Bulletin of Pure and Applied Sciences
Geology, Vol.45F, No.2,
July-December 2026: P.59-77
Original Article

Print version ISSN 0970 4639
Online version ISSN 2320 3234
Available online at www.bpasjournals.com

SPATIO-TEMPORAL ANALYSIS OF RAINFALL VARIABILITY AND LONG-TERM PRECIPITATION TRENDS IN TIKAMGARH DISTRICT, CENTRAL INDIA

Mumtaj Jahan Mansoori[1*], Pradeep Kumar Jain[2]

Author's Affiliations:
[1]Research Scholar, Department of Geology, Maharaja Chhatrasal Bundelkhand University, Chhatarpur, Madhya Pradesh, India
[2]HOD Department of Geology, Maharaja Chhatrasal Bundelkhand University, Chhatarpur, Madhya Pradesh, India

[*]**Corresponding Author: Mumtaj Jahan Mansoori,** Research Scholar, Department of Geology, Maharaja Chhatrasal Bundelkhand University, Chhatarpur, Madhya Pradesh, India
E-mail: mumtaj01992@gmail.com

Received on 14.08.2026, Revised on 24.09.2026, Accepted on 31.10.2026

How to cite this article: Mansoori M.J., Jain P.K. (2026). Spatio-Temporal Analysis of Rainfall Variability and Long-Term Precipitation Trends in Tikamgarh District, Central India. *Bulletin of Pure and Applied Sciences- Geology,* 45F (2), 59-77.

Abstract:
Variability in rainfall and the trend in precipitation have profound effects on rain-fed agriculture and water resources management in the drought prone Bundelkhand region of Central India. In this study, 40 years (1986–2025) monthly rainfall data set of Tikamgarh rain gauge station in Tikamgarh district of Madhya Pradesh was analyzed to understand the nature of rainfall variability and precipitation trend in the area. The monthly data were quality controlled and summarized into seasonal and annual time-series. Rainfall variability was analyzed using coefficient of variation (CV), precipitation concentration index (PCI) and IMD departure classes, while rainfall trend analysis was done using Mann-Kendall test, Sen's Slope Estimator and Pettitt Test, assisted by decade-wise comparison and five year moving average plot. The annual mean rainfall was 986.25 mm (CV = 34.91%) varying between 348.00 mm in 2007 and 2,207.00 mm in 1999. South-West Monsoon season (June – September) contributed to 88.64% of total annual rainfall, annual mean PCI being 31.99 and post-monsoon seasons showing very high relative variability (post-monsoon CV = 268.24%). Eleven years were classified as excess, 17 years as normal, 11 years as deficient and one year as scanty. An insignificant increasing trend in annual rainfall (+6.31 mm yr^{-1}, $p = 0.177$) and SW monsoon rainfall was noted, but a significant increase (+0.64 mm yr^{-1}, $p < 0.001$) in pre-monsoon rainfall was noted, particularly during March – May period. No significant change point in annual rainfall could be detected (Pettitt test, $p = 0.787$). Results suggest considerable inter-annual variability coupled with trend in particular season and no long-term trend in annual rainfall. There is a need for rain water harvesting and in situ moisture conservation in the area.

Keywords: *Rainfall variability, Precipitation trends, Mann–Kendall test, Precipitation concentration index, Tikamgarh, Bundelkhand*

1. INTRODUCTION

Approximately 50% of net sown area in India is rainfed, and thus rainfall becomes the single most important climatic variable affecting agriculture, water resources and livelihoods. Warming results in intensification of global water cycle, leading to changes in intensity, quantity and timing of rainfall in many parts of world (Masson-Delmotte et al., 2021). In India, these changes are manifested in seasonality of south-west monsoon, inter-annual variability of south-west monsoon, occurrences and intensity of heavy rainfall events and availability of water for crops (Guhathakurta & Rajeevan, 2008; Guhathakurta et al., 2015; Dhara et al., 2025; Soni et al., 2025).

Changes in rainfall over India are regionally heterogeneous, with significant decreases in some and increases in some other meteorological subdivisions (Guhathakurta & Rajeevan, 2008) and pronounced epochal variability in south-west monsoon over past century (Guhathakurta et al., 2015). Central India has emerged as hotspot of these changes; increase in frequency and intensity of extreme rainfall events from mid-twentieth century onwards has been observed (Goswami et al., 2006); number of widespread extreme rainfall events has increased by three times during 1950-2015 despite decreasing total rainfall (Roxy et al., 2017). In Madhya Pradesh, decreasing precipitation trends in most districts for 1901-2002 were reported by Duhan and Pandey (2013), whereas Kumar et al. (2023) observed insignificant annual and monsoon trends, while pre-monsoon trend was positive with change point occurring around 1998 for 1951-2021. At the district level, climate vulnerability across Madhya Pradesh has also been assessed by Kumar and Mohanasundari (2024). In neighbouring Uttar Pradesh, summer monsoon rainfall showed a progressive decline in spatial coherence across successive sub-periods since 1901 (Yadav et al., 2026).

Tikamgarh district falls in Bundelkhand region of Madhya Pradesh (Yadav et al., 2025); it is the most drought-prone region of central India. Significant decreasing annual rainfall trends across thirteen districts for 1961-2016 were reported by Gupta et al. (2022). Rain-fed agriculture, scanty irrigation, repeated occurrences of droughts, alternating with periods of excessive rainfall characterise Bundelkhand region. Increase in rainfall variability and non-significant negative annual trends during 1951-2018 among five Bundelkhand districts of Madhya Pradesh including Tikamgarh district were reported by Som and Dey (2022), whereas decrease in south-west monsoon rainfall in majority of Bundelkhand districts during 1981-2020 were found by Fanai et al. (2022). Historical precipitation patterns of Tikamgarh district have also been examined by Sahu et al. (2023). Large-scale ENSO signals were found insufficient for explaining rainfall variability in the region as reported by Yadav et al. (2025), thereby underlining the importance of localized study.

But most of above studies used regional, district averaged or gridded rainfall products (Pai et al., 2014; Kumar et al., 2023) and results are different depending upon study period, data sources and spatial scales. Comparable variability and trend analyses, often combined with change-point tests, have been carried out for Indian river basins (Pawar et al., 2023, 2025) and for Bihar (Kumar & Thangavel, 2025). Local agencies and farmers plan crop activities according to rainfall received at their location; hence information based on station rainfall data is useful for crop planning, construction of water harvesting structures and preparation against drought and flood. Thus far, long term rainfall data of Tikamgarh district has received very little attention in terms of combined variability and seasonality. This study therefore analyses 40 years (1986-2025) of monthly rainfall data available at Tikamgarh rain gauge station with the following objectives:

- To compile the monthly rainfall record of Tikamgarh for 1986–2025 into seasonal and annual series and describe their statistical characteristics;
- To assess rainfall variability, seasonal concentration and the frequency of excess and deficient years;

- To detect trends and change points using the non-parametric Mann–Kendall test, Sen's slope estimator and Pettitt test;
- To compare decadal and seasonal changes in rainfall over the study period. The results are expected to support climate-resilient agricultural and water-resource planning in the study area.

2. MATERIALS AND METHODS

The study used a quantitative and retrospective time series method to study long-term variations and precipitation trends in Tikamgarh district in Madhya Pradesh, Central India. The monthly rainfall data obtained from the Tikamgarh rain-gauge station were subjected to analysis for the years 1986-2025 with respect to season-wise and yearly rainfall pattern, inter-annual variation, temporal concentration, rainfall anomaly, monotonic trend, and change point, if any. The aim of the analysis was to find out the main features of rainfall variability over 40 years, and to see whether there were statistically significant temporal variations in the precipitation patterns. The monthly data were first converted into seasonal and annual sums, followed by statistical analysis. Below are descriptions of the study area, data preparation and analysis methods.

2.1 Study Area

The Tikamgarh district is located in the northern region of Madhya Pradesh state, Central India. It is located roughly between the latitudes 24°26′ and 25°34′ N, and the longitudes 78°26′ and 79°21′ E. The study area is a part of the Bundelkhand Plateau and has a tropical monsoon type of climate, with marked seasons in temperature and precipitation. The main precipitation occurs in the south-west monsoon period; the winter and pre-monsoon seasons usually have very low precipitation.

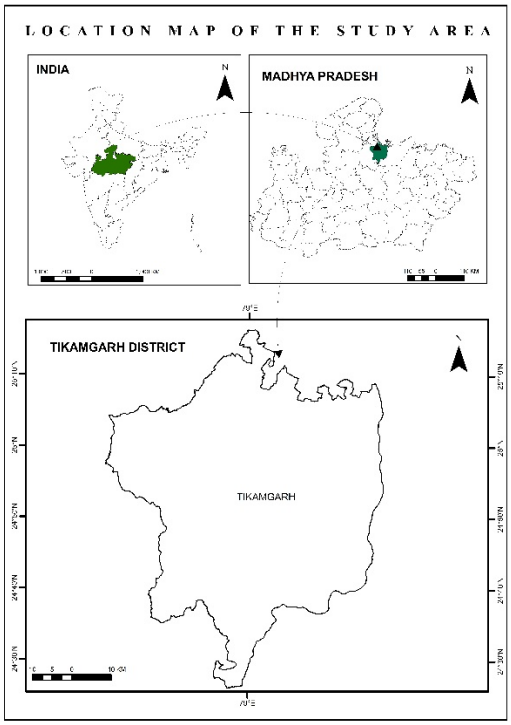


Figure 1: Location map of the study area Tikamgarh district Madhya Pradesh

The onset, progress and withdrawal of the monsoons, together with the total seasonal precipitation, are the most significant factors affecting agricultural activity, availability of surface water resources and groundwater recharge in the region. Due to the dominance of rainfed agricultural practices in the region, any changes in monsoonal precipitation can significantly affect the productivity of agriculture. Thus, the analysis of rainfall

variability on a long period is essential for the description of hydroclimate in the region. The Tikamgarh rainfall gauge was chosen as a reference station for studying precipitation variability for the time period considered in the research. The geographical location of the study area is shown in Fig. 1.

2.2 Data Source and Quality Control

The dataset comprised monthly rainfall amounts expressed in millimeters (mm) extracted from the rainfall dataset provided. The time range of this data is from January 1986 to September 2026. However, the main statistical analysis was carried out on the dataset of 40 full years covering January 1986 to December 2025. It consists of 480 monthly observations where 12 months are present for each of the analyzed years. Observations for the year 2026 cover January – September only, and thus they have not been included in the analysis.

The dataset was checked for the presence of any missing observations, negative rainfall amounts, non-numeric observations and duplicate observations. There were no missing monthly observations or negative rainfall values found in the analytical series covering the 1986 – 2025 range. In total, 189 monthly observations show zero rainfall amounts. They have been left in the dataset since zero amount is a valid rainfall observation rather than missing one. Furthermore, the monthly observations were checked for extremely large values that could appear to be outliers considering the distribution of rainfall in the respective month. Outlier observations were evaluated in terms of monsoon regime in the region rather than deleted from the dataset as statistical outliers.

Thus, the procedure of quality control of the dataset was aimed at detecting potential inconsistencies in the observations while preserving their variability. The cleaned monthly series has been further used to generate seasonal and annual rainfall amounts. Since the analysis is based on a single rain-gauge station, the results can be interpreted mainly in terms of temporal variability of rainfall at the station and the study area.

2.3 Construction of Monthly, Seasonal and Annual Rainfall Series

Monthly rainfall readings were arranged in chronological order and then aggregated to four meteorological seasons to explore whether there were any differences in precipitation patterns in different seasons. These included the following: winter (January-February), pre-monsoon (March-May), south-west monsoon (June-September), and post-monsoon (October-December).

The calculation of seasonal precipitation involved summing up monthly precipitation readings allocated to each particular season. On the other hand, annual rainfall was obtained by summing up the monthly precipitation readings observed throughout 12 months of one particular year. Consequently, the annual time series consisted of 40 observations for the period between 1986 and 2025, while each seasonal time series consisted of 40 annual observations.

These three types of time series were used to analyze precipitation patterns, year-to-year variations, and temporal trends. Monthly analysis helped identify precipitation seasonality, while the seasonal aggregation allowed comparing precipitation in four meteorological seasons. Annual aggregation served as the basis for analyzing temporal trends and anomalies.

2.4 Descriptive Statistics and Rainfall Variability

Statistical parameters such as the mean, standard deviation (SD), median, minimum, maximum and skewness were determined in order to describe the characteristics of rainfall in terms of their distribution and variability on monthly, seasonal and annual time scales. This was done by analysing the rainfall data sets using the above-mentioned statistical parameters.

Relative rainfall variability was determined by calculating the coefficient of variation (CV) expressed as:

$$CV = \frac{SD}{\bar{P}} \times 100$$

where (SD) is the standard deviation of rainfall while (\bar{P}) is the mean rainfall for the respective series. The CV ratio was used to determine the comparative variability of rainfall on monthly and seasonal basis since the magnitude of rainfall could vary considerably for each month/season. High values of the ratio denote greater variability in relation to the mean value. Since the Coefficient of Variation is undefined for a zero mean value, it was not computed for any series having a zero mean value.

The contribution of each season/month in total annual rainfall was also estimated to find out the seasons and months contributing the highest amount of rainfall. The percentage contribution of the season/month rainfall was determined relative to the total annual rainfall. This was done by taking the respective mean rainfall of the season/month and dividing it by the mean annual rainfall.

The concentration of rainfall during each year was determined by using Precipitation Concentration Index (PCI), following Oliver (1980). The PCI for the year was determined as:

$$PCI = 100 \times \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2}$$

where (P_i) defined as the amount of rainfall received in month (i). It reflects the degree of concentration of annual rainfall into a few months. The smaller the index, the more evenly distributed the rainfalls per month; otherwise, the larger the index, the more irregular the rainfall distribution. PCI was classified based on the conventional criteria: less than 10 means a uniform distribution of rainfall, 10 to 15 is moderately concentrated, 15 to 20 is irregular distribution, and more than 20 is strongly irregular/concentrated distribution. PCI was determined on the annual basis only if the annual rainfall amount is positive.

2.5 Rainfall Anomalies and Wet–Dry Year Classification

Year-to-year variations of precipitation anomalies were used to pinpoint years where there was significantly higher or lower precipitation than the long-term average. The precipitation anomaly percentages of each year were computed based on the mean annual precipitation from 1986-2025:

$$A_t = \frac{P_t - \bar{P}}{\bar{P}} \times 100$$

where (A_t) represents the percentage anomaly for year (t), where (P_t) is the annual rainfall for year t and \bar{P} is the long-term average annual rainfall during the period of study.

Departures from annual rainfall were categorised using the standard IMD classifications of percentage-departure in rainfall, which include Excess rainfall (above 20% of the long-term average), Normal rainfall (from -19% to +19%), Deficient rainfall (-20% to -59%), Scanty rainfall (-60% to less than -100%), and No rainfall (-100%). The classification was done on annual rainfall data using a consistent long term reference average throughout the study period.

Standardised annual rainfall anomalies were obtained using the z-score:

$$Z_t = \frac{P_t - \bar{P}}{SD_P}$$

where (SD_P) stands for the standard deviation of rainfall per year throughout the 40-year study period. Wet years were indicated by the condition $Z_t \geq +1$while dry years were indicated by the condition $Z_t \leq -1$. Years that fall outside these two limits were classified as one standard deviation away from the long-term average. Percentage anomalies and standardized anomalies were applied together in distinguishing between departures based on long-term average versus standard deviation measurements.

2.6 Long-Term Trend Analysis

Temporal variations in rainfall were analyzed through the use of non-parametric Mann–Kendall (MK) test (Mann, 1945; Kendall, 1948). This test detects whether there exists a monotonic increase or decrease trend in a time series data which does not have to be normally distributed. This test was used for annual

rainfall data and for annual series of rainfall for seasons and months.

The Mann–Kendall statistic was calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i)$$

where (X_i) and (X_j) represent rainfall observations at times (i) and (j), respectively, and (n) is the number of observations. The sign function is defined as:

$$\operatorname{sgn}(X_j - X_i) = \begin{cases} +1, & X_j - X_i > 0 \\ 0, & X_j - X_i = 0 \\ -1, & X_j - X_i < 0 \end{cases}$$

The MK variance was corrected for ties in the data and the standardised test statistic was used to test for the significance of the trend. Statistical significance was tested at the 1%, 5% and 10% level. Kendall's tau ((\tau)) was used to determine the direction and extent of the monotonic relation between rainfall and time; positive values representing increasing trends while negative values represent decreasing trends.

The extent of the trend was determined by the slope estimated by the Sen's slope estimator (Sen, 1968), which is the median of all pairwise slopes:

$$Q_{ij} = \frac{X_j - X_i}{j - i}, \qquad i < j$$

The slope estimate using Sen's method is given in mm/year assuming annual data observations. For the seasonally or monthly distributed rainfall time series, it indicates the change in the seasonal or monthly total rainfall amount annually. This estimator gives a more robust estimate of the rate of change, which is not influenced much by extreme observations as compared to least square regression. Because serial correlation can influence the variance and significance of the Mann-Kendall trend test, the first order autocorrelation was tested for the selected rainfall series. In the case of statistical evidence of autocorrelation in the series, the variance adjusted Mann-Kendall test suggested by Hamed and Rao (1998) was used.

2.7 Change-Point Detection and Decadal Analysis

Possible sudden changes in the annual rainfall series were analyzed based on a non-parametric change point test developed by Pettitt (1979). This test finds the possible time point when there is a change in distributional location of the series between two periods. The Pettitt test was performed on annual rainfall series to find out whether there was any statistically significant change in rainfall in 1986-2025.

In the Pettitt test, the test statistic was obtained from the relative ranks of the observations on the left and right sides of the potential change points. The year with the highest value of absolute value of test statistic was defined as the change-point year while its significance level was evaluated through test probability. Any change point was taken as an indicator of a possible rainfall change and not the exact climatic reason for it. To support the trend and change point analyses, the 40-year rainfall series was split into four successive decades; 1986-1995, 1996-2005, 2006-2015 and 2016-2025. The mean annual and seasonal rainfall were computed in each of the decades and compared to analyze the difference in rainfall amount and seasonal distribution among the decades. Five-year moving average of annual rainfall was also determined.

The decadal comparison and moving average analyses served as descriptive analysis techniques instead of alternatives for the statistical test of the Mann-Kendall trend. The results from the two analyses were evaluated in conjunction with the findings of the Mann-Kendall trend, Sen's Slope, and Pettitt change point analysis.

2.8 Software and Statistical Implementation

The organising of the source data, checking of monthly data and verification of seasonal and annual rainfall sums was done in Microsoft Excel. The statistical analyses were performed in Python 3 software utilising pandas and NumPy modules for the data handling and numerical calculations and SciPy module for statistical analyses. The following procedures were performed in the analysis: descriptive statistics,

indices of variability, precipitation concentration, annual anomalies, trends, slope of trends, autocorrelations, change points, decadal comparison and moving averages.
All annual, seasonal and trend analyses have been limited by the full period 1986-2025. The partially missing year 2026 has been kept as additional source data but excluded from all main statistical analyses. The interpretation of the results takes into account temporal resolution of the data; characteristics of the study area and limitations connected with rain-gauge data from one station.

3. RESULTS AND INTERPRETATION

The following paragraphs contain the outcomes from the statistical analysis of the monthly precipitation data from Tikamgarh district from 1986-2025.

3.1 Long-Term Characteristics of Annual Rainfall

Analysis of monthly rainfall measurements from 1986 to 2025 showed the presence of significant variability in the precipitation data at the Tikamgarh rain-gauge station. The average annual rainfall was 986.25 mm; the standard deviation was 344.30 mm, and the coefficient of variation amounted to 34.91%. Median value of annual rainfall equaled 961.10 mm; thus, the central tendency of this series turned out rather close to its average value. However, there was a significant variability in the annual rainfall observed since it varied from 348.00 mm in 2007 to 2,207.00 mm in 1999. The maximum annual rainfall was more than six times greater than the minimum one, which proves significant annual precipitation variations.

Annual rainfall was positively skewed (1.13); therefore, there were some years when the rainfall level was unusually high, resulting in right tail of the distribution being formed by only several values. The mentioned feature was also demonstrated by the difference between the maximum annual rainfall and the long-term average. Coefficient of variation greater than 30% means high variability according to the classification used in the study. The latter suggests that the long-term average cannot reflect rainfall condition of separate years.

Table 1: Descriptive statistics of annual rainfall in Tikamgarh district, 1986–2025

Statistical parameter	Value
Number of years	40
Mean annual rainfall (mm)	986.25
Standard deviation (mm)	344.30
Median (mm)	961.10
Minimum (mm)	348.00
Year of minimum rainfall	2007
Maximum (mm)	2,207.00
Year of maximum rainfall	1999
Coefficient of variation (%)	34.91
Skewness	1.13

This shows that rainfalls in Tikamgarh had considerable variations compared to constant rainfall per year. Rainfall years 1999 and 2007 were exceptional as they show the extent of the variations. In terms of water resources, this kind of variation has some significance because above average rainfall will result in increased inflows while below average rainfall will pose additional strain on agriculture water and underground resources. The above conclusion about water resources is inferred from the above findings and will need further evidence for validation.

3.2 Monthly Rainfall Distribution and Variability

The climatic rainfall showed a high seasonality in terms of its occurrence. July had the highest mean rainfall (303.44 mm) while August and September had 296.15 mm and 153.98 mm respectively. The mean rainfall in June was 120.60 mm. These four months contributed about 88.64% of the mean annual rainfall. This was due to the major influence of the south-west monsoon in the precipitation pattern, as it does in other parts of the Bundelkhand region where it contributes about 90% of the rainfall (Fanai et al., 2022). On the other hand, the mean rainfall during the month of January, February, March, April, May, November, and December was significantly low. April had the least mean rainfall of 2.91 mm while November had 4.10 mm.

Table 2: Monthly Rainfall Characteristics of Tikamgarh 1986–2025

Month	Mean (mm)	SD (mm)	CV (%)	Contribution to annual rainfall (%)
January	10.80	17.19	159.2	1.10
February	10.86	20.46	188.4	1.10
March	8.45	16.21	191.9	0.86
April	2.91	5.94	204.1	0.30
May	8.05	12.75	158.3	0.82
June	120.60	147.85	122.6	12.23
July	303.44	148.23	48.9	30.77
August	296.15	141.81	47.9	30.03
September	153.98	152.66	99.1	15.61
October	59.67	176.80	296.3	6.05
November	4.10	11.69	285.5	0.42
December	7.24	19.33	266.9	0.73

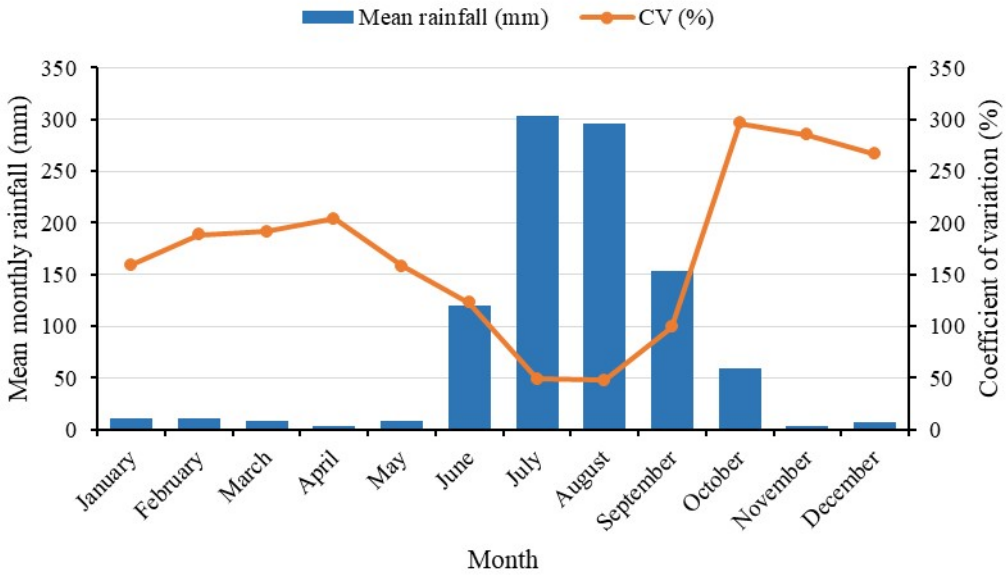


Figure 2: Mean monthly rainfall (bars) and CV (line) at Tikamgarh, 1986–2025.

The variations in monthly Coefficient of Variation demonstrate one important difference between rainfall volume and rainfall reliability. While July and August months have the highest means of rainfall, they have lower CVs of 48.9% and 47.9%, respectively. It means that variability in these months in comparison with their mean value is lower than in any other month. On the contrary, April, October, November and December months have higher CVs. It should be noted that very high CV value for October month (296.3%) requires special consideration. The reason for such high CV is that the rainfall means for this month are lower, while there are very high monthly rainfall values. Therefore, in the situation when some values are very high and there are many low and equal to zero values, the CV may be significantly high. The information about CV cannot be interpreted as a proof that all months are characterized by the same rainfall unreliability. The high concentration of rainfall in July and August months is significant for agriculture planning and water reservoirs management. Despite the

fact that these months have the highest rainfall volumes, the lack of rainfall in the other months requires a seasonal variability of monsoon rainfall in this region.

3.3 Seasonal Rainfall Variability and Contributions

The other factor that proved the domination of south-west monsoon was seasonal grouping. In this regard, the seasonal average rainfall is 874.17 mm, which is equivalent to 88.64% of annual average rainfall. The post-monsoon season received 71.01 mm (7.20%), winter and pre-monsoon rainfall is 21.66 mm (2.20%) and 19.41 mm (1.97%), respectively.

Table 3: Seasonal rainfall statistics for Tikamgarh, 1986–2025

Season	Mean (mm)	SD (mm)	CV (%)	Contribution (%)
Winter (January–February)	21.66	29.74	137.3	2.20
Pre-monsoon (March–May)	19.41	22.82	117.5	1.97
South-west monsoon (June–September)	874.17	269.57	30.8	88.64
Post-monsoon (October–December)	71.01	190.47	268.2	7.20
Annual total	986.25	344.30	34.9	100.00

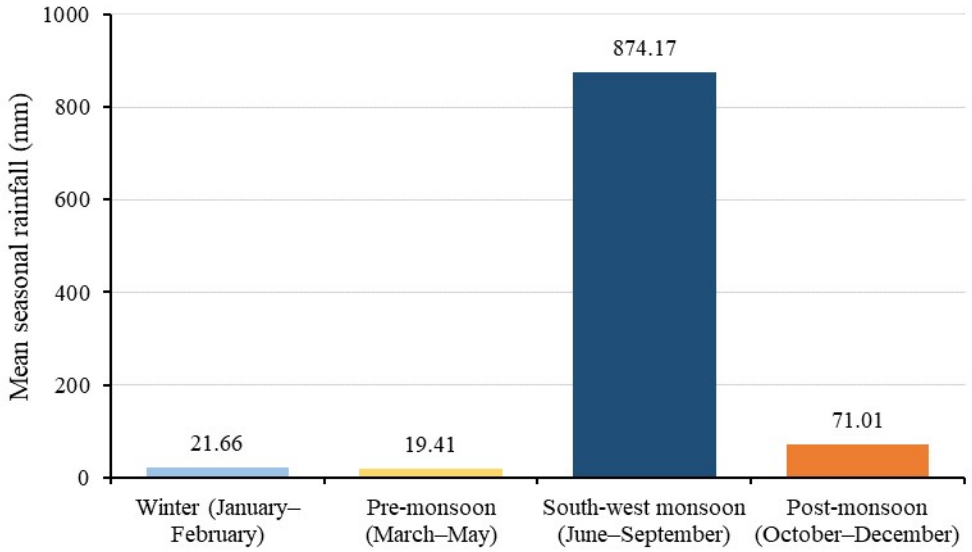


Figure 3: Mean seasonal rainfall at Tikamgarh, 1986–2025.

The seasonal results indicate that rainfall variability differs considerably across the year. The south-west monsoon showed the maximum value of absolute standard deviation due to a high magnitude of rainfall. At the same time, its coefficient of variation of 30.84% is much smaller compared to those of winter, pre-monsoon and post-monsoon rainfall. The post-monsoon season demonstrated the maximum value of relative variability with a coefficient of variation of 268.24%. This finding is a reflection of the difference between the usually low volume of post-monsoon rainfall and sometimes considerable monthly volumes of rainfall. It is consistent with the previously mentioned very high value of relative variability of non-monsoon rainfall found in Bundelkhand and other regions of India (Som & Dey, 2022; Guhathakurta & Rajeevan, 2008). It can be seen from the seasonal variability pattern that the annual rainfall variability is directly connected with the monsoon rainfall variability, while the relative variability of non-monsoon rainfall is influenced by its low average value. The difference is significant since the change in rainfall that occurs in the dry season may be quite considerable in percentages while having an insignificant contribution to the annual

rainfall volume. Thus, the findings show that there is a strong seasonality in precipitation regime in the region under discussion. In this way, the effect of the change in monsoon rainfall on the annual precipitation may be higher than in winter or pre-monsoon seasons. However, the current analysis cannot determine whether the changes in the beginning and termination of the monsoon or rainy days' frequency occur.

3.4 Annual Rainfall Anomalies and Identification of Wet and Dry Years

Anomalies in annual rainfall were computed based on the 1986–2025 mean of 986.25 mm. There were observed large departures from the long-term mean in either direction. The highest annual rainfall was 2,207.00 mm, registered in 1999, and this was 123.78% higher than the long-term mean rainfall. On the other hand, the driest year was 2007, with 348.00 mm, which is 64.71% lower than the long-term mean.

Based on the departure-in-percentage scheme of classification, 11 years were classified as excess rainfall, 17 as normal, 11 as deficient rainfall, and one year as scanty. Therefore, 22 out of 40 years fell outside the normal classification. These are classifications of annual departures from the fixed long-term mean, and should not be confused with the standardised anomaly classification.

Table 4: Selected years with the highest and lowest annual rainfall

Category	Year	Annual rainfall (mm)	Percentage anomaly (%)	Standardised anomaly
Wettest year	1999	2,207.0	+123.78	+3.55
Second-highest rainfall	1997	1,479.4	+50.00	+1.43
Third-highest rainfall	2013	1,462.0	+48.24	+1.38
Fourth-highest rainfall	2011	1,429.0	+44.89	+1.29
Fifth-highest rainfall	2008	1,406.0	+42.56	+1.22
Driest year	2007	348.0	−64.71	−1.85
Second-lowest rainfall	1986	565.8	−42.63	−1.22
Third-lowest rainfall	1989	576.4	−41.56	−1.19
Fourth-lowest rainfall	2017	580.0	−41.19	−1.18
Fifth-lowest rainfall	2010	624.0	−36.73	−1.05

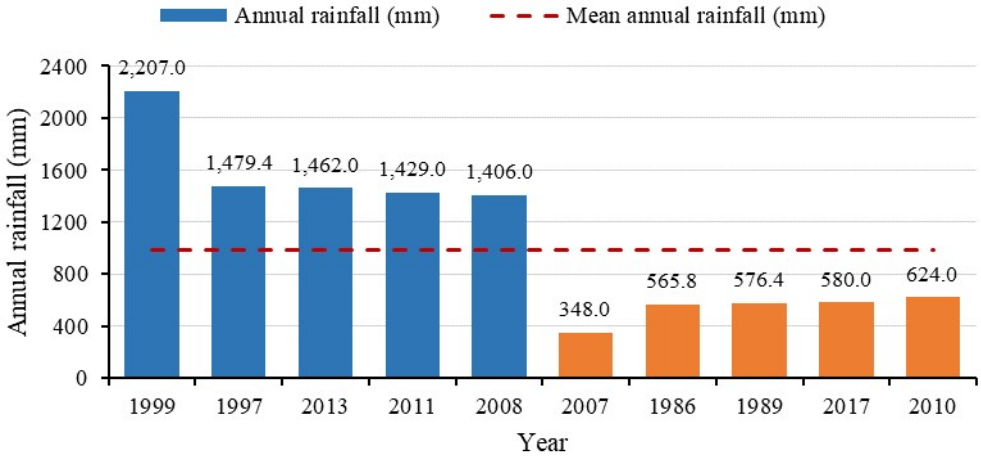


Figure 4: Five wettest and five driest years at Tikamgarh (blue: five wettest; orange: five driest; dashed line: 1986–2025 mean).

Seven relatively wet years having ($Z \geq +1$) and six relatively dry years with ($Z \leq -1$) were determined through the standardized anomalies test. These years included 1990, 1997, 1999, 2008, 2011, 2013 and 2025 for the former and 1986, 1988, 1989, 2007, 2010 and 2017 for the latter respectively. Both the wet and dry years identified above show that there was variability in rainfall but not in a single direction. In addition to these, there have been high-rainfall years and drought years during the study period that indicate there is substantial variability. However, wet and dry years alone cannot prove an increasing or decreasing trend on their own. Another important finding that emerged from this test is that percentage anomalies and standardized anomalies should not be mixed up as one. The difference between the two is that the former measure rainfalls against the average while the latter takes into account the variability of the series.

3.5 Temporal Concentration of Rainfall

PCI was computed for each year to determine the concentration of precipitation in specific months during the year. The average value of PCI per year was 31.99, while the median value was 30.75. The minimum value was recorded in 2009 at 18.74, whereas the highest value of PCI was observed in 2002 at 54.89. Out of all 40 years, 39 were categorized as having strong rainfall concentration or irregularities, while one year had irregular distribution.

The PCI analysis suggests that the amount of rainfall was generally limited to a small fraction of the year. It is clearly supported by the fact that the majority of the annual rainfall (approximately 88 percent) was received through south-west monsoon season. So, high PCI values further confirm the fact that rainfall pattern at Tikamgarh is highly seasonal in nature.

Table 5: Summary of annual Precipitation Concentration Index

Statistical measure	**PCI value**
Mean	31.99
Median	30.75
Standard deviation	7.77
Minimum	18.74
Year of minimum	2009
Maximum	54.89
Year of maximum	2002
Years with strong irregularity (PCI ≥ 20)	39
Years with irregular distribution (15 ≤ PCI < 20)	1

A higher PCI value in the year 2002 suggests more concentrated annual rainfall in comparison to other years in a single year, while a smaller PCI value in the year 2009 suggests less concentrated annual rainfall in comparison to other years in a single year. This shows that rainfall concentration differs from one year to another despite being highly seasonal in nature.

However, PCI can only be used as an indicator of monthly rainfall concentration but not as an indicator of rainfall intensity, drought frequency or rainfall extremes. This is because it is calculated using the monthly rainfall data. The daily rainfall data is required to determine such aspects of rainfall pattern.

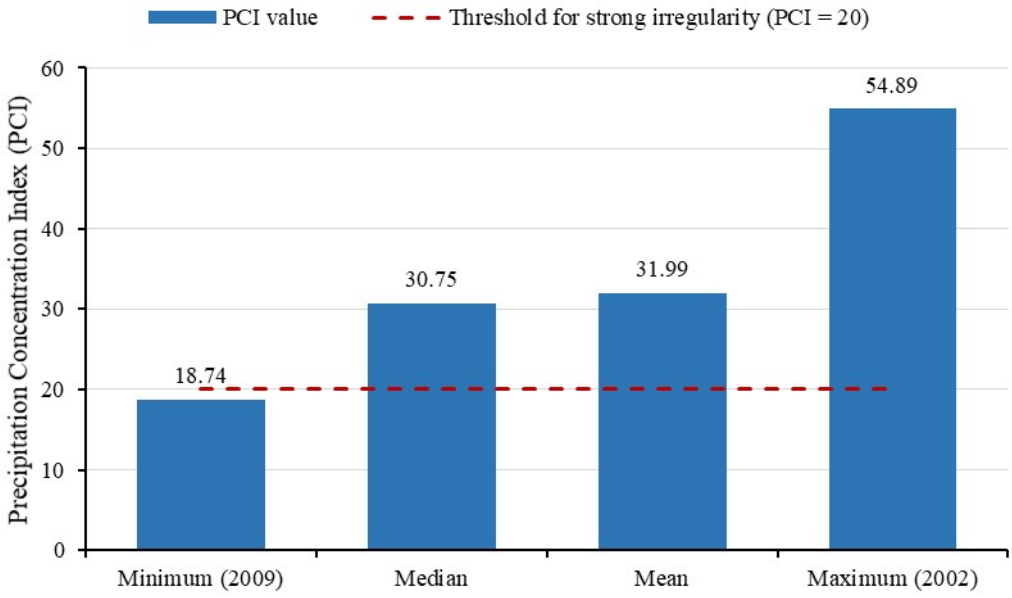


Figure 5: Summary of the annual Precipitation Concentration Index (PCI) at Tikamgarh (dashed line: PCI = 20).

3.6 Decadal Variations in Annual and Seasonal Rainfall

To examine the changes that have occurred between the successive periods, the research period has been subdivided into four decades, namely: 1986-1995, 1996-2005, 2006-2015, and 2016-2025. The highest decadal mean annual rainfall was noted in 1996-2005, which was 1,096.70 mm. The lowest decadal mean annual rainfall was noted in 1986-1995, which was 880.08 mm. Thereafter, it decreased to 957.24 mm in 2006-2015.

Table 6: Decadal variation in annual and seasonal rainfall

Decade	Mean annual rainfall (mm)	Winter (mm)	Pre-monsoon (mm)	South-west monsoon (mm)	Post-monsoon (mm)
1986–1995	880.08	15.97	3.06	842.87	18.18
1996–2005	1,096.70	16.93	21.68	871.90	186.19
2006–2015	957.24	39.30	26.20	848.30	43.44
2016–2025	1,010.97	14.45	26.70	933.60	36.22

The decadal comparison shows that annual rainfall did not increase or decrease consistently across the four periods. The above-average mean from 1996 to 2005 is linked to higher precipitation in some years such as 1997 and 1999. It can be noted that the mean annual rainfall from 2016 to 2025 was greater than that from 2006 to 2015 due to a restoration of average precipitation in light of the below-mean period during 2006-2015.

It can be noted that the mean of the south-west monsoon rose from 842.87mm between 1986-1995 to 933.60mm between 2016-2025. Nevertheless, differences between the four decadal means of monsoons were quite small in comparison with variations in some other seasonal aggregates. The post-monsoon mean was higher during 1996 to 2005 than other decades. This variation is a consequence of higher monthly post-monsoon values in some

years and it is not an indicator of an increase in post-monsoon rainfall.

Therefore, the above analysis demonstrates that variations in annual rainfall are caused by changes in seasonal contribution as well as higher precipitation in some years. Although the current decade has a greater mean annual rainfall than the two previous decades, this fact alone does not mean the presence of statistically significant increase in the long run. For this purpose, the Mann–Kendall test and Sen's slope are more appropriate.

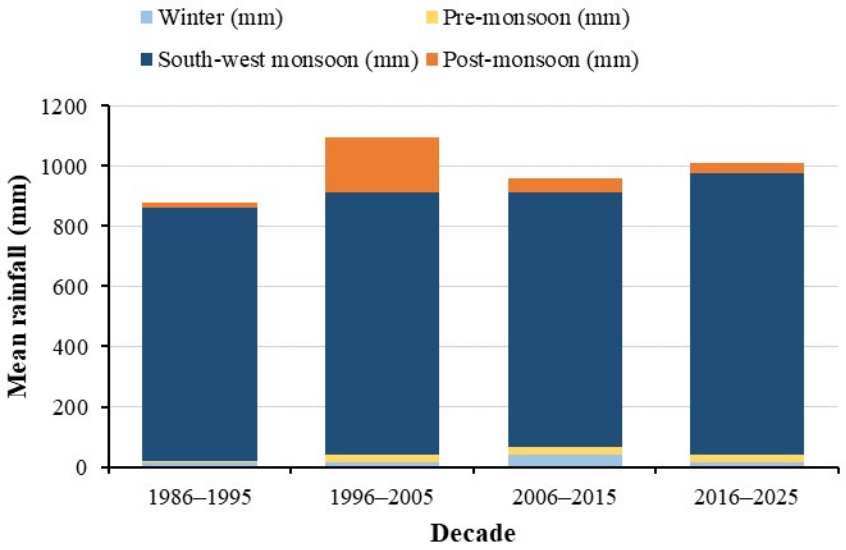


Figure 6: Decadal mean rainfall by season at Tikamgarh.

3.7 Long-Term Rainfall Trends

The Mann-Kendall test was employed to detect monotonic trends for the annual and seasonal data, and Sen's slope estimated the rate of change in trend. There was a positive Kendall's tau value of 0.149 and an estimated Sen's slope value of 6.31 mm/yr for the annual data. However, the trend was not statistically significant at 10%, 5% or even 1% level (p=0.177).

On the other hand, there was a different result from the seasonal data. In the pre-monsoon season, rainfall showed a statistically significant increasing trend with a positive Kendall's tau value of 0.411 and Sen's slope value of 0.64 mm/yr ($p<0.001$). There was also an increasing trend for post-monsoon rainfall, although statistically significant at 5% level. Winter and South-West monsoon rainfall did not show any statistically significant monotonic trend.

Table 7: Mann–Kendall trend test and Sen's slope for annual and seasonal rainfall

Rainfall series	Kendall's tau	Mann–Kendall p-value	Sen's slope (mm/year)	Trend interpretation
Annual rainfall	0.149	0.177	+6.31	Positive, not significant
Winter	0.176	0.120	+0.13	Positive, not significant
Pre-monsoon	0.411	<0.001	+0.64	Positive, significant
South-west monsoon	0.112	0.311	+4.30	Positive, not significant
Post-monsoon	0.221	0.051	+0.45	Positive, marginal at 10%

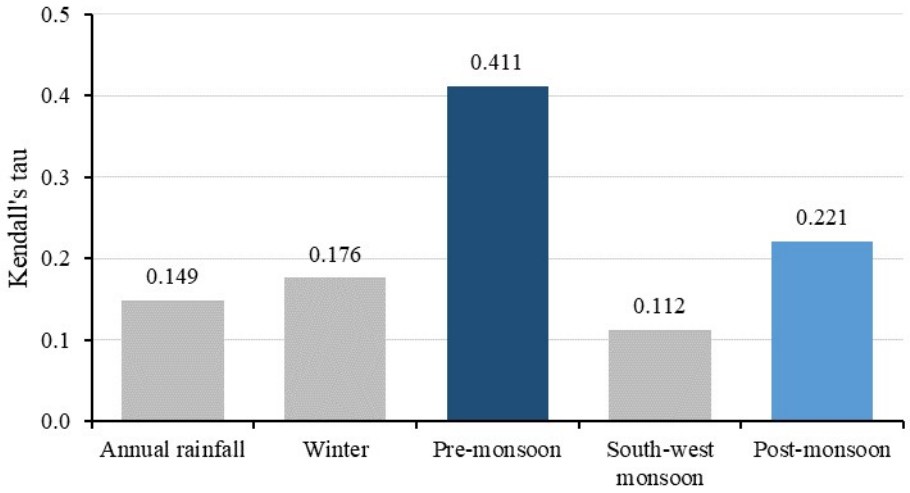


Figure 7: Mann–Kendall tau for annual and seasonal rainfall (dark blue: $p < 0.05$; light blue: $0.05 \leq p < 0.10$; grey: not significant).

The pre-monsoon trend is a noteworthy finding in view of the fact that the rainfall amount received from March–May might have changed during the study period, even though the pre-monsoon accounts for a minor share of the annual rainfall. The slope of 0.64 mm/year is equivalent to 6.41 mm/decade in case of linear interpretation of the Sen's slope. The estimate describes the median rate of change in the observed sequence, not a forecast. The positive pre-monsoon trend has been noted for the Madhya Pradesh state (Kumar et al., 2023), in contrast with the decreasing linear trend in pre-monsoon rainfall in the Central India (Guhathakurta & Rajeevan, 2008), showing that pre-monsoon rainfall shows different trends according to the region, time period, and dataset used. At the same time, the lack of statistically significant annual trend means that the inter-annual variability does not result in the monotonic change in the 40-year series. Thus, the positive Sen's slope for annual rainfall should be regarded as an indication of the tendency rather than the long-term increasing trend in the rainfall. The non-significant annual trend has been reported in Bundelkhand (Som & Dey, 2022) and Madhya Pradesh (Kumar et al., 2023), while the Sen's slopes have been reported negative in Bundelkhand, in contrast with the positive slope in question. Similarly, the south-west monsoon series demonstrates positive estimated slope, yet the test did not indicate statistically significant monotonic trend. In view of the fact that the monsoon provides almost 89% of the annual rainfall, it is essential: a major season can demonstrate strong variability from one year to another without showing any statistically significant trend (Kumar et al., 2023). This is different from the declining south-west monsoon trends observed in most Bundelkhand districts from 1981 to 2020 (Fanai et al., 2022).

3.8 Monthly Trends and Seasonal Differences

The trend analysis on a monthly basis was conducted in order to identify whether there was any connection between the seasonal trends and some particular months of the year. In terms of the Mann–Kendall tests, positive trends were revealed in March, April and May (the p-values for those months were equal to 0.011, 0.005 and 0.012). There was also a positive trend in December (p-value = 0.077), which was statistically significant at 10%.

Table 8: Monthly rainfall trend results

Month	Kendall's tau	p-value	Sen's slope (mm/year)
January	0.179	0.133	0.00
February	0.032	0.791	0.00
March	0.308	0.011	0.00
April	0.345	0.005	0.00
May	0.296	0.012	+0.08
June	0.169	0.124	+1.34
July	0.089	0.421	+1.83
August	0.010	0.926	+0.29
September	0.063	0.569	+0.70
October	0.138	0.245	0.00
November	0.106	0.398	0.00
December	0.218	0.077	0.00

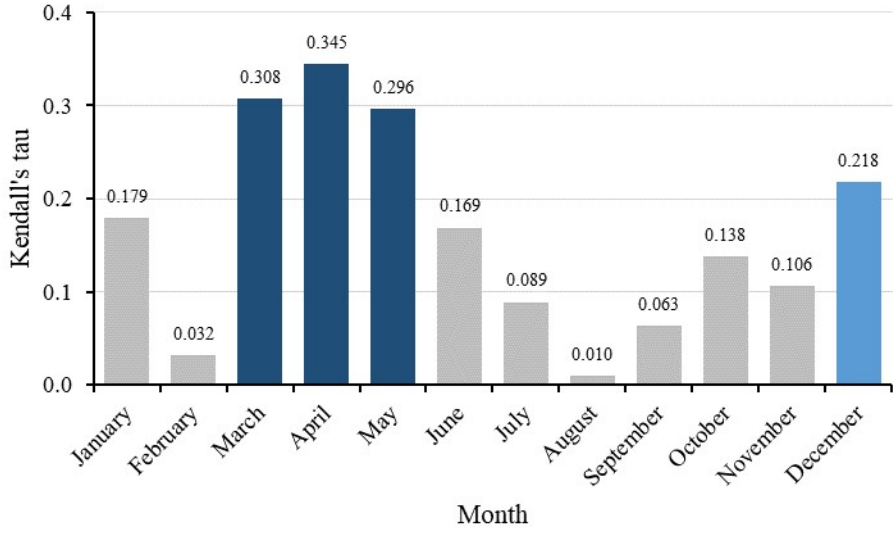


Figure 8: Mann–Kendall tau for monthly rainfall at Tikamgarh, 1986–2025 (dark blue: $p < 0.05$; light blue: $0.05 \leq p < 0.10$; grey: not significant).

The trends for the monthly series indicate that the positive seasonal pre-monsoon trends are possibly linked to rainfall in March to May. The series in March had statistically significant autocorrelation lag-1; therefore, the unadjusted Mann-Kendall p-value for this series must be treated with caution. The comparison of the positive trends in some pre-monsoon months and the lack of significant trends in July and August months is also important to note. This implies that the rainfall might have different temporal attributes in various months of the year than having a consistent trend. However, such results for monthly data need to be taken with care since the monthly total values contain a lot of zero and tied values. Therefore, the analysis of the monthly series must be made by making a distinction between the trend direction, trend value, and statistical significance of trends. In other words, the positive trend value alone cannot be used to say that there has been a statistically significant increase in rainfall in a month.

3.9 Change-Point Analysis and Moving-Average Behaviour

The Pettitt test was performed on the annual rainfall data set to detect the possibility of any sudden change in the distribution of annual rainfall. The maximum value for the test statistic was observed in the year when a change point was considered. But the value of p-value for the same was around 0.787.

Table 9: Pettitt change-point test for annual rainfall

Parameter	Result
Candidate change-point year	2010
Pettitt test statistic (*K*)	101
Approximate p-value	0.787
Statistical significance at 5%	No

The conclusion of the Pettitt test states that there is no statistical significance of annual rainfall changes that would indicate the presence of one abrupt shift in the annual rainfall location. Such a result is consistent with the absence of a statistically significant annual Mann–Kendall trend. It is still necessary to note that both tests measure various properties of the temporal behaviour: while the Mann–Kendall test assesses the presence of a monotonic trend, the Pettitt test identifies a potential shift. The absence of a significant change point differs from a shift found in 1998 concerning annual and monsoon rainfall in Madhya Pradesh (Kumar et al., 2023).

It was possible to conduct analysis of the five-year moving average to reduce the influence of short-term annual rainfall fluctuations. According to calculations, values of the moving averages varied in the range from 755.10 mm to 1,349.20 mm. It is obvious that such fluctuations are connected with periods of lower and higher precipitation in the record. Nonetheless, the moving average must be used only as a descriptive property of the medium-term variability, but not as a statistical test for trend significance.

Thus, the conducted analysis indicates that the annual rainfall series demonstrates significant fluctuations, but no statistically significant single abrupt shift was detected. Thus, it is possible to interpret annual precipitation data as variable with differences between successive periods.

4. DISCUSSION

The results indicate that the rainfall at the Tikamgarh rain-gauge station within the timeframe 1986 – 2025 had been characterized by a high seasonality and inter-annual variability, as well as considerable differences in temporal concentration. South-west monsoon has accounted for 88.64% of mean annual precipitation, which demonstrates that it was the leading component of the precipitation regime.

As one can see from the annual coefficient of variation (34.91%) and rainfall range (348.00 – 2,207.00 mm), the precipitation totals varied considerably throughout the years. Excess and deficient rainfall years further support the fact that the long-term mean cannot be considered as a representative characteristic of rainfall in individual years. As far as the practical aspect is concerned, it is important to take into account both annual precipitation totals and seasonality in order to determine the agricultural and water-resources conditions.

The PCI value provides additional evidence of high monthly rainfall concentration. It has turned out that most of the years have strongly irregular rainfall distribution, which correlates with the domination of the south-west monsoon. However, the high relative variability of post-monsoon rainfall indicates that the low rainfall seasons could be affected greatly by several abnormal rainy observations. The issue is important for the interpretation of percentage-based variability.

Trend analysis reveals a slightly more complicated pattern compared to the descriptive statistics. The annual Sen's slope was positive; however, the annual Mann-Kendall test did not show any significant trends. Similarly, the trend analysis of south-west monsoon, which makes the major part of annual rainfall, did not reveal any significant trend. On the contrary, there is a significant upward trend for pre-monsoon precipitation. Such a discrepancy is probably associated with a possible non-uniform change of annual precipitation throughout the year. Furthermore, it should be noted that there is no significant annual trend despite the decreasing precipitation trends for Madhya Pradesh during 1901 – 2002 (Duhan & Pandey, 2013) and the significant decreasing annual trends for Bundelkhand during 1961 – 2016 (Gupta et al., 2022); the latter might be explained by the different record length, study period, data source, and geographical scale. The lack of a

significant annual trend is also consistent with the high inter-annual fluctuations that weaken long-term rainfall trends in several regions of India (Soni et al., 2025).

The comparison of mean annual rainfall totals for consecutive decades provides additional evidence for the above interpretation. As one can see, the means varied throughout the decades; however, there was no definite increasing or decreasing trend. For instance, the highest mean value has been recorded for 1996 – 2005 decade followed by fluctuations of the mean values in next decades. The absence of significant Pettitt change point proves that the mentioned variability cannot be associated with the abrupt change of annual rainfall.

The results must be understood within the context of limitations associated with the dataset. The study uses only one rain gauge station and monthly rainfall sums and hence is able to assess variations in rainfall on a temporal scale and not the spatial distribution in the whole district. The use of monthly sums also restricts the assessment of daily extremes, rainy day occurrence, rainfall intensities and intra-seasonal dry spells since there has been an increase in extreme rain events in the central region of India despite a decrease in rainfall totals (Roxy et al., 2017). Also, the reasons for the trends can never be determined through rain gauge observation alone, and the large-scale effects of ENSO fail to explain rainfall variability in Bundelkhand, thus the necessity for localized studies (Yadav et al., 2025).

5. CONCLUSION

Rainfall variability and long-term precipitation trends were investigated for 40 years (1986-2025) of monthly rainfall data from Tikamgarh rain-gauge station for Tikamgarh district in Central India. The mean annual rainfall was 986.25 mm with a coefficient of variation of 34.91%. While there was high inter-annual variability of rainfall, the annual total rainfall varied between 348.00 mm in 2007 and 2,207.00 mm in 1999. South-west monsoon period (June-September) accounted for 88.64% of the annual rainfall with July and August being the rainiest months of the year. However, the relative variability of the rainfall during periods other than the monsoon period was found to be quite high (CV = 268.24% in the post-monsoon period). With the mean annual Precipitation Concentration Index being 31.99, there was a high concentration of rainfall in all except one year (39 out of 40 years). Out of the 40 years studied, 11 years were excess, 17 years normal, 11 years deficient and 1 year scanty based on IMD departure classes. There was an increasing decadal trend in the mean annual rainfall from 880.08 mm in 1986-1995 to 1,096.70 mm in 1996-2005 and then a decreasing decadal trend from 957.24 mm in 2006-2015 to an increase to 1,010.97 mm in 2016-2025.

There was a positive non-significant trend in the annual rainfall (+6.31 mm per year, $p = 0.177$) and similarly no monotonic trend in the south-west monsoon period and the winter period. On the contrary, the pre-monsoon rainfall increased significantly at 0.64 mm per year rate, especially from March, April and May. The post-monsoon trend was statistically significant only at 10% significance level. There was no significant change point detected in the annual rainfall using Pettitt Test for the candidate year 2010 ($p = 0.787$). Hence, there is no sufficient statistical evidence of long-term increase or decrease in annual rainfall, but there are different trends for different seasons. Thus, the findings of the paper indicate the necessity for rain water harvesting, moisture conservation in situ and contingency plans for monsoon rainfall variability in the district. Since the analysis used monthly data from a single rain-gauge station, further analysis using multiple stations or gridded data and daily data is necessary.

Conflict of Interest

There are no conflicts of interest.

Acknowledgements

The authors are grateful to the concerned agency for providing the monthly rainfall data of the Tikamgarh rain-gauge station used in this study. The authors also acknowledge the institutional facilities and technical support that made this research possible, and thank all those who assisted with data processing, language editing and proofreading of the manuscript.

REFERENCES

Dhara, C., Deshpande, A., Roxy, M. K., Dalpadado, P., & Shrestha, M. S. (2025). A post-AR6 update on observed and projected climate change in India. *PLOS Climate*, *4*(11), e0000724.

Duhan, D., & Pandey, A. (2013). Statistical analysis of long term spatial and temporal trends of precipitation during 1901–2002 at Madhya Pradesh, India. *Atmospheric Research*, *122*, 136-149.

Fanai, L., Singh, K. N., Singh, R., Singh, R. M., & Khalkho, D. (2022). Statistical and temporal trends analysis of rainfall in Bundelkhand region, Central India. *Environment Conservation Journal*, *23*(1&2), 131-142.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., & Xavier, P. K. (2006). Increasing trend of extreme rain events over India in a warming environment. *Science*, *314*(5804), 1442-1445.

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

Guhathakurta, P., Rajeevan, M., Sikka, D. R., & Tyagi, A. (2015). Observed changes in southwest monsoon rainfall over India during 1901–2011. *Int. J. Climatol*, *35*(8), 1881-1898.

Gupta, N., Gond, S., & Gupta, S. K. (2022). Spatiotemporal trend characteristics of rainfall and drought jeopardy over Bundelkhand Region, India. *Arabian Journal of Geosciences*, *15*(12), 1155.

Kumar, A., & Mohanasundari, T. (2024). Assessing district-level climate vulnerability in Madhya Pradesh, Central India: an integrated environmental and socio-economic approach: A. Kumar, M. Thangavel. *Theoretical and Applied Climatology*, *155*(4), 3449-3471.

Kumar, A., & Thangavel, M. (2025). Unravelling the dynamics of rainfall patterns in Bihar, India: A comprehensive spatiotemporal analysis. *Environmental Science and Pollution Research*, *32*(13), 8564-8584.

Kumar, A., Kumar, S., Rautela, K. S., Shekhar, S., Ray, T., & Thangavel, M. (2023). Assessing seasonal variation and trends in rainfall patterns of Madhya Pradesh, Central India. *Journal of Water and Climate Change*, *14*(10), 3692-3712.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., ... & Zhou, B. (2021). Climate change 2021: the physical science basis. *Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change*, *2*(1), 2391.

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

Pawar, U., Hire, P., Gunathilake, M. B., & Rathnayake, U. (2023). Spatiotemporal rainfall variability and trends over the Mahi basin, India. *Climate*, *11*(8), 163.

Pawar, U., Kumar, P., Rathnayake, U., & Muttil, N. (2025). Analyses of Rainfall Variability, Trend, and Change-Point Detection Over the Upper Krishna Basin, India. *Advances in Meteorology*, *2025*(1), 9971048.

Roxy, M. K., Ghosh, S., Pathak, A., Athulya, R., Mujumdar, M., Murtugudde, R., ... & Rajeevan, M. (2017). A threefold rise in widespread extreme rain events over central India. *Nature communications*, *8*(1), 708.

Sahu, Om & Sahu, Pitambra & Jain, Pradeep & Singh, Vineesha & Dwived, Sushila. (2023). Trends of Historical Precipitation Patterns in Tikamgarh District Central India. Bundelkhand Research Journal. 1. 40. 10.65554/brj.v1i1.09.

Som, K. S., & Dey, M. (2022). Analysis and forecasting of rainfall trends in semi-arid Bundelkhand region of Madhya Pradesh, India: using statistical methods. *Environmental Earth Sciences*, *81*(3), 98.

Soni, D., Dass, A., Kamble, P., & Kumar, R. (2025). Decoding of long-term spatio-temporal precipitation dynamics over India: insights from 115 years of meteorological data. *Global and Earth Surface Processes Change*, *3*, 100005.

Yadav, A., Singh, G. P., Rai, P. K., Kumar, S., & Paswan, A. (2026). The impact of spatiotemporal variability of rainfall across Uttar Pradesh, India. *Journal of Earth System Science*, *135*(4), 241.

Yadav, V. S., Galkate, R. V., Chandola, V. K., Shukla, A. K., Panda, S., & Shukla, S. (2025). Spatiotemporal characterization of meteorological drought and rainfall variation during El Niño/La Niña event over Bundelkhand region of India. *Discover Applied Sciences*, *7*(5), 464.