Received: 28 November 2023 | Accepted: 1 August 2024

DOI: 10.59797/ijsc.v52.i2.169

ORIGINAL ARTICLE

Indian Journal of Soil Conservation

Assessing rainfall patterns, erosivity dynamics, and sustainable soil and water management strategies across agro-climatic zones of Chhattisgarh, India

Ch. Jyotiprava Dash[1,2] | **Prachi Yadav**[1] | **Randhir Kumar**[1] | **Sitanshu Sekhar Patra**[1] | **H.C. Hombegowda**[1]
Partha Pratim Adhikary[1,2,*]

[1]ICAR-Indian Institute of Soil & Water Conservation, Research Centre, Koraput, Odisha, India.
[2]ICAR-National Bureau of Soil Survey & Land Use Planning, Nagpur, Maharashtra, India

Corresponding Author :
E-mail: Partha.Adhikary@icar.gov.in;
ppadhikary@gmail.com

Handling Editor :
Dr Deepak Singh

ABSTRACT

The study explored the trend of rainfall and rainfall erosivity (R-factor) over 120 years (1901-2020) using monthly precipitation data from 16 stations in Chhattisgarh state, India. Various statistical methods were employed to discern the trend and slope values, including homogeneity tests, non-parametric trend tests, and Sen's slope estimator. The results, at a 5% significance level, underscored a significant increasing trend in rainfall for the Bastar plateau, while the Chhattisgarh plains, Northern hills, and Chhattisgarh state exhibited a declining trend in annual rainfall. However, no specific trend was observed in pre- and post-monsoon seasons. During the winter, the Bastar plateau, Northern Hills, and Chhattisgarh state experienced declining rainfall, whereas the Chhattisgarh plains showed no discernible trend. Notably, the Northern hills exhibited the highest mean annual R-factor (12519.4 MJ mm ha^{-1} h^{-1} yr^{-1}), followed by the Chhattisgarh plains (11587.7 MJ mm ha^{-1} h^{-1} yr^{-1}) and the Bastar plateau (9633.5 MJ mm ha^{-1} h^{-1} yr^{-1}). On the broader scale, the annual R-factor for Chhattisgarh state indicated a declining trend, estimated at a rate of 7.4 MJ mm ha^{-1} h^{-1} yr^{-1}. This decline was attributed to a reduction in overall rainfall. However, it is important to note that this decrease in the R-factor does not necessarily signify a decline in soil erosion or soil health deterioration. In order to adapt to changing rainfall patterns, it is important to implement region-specific measures. These measures include dhodhi (well-like structures in natural drains), ponds, gabion structures, loose boulder check dams, gunny bag check dams, vegetative barriers, peripheral stone bunds, and borrow pits. Deep ploughing can also be used to address both increasing and decreasing trends in rainfall effectively. This targeted approach is crucial for sustainable soil erosion management and preserving soil health in the study area.

Key words:
Agro-climatic zones
Rainfall erosivity factor
Rainfall trend
Soil erosion

HIGHLIGHTS

- Chhattisgarh is experiencing a notable decline in the trend of southwest monsoon rainfall, with potential implications for regional water availability and agricultural productivity.
- The average annual rainfall erosivity (R-factor) for Chhattisgarh is 11396 MJ mm ha^{-1} h^{-1} yr^{-1}, indicating a considerable potential for soil erosion.
- The Bastar Plateau is showing a concerning upward trend in the R-factor, increasing at 30.9 MJ mm ha^{-1} h^{-1} yr^{-1}, underlining an urgent need to address the growing erosion risk in this region.
- Location-specific interventions are critical for ensuring sustainable environmental management and agricultural resilience over the long term.

1 | INTRODUCTION

Water-induced soil erosion is the most prominent form of land degradation, posing a significant threat to ecosystems and the environment. Improper land use, inadequate management of natural resources, and unsustainable agricultural practices exacerbate this issue by causing excessive runoff, primarily due to intense rainfall, reducing soil infiltration capacity. Soil erosion impacts the agricultural sector and affects the economy through erosion processes, sedimentation, alterations in hydrological patterns, and subsequent water quality changes. It risks nutrient loss from topsoil, resulting in food shortages, deteriorating soil quality, and environmental degradation (Panagos *et al.,* 2015) and negatively impacting future economic growth.

Soil erosion is particularly concerning in Africa, South America, and Asia (China and India). According to Borrelli *et al.* (2017), at a continental level, Africa shows the highest prediction of average soil erosion rate (3.88 Mg $ha^{-1}yr^{-1}$, followed by South America (3.81 Mg $ha^{-1}yr^{-1}$) and Asia (3.50 Mg $ha^{-1}yr^{-1}$). North America shows considerably lower predicted value of 2.12 Mg $ha^{-1}yr^{-1}$. Globally, an estimated 35.9 billion tonnes of soil erode yearly (Borrelli *et al*., 2017). In India, soil erosion due to water and wind affects approximately 71 % of the total geographic area (85.7 M ha), highlighting the urgency for proper quantification and subsequent conservation measures (Jinger *et al*., 2023). The Universal Soil Loss Equation (USLE) utilises the rainfall erosivity factor (R-factor) as a critical variable to estimate potential soil loss. The R-factor is directly related to rainfall intensity and other rainfall characteristics, such as the size of a raindrop and its velocity. Climate change has directly impacted rainfall intensity and its erosive potential through extreme weather events. Climate change has led to increased air temperature, enhancing the evaporative demand of the atmosphere, which results in frequent and intense precipitation. Researchers revealed that every 1°C rise in temperature leads to a 7% increase in the moisture-holding capacity of air (Tabari, 2020). Hence, an atmosphere with more moisture can produce more intense precipitation events.

Due to climate change, India has recently experienced extreme, irreversible, and catastrophic weather events. Climate change alters the hydrologic cycle, affecting precipitation, runoff, infiltration, temperature, humidity, and solar radiation, consequently influencing rainfall erosivity (Dash *et al.,* 2020). Regions with higher R-factor values, indicating vulnerability to rainfall-induced erosion, are found in the north-eastern Himalayan belt (including Assam and Meghalaya) and along India's eastern and western Ghats (Raj *et al*., 2022). They reported an average R-factor value of 3312.39 MJ mm ha^{-1} h^{-1} yr^{-1} for the Eastern Ghats and north-east India and 615.61 MJ mm ha^{-1} h^{-1} yr^{-1} for the southern Peninsula region. Climate change has significantly altered rainfall patterns nationwide, suggesting potential changes in R-factor values. These variations directly affect soil health, influencing crop growth and productivity. Monitoring changes in the R-factor over the years is crucial to identify erosion-prone areas and plan appropriate land management policies.

Chhattisgarh, located in central India, is an agrarian state where the rural population heavily relies on land and forests for their livelihoods. The major crop in the state is rainfed rice, and any decrease in precipitation will definitely affect rice productivity and, consequently, the state's economy. Additionally, high-intensity rainfall can detach and remove top fertile soil, negatively impacting crop growth. Rainfall in most districts of Chhattisgarh exhibits significant inter-annual and seasonal variations (Meshram *et al*., 2016; Nema *et al*., 2018). The average R-factor value in Chhattisgarh (12892 MJ mm ha^{-1} h^{-1} yr^{-1}) (Tiwari *et al*., 2016) exceeds the country's average rainfall erosivity value (1200 MJ mm ha^{-1} h^{-1} yr^{-1}), underscoring the significance of understanding rainfall trend and their effects on erosivity and soil erosion (Raj *et al*., 2022). Given the heavy reliance on rainfall by the farming community, analysing shifting rainfall patterns across the state's agro-climatic zones can shed light on how these patterns impact water availability. Such insights are crucial for water resources managers to comprehend fully the dynamics of local water supply and demand. Similarly, understanding the trend in rainfall erosivity can help identify areas susceptible to soil erosion, enabling the planning and implementation of appropriate conservation measures. There is no published research on the state's temporal variation of the R-factor. The accurate estimation of the R-factor depends on the kinetic energy of rainfall and the maximum 30-minute rainfall intensity. Calculating the R-factor is time-consuming, leading researchers worldwide to use empirical models correlating the R-factor with rainfall data. The Fournier Index (FI) and the Modified Fournier Index (MFI) are good options in this context. However, FI is biased towards the month with the highest rainfall and does not consider the monthly distribution of rainfall. The MFI gained an advantage over FI (Arnoldus, 1980). The MFI method considers the rainfall amounts of all months and calculates the rainfall aggressiveness towards soil erosion. This study aims to analyse the trend in rainfall and R-factor using the MFI method for different agro-climatic regions of Chhattisgarh and thereby suggest various measures to conserve soil and water resources.

2 | MATERIALS AND METHODS

2.1 | Study Area

Chhattisgarh state of India is situated between latitudes 17°46' and 24°5' north and longitudes 80°15' and 84°20' east (Fig. 1). Chhattisgarh is home to approximately 25.5 million people, with 70% of the population employed in the agriculture sector. The state claims a net sown area of 4.65 M ha, constituting 34% of the total geographical area. The study area is divided into three distinct agro-climatic zones: the Bastar plateau, the Chhattisgarh plains and the Northern hills. The Chhattisgarh plains and the Northern hills collectively encompass 20 districts, including Balod, Balodabazar, Bemetara, Bilaspur, Dhamtari, Durg, Gariyaband, Janjgir, Kabirdham, Korba, Korea, Mahasamund, Mungeli, Raipur,

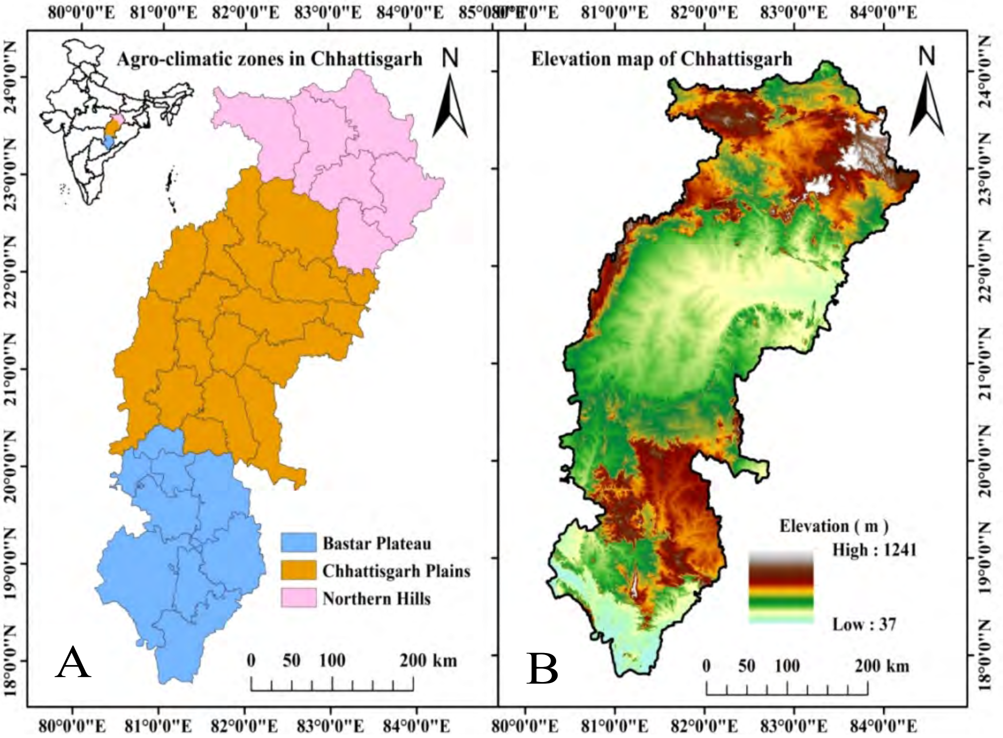

FIGURE 1 Map of Chhattisgarh showing (A) different agro-climatic zones, and (B) elevation

Raigarh, Rajnandgaon, Surajpur, and Sarguja. On the other hand, the Bastar plateau comprises seven districts: Bastar, Bijapur, Dantewada, Kanker, Kondagaon, Narayanpur, and Sukma.

In terms of land area, the Chhattisgarh plains have the largest expansion (6.84 M ha) with a net sown area of 3.29 M ha, followed by the Bastar plateau (3.90 M ha) with a net sown area of 0.64 M ha, and the Northern hills (2.85 M ha) with a net sown area of 0.84 M ha. The region experiences a tropical climate characterised by hot summers, cold winters, and a rainy season dominated by the southwest monsoon. The average annual rainfall in the study area is approximately 1400 mm. Regarding soil types, Alfisols constitute the majority (39.0%) of the study area, followed by Vertisols (26.4%), Entisols (19.5%), and Inceptisols (14.8%). Notably, the area is rich in biodiversity, with 5.56 Mha (41.2% of TGA) covered by forests (FSI, 2021), making it one of the most bio-diverse regions in the country (Fig. 2). Among the agro-climatic zones, the percentage of area covered with forest is maximum for the Baster Plateau (57.37%) followed by the Northern hills (47.33%) and the Chhattisgarh Plains (29.37%) (FSI, 2021). Nearly 90% of the cultivated area in the state relies on rainfed agriculture. Primary crops during the rainy season include paddy, soybean, black gram, and pigeon pea, while chickpea and grass pea (*Lathyrus sativus*) are the main crops grown during winter. Common cropping systems under rain-fed conditions include rice-fallow, rice-chickpea, or rice-linseed systems (Nema *et al.*, 2018).

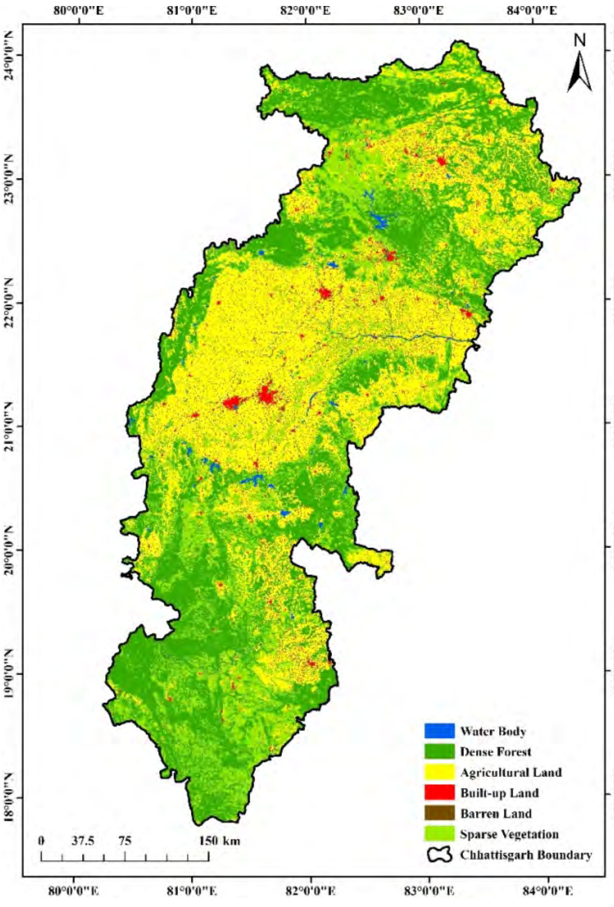

FIGURE 2 Land use map of Chhattisgarh state

2.2 | Data Used

The monthly rainfall data was collected from the India Water Portal (http://www.indiawaterportal.org/metdata) and the India Meteorological Department (IMD), Pune, spanning a period of 120 years (1901-2020). To facilitate analysis, annual series were derived from the monthly data. Additionally, to conduct a seasonal analysis, the monthly rainfall data was segmented into four distinct periods: pre-monsoon (March to May), monsoon (June to Sept), post-monsoon (Oct to Nov), and winter (Dec to Feb). To assess rainfall erosivity, the Modified Fournier Index (MFI), defined by Arnoldus (1980), was utilised.

2.3 | MFI and R-factor Estimation

The estimation of the R-factor needs rainfall intensity and rainfall duration data sets. Such high-resolution data is not available in many places around the globe. Therefore, many indices are developed to determine the R-factor. One of the most popular indices for estimating the R-factor is the MFI because it strongly correlates with the R-factor (Tiwari *et al*., 2016). MFI is defined as the summation of monthly to annual rainfall for a year and is presented in equation 1.

$$MFI = \frac{1}{P}\sum_{i=1}^{i=12} p_i^2 \qquad ...(1)$$

P is the annual rainfall, and *pi* is the month *i* (mm) rainfall.

For those regions where it is impossible to obtain high temporal resolution pluviographic data, MFI provides a good approximation of the R-factor (Arnoldus, 1980). The following relationship was utilised to calculate the R-factor after obtaining MFI (Tiwari *et al*., 2016).

$$\mathrm{R} = 1.735 \times 10^{(1.5 \times logMFI - 0.8188)} \qquad ...(2)$$

Where *R* is the rainfall erosivity (MJ mm $ha^{-1} h^{-1} yr^{-1}$).

2.4 | Trend Evaluation

Annual R-factor and seasonal and annual rainfall trend analyses were carried out using various tests described in the following section.

2.4.1 | Test of homogeneity

At the 5% significance level, the Standard Normal Homogeneity Test (SNHT) was used to assess the homogeneity of the rainfall and R-factor data series over the study area.

2.4.2 | Method of linear regression

A trend is a long-term change in the dependent variable over time. Linear regression is the parametric statistical method commonly used for trend analysis.

$$x_t = \alpha + (\beta \times t) + \varepsilon_t \qquad ...(3)$$

Where x_t (t =1, 2,..., n) denotes the observed value at time *t*. α and β denote the regression coefficients, and ε_t denotes the random error with a mean of zero and a variance of S_v^2. Linear regression is frequently employed to determine seasonal and annual rainfall long-term trends. Positive and negative slope values indicate an increasing or decreasing trend, respectively.

2.4.3 | Mann-Kendall approach

The Mann-Kendall (MK) nonparametric test is most frequently used in analysing hydrological and climatological time series data. The test is appropriate for data not required to follow a normal distribution. This robust method still works even when some values are missing. In this study, the alternative hypothesis H_1 is tested against the null hypothesis H_0, which presupposes no trend. The MK statistic, S, is defined as follows:

$$S = \sum_{j=1}^{m-1}\sum_{k=j+1}^{m} sign\left(x_k - x_j\right) \qquad ...(4)$$

Where x_j and x_k are the j^{th} and k^{th} terms in the sequential data of sample size *m* and for x_k-x_j = 0.

$$Sign(\theta) = \begin{cases} +1 & if \quad \theta > 1 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 1 \end{cases} \qquad ...(5)$$

Assuming independent data with identically scattered, the variance and mean of the *S* statistic in eq. (5) may be calculated as given by (Kendall, 1975):

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

The standard normal deviate (*Z* statistics) is computed as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \qquad ...(7)$$

Very high positive and negative S values identify the increasing and decreasing trends. The Z value is used to assess the existence of a statistically significant trend. If the absolute value of Z is greater than 1.96, then the null hypothesis is rejected at the 5% significance level.

2.4.4 | Sen's slope

Sen's slope estimator test assessed the trend's magnitude in the rainfall and R-factor data series (Nema *et al*., 2018). Initially, a set of linear slopes for all data pairs is calculated using the following equation.

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for i = 1, 2, 3, ..., n} \qquad ...(8)$$

Where Q_i is the slope, x_j and x_k are data values at time j and k (j>k), respectively.

The median of the n values of Q_i is symbolised as Sen's slope estimator (β) and is calculated as:

$$\beta = \begin{cases} Q_{(n+1)/2} & \text{if } n \text{ is odd} \\ \frac{1}{2}\left(Q_{n/2} + Q_{(n+2)/2}\right) & \text{if } n \text{ is even} \end{cases} \qquad ...(9)$$

A positive value of β denotes an upward trend in the data, while a negative value denotes a downward trend.

2.4.5 | Pettitt's approach

This non-parametric test was developed by Pettitt (1979) and used to determine whether abrupt changes or change detection are likely to occur in sets of meteorological data. Pettitt's test is the most frequently employed method for change point identification because of its sensitivity to breaks in any time series data (Nema *et al*., 2018).

3 | RESULTS AND DISCUSSION

3.1 | Characteristics of Monthly and Seasonal Rainfall

In Chhattisgarh, sixteen rain gauge stations are overseen by IMD. Their details and the average annual rainfall, MFI, and R-factor values are summarised in Table 1. Table 2 outlines the rainfall characteristics for different agro-climatic zones of Chhattisgarh state from 1901 to 2020, encompassing mean, standard deviation (SD), and coefficient of variation (CV). Notably, the Northern hills exhibit the highest mean annual rainfall at 1264.5 mm, followed by the Chhattisgarh plains at 1220.2 mm and the Bastar plateau at 1219.2 mm. The long-term mean annual rainfall for the entire state is 1228.2 mm. However, Meshram *et al*. (2016) and Nema *et al*. (2018) reported mean rainfall of 1360 and 1235 mm, respectively, for the Chhattisgarh state. The highest average monthly rainfall occurs in August, with the Northern Hills recording 394.9 mm, followed by the Chhattisgarh plains at 355.9 mm and the Bastar plateau at 323.9 mm. Conversely, the Bastar plateau experiences the lowest average monthly rainfall in December (4.0 mm), trailed by the Chhattisgarh plains (5.5 mm) and the Northern hills (6.0 mm) (Fig. 3). The Baster plateau displays the lowest variation in annual rainfall having a coefficient of variation value of 18.9%, followed by the Northern hills (20.1%) and the Chhattisgarh plains (20.6%). Indian monsoons are complex phenomena influenced by various factors such as sea surface temperature, land-sea temperature gradient, and atmospheric circulation. Alterations in any of these factors can lead to changes in rainfall patterns. Anthropogenic activities like land use changes, deforestation, and urbanisation are examples of local and regional climate factors affecting rainfall patterns. Hence, higher variation in annual rainfall in the Chhattisgarh plains and the Northern hills compared to the Baster plateau can be related to more anthropogenic activities. Concerning monthly rainfall variation, December

TABLE 1 Characteristics of rain gauge stations

District	Latitude (Degree decimal)	Longitude (Degree decimal)	Elevation (m)	Annual rainfall (mm)	MFI	R-factor (MJ mm ha^{-1} hr^{-1} yr^{-1})
Bastar plateau						
Bastar	19.10	81.95	610	1286.5	242.2	9927.2
Dantewada	18.89	81.34	351	1129.3	208.2	7910.7
Kanker	20.19	81.07	388	1241.7	260.4	11062.7
Average					**236.9**	**9633.5**
Chhattisgarh plains						
Bilaspur	22.07	82.14	207	800.7	157.5	5206.1
Dhamtari	20.70	81.55	317	1242.7	259.3	10997.3
Durg	21.19	81.28	289	1201.6	260.4	11067.6
Janjgir	22.01	82.57	294	1292.0	291.3	13089.2
Kawardha	22.01	81.23	353	1274.0	286.5	12769.8
Korba	22.35	82.75	252	1260.9	285.0	12669.6
Mahasamund	21.11	82.09	318	1274.3	278.1	12214.2
Raigarh	21.89	83.39	219	1359.6	312.9	14577.2
Raipur	21.25	81.62	298	1253.1	265.8	11409.8
Rajnandgaon	21.09	81.03	307	1242.3	273.0	11875.8
Average					**267.0**	**11587.7**
Northern hills						
Jashpur	22.87	84.13	753	1392.3	316.3	14811.8
Koriya	23.38	82.38	667	1144.8	253.0	10595.1
Surguja	22.94	83.16	623	1256.6	277.2	12151.3
Average					**282.2**	**12519.4**
State average					**264.2**	**11396.0**

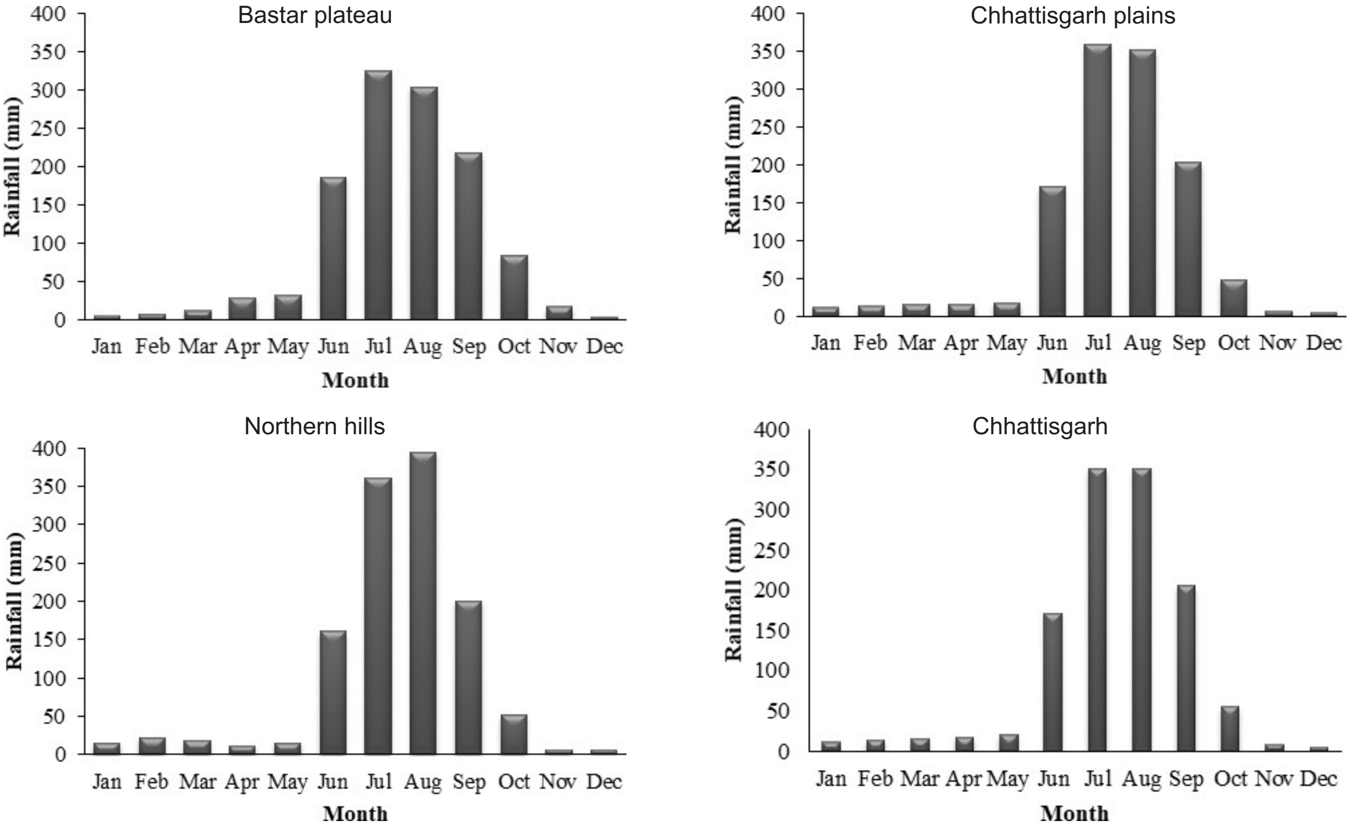

FIGURE 3 Monthly rainfall pattern in different agro-climatic zones of the study area

TABLE 2 **Monthly rainfall characteristics over different agro-climatic zones of Chhattisgarh state (1901-2020)**

Month	Bastar plateau				Chhattisgarh plains				Northern hills				Chhattisgarh state			
	Mean (mm)	SD (mm)	CV (%)	% of annual rainfall	Mean (mm)	SD (mm)	CV (%)	% of annual rainfall	Mean (mm)	SD (mm)	CV (%)	% of annual rainfall	Mean (mm)	SD (mm)	CV (%)	% of annual rainfall
Jan	5.2	8.5	161.4	0.4	11.9	15.8	133.6	1.0	15.7	16.9	107.5	1.2	11.3	15.3	134.9	0.9
Feb	7.5	10.1	133.9	0.6	14.3	16.1	112.4	1.2	22.2	22.1	99.2	1.8	14.5	17.1	117.6	1.2
Mar	11.5	15.1	131.2	0.9	16.7	16.9	101.1	1.4	18.4	20.0	108.5	1.5	16.0	17.3	108.0	1.3
Apr	28.5	24.8	87.1	2.3	16.5	16.5	99.6	1.4	11.6	13.6	116.9	0.9	17.9	18.7	104.6	1.5
May	32.1	24.7	76.9	2.6	18.3	15.4	84.0	1.5	15.3	14.6	95.4	1.2	20.4	18.3	89.8	1.7
Jun	185.6	81.8	44.1	15.2	170.9	83.0	48.6	14.0	160.8	92.9	57.7	12.7	171.8	85.0	49.5	14.0
Jul	323.9	102.7	31.7	26.6	355.9	114.3	32.1	29.2	361.0	110.2	30.5	28.5	305.8	112.1	31.9	28.6
Aug	303.4	102.7	33.8	24.9	352.2	109.3	31.0	28.9	394.9	123.8	31.4	31.2	351.0	114.3	32.6	28.6
Sep	217.3	85.6	39.4	17.8	202.7	81.9	40.4	16.0	200.7	80.8	40.3	15.9	205.1	85.6	40.3	16.7
Oct	83.0	62.8	75.7	6.8	48.6	42.5	87.4	4.0	51.6	40.8	79.1	4.1	55.6	48.5	87.2	4.5
Nov	17.3	23.5	136.3	1.4	6.6	10.6	159.3	0.5	6.4	10.0	155.8	0.5	8.6	14.5	168.5	0.7
Dec	4.0	9.2	232.1	0.3	5.5	10.7	195.7	0.4	6.0	10.5	176.1	0.5	5.3	10.4	197.0	0.4
Total	1219.2				1220.2				1264.6				1228.2			

month shows the most significant variation in rainfall, notably in the Bastar plateau (230.8%), followed by the Northern Hills (175.8%) and the Chhattisgarh plains (176.1%). In contrast, the monthly rainfall variation is the lowest in July for the Bastar plateau (31.7%) and Northern hills (30.5%), while the lowest in August in the Chhattisgarh plains (31.0%).

Regarding seasonal rainfall, the southwest (SW) monsoon season contributes significantly, accounting for over 80% of the total rainfall in all three agro-climatic regions and the entire state, as shown in Table 3. The SW monsoon contributes nearly 90% towards the total rainfall in Chhattisgarh. Among the agro-climatic zones, the Northern hills receive the highest southwest seasonal rainfall (1241.9 mm),

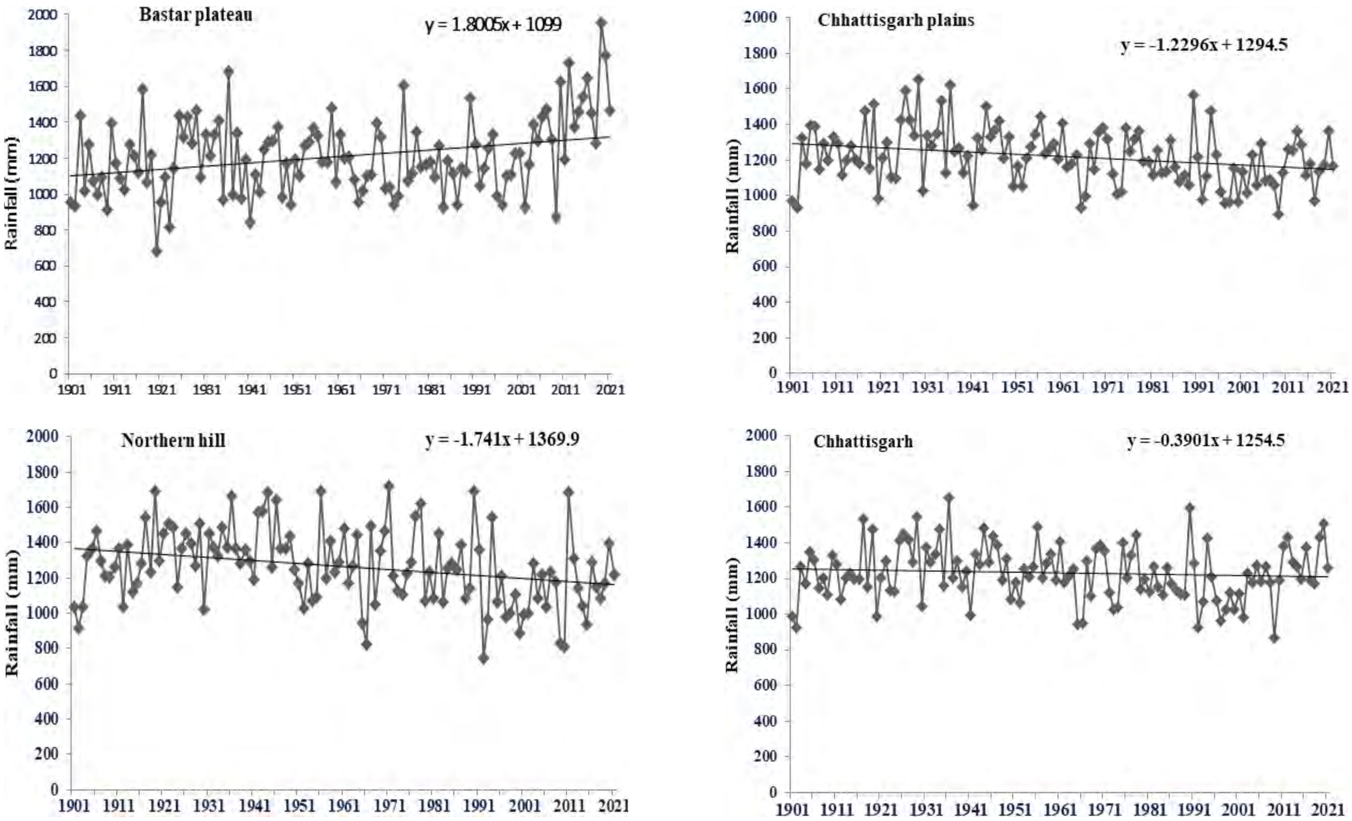

FIGURE 4 Variation in annual rainfall over the study area (1901-2020)

TABLE 3 Seasonal rainfall characteristics over different agro-climatic zones of Chhattisgarh state (1901-2020)

Season	Bastar plateau				Chhattisgarh plains				Northern hills				Chhattisgarh state			
	Mean (mm)	SD (mm)	CV (%)	% of annual rainfall	Mean (mm)	SD (mm)	CV (%)	% of annual rainfall	Mean (mm)	SD (mm)	CV (%)	% of annual rainfall	Mean (mm)	SD (mm)	CV (%)	% of annual rainfall
Pre-monsoon	72.1	40.7	56.5	5.9	51.6	30.3	58.8	4.2	50.7	30.7	67.8	3.6	54.2	12.5	23.1	4.4
Monsoon	1030.2	215.7	20.9	84.5	1081.7	235.6	21.8	88.7	1241.9	233.9	20.9	88.4	1078.7	133.9	12.4	87.8
Post monsoon	100.2	68.3	68.1	8.2	55.2	43.2	78.3	4.5	62.3	41.4	71.4	4.6	64.2	22.3	34.8	5.2
Winter	16.7	15.9	95.2	1.4	31.7	26.7	84.3	2.6	37.3	30.1	68.6	3.5	31.2	13.3	42.8	2.5
Total	1219.2				1220.2				1264.6				1228.2			

followed by the Chhattisgarh plains (1081.7 mm) and the Bastar plateau (1030.2 mm). For the state of Chhattisgarh, the SW seasonal rainfall is observed to be 1078.7 mm (Table 3). Conversely, the winter season (Dec, Jan, and Feb) contributes the least towards annual rainfall, accounting for 1.4% to 3.5%. The SW monsoon season exhibits the slightest variation in seasonal rainfall, ranging from 20.9% to 21.8% across the agro-climatic zones of the study area.

3.2 | Rainfall Trend

Table 4 illustrates the outcomes of the rainfall trend analysis for each agro-climatic zone and the state as a whole. In Chhattisgarh state, the annual rainfall demonstrated a declining trend, decreasing at a rate of 0.39 mm yr^{-1}, as depicted in Fig. 4. However, this decline was not statistically significant at the 5% significance level, as indicated in Table 5. The Northern hills exhibited a significant decreasing trend, with rates of 1.74 mm yr^{-1} (linear regression) and 1.89 mm yr^{-1} (Sen's slope estimator). Similarly, the Chhattisgarh plains also displayed a significant decreasing trend, with rates of 1.23 mm yr^{-1} (linear regression) and 1.32 mm yr^{-1} (Sen's slope estimator). In contrast, the Bastar plateau experienced an increasing trend in rainfall, with rates of 1.80 mm yr^{-1} (linear regression) and 1.89 mm yr^{-1} (Sen's slope estimator). The increasing or declining rainfall trend in a particular agro-climatic zone may be linked to its forest cover. Extensive deforestation often lessens cloud formation and rainfall. Further forest clearings can cause a distinct, convection-driven "vegetation breeze" in which moist air is drawn out of the forest, whereas forests act as a biotic pump,

TABLE 4 Rainfall trend over different agro-climatic zones of Chhattisgarh

Agro-climatic zone	Annual trend	Seasonal trend			
		Pre-monsoon (Mar-May)	Monsoon (Jun-Sep)	Post-monsoon (Oct-Nov)	Winter (Dec-Feb)
Bastar plateau	Increasing	No trend	Increasing	No trend	Decreasing
Chhattisgarh plains	Decreasing	No trend	Decreasing	No trend	No trend
Northern hills	Decreasing	No trend	Decreasing	No trend	Decreasing
State	Decreasing	No trend	Decreasing	No trend	Decreasing

TABLE 5 Annual rainfall trend with regression equation, Z statistic value (MK test) and Sen's slope

Agro-climatic zones	Equation	Z statistics	Sen's slope
Bastar plateau	$y = +1.80x + 1099.0$	+2.14*	+1.89
Chhattisgarh plains	$y = -1.23x + 1294.5$	-3.05*	-1.32
Northern hills	$y = -1.74x + 1369.9$	-3.16*	-1.89
Chhattisgarh state	$y = -0.39x + 1254.5$	-1.40	-0.39

*Note: *significance at 5% level*

generator or recycler, increasing the overall water balance in a region (Sheil, 2014). In Chhattisgarh, among the agro-climatic zones, the percentage of area covered with forest is maximum for the Baster Plateau (57.37%), followed by the Northern hills (47.33%) and the Chhattisgarh Plains (29.37%). Therefore, the Baster plateau is experiencing increasing rainfall while the other two zones are declining.

For the Northern hills, the Chhattisgarh plains, and the entire state, the SW monsoon rainfall exhibited a declining trend analogous to the annual rainfall. Conversely, pre- and post-monsoon rainfall displayed no distinct trend. In contrast, the winter season rainfall exhibited both decline (the Bastar plateau, the Northern hills, and Chhattisgarh state) and no trend (the Chhattisgarh plains). Meshram *et al.* (2016) reported a decreasing trend in rainfall at a 5% significance level using the linear regression method and the Mann-Kendell test for 14 out of 16 rain gauge stations in Chhattisgarh state. The decrease in annual rainfall varied between 1.04 to 2.43 mm yr^{-1} across different stations in the state. Similarly, Nema *et al*. (2018) found a declining trend in annual, monsoon, and post-monsoon rainfall in Chhattisgarh state based on the analysis of rainfall data from 1901 to 2015.

3.3 | R-factor trend

In Chhattisgarh state, the estimated average Modified Fournier Index (MFI) and annual R-factor values were 264.2 and 11396.0 MJ mm ha^{-1} h^{-1} yr^{-1}, respectively (Table 1). The Northern hills exhibited the highest mean annual MFI (282.2), followed by the Chhattisgarh plains (267.1) and the Bastar plateau (267.0). Assessing soil erosive levels across three agro-climatic regions revealed high MFI values. Similarly, regarding mean annual R-factor values, the Northern hills have the highest (12519.4 MJ mm ha^{-1} h^{-1} yr^{-1}), followed by the Chhattisgarh plains (11587.7 MJ mm ha^{-1} h^{-1} yr^{-1}) and the Bastar plateau (9633.5 MJ mm ha^{-1} h^{-1} yr^{-1}).

Analysing the data spanning from 1901 to 2020, the annual R-factor in Chhattisgarh state was observed a non-significant decreasing trend with a rate of 7.4 MJ mm ha^{-1} h^{-1} yr^{-1} (Fig. 5). Furthermore, the Northern hills (33.8 MJ mm ha^{-1} h^{-1} yr^{-1}, as per linear regression, and 35.61 MJ mm ha^{-1} h^{-1} yr^{-1}, as per Sen's slope) and the Chhattisgarh plains (19.2 MJ mm ha^{-1} h^{-1} yr^{-1}, as per linear regression, and 17.55 MJ mm ha^{-1} h^{-1} yr^{-1}, as per Sen's slope) demonstrated a significant decreasing trend (Table 6). The decline in the annual R-factor in two agro-climatic zones of Chhattisgarh state can be linked to reduced rainfall (Raj *et al*., 2022). However, the decrease in rainfall does not necessarily indicate a reduction in soil erosion and subsequent deterioration of soil health. The declining rainfall trend could impact vegetation cover and growth, leading to increased erosion due to a lack of protective covering. Conversely, the Bastar plateau exhibited a significant increasing trend in R-factor (30.9 MJ mm ha^{-1} h^{-1} yr^{-1}, as per linear regression, and 23.5 MJ mm ha^{-1} h^{-1} yr^{-1}, as per Sen's slope, respectively). The rise in the R-factor trend due to increased rainfall, especially when the land is bare and rainfall intensity is high, could contribute to higher erosion.

The literature review noted that there are only a limited number of studies on erosivity trend analysis across the world, with just two reported for India (Singh and Singh, 2020; Dash *et al.,* 2024). The Himalayan catchment in India displayed a general decreasing trend in long-term average annual R-factor and erosivity density (Singh and Singh, 2020). Most parts of the Odisha displayed an increasing trend in R-factor, while a declining trend is observed in the North Eastern Ghats, North Western Plateau and Western Undulating Zone (Dash *et al.,* 2024). Similarly, in the Central Rift Valley, Ethiopia, there was reported a decreasing trend in monthly and annual R-factor (2000 to 2010), attributed to land use changes due to human activities and variations in topography as contributing factors to increased soil erosion in the area (Meshesha *et al*., 2015).

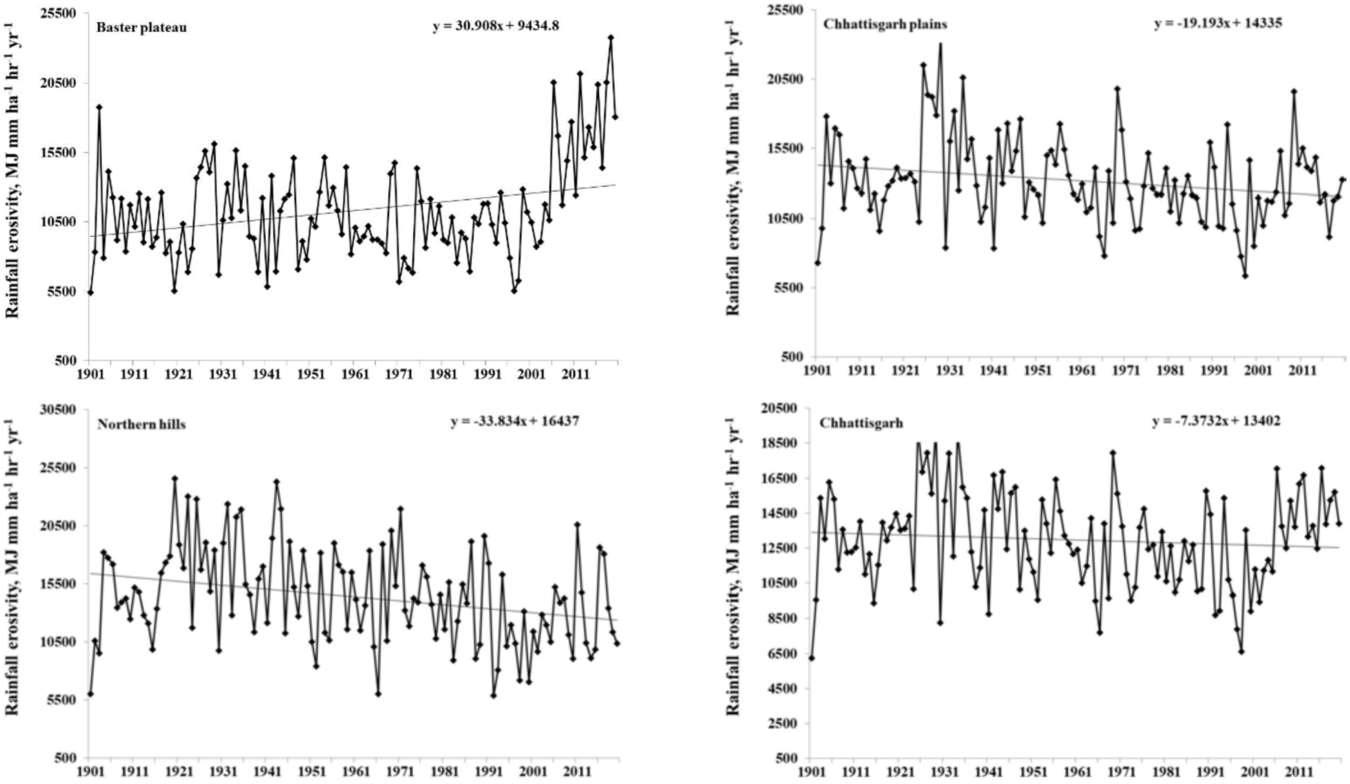

FIGURE 5 Variation in annual R-factor over the study area (1901-2020)

TABLE 6 Annual R-factor trend with regression equation, Z statistic value (MK test) and Sen's slope

Agro-climatic zones	Equation	Z statistics	Sen's slope
Bastar plateau	y = +30.908x + 9434.8	+1.73	+ 23.50
Chhattisgarh plains	y = -19.193x + 14335	-2.29*	-17.55
Northern hills	y = -33.834x + 16437	-2.78*	-35.61
Chhattisgarh state	y = -7.3732x + 13402	-1.32	-6.91

*Note: *significance at 5% level*

3.4 | Changepoint in Annual Rainfall and R-factor

In the quest to identify potential change points or shift years, the annual rainfall and R-factor time series data underwent scrutiny through the standard normal homogeneity test (SNHT) and Pettitt's test, both at a 5% significance level. Remarkably, both analyses revealed different years as the most probable change points in the rainfall and R-factor series across three agro-climatic regions of the Chhattisgarh State. Table 7 provides a concise overview of these shifting years or change points.

Specifically, the annual rainfall on the Bastar plateau displayed changes only in the early years of this century (2003/2005), subsequently affecting the annual R-factor (2003/2005). Conversely, the other two agro-climatic zones of the Chhattisgarh state showcased a likely shift in rainfall and the R-factor around the mid-20th century (1958 to 1978). Nema *et al.* (2018) found similar results by utilising rainfall data from 1901 to 2015 for Chhattisgarh state. They also found changes in the region's rainfall pattern (1946 to 1974), aligning with the outcomes observed in this study.

3.5 | Impact on Crop Growth

In two agro-climatic zones of Chhattisgarh state and across the entire state, there is a noticeable and concerning trend: a decline in rainfall, especially during the rainy season. Various studies have corroborated this trend, including research by Shrivastava and Paul (2013) and Meshram *et al.* (2016), who have observed a reduction of approx. 150 mm in average annual rainfall over the past 50 years. Apart from the declining trend in rainfall, delays in monsoons and irregularity in monsoons are other major concerns in the state.

In the study area, the primary crop cultivated is paddy, a staple food. Paddy crops have a considerable water requirement, ranging from 1000 to 1500 mm. This reliance on adequate rainfall makes the declining trend of rainfall a severe concern. Researchers have highlighted the potential

TABLE 7 Change point analysis for annual rainfall and R-factor for different agro-climatic zones of Chhattisgarh state (1901-2020)

Agro-climatic zones	Test type	Annual rainfall		Annual R-factor	
		P value	Year of shift	P value	Year of shift
Bastar plateau	Pettitt's test	0.015*	2003	0.001*	2003
	HNST	<0.0001*	2005	<0.0001*	2005
Chhattisgarh plains	Pettitt's test	0.003*	1961	0.009*	1958
	HNST	0.009*	1961	0.048*	1958
Northern hills	Pettitt's test	0.002*	1978	0.005*	1977
	HNST	0.001*	1991	0.005*	1977
Chhattisgarh state	Pettitt's test	0.244	1961	0.195	1967
	HNST	0.199	1961	0.144	1961

*Note: *significance at 5% level*

impact of late monsoons, indicating a 27% decrease in paddy yield during late monsoon years compared to normal monsoon years. In general, the declining rainfall trend in the study area can result in the drying up of water bodies and soil moisture availability to crops, thereby influencing agricultural production. Further, adverse weather conditions during crop growing season may force farmers to leave their fields bare for extended periods, which can create a favourable condition for soil erosion, and soil erosion can lead to loss of soil fertility, thereby affecting crop yield and nutritional security.

Interestingly, while the Bastar plateau experiences a rising trend in rainfall and R-factor, this also presents challenges. The increased rainfall and R-factor can potentially induce significant soil erosion, adversely affecting crop yield and nutrient retention. Whether it is an increasing or decreasing trend in rainfall, both scenarios necessitate implementing location-specific soil and water conservation measures to mitigate the associated impacts effectively.

3.6 | Suitable Management Options

To effectively combat the impact of climate change on agriculture, it is imperative to adopt comprehensive crop management practices and implement soil and water conservation measures. Utilizing harvested rainwater can promote low-water-requirement crops, including lathyrus, chickpea, pea, green gram, black gram, sesame, groundnut, and soybean. Additionally, farmers should consider direct dry seeding with line sowing techniques to enhance crop yield, especially during scarce rainfall, with a recommended 25% higher seed rate.

In the realm of soil and water resource management, strategic conservation measures are crucial. These measures, illustrated in Fig. 6 and Fig. 7, fall into three interrelated categories: biological, mechanical and drainage line treatment. The traditional soil and water conservation practices followed by farmers in the Northern hill zone of Chhattisgarh are borrow pit, brushwood structure, *dhodhi* (well-like structure with a dimension of 1.5 × 1.5 × 2.0 m, constructed in low land to harvest canal seepage), farm pond, fencing trench as recharging trench, earthen field bund, FYM pit, peripheral stone bunding, deep ploughing, sandbag check dam, and Ipomoea vegetative barrier (Sinha *et al.,* 2015). In addition to practices mentioned above, biological measures such as cultivating crops along contours, intercropping of finger millet with pigeon pea (6:2) and maize with cowpea (2:2), strip cropping of groundnut and finger millet (4:6), alley cropping, conservation tillage should be adopted in arable areas of Baster plateau with a land slope less than 5%. Similarly, in the Northern hill region, intercropping of pigeon pea with groundnut (2:5), maize with arhar (4:2), and paddy with sesamum are feasible options to conserve soil moisture (Vanitha *et al.,* 2023). In areas with land slopes confined to 8 to 10%, it is essential to construct field and contour bunds and stone bunds within the field. For degraded, non-arable land, staggered contour trenching and diversion drains at the foothills are recommended for safe runoff disposal. Other mechanical structures like loose boulder check dams in second-order streams and gabions and reinforced cement concrete check dams in higher-order streams are effective in reducing soil erosion. Implementing *in-situ* soil and water conservation techniques, such as micro-catchments with circular basins, half-moon trenching, contour trenches with straw mulching, and constructing silpauline-lined micro ponds, is vital for water storage and enhancing soil moisture (Adhikary *et al.,* 2021). Apart from these measures, the agroforestry system's promotion and restoration can meet the rural people's basic needs and minimise environmental degradation. Therefore, tree species like *Acacia nilotica, Albizia procera, Butea monosperma, Gmelina arborea, Tectona grandis, Dalbergia sissoo* and *Madhuca indica* can be raised as boundary plantations with crops like paddy, soybean and maize during *kharif* season. Implementing the measures mentioned above at suitable places will help mitigate the adverse impacts of climate change on agriculture by ensuring adequate water availability and promoting soil health.

3.7 | Policy Recommendations for Different Zones

As the Chhattisgarh state has three distinct agro-climatic

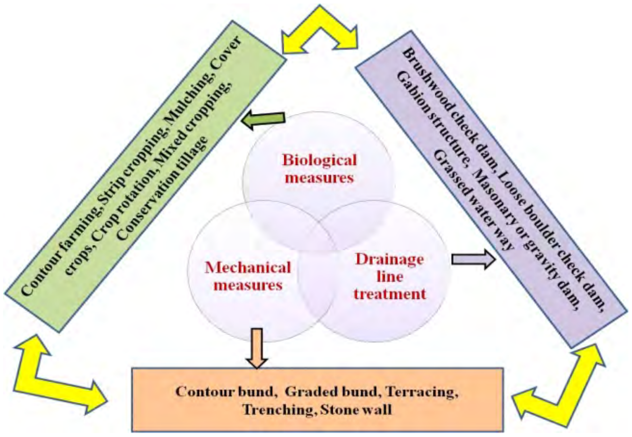

FIGURE 6 **Management options to conserve soil and water**

zones, namely the Baster plateau, the Chhattisgarh plain, and the Northern hills, the policies recommended in this study are separately recommended for these three regions.

a | Bastar Plateau:

- **Address increasing rainfall:**
  - Implement water harvesting structures to manage increased runoff due to a nearly 200 mm rise in rainfall.
- **Combat soil erosion:**
  - Develop / adopt measures to reduce soil erosion, especially considering the area's high elevation and slopes.
- **Counteract deforestation:**
  - Focus on reforestation and sustainable land use to counteract the ongoing deforestation (rate of 53 km^2 yr^{-1}, from 23,550 km^2 in 2000 to 22,437 km^2 in 2021).

b | Chhattisgarh Plain:

- **Adapt to decreasing rainfall:**
  - Promote water-efficient rice cultivation methods such as:
    - » Alternate wetting and drying (AWD)
    - » Direct seeded rice (DSR)
    - » System of rice intensification (SRI)
    - » Use less water-demanding rice varieties
- **Introduce diversified cropping:**
  - Encourage cultivating crops requiring less water, like maize and soybean.
- **Enhance water storage:**
  - Construct dug-out ponds for water harvesting to make up for decreasing rainfall.
- **Utilize excess water:**
  - Channel excess water from the Bastar region to supplement the water deficit.

c | Northern Hills:

- **Adapt to decreasing rainfall:**
  - Implement water-efficient rice cultivation methods such as AWD, DSR, and SRI.
  - Introduce less water-demanding rice varieties.
- **Diversify cropping patterns:**
  - Promote cultivating crops like maize and soybean that require less water.
- **Soil and water conservation:**
  - Construct trenches with plantations to manage water runoff and prevent soil erosion.
  - Develop water harvesting structures to conserve water in the highly undulating terrain.
- **Prevent deforestation:**
  - Take action to reduce the deforestation rate (currently 3.0 km^2 yr^{-1}) through reforestation and sustainable forest management practices.

The policy recommendations tailored for the Bastar plateau, Chhattisgarh plain, and Northern hills aim to address the unique environmental challenges faced by each region. The Bastar plateau focuses on managing increased rainfall through water harvesting structures, reducing soil erosion, and countering deforestation with reforestation initiatives. Adapting to decreasing rainfall is crucial for the Chhattisgarh plain, which involves promoting water-efficient rice cultivation methods, diversifying crops to include less water-intensive varieties like maize and soybean, enhancing water storage through dug-out ponds, and utilising excess water from Bastar. In the Northern hills, addressing decreased rainfall and preventing soil erosion are prioritised through similar water-efficient farming techniques, diversified cropping, and constructing trenches and water harvesting structures. Additionally, reforestation and sustainable forest management practices are essential to curb deforestation. By implementing these strategies, each region can sustainably manage its water resources, maintain soil health, and preserve forest cover, ensuring long-term environmental and agricultural stability.

4 | CONCLUSIONS

This study analysed rainfall trends and the R-factor (erosivity) across three agro-climatic zones in Chhattisgarh, India, from 1901 to 2020. Statistical tests revealed significant shifts in seasonal and annual rainfall and erosivity. The Bastar plateau showed an increasing rainfall trend (1.8 mm yr^{-1}), while the Chhattisgarh plains, Northern hills, and the state experienced decreasing rainfall trends. Similar patterns were observed for the southwest monsoon period and annual erosivity. The R-factor for Chhattisgarh showed a declining trend (7.34 MJ mm ha^{-1}h^{-1}yr^{-1}), except in the Bastar plateau, which displayed an increase (31.91 MJ mm ha^{-1}h^{-1}yr^{-1}), highlighting growing soil erosivity risks.

a. Contour farming (potato) b. Mixed cropping c. *Sambuta* vegetative barrier

d. Earthen field bunds e. Stone field bunds f. Trench cum field bunds

g. Brush wood check dam h. Loose boulder check dam i. Gabions in the channel

j. Trench in plantation field bunds k. Micro-catchment l. Silpaulene lined farm pond

FIGURE 7 Various conservation measures implemented in the field

The outcomes of this study bear significance for several key stakeholders, including soil and water conservationists, agricultural water managers, and natural resource planners. By shedding light on this shifting rainfall and erosivity patterns, this research equips decision-makers with essential insights to design adequate soil and water conservation strategies, agricultural planning, and sustainable utilisation of natural resources in the region. Such informed planning and management are vital to mitigate the potential challenges posed by changing climatic conditions and ensure the sustainable development of the agro-climatic zones in Chhattisgarh state.

DATA AVAILABILITY STATEMENT

The data presented in this study are available upon request from the corresponding author.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR'S CONTRIBUTION

Ch. Jyotiprava Dash: Conceptualization, data analysis, writing; Prachi Yadav: Data collection, data analysis; Randhir Kumar: GIS mapping; Sitanshu Sekhar Patra: Data analysis; HC Hombegowda: Reviewing; Partha Pratim Adhikary: Writing, reviewing and editing.

FUNDING

This work was not supported by any funding.

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How to cite this article: Dash, Ch. J., Yadav, P., Kumar, R., Patra, S.S., Hombegowda, H.C. and Adhikary, P.P. 2024. Assessing rainfall patterns, erosivity dynamics, and sustainable soil and water management strategies across agro-climatic zones of Chhattisgarh, India. *Indian J. Soil Cons.,* 52(2): 147-159.