe erosivity class, where values of R-factor were found more than 4905 MJ.mm ha^{-1} h^{-1}. However, rest 10 districts belong to moderate erosivity class, since, the values vary between 2542-4905 MJ.mm ha^{-1} h^{-1}. Overall, the whole region belongs to moderate erosivity class.

On seasonal basis, Monsoon is the most erosive season with mean R-factor value of 3964.08 MJ.mm ha^{-1} h^{-1}. About 97 % of rainfall erosivity occurs in monsoon season, since the region receives about 80-90% rainfall in this season by south-west monsoon. Rest other seasons show very less R-factor value. The mean monsoon R-factor value ranges from 2904.16 MJ.mm $ha^{-1}h^{-1}$ to 5188.83 MJ.mm ha^{-1} h^{-1} for all districts, with highest value for Sagar district and lowest value for Jalaun district. The mean R-factor values for winter, pre-monsoon and post-monsoon districts are 93.68, 1.17 and 92.58, respectively.



Sagar
Annual Rainfall (mm), MFI values,R factor (MJ-mm/ha.h)
Year
AR
MFI
R
Chitrakoot
Annual Rainfall (mm), MFI values,R
Year
AR
MFI
R
Banda
Annual Rainfall (mm), MFI values,R factor (MJ-mm/ha.h)
Year
AR
MFI
R
Chhatarpur
Annual Rainfall (mm), MFI values,Rfactor (MJ-mm/ha.h)
Year
AR
MFI
R
Damoh
Annual Rainfall (mm), MFI values,Rfactor (MJ-mm/ha.h)
Year
AR
MFI
R
Datia
Annual Rainfall (mm), MFI values,Rfactor (MJ-mm/ha.h)
Year
AR
MFI
R
Hamirpur
Annual Rainfall (mm), MFI values,R factor (MJ-mm/ha.h)
Year
AR
MFI
R
Jalaun
Annual Rainfall (mm), MFI values,R factor (MJ-mm/ha.h)
Years
AR
MFI
R

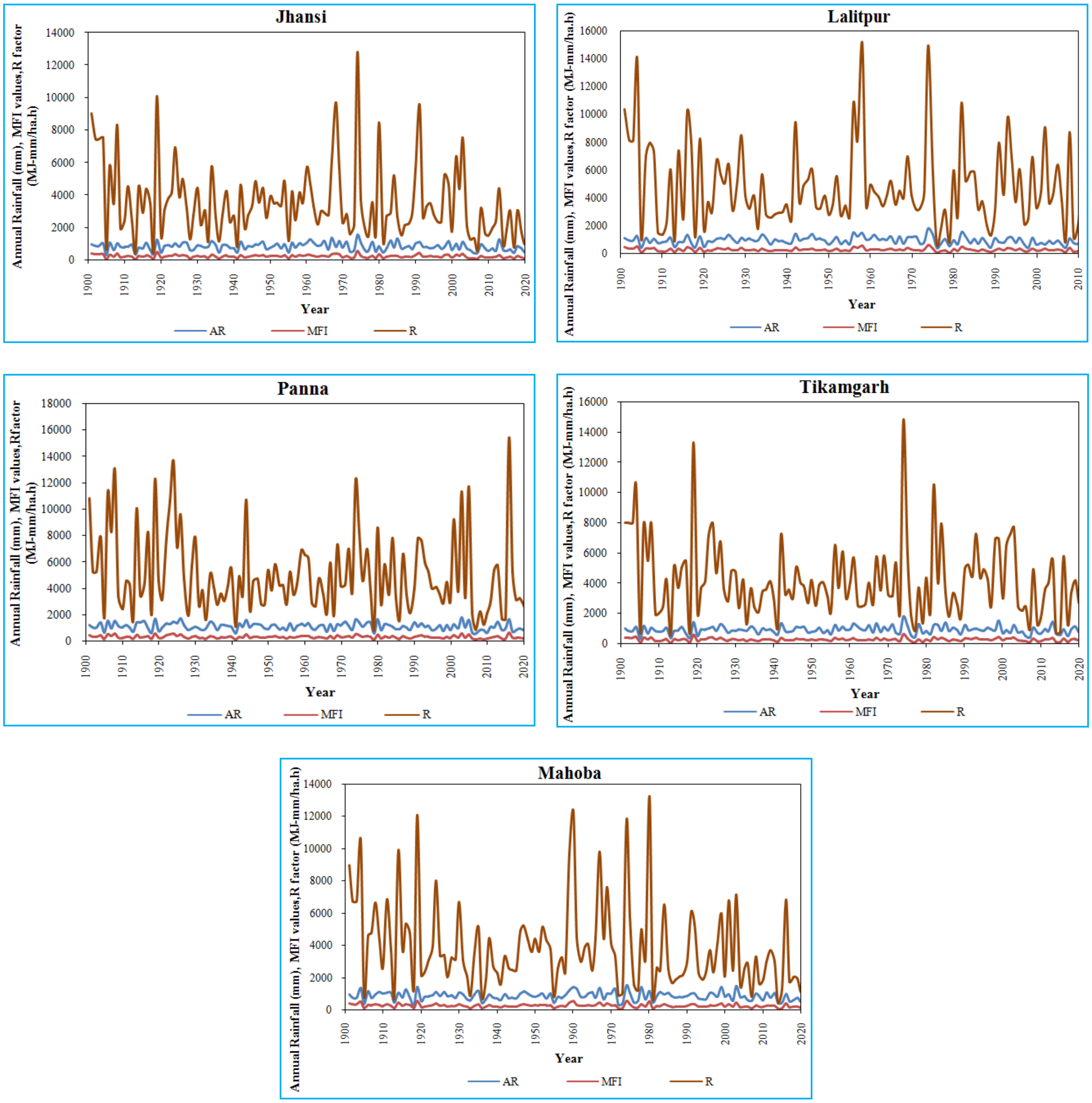


Fig. 5. Year-to-year variations of annual rainfall, MFI and R-factor values of different districts

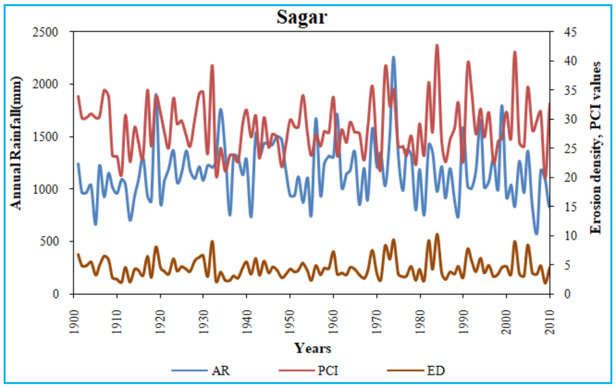
Looking at the spatial variability maps (Figs. 3&4) of annual and monsoon rainfall erosivity (R-factor) of study area, it is evident that value of R-factor increases as one moves from north to south. However, no such change is observed, while moving from east to west. The spatial pattern of R-factor variation is similar to the variation of annual rainfall of the study area. Districts located at the southeast side show high R-factor value compared to other parts of study area. The districts with high R-factor value are the most vulnerable for soil erosion problem.

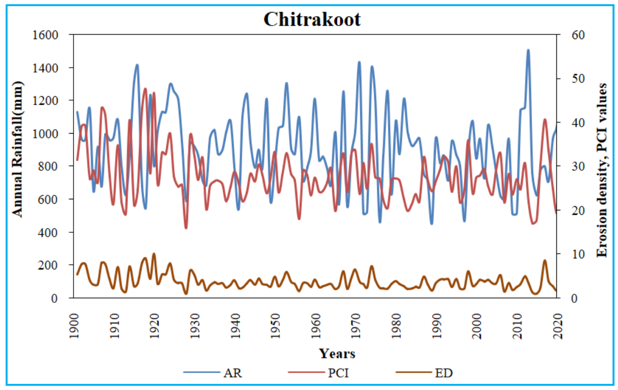
Year-to-year variation in R-factor for each district are presented in Fig. 5. From the Figure, it was clearly observed that there is drastic change in the annual R-factor from year to year. These fluctuations in the value of R-factor for whole study period (1901-2021), closely resemble the pattern of rainfall in the respective districts. High rainfall year creates high rainfall erosivity value, while deficit rainfall years show less value of rainfall erosivity factor. Mean spatial distribution pattern of the annual R-factor is similar to the annual rainfall of the

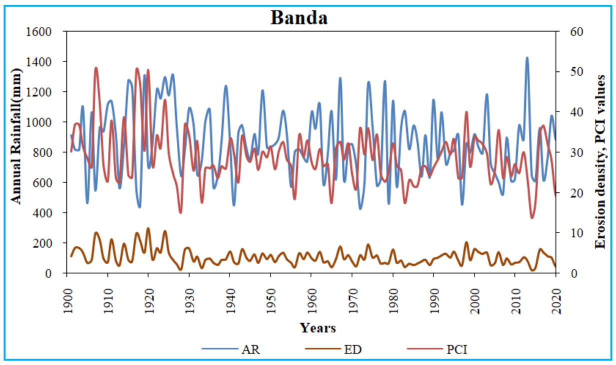
TABLE 4

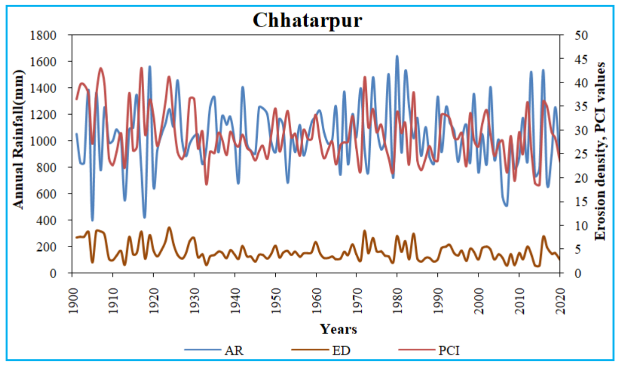
Statistical analysis of erosivity density (ED) and PCI

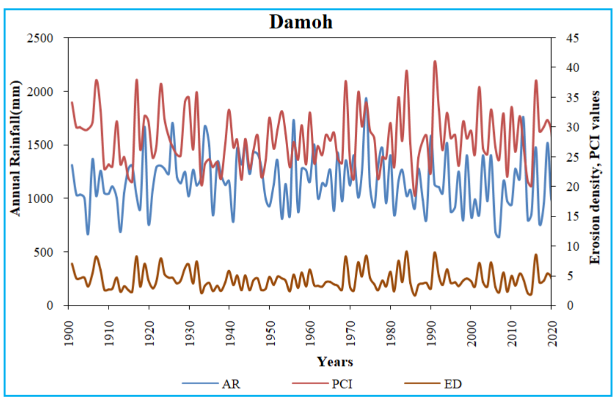
District	Statistics	ED(MJ/ha.h)					PCI				
		Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon
Jhansi	Mean	4.02	0.17	0.03	3.50	0.13	29.03	15.50	14.90	11.54	12.97
	SD	1.92	1.22	0.05	2.88	0.28	5.73	5.01	4.42	2.04	3.23
	CV	47.84	718.54	201.84	82.15	216.62	19.75	32.33	29.67	17.66	24.89
Hamirpur	Mean	3.78	0.17	0.03	3.50	0.12	28.52	15.87	15.20	11.39	13.50
	SD	1.59	1.16	0.07	2.48	0.25	5.44	5.00	4.57	1.91	3.21
	CV	41.98	677.36	255.28	70.72	208.20	19.07	31.50	30.08	16.79	23.76
Mahoba	Mean	4.22	0.17	0.04	3.78	0.11	29.45	16.45	15.18	11.68	12.94
	SD	2.03	1.17	0.11	3.14	0.20	5.83	4.99	4.94	1.96	3.25
	CV	48.04	703.80	290.77	82.99	187.40	19.79	30.34	32.54	16.77	25.13
Banda	Mean	4.02	0.17	0.03	3.78	0.12	28.83	15.78	15.22	11.51	13.30
	SD	3.87	1.17	0.01	8.54	0.08	6.63	4.89	4.82	2.31	3.30
	CV	96.10	706.06	20.00	225.85	62.10	22.98	31.01	31.65	20.06	24.82
Chitrakoot	Mean	3.783	0.176	0.030	3.200	0.118	27.82	16.23	15.16	11.14	13.32
	SD	1.806	1.122	0.076	2.720	0.206	6.01	4.66	4.22	2.06	3.28
	CV	47.74	636.34	253.12	84.99	174.55	21.60	28.73	27.81	18.50	24.65
Jalaun	Mean	3.72	0.19	0.03	2.26	0.15	28.56	16.27	14.94	11.59	13.22
	SD	1.654	1.217	0.064	2.765	0.322	5.30	4.86	4.53	1.99	3.41
	CV	44.44	624.26	225.70	122.35	214.35	18.56	29.87	30.33	17.16	25.80
Chhatarpur	Mean	4.395	0.160	0.022	4.100	0.117	28.85	16.26	14.79	11.37	13.15
	SD	1.855	1.140	0.049	2.887	0.237	5.40	5.22	4.47	1.83	3.28
	CV	42.20	713.52	220.49	70.40	202.51	18.70	32.12	30.22	16.08	24.95
Datia	Mean	3.941	0.168	0.031	3.720	0.145	29.49	15.58	14.69	11.64	12.73
	SD	1.830	1.141	0.077	2.917	0.368	5.87	5.00	4.66	1.95	3.42
	CV	46.43	678.65	250.25	78.41	253.37	19.91	32.11	31.72	16.73	26.83
Lalitpur	Mean	4.79	0.17	0.01	4.30	0.12	30.61	16.15	15.03	11.83	13.21
	SD	2.23	1.28	0.03	3.09	0.29	6.26	5.11	4.40	2.15	3.36
	CV	46.53	770.94	228.53	71.89	253.47	20.44	31.61	29.29	18.15	25.42
Sagar	Mean	4.473	0.178	0.024	4.130	0.092	28.44	16.42	16.07	11.08	13.54
	SD	1.772	1.408	0.049	2.597	0.170	4.77	5.20	4.52	1.70	2.91
	CV	39.61	793.23	204.92	62.88	185.14	16.77	31.65	28.09	15.34	21.51
Damoh	Mean	4.29	0.17	0.03	3.80	0.09	27.94	16.57	15.47	10.94	13.47
	SD	1.72	1.30	0.06	2.62	0.15	4.77	5.20	4.36	1.68	3.18
	CV	40.06	750.10	228.48	68.90	165.57	17.07	31.39	28.20	15.37	23.63
Panna	Mean	4.33	0.17	0.03	3.45	0.11	28.20	16.29	14.81	11.13	13.49
	SD	1.87	1.20	0.06	3.11	0.20	5.14	4.99	4.22	1.75	3.13
	CV	43.05	697.09	244.44	90.10	187.82	18.22	30.66	28.52	15.75	23.22
Tikamgarh	Mean	4.42	0.17	0.03	3.75	0.13	29.75	15.83	14.66	11.68	13.09
	SD	2.02	1.27	0.06	3.00	0.30	6.12	5.03	4.75	2.03	3.28
	CV	45.77	755.16	252.73	79.94	240.76	20.58	31.79	32.40	17.34	25.04
Bundelkhand	Mean	4.17	0.17	0.03	3.64	0.12	28.88	16.09	15.09	11.42	13.22
	SD	2.00	1.21	0.06	3.26	0.24	5.65	5.01	4.54	1.95	3.26
	CV	48.45	709.62	221.27	91.66	196.30	19.50	31.16	30.04	17.05	24.59

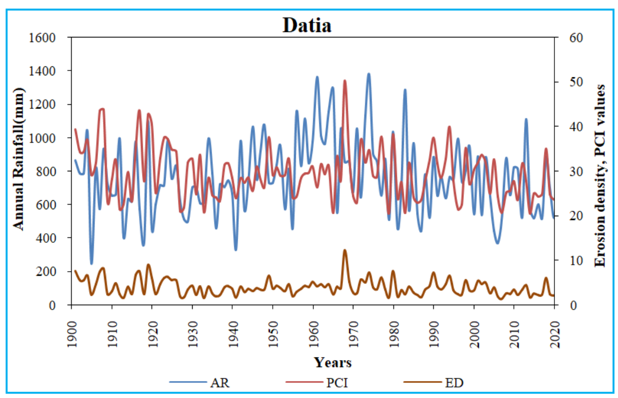

Sagar
Annual Rainfall(mm)
Erosion density, PCI values
Years
AR
PCI
ED

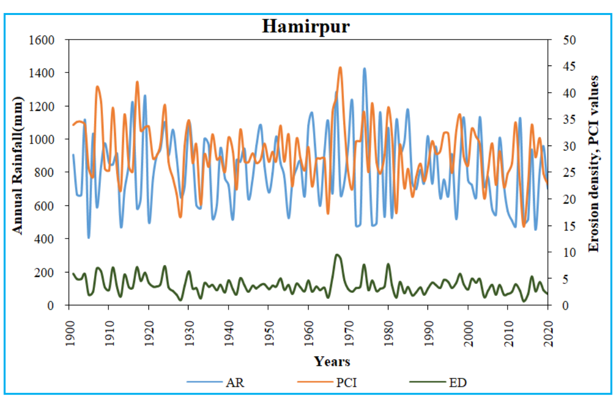

Chitrakoot
Annual Rainfall(mm)
Erosion density, PCI values
Years
AR
PCI
ED

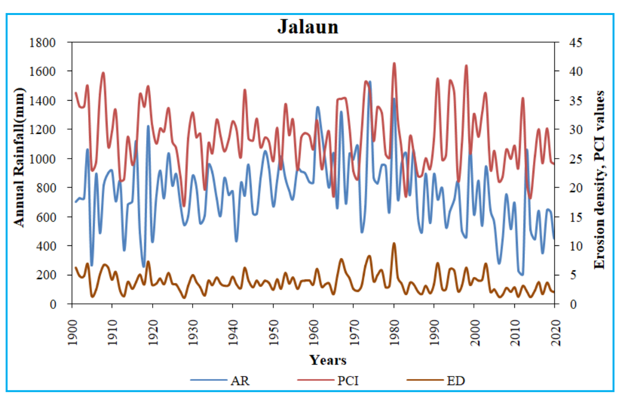

Banda
Annual Rainfall(mm)
Erosion density, PCI values
Years
AR
ED
PCI


Chhatarpur
Annual Rainfall(mm)
Erosion density, PCI values
Years
AR
ED
PCI


Damoh
Annual Rainfall(mm)
Erosion density, PCI values
Years
AR
PCI
ED


Datia
Annual Rainfall(mm)
Erosion density, PCI values
Years
AR
PCI
ED


Hamirpur
Annual Rainfall(mm)
Erosion density, PCI values
Years
AR
PCI
ED


Jalaun
Annual Rainfall(mm)
Erosion density, PCI values
Years
AR
PCI
ED

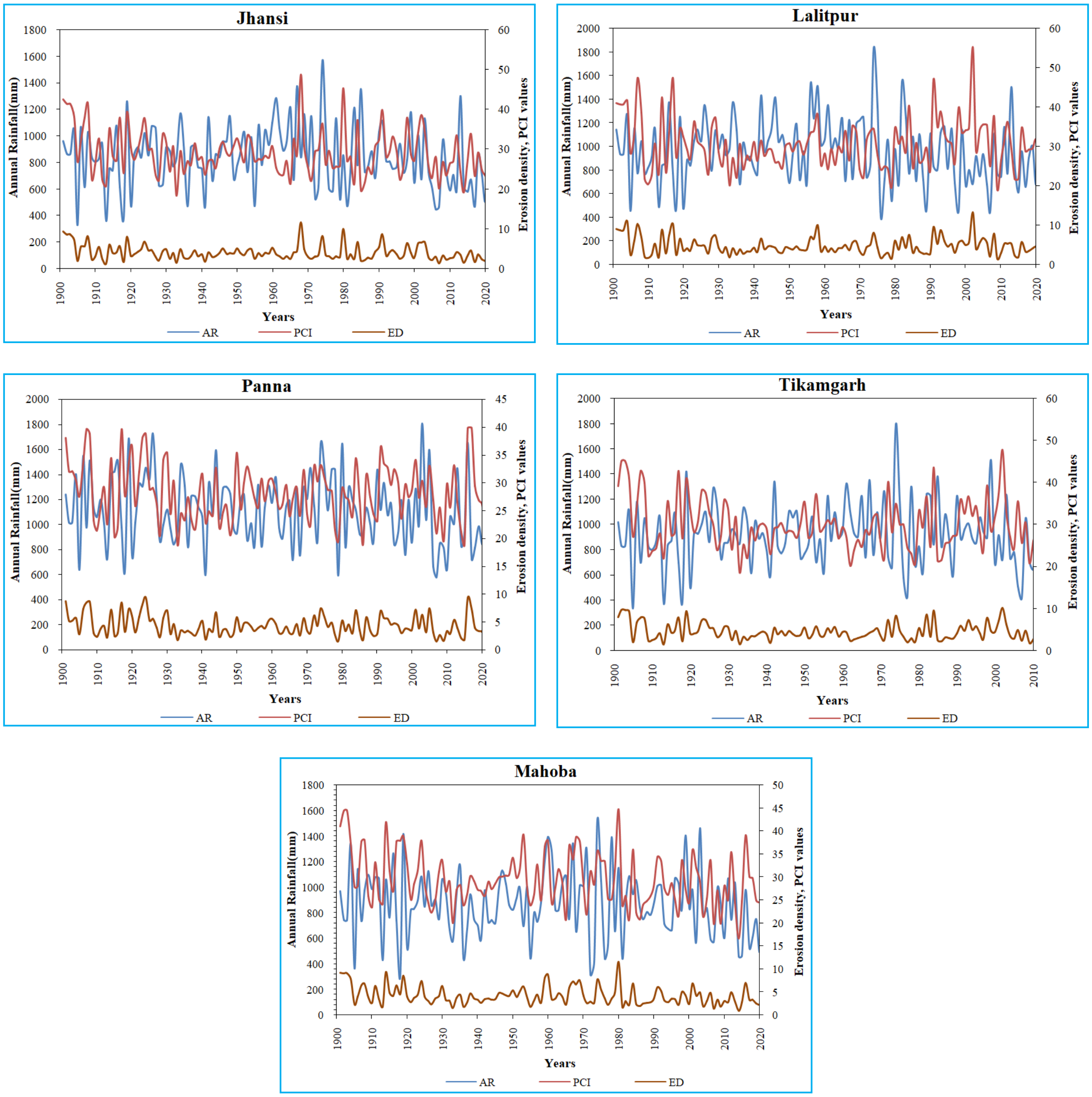


Fig. 6. Year-to-year variations of annual rainfall, ED and PCI values of different districts

region. This large inter-annual variation in the value of R-factor is due to extreme rainfall events since the magnitude and intensity of rainfall greatly affect the value of R factor.

3.4. *Spatial and temporal variations of annual and seasonal erosivity density (ED)*

Annual and seasonal ED values were obtained by dividing the annual and seasonal R-factor values by corresponding rainfall amount. Statistical analysis of ED is given in Table 4. The mean annual ED value for the study area was found as 4.17 MJ ha^{-1} h^{-1}, with highest value for Lalitpur district (4.79 MJ ha^{-1} h^{-1}) and lowest value for Hamirpur and Chitrakoot districts (3.78 MJ ha^{-1} h^{-1}). The mean annual SD and the CV of the ED for Bundelkhand region were found as 2.00 MJ ha^{-1} h^{-1} and 48.45 %, respectively. The ED values show high seasonal variability as the mean ED for monsoon was calculated as 3.66 MJ ha^{-1} h^{-1} followed by winter season with value of 0.17 MJ ha^{-1} h^{-1}, post-monsoon season with 0.12 MJ ha^{-1} h^{-1} and pre-monsoon season with 0.03 MJ ha^{-1} h^{-1}

TABLE 5

Statistical test results for 13 districts of Bundelkhand region of India (1901-2021)

Districts	Correlation Between annual rainfall and R	Correlation Between rainfall and modified Fournier index (MFI)	Linear regression model between Annual rainfall and R	R^2	Linear regression model between rainfall and modified Fournier index (MFI)	R^2
Jhansi	**0.661**	0.814	R = -1670.38+6.19*AR	0.437	MFI = -9.47+0.30*AR	0.663
Hamirpur	0.651	0.803	R = -1344.69+5.53*AR	0.423	MFI = 4.35+0.27*AR	0.644
Mahoba	0.721	0.849	R= -2438.64+7.30*AR	0.520	MFI = -25.02+0.32*AR	0.721
Banda	*0.611*	0.768	R = -1321.74+5.64*AR	0.374	MFI = 5.20+0.28*AR	0.590
Chitrakoot	0.568	0.742	R = -816.55+4.74*AR	0.323	MFI = 21.01+0.25*AR	0.551
Jalaun	0.750	0.872	R = -2055.79+6.63*AR	0.562	MFI = -21.93+0.31*AR	0.760
Chhatarpur	0.673	0.808	R = -2649.70+7.09*AR	0.453	MFI = -20.97+0.30*AR	0.654
Datia	**0.676**	0.825	R = -1302.63+5.83*AR	0.457	MFI = -4.85+0.30*AR	0.680
Lalitpur	**0.692**	0.828	R = -2303.27+7.37*AR	0.479	MFI = -4.02+0.31*AR	0.685
Sagar	0.688	0.828	R = -3004.92+7.17*AR	0.473	MFI = -10.61+0.29*AR	0.686
Damoh	**0.656**	0.799	R = -2661.26+6.71*AR	0.431	MFI = -10.25+0.28*AR	0.639
Panna	0.746	0.845	R = -4025.39+8.16*AR	0.557	MFI = -50.35+0.32*AR	0.714
Tikamgarh	**0.659**	0.806	R = -1675.82+6.41*AR	0.434	MFI = 0.27+0.297*AR	0.650

(Table 4). Monsoon season alone contributed about 99% of total annual ED value since 80-90% rainfall occurred in this season. Highest monsoon ED value was observed in Sagar (4.130 MJ ha^{-1} h^{-1}) district, while lowest value was observed in Jalaun (2.26 MJ ha^{-1} h^{-1}) district. The SD and the CV of the monsoon mean of ED for Bundelkhand region were 3.26 MJ ha^{-1} h^{-1} and 91.66%, respectively. According to classification given by Dabney *et al*., (2011), ED values (>3 MJ ha^{-1} h^{-1}) indicates high intensity of rainfall, which signifies high erosion and more runoff events. This corroborates that the whole study area with high ED value may face flooding as well as high runoff due to intensive and erosive rain events.

The spatial variability maps of annual and seasonal ED are shown in Figs. 3&4. The different patterns in ED were noticed for annual and monsoon seasons. The annual ED pattern reflects that for most of the districts ED value varies between 3-4 MJ ha^{-1} h^{-1} and no change was observed in the spatial pattern of ED as one moves from north to south. However, district situated at south-east part shows highest ED value. The seasonal ED spatial pattern is similar to the spatial pattern of R-factor as well as precipitation, which reflects high intensity of rainfall during monsoon season (Fig. 4). In the study area, high-intensity rainfall events occurred between July and September during monsoon season. Moreover, the temporal variation of ED values for each district resembles the pattern of rainfall (Fig. 6). However, the fluctuations are more moderate and uniform compared to rainfall pattern. Annually, lowest ED value (2.1 MJ $ha^{-1}h^{-1}$) was observed in 1912 and highest value (8.32 MJ ha^{-1} h^{-1}) in 1962 for Bundelkhand region.

3.5. *Spatial and temporal variations of annual and seasonal precipitation concentration index (PCI)*

The annual and seasonal PCI mean along with other related statistics have been shown in Table 4. The mean annual PCI value for the Bundelkand region was obtained as 28.88, with SD and CV as 5.65 and 19.50%, respectively. Highest PCI value was observed for Lalitpur (30.61) district and lowest value for Chitrakoot (27.82) district. Based on temporal distribution (Fig. 5) for Bundelkhand, the highest value (43.23) was calculated in the year 1906 and lowest value (19.56) recorded in 1936 and 1956. However, the yearly pattern of PCI values fluctuation of all districts same as rainfall pattern of their respective districts. The PCI values obtained for 64 years were found above the mean value whereas the PCI values for rest of the 67 years were below the mean value out of total 121 years of data. On seasonal basis, the highest PCI value was calculated for winter season with mean, SD and CV are 16.09, 5.01 and 31.16%, respectively. The lowest PCI value (11.42) was calculated for monsoon season. As per the classification, PCI values greater than 21 shows highly irregular precipitation distribution. Therefore, the whole study area shows strong irregularity in the precipitation concentration. About 98% of 121 years under this study produced PCI value greater than 21 representing strong value of the precipitation irregularity.

The spatial distribution of the annual and monsoon mean PCI values are presented in Figs. 3&4 which show the differences in precipitation distribution throughout the year in Bundelkhand. The minimum value of PCI is observed in south-eastern part, while approximately entire area shows PCI value between 22-30, and the peak value is observed in the north-western part of Bundelkhand (Fig. 3). On monsoon basis, for the entire region PCI values vary from 10-15 and values above 15 were detected only in few points in the central part of study area. The spatial distribution of annual PCI values reveals precipitation zone of Bundelkhand, which is identified by longer rainy season and heavy rainfall amount.

3.6. *Correlations between annual rainfall and corresponding R and MFI*

The correlations between annual rainfall and corresponding R and MFI reveal significant degree of relationship but with stronger correlation between annual rainfall and MFI compared to R (Table 5). The correlation test between annual rainfall and MFI is positive and highly significant at the 0.05 level (two-tailed) for all the 13 districts with correlation coefficient ranging from 0.742 to 0.872. However, correlation coefficient between rainfall and R ranged from 0.568 to 0.750. The correlation was significant for Jhansi, Banda, Datia, Lalitpur, Damoh, Tikamgarh districts.Several researchers (Bazzano *et al*., 2010; Silva *et al*., 2004) have cautioned that the occurrences of high precipitation are not necessarily associated with high erosivity. The high erosivity values and strong correlation exhibited by MFI are due to high intensity rainfall events during peak periods of the rainy season. Despite the rather low correlation coefficient exhibited by R, it however reveals an increase in erosivity values on annual basis in most districts across the country. In as much as R factor accounts for about 80% of soil loss (Wischmeier and Smith 1978), It is important to note that this situation may worsen when other soil erosion influencing factors such as soil characteristics, length and steepness of slope, land cover characteristics and management implications come into play. Similarly, the results of linear regression model showed a strong relationship between rainfall amount and erosivity indices (R and MFI) for all districts where the coefficient of determination R^2 ranges from 0.32 to 0.76. This means that annual erosivity indices are directly proportional to mean annual rainfall.

4. Conclusions

Rainfall erosivity (R) factor, MFI, PCI and ED values for Bundelkhand region of central India were obtained using 121 years of monthly rainfall data for all 13 districts of the study area. Simplified equations were used for the calculation of erosivity related variables to facilitate watershed related development in this erosion-prone region of India. Rainfall erosivity factors were calculated by the most widely used modified Fournier Index (MFI) using easily available and assessable monthly rainfall data. This method is a promising solution for those regions where high resolution pluviographic data for the longer duration is not available. It has been established that the monthly/seasonal rainfall amount shows a strong relationship with rainfall erosivity, which can be expressed in potential form. Therefore, the MFI values for the study area were calculated using monthly rainfall data. MFI values were used for calculation of R-factor. The R-factor values of Bundelkhand varies from 5346.53 MJ.mm ha^{-1} h^{-1} to 3010.61 MJ.mm ha^{-1} h^{-1} with mean standard deviation of 2418.18 MJ.mm ha^{-1} h^{-1}. According to the classification of R- factor, northern region belongs to moderate erosivity class whereas, eastern and south-western region are associated with moderate to severe erosivity characteristics. Therefore, soil and water measures need to be adopted in these severe erosivity zone with priority. Similarly, MFI values of the study area varied from 331.09 mm to 220.03 mm with satndard deviation of 91.49 mm, representing strong erosivity class. The mean annual ED and PCI values of the region were 4.17 MJ ha^{-1} h^{-1} and 28.88 with mean standard deviation of 2 MJ ha^{-1} h^{-1} and 5.65, respecitvely. Seasonal analysis of R-factor, MFI, ED and PCI was also carried out. Among all season, monsoon was the most erosive with highest value of R-factor (3964.08 MJ.mm ha^{-1} h^{-1}) MFI (262.37 mm), ED (3.66MJ ha^{-1} h^{-1}) and PCI (11.42). Monsoon season of this region was characterized by short and intensive rain events of long duration which showed high irregularity in rainfall and accelerated erosion rate in the region. The understanding of spatio-temporal distribution of erosivity related variables of the region is very important, hence spatial map was drawn for each rainfall district to understand the pattern and severity of these variables as well as temporal graphs of districts were prepared for identifying the inter-annual variability. The region grapples with severe ecological degradation stemming from both topsoil erosion and deforestation, resulting in diminished land productivity. This enduring issue of soil erosion is compounded by the region's hilly terrain, strong winds, and the subpar quality of its soil, ultimately giving rise to extensive gully formation. Bundelkhand once boasted dense forests until the late 18^{th} century. However, a surge in demand for timber and the expansion of agriculture initiated significant deforestation during the mid-19th century. Following India's independence, rapid population growth and the advent of the Green Revolution further extended cultivation, exacerbating the region's reliance on wood-based energy sources.The region saw a significant reduction in its forested area due to a combination of these factors along with inadequate land management practices and government-sanctioned commercial logging. Presently, only small remnants of dry miscellaneous and thorn forests, featuring species like dhak (Anogeissus latifolia), teak (Tectona grandis), mahua-chiranji (Madhuca longefolia/Madhuca Indica), khardai (Anogeissus pendulai), khai, and thar trees, can be found in the area. Over the past two decades, the agricultural land in the region has remained relatively stable. However, during the *kharif* season, the local practice of free grazing, known as "chhooth pratha" or "annpratha," poses challenges due to stray cattle causing damage to crops (UNDP, 2012). The undulating topography of the area, coupled with extensive deforestation over the past century and a half, has significantly limited groundwater recharge, thereby impacting the perennial flow of rivers and rivulets in Bundelkhand.The issue has escalated in recent times due to unregulated mining in the name of industrialization. In many areas of this region, there exists a relatively shallow impermeable rocky layer. The sloping terrain in this region accelerates the rapid runoff of both rainwater and soil. This challenge is further exacerbated by unpredictable rainfall patterns and a severe lack of forest cover in numerous districts. Approximately 54 percent (3.8 mha), of the total reported land area (7.1 m ha) in the Bundelkhand region, is dedicated to cultivation (Sah *et al*., 2021). An observed decrease in dense vegetation cover on the Kaimur ranges from 2000 to 2015 has been documented, declining from 1243.75 square kilometers to 620.25 square kilometers, representing a substantial 24.94% reduction.The spatial extent of agricultural land underwent a significant transformation, expanding from 795.50 square kilometers in 2000 to 1442.5 square kilometers in 2015 (Ghosh, 2017). Furthermore, there was a consistent reduction in forested areas in central India during the period between 1985 and 2005. The decline in vegetation cover within the Bundelkhand region can largely be attributed to fragmentation (Roy *et al*., 2015). Deforestation plays a pivotal role in intensifying erosion rates. The undulating topography, coarse soil texture, low organic matter content, insufficient vegetation cover, dry farming practices, and human mismanagement all contribute significantly to soil erosion in Bundelkhand. Given the gravity of this issue, it is imperative that the most affected areas receive immediate conservation efforts such as afforestation, the implementation of scientific terracing, and judicious crop selection. These measures are crucial for the long-term preservation of the region's land resources and overall sustainability. The suggestions of this study are comprehensive and diverse given region is susceptible to erosion due to the variable nature of rainfall, week soil properties and soil profile and sparse vegetation make study are vulnerable to erosion risk. No such detailed study of this region had been reported earlier, hence the finding of this study can be taken as a basis for more advanced study of rainfall and erosivity relationship development in future research works.

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