Open Access
Volume 6 Issue 1
Research Article

Journal of Water Engineering and Management
ISSN: 2582-6298

Rainfall Trend and Drought Analysis in Magadh Region Bihar

Vikash Kumar[1], Shikha Chourasiya[1]
[1]Department of Civil Engineering
Central University of Jharkhand, Ranchi, India

Article Info

Article History:
Received on: February 25, 2025
Revised on: March 28, 2025
Accepted on: April 20, 2025
Published on: April 30, 2025
Published by Academic Hope

***Corresponding author** Shikha Chourasiya
Email: shikha.chourasiya@cuj.ac.in

How to Cite:
Kumar, V. and Chourasiya, S. 2025. Rainfall Trend and Drought Analysis in Magadh Region Bihar, Journal of Water Engineering and Management 4(3): 27-32.
DOI:
https://doi.org/10.47884/jweam.v6i1pp27-32

Abstract

Climate change is increasingly influencing regional hydrology, and Bihar reflects this sensitivity through contrasting climatic patterns. While northern Bihar regularly experiences floods, the southern part, including the Magadh division, is witnessing declining rainfall and recurring droughts. This study examines long-term rainfall trends in the five districts of Magadh division—Arwal, Aurangabad, Gaya, Jehanabad, and Nawada, using rainfall records from 1970 to 2020. The Mann–Kendall test and Sen's slope estimator were applied to analyze annual, seasonal, and monthly precipitation trends. The results indicate a significant decrease in rainfall in Nawada, Aurangabad, and Jehanabad. Nawada, in particular, shows a notable reduction in both monsoon (4.8 mm/year) and annual rainfall (5.8 mm/year), suggesting increasing hydro-climatic stress. Frequent drought events, occurring every 2-4 years, were also observed across the region. To assess drought severity, the standardized precipitation index (SPI) was computed by fitting the long-term rainfall data to a probability distribution and normalizing it. Positive SPI values indicate wetter-than-normal years, while negative values represent rainfall deficits. The SPI results reveal extreme drought occurrences in Nawada, Aurangabad, Gaya, and Jehanabad, with severe drought recorded in all districts. Nawada experienced the highest drought frequency (four severe events), followed by Aurangabad and Gaya (three each), Arwal (two), and Jehanabad (one). These findings underscore the growing vulnerability of southern Bihar and highlight the need for climate-resilient planning and drought-mitigation strategies.

Keywords: Rainfall trend: Mann–Kendall test: Sen's slope: Standardized Precipitation Index (SPI): Drought frequency: Magadh division: Bihar.

Introduction

Climate change has arisen as one of the most tenacious global concerns, with its impacts clearly noticeable through rising temperatures, irregular monsoon patterns, and increasing frequency of risky events such as droughts. In India, the economy is still principally dependent on agriculture, the summer monsoon plays a perilous role in nourishing agricultural productivity, hydrological planning, and overall socio-economic firmness. However, current years have shown substantial variability in monsoon behaviour, leading to crop failure, water crises, and frequent droughts mainly in drought-prone regions like the Magadh division of Bihar, where rainfall vagueness has deepened floods in some districts and severe drought in others. Given that past studies often depend on century-scale data and oversee recent climatic shifts, the present study analyses 51 years (1970–2021) of rainfall data to assess monthly, seasonal, and annual rainfall trends using the Mann–Kendall test, Sen's slope, coefficient of variation (COV), standard deviation (SD), and rainfall contribution. Drought sternness is further evaluated using the IMD arrangement and the Standardized Precipitation Index (SPI). This cohesive assessment aims to provide an updated understanding of varying rainfall patterns and drought physical characteristics essential for effective water resource management and climate-resilient planning in the region.

Previous studies across India and beyond highlight momentous spatial and temporal dissimilarities in rainfall and drought characteristics, emphasizing the importance of trend detection and SPI-based drought assessment. Mishra and Desai (2005) examined drought severity in the Kansabati basin using SPI and conveyed severe droughts during the 1980s, while Kumar et al. (2010) analysed 135 years of rainfall across 30 Indian subdivisions and observed increasing trends in half of them, with noteworthy monthly variations. Numerous studies combined remote sensing with ground data, such as Jain et al. (2009) and Dutta et al. (2015), who demonstrated that NDVI-based indices correlate well with SPI for current drought monitoring in Rajasthan. Regional rainfall trend studies, including Mondal et al. (2012) for Odisha, Mudentia et al. (2014) for Rajasthan, Karnewar (2018) for Maharashtra, and Giri (2015) for Bihar, collectively reveal mixed increasing and decreasing trends with rising temperature extremes. Large-scale SPI analyses, such as those by Caloiero (2018) in Europe and Bhunia et al. (2020) in West Bengal, indicate frequent negative SPI events and increasing drought occurrences. More topical works like Deb et al. (2020) and Chinchorkar (2019) further authenticate the usefulness of Mann–Kendall, Sen's slope, and IMD drought criteria in noticing both long-term rainfall variability and recurrent drought episodes. Overall, the literature unswervingly highlights the growing need to assess rainfall trends and drought sternness using integrated statistical and remote-sensing methods to recognize evolving climate impacts.

Materials and Methods

Study Area

Magadh division, located in southern Bihar and bordering Jharkhand, includes five districts—Gaya, Jehanabad, Arwal, Nawada, and Aurangabad, with Gaya as its headquarters. It covers about 10,459 sq. km, nearly 9% of Bihar's total geographical area, and lies between 24°30′–25°27′ N latitude and 84°57′–86°11′ E longitude. The region is drained by major rivers such as the Sone on the west, the Falgu, and the Sakri in Nawada (Fig. 1). While the northern part (Arwal, Jehanabad) consists of fertile plains, the southern portion adjoining Jharkhand (Gaya, Nawada) features rocky terrain and hill ranges.

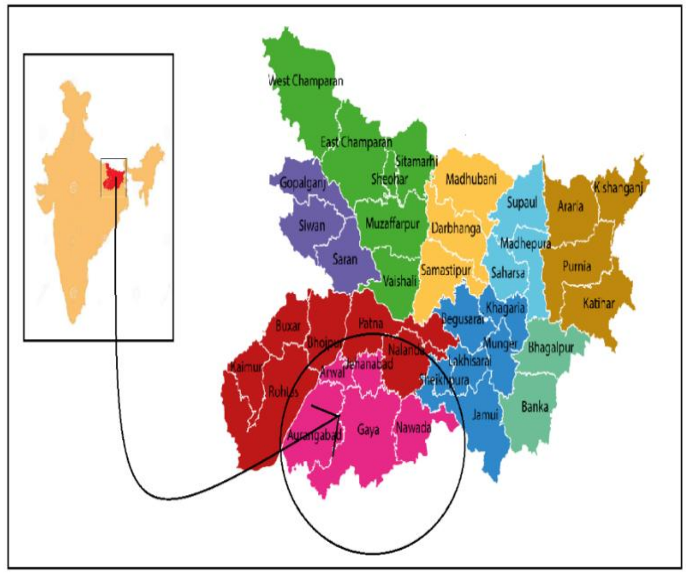

Fig.1 Location details of study area

Data Collection and Analysis

Daily rainfall data for all five districts of the Magadh division (1970–2020) were obtained from WRIS and used to compute monthly, seasonal (winter: Jan–Feb; summer: Mar–May; monsoon: Jun–Sep; post-monsoon: Oct–Dec), and annual rainfall totals. From these, mean rainfall, standard deviation, coefficient of variation (COV), and rainfall contribution were calculated for each district. Finally, long-term rainfall trends were assessed using the Mann–Kendall test and Sen's slope estimator.

Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is a widely used drought index for assessing drought severity and duration in a region. It was originally developed by McKee et al. (1993) and requires long-term precipitation records for computation. In the SPI method, the long-term rainfall data is first fitted to an appropriate probability distribution, which is then transformed into a standard normal distribution. As a result, the mean of SPI values for the selected time period becomes zero. Positive SPI values indicate above-normal precipitation, representing wet or no-drought conditions, whereas negative SPI values signify below-normal precipitation, indicating varying levels of drought intensity.

$$SPI = (X_i - \bar{X}) / \sigma \quad .... (1)$$

where, X_i is data point, $\bar{X}$ - mean, σ - standard deviation of the data

The SPI classification provides a systematic way to identify and categorize drought and wetness conditions based on deviations of precipitation from the long-term mean (Table 1). As shown in the table, SPI values are grouped into eight categories ranging from Extreme Wet (≥ +2.00) to Extreme Drought (≤ −2.00). Positive SPI values indicate wetter-than-normal conditions, while negative values represent rainfall deficiency leading to drought conditions. This classification system was developed by McKee et al. (1993) and has since become one of the most widely used indices for drought monitoring due to its simplicity, reliability, and ability to assess drought severity over multiple time scales (e.g., 1-month, 3-month, 6-month, 12-month periods). The table helps researchers, planners, and government agencies objectively interpret SPI values and determine the intensity of hydrological and meteorological drought events.

Table 1 SPI Classification for Drought and Wet Conditions

SPI Value Range	Classification
≥ +2.00	Extreme Wet
+1.50 to +1.99	Severe Wet
+1.00 to +1.49	Moderate Wet
0.00 to +0.99	Mild Wet
0.00 to −0.99	Mild Drought
−1.00 to −1.49	Moderate Drought
−1.50 to −1.99	Severe Drought
≤ −2.00	Extreme Drought

Results and Discussion

Analysis of annual seasonal and monthly rainfall

Analysis of 51 years of rainfall data (1970–2020) for all five districts of Magadh division shows that annual rainfall varies moderately across the region, ranging from about 945 mm in Arwal to over 1040 mm in Nawada, with relatively high coefficients of variation (75–91%) indicating considerable year-to-year variability. Monsoon months contribute the largest share of annual rainfall, about 85–88% in all districts, with July consistently recording the highest monthly rainfall (285–293 mm), while December receives the least (4–5 mm). Seasonal analysis reveals that winter and post-monsoon rainfall have the lowest variability, indicating more stable rainfall patterns, whereas summer and certain monsoon months show higher COV values, reflecting irregular rainfall distribution. Overall, the rainfall regime of Magadh division is strongly monsoon-dominated, with substantial spatial and temporal variability, and the district-wise monthly, seasonal, and annual statistics highlight the region's dependence on monsoon performance and its vulnerability to seasonal fluctuations. The rainfall and time exhibit predominantly negative correlations across the five stations. Nawada district records the strongest negative correlation for both annual and monsoon rainfall (–0.33), consistent with the decreasing trend indicated by the Mann–Kendall test. Jehanabad shows the highest positive correlation in the summer season (0.25). Except for summer, all stations display negative correlations in annual, winter, monsoon, and post-monsoon rainfall, while summer rainfall shows a positive correlation at all stations.

Mann Kendall and Sen Slope Analysis

The rainfall trend analysis for the Magadh Division (1970–2020) shows a general decline in monsoon and annual rainfall across most districts. Nawada demonstrates a statistically significant decreasing trend, with monsoon rainfall falling by −4.82 mm/year and annual rainfall by −5.91 mm/year, confirmed by negative Mann–Kendall Z-values beyond the 0.05 significance level. Aurangabad, Gaya, and Jehanabad also show declining monsoon and annual rainfall, but their trends are not statistically significant, although the magnitudes suggest a weakening rainfall pattern. Arwal exhibits minimal change, indicating relatively stable annual rainfall in comparison. A slight positive trend in summer rainfall is observed in Jehanabad, but it is not significant. Overall, the results indicate a gradual reduction in rainfall in the region, with Nawada emerging as the most vulnerable district, highlighting the need for improved water management and drought-resilience measures (Table 2).

The p-value-based trend results indicate that most districts in the Magadh Division do not show statistically significant rainfall trends at the 5% level (Table 3). However, Nawada exhibits a significant decreasing trend in both monsoon and annual rainfall, confirming a clear long-term drying pattern. In addition, Aurangabad and

Jehanabad show significant post-monsoon decreases, suggesting weakening late-season rainfall that may affect groundwater recharge and rabi cropping. All other seasonal and annual values across Gaya and Arwal are non-significant, indicating relatively stable rainfall patterns in those districts. Overall, the findings highlight Nawada as the most rainfall-vulnerable district, followed by localized post-monsoon decline in Aurangabad and Jehanabad.

Table 2 Mann–Kendall (Z) and Sen's Slope (mm/year) Statistics for Seasonal and Annual Rainfall Trends in Magadh Division (1970–2020)

Station	Winter		Summer		Monsoon		Post-Monsoon		Annual	
	Sen's Slope (mm/yr)	M-K Z	Sen's Slope (mm/yr)	M-K Z	Sen's Slope (mm/yr)	M-K Z	Sen's Slope (mm/yr)	M-K Z	Sen's Slope (mm/yr)	M-K Z
Nawada	−0.211	−1.47	0.205	0.53	−4.821	−2.47	−0.633	−1.15	−5.906	−2.27
Aurangabad	−0.197	−1.20	0.211	0.79	−2.146	−0.97	−0.624	−1.84	−2.809	−1.34
Gaya	−0.183	−1.12	0.202	0.62	−2.730	−1.58	−0.817	−1.76	−3.370	−1.55
Arwal	−1.849	−0.67	0.281	0.88	−1.344	−0.58	−0.568	−1.34	−0.108	−0.71
Jehanabad	−0.095	−0.91	0.659	1.63	−1.428	−0.71	−0.882	−1.86	−2.027	−0.71

Table 3 Seasonal and Annual Rainfall Trend Significance Based on p-Values (1970–2020)

Station	Winter		Summer		Monsoon		Post-Monsoon		Annual	
	p-Value	Trend	p-Value	Trend	p-Value	Trend	p-Value	Trend	p-Value	Trend
Nawada	0.141	NT	0.592	NT	0.013	DT	0.248	NT	0.023	DT
Aurangabad	0.304	NT	0.422	NT	0.332	NT	0.046	DT	0.216	NT
Gaya	0.262	NT	0.536	NT	0.132	NT	0.088	NT	0.128	NT
Arwal	0.503	NT	0.380	NT	0.569	NT	0.213	NT	0.487	NT
Jehanabad	0.362	NT	0.103	NT	0.477	NT	0.048	DT	0.477	NT

Drought Analysis by SPI

SPI analysis using annual (Oct–Sept) rainfall data shows distinct drought patterns across the five districts. Extreme drought occurred in Aurangabad, Jehanabad, and Gaya (2005–06) and in Nawada (2004–05), while Arwal experienced none in the last 50 years. The SPI time-series for Arwal shows alternating wet and dry years over the study period, but dry conditions dominate, especially after the mid-1990s (Fig. 2). Positive SPI bars (in green) represent wetter-than-normal years, while negative SPI bars (in red) indicate drought years. In the early decades (1970s–1980s), Arwal experienced a mix of mild droughts and moderate wet spells, with occasional positive peaks indicating favourable rainfall periods. However, from the mid-1990s onward, negative SPI values become more frequent and deeper, reflecting increasing drought intensity and frequency. Severe drought episodes are evident in years such as 2007–08, 2014–15, 2017–18, and 2019–20, where SPI drops significantly below zero. Wet years do occur periodically (1989, 1998–99, 2008–09, and 2012–13), but these are fewer and scattered compared to persistent negative years. This pattern suggests a shifting rainfall regime, where Arwal is gradually transitioning toward more frequent and intense drought conditions, aligning with observed declining monsoon strength in southern Bihar.

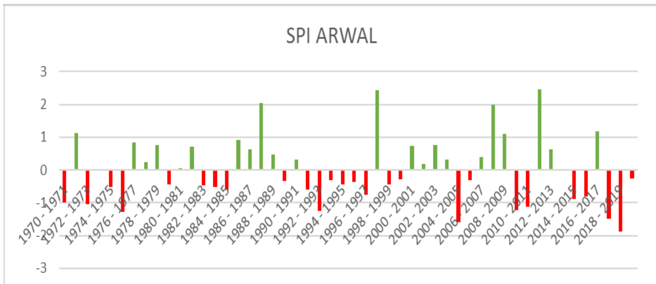

Fig. 2 Standardized precipitation index variability in Arwal district (1970–2020)

Similarly, the SPI plot for Aurangabad shows alternating wet and dry years, but dry periods are more frequent and intense, especially after the mid-1990s. Severe drought events are visible in several years such as 2002–03, 2009–10, 2014–15 and 2017–18, indicating increasing rainfall variability. Although occasional wet years occur, the dominance of negative SPI bars suggests a gradual shift toward drought-prone conditions in the district. The SPI series for Gaya shows frequent negative SPI values over time, indicating recurring drought conditions, particularly after the mid-1990s. Several severe drought years appear (e.g., 2009–10, 2014–15, 2017–18), while wet years are fewer and mostly confined to early decades. Overall, the dominance of red bars in recent years suggests that Gaya is increasingly shifting toward a drought-prone climate with declining rainfall reliability. Jehanabad shows alternating wet and dry years, but negative SPI values dominate, particularly after the mid-1990s, indicating increasing drought frequency. Severe drought episodes are visible around 2009–10 and 2015–16, reflecting significant rainfall deficit years. Although a few wet events occur, the trend suggests Jehanabad is gradually becoming more drought-prone with growing rainfall variability. The SPI plot for Nawada shows a clear shift toward more frequent and intense drought years, especially after the mid-1990s. Several severe drought events appear (e.g., 2006–07, 2010–11, 2014–15, 2017–18), while wet years are fewer and mostly concentrated in the earlier decades. Overall, the pattern indicates pronounced drying and increasing rainfall deficit, making Nawada one of the most drought-vulnerable districts in the region.

Conclusions

The analysis of 51 years of rainfall data (1970–2020) shows that only a few districts in Magadh division exhibit significant trends: Nawada displays a clear decreasing annual and monsoon rainfall trend, while Aurangabad and Jehanabad show declining post-monsoon rainfall. Shorter time-window analysis also indicates decreasing trends in Gaya and Arwal during recent decades. SPI-based drought assessment reveals that extreme droughts occurred mainly in 2004–2006, with Nawada, Gaya, and Aurangabad emerging as the most drought-prone districts matching classifications by the Bihar State Disaster Management Authority. The simultaneous decrease in rainfall and increase in drought frequency, especially in southern districts, highlights the growing vulnerability of this region, which is already facing reduced groundwater recharge and over-extraction (Zone 3B). To address this, urgent conservation measures such as restoring and constructing water-harvesting structures (ponds, tanks, farm ponds, wells, watersheds) and promoting in-situ practices like bunding, terracing, levelling, trenching, and fallow ploughing are essential for improving water security and supporting sustainable resource management.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research received no external funding.

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