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Short communication

Rainfall variability and trends in different agroclimatic zones of Bihar, India

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Precipitation is a key indicator of water availability in ecosystems, with various hydrological and climatological factors influencing its cyclical variations (Khaniya *et al.,* 2020). Precipitation variability, often linked to climate change, has been associated with hydrometeorological disasters like droughts and floods (Pastagia and Mehta, 2022; Singh *et al.,* 2021). Global warming has caused regional variations in annual precipitation trends, although the global trend remains unclear (Aher *et al.,* 2019; Singh *et al.,* 2020). In Bihar, where 77% of the workforce is involved in agriculture, precipitation anomalies affect crop yields and farmers' incomes (Sharma and Priya, 2023; Shankar *et al.,* 2022). Understanding rainfall trends is crucial for mitigating economic losses, ensuring food security, and planning for climate resilience. The state's three agroclimatic zones—North West, North East, and South Bihar Alluvial Plains—experience distinct rainfall patterns (Sattar *et al.,* 2021). Zones I and II face floods, while Zone III, particularly Zone III B, suffers from droughts (Haris *et al.,* 2015). Research shows an increasing frequency of extreme rainfall events in areas like Patna, alongside reduced rainy days in Zones I and II, prompting shifts in cropping patterns (Singh *et al.,* 2023). Standard precipitation index (SPI) has been used by various workers to understand the rainfall variability and drought characteristics in different regions of India (Maity *et al.,* 2024; Panday *et al.,* 2020). This study aims to analyze rainfall variability to assess drought frequency using the Standard Precipitation Index (SPI) in different agroclimatic zones of the Bihar State.

Bihar, a densely populated state in East India, spans approximately 94,163 square kilometers between 83° 20′ E to 88° 18′ E and 24° 20′ N to 27° 31′ N, with an average elevation of 52 meters. The state is divided by the Ganga River into North Bihar, prone to floods from rivers like Gandak and Kosi, and South Bihar, characterized by rain-scarce plains and seasonal rivers such as Sone and Punpun. Bihar's climate, dominated by subtropical monsoons, provides about 84.8% of its annual rainfall (992.3 mm), though droughts are frequent. Four agroclimatic zones (Table 1) define the state's agriculture: Zone I in the north supports rice and sugarcane, Zone II (central) focuses on paddy and wheat, and Zones IIIA and IIIB (south) grows maize, pulses, and oilseeds. Bihar's agriculture, heavily reliant on monsoons, is vulnerable to climate variability, requiring effective flood management in the Ganga's sub-basins.

This daily precipitation data (1901–2023) were obtained from the National Data Centre (NDC), IMD Pune, and IMD Patna. Stations were grouped by agroclimatic zones, and rainfall was analyzed on monthly, seasonal, and annual scales using central tendency and dispersion. Seasons were classified as per IMD: Southwest monsoon (June–October), Post-monsoon (November–December), Winter (January–February), and Pre-monsoon (March–May). Meteorological droughts were identified based on SPI. Rainfall trends were analyzed using the Mann-Kendall (MK) test and Sen's slope (SS) estimator. The MK test, a non-parametric method (Mann, 1945) resistant to outliers, calculates trend probability using:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(Xj - Xi) \qquad (1)$$

$$Sign(Tj - Ti) = \begin{cases} 1 \;\; if\ Xj - Xi > 0 \\ 0 \;\; if\ Xj - Xi = 0 \\ -1 \;\; if\ Xj - Xi < 0 \end{cases} \qquad (2)$$

The variance(σ2) for the S-statistics is as $\sigma^2 = \sigma^2 = \frac{[n(n-1)(2n+5)]}{18}$ (3)

Where n is the number of data points, Xj and Xi are the data values in the times series i and j (j>i) and in the case where the test sample size is n>10, the standard normal test statistic (Zs) is calculated using the following formula:

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Table 1: Description of agroclimatic zones of Bihar

Agroclimatic Zones	Districts	Annual rainfall
Zone I	Begusarai, Darbhanga, East Champaran, Gopalganj, Madhubani, Muzaffarpur, Samastipur, Saran, Sheohar, Sitamarhi, Siwan, Vaishali, West Champaran	1207.4 mm
Zone II	Araria, Katihar, Khagaria, Kishanganj, Madhepura, Purnia, Saharsa, Supaul	1381.8 mm
Zone III A	Banka, Bhagalpur, Jamui, Lakhisarai, Munger, Sheikhpura	1130.5 mm
Zone III B	Arwal, Aurangabad, Bhojpur, Buxar, Gaya, Jahanabad, Kaimur, Nalanda, Nawada, Patna, Rohtas	1025.8 mm

Table 2: Seasonal distribution of rainfall (mm) in different agroclimatic zones of Bihar

Seasons/annual	Zone-I	Zone-II	Zone-IIIA	Zone-IIIB
Winter (January-February)	25.4 (2.10%)	19.2 (1.39%)	27.7 (2.45%)	32.0 (3.12%)
Pre-monsoon (March-May)	83.9 (6.95%)	143.4 (10.38%)	79.3 (7.01%)	37.7 (3.68%)
Monsoon (June-September)	1030.6 (85.36%)	1136.3 (82.23%)	937.9 (82.96%)	897.2 (87.46%)
Post-monsoon (October-December)	67.5 (5.59%)	82.8 (6.0%)	85.6 (7.57%)	58.9 (5.74%)
Annual	1207.4	1381.8	1130.5	1025.8

Values in parenthesis indicate percent contribution to annual rainfall

$$Zs=\begin{cases}\frac{S-1}{\sigma}\ for\ S>0\\ 0\ for\ S=0\\ \frac{S+1}{\sigma}\ for\ S<0\end{cases} \quad (4)$$

All positive value of Zs indicates increasing trends while negative values of Zs represent decreasing trends. Sen's slope (m) is calculated by: $m_i = \frac{(Y_j - Y_i)}{(J-1)}$ (5)

Spatial and seasonal variability of rainfall

Rainfall across Bihar's agroclimatic zones (I, II, IIIA, IIIB) from 1901 to 2023 shows distinct spatial and temporal variability (Table 2). Most precipitation occurs during the monsoon season (June-September), contributing over 80% of the annual rainfall in all zones. Zone II receives the highest annual rainfall (1381.8 mm), followed by Zone I (1207.4 mm), with Zones IIIA and IIIB receiving less (1130.5 mm and 1025.8 mm, respectively). Table 2 depicts that the winter (January-February) accounts for a minimal portion of annual rainfall, especially in Zone II (1.39%), while Zone IIIB experiences slightly higher rainfall (3.12%). Pre-monsoon rainfall is most significant in Zone II (10.38%), with post-monsoon variability highest in Zones IIIA and IIB. Monsoon season contributes about 82-87% of the annual rainfall. This variability is driven by geographic factors, including the Himalayas' orographic effects and the Chotanagpur Plateau's topography.

Drought characteristics using SPI

The Standardized Precipitation Index (SPI) measures rainfall behaviour over 3, 6, 9, and 12 months across Bihar's agroclimatic zones (Table 3). Zone I consistently has an SPI of -0.06, indicating near-normal precipitation conditions. Zone II shows moderate dryness with an SPI of -0.31. Zone III A indicates mild dryness with an SPI of -0.14, while Zone III B suggests near-normal conditions with an SPI of -0.07, reflecting manageable moisture stress across the zones.

Trend analysis of the rainfall

A time-series analysis using Mann-Kendall statistics and Sen's slope estimator on rainfall data from 1901 to 2023 revealed significant trends across Bihar's agroclimatic zones (Table 4). During the winter season, all zones show declining trends, especially Zones IIIA and IIIB, with reductions of -0.167 mm yr^{-1} and -0.161 mm yr^{-1}, respectively, likely due to weakened western disturbances. In the pre-monsoon season, Zone I demonstrates an increasing trend (S: 0.336), while Zone IIIA remains stable, and Zone IIIB experiences a slight decrease of -0.035 mm yr^{-1}. The monsoon season indicates significant declines in Zones II and IIIA, with reductions of -1.235 mm/year and -1.725 mm yr^{-1}, reflecting changes in monsoon patterns. For the post-monsoon season, Zone IIIB shows a decline of -0.078 mm yr^{-1}, while other zones remain stable. The annual analysis highlights that Zone IIIA experiences the most substantial reduction at -1.923 mm yr^{-1}, indicating increasing rainfall variability, particularly in Zones II and IIIA. The study highlights the urgent need for climate-resilient agricultural practices in Zone IIIA due to significant declines in monsoon and annual rainfall, emphasizing the complex interactions between seasonal trends and regional weather systems.

This study revealed significant variability in rainfall in different zones of Bihar, with notable declines in monsoon and annual rainfall, especially in Zone IIIA. While Zone I shows no significant trends, Zone II experiences decreasing precipitation during the monsoon, and both Zones IIIA and IIIB reflect declining trends. The Standardized Precipitation Index indicates Zone I has near-normal conditions, Zone II faces moderate dryness, and Zone IIIA shows mild moisture stress. Overall, the trends highlight the agricultural sector's vulnerability to climate variability, necessitating climate-resilient practices.

Table 3: Standard precipitation index (SPI) across agroclimatic zones of Bihar

Agroclimatic Zones	SPI3	SPI6	SPI9	SPI12
Zone I	-0.0605	-0.0606	-0.0620	-0.0618
Zone II	-0.3074	-0.3074	-0.3081	-0.3082
Zone III A	-0.1362	-0.1363	-0.1368	-0.1371
Zone III B	-0.0735	-0.0734	-0.0738	-0.0739

Table 4: Sen's slope estimates of the monthly, seasonal, and annual rainfall(mm/year)

Seasons	Zone I		Zone II		Zone III A		Zone III B	
	Zs trend	Sen's slope	Zs trend	Sen's slope	Zs trend	Sen's slope	Zs trend	Sen's slope
Winter	-0.11	-0.06	-0.11	-0.08	-0.19	-0.17	-0.20	-0.16
Pre-monsoon	0.13	0.34	0.07	0.13	0.05	0.05	-0.01	-0.04
Monsoon	-0.06	-0.51	-0.13	-1.24	-0.23	-1.73	-0.14	-1.04
Post-monsoon	-0.01	-0.02	-0.03	-0.05	-0.03	-0.05	0.04	0.08
Annual	-0.06	-0.48	-0.14	-1.21	-0.23	-1.92	-0.16	-1.46

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