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Spatial and temporal trends of rainfall and temperature in Sakri river basin, Eastern India

Pawan Jeet[1,*] | Anil Kumar Singh[1] | Ashutosh Upadhyaya[1] | Prem Kumar Sundaram[1] | Anup Das[1] | Deepak Singh[2] | Pankaj Kumar Sinha[3]

[1]ICAR-Research Complex for Eastern Region, Patna.
[2]ICAR-Indian Institute of Soil and Water Conservation, Dehradun.
[3]ICAR-Indian Agricultural Research Institute, Hazaribagh.

Corresponding Author :
E-mail: pawan.icar89@gmail.com

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ABSTRACT

The amount of rainfall is crucial for the hydrological cycle and has significant implications for engineering structures and agriculture. Studying its variations is important, especially due to its effect on water resources. Alterations in rainfall patterns and temperature levels can reduce agricultural output, particularly in eastern India. This study analysed the rainfall and temperature changes in the Sakri river basin (SRB), eastern India, over the last thirty years (1991-2020). Statistical analyses, including the non-parametric Mann-Kendall (M-K) test and Sen's slope estimator (SSE), were utilized to evaluate trends in rainfall and temperature. The spatial distribution of rainfall and temperature in the basin was evaluated using statistical techniques. The long-term analysis exhibits an upward trend in monsoon and annual rainfall, with monsoon contributing around 84% of the total annual rainfall. Annual rainfall increased by 2.3 to 7.6 mm/year, with a percentage change of 0.8 to 2.3%. The maximum monthly temperature significantly increased in September and showed a decreasing trend in May. The minimum monthly temperature also showed significant variations at different stations. The results from this study can provide valuable insights for decision-making in flood and drought management and for understanding the hydrological processes in the basin. This information can helps in formulating adaptive measures for agricultural and water resources management activities.

HIGHLIGHTS

- M-K test and SSE were utilized to assess trends in rainfall and temperature.
- The long-term rainfall analysis for Sakri river basin show upward trend with an annual increase by 0.8 to 2.3%.
- The maximum monthly temperatures also show significant increase for September months while a decreasing trend for May month.

1 | INTRODUCTION

Climate change induced by human activities influences a range of weather and climate extremes, such as intense rainfall, droughts, floods, and heat waves, across all regions of the world. The consequences have resulted in extensive negative effects, causing significant losses and damage to both individuals and the environment. Financial losses from climate change have been recognized across various sectors, including agriculture and it's allied, as well as tourism. The preservation of biodiversity and ecosystem services on the global level relies on efficient and fair preservation of 30-50% of the planet terrestrial, freshwater and marine environments (IPCC, 2023). Comprehending the distribution of climatic variables in any country is crucial for recognizing the effect of climate change and for effective water management (Meena *et al*., 2022). Climate variability is mainly responsible for situations like droughts and floods worldwide. This issue is particularly significant for agricultural economies like India (Pastagia and Mehta, 2022). A study of the rainfall pattern changes and temperature regimes at the local level is desirable to understand the regional scenarios. In India, the unevenness of rainfall and number of rainy days in winter, pre- and post-monsoon seasons is high (Jain and Kumar, 2012). Temporal variations in rainfall are considerable; expectedly, the coefficient of variation (CV) is greatest in arid regions characterized by low rainfall and least in rivers having high productivity. Changes in rainfall pattern of the region adversely affect land use land cover (LULC), future irrigation projects, biodiversity, agricultural productivity, food security and the overall climatic conditions (Srivastava *et al.,* 2021). A possible alteration in rainfall of the region could affect soil moisture levels, ground water availability and surface runoff. In this regards, identifying rainfall trends and its spatial variability are essential challenges due to significant changes in the global climate observed over the past century. The impact of climate change (CC) on water resources is felt worldwide, they are particularly pronounced in regions affected by floods or droughts. This is largely attributable to the countries varied geography, which results in significant spatial as well as temporal variations in climatic conditions. An effective strategy planning is needed for mitigating extreme events, and this can be achieved by the analysis of trend data (Anil, 2018). Therefore, it is essential to evaluate the long-term trend of rainfall, which serves as the foundation of future predictions of fluctuations of hydro-meteorological variables for implementing preventive measures (Pastagia and Mehta, 2022).

The non-parametric (NP) M-K test and SSE methods are mainly used for trend identification of hydro-meteorological variables (Worku *et al.,* 2019; Xu *et al.,* 2022; Singh *et al.,* 2023). The primary objective of these two NP rank-based tests is to detect monotonic trends, whether positive or negative, in time series data. Earlier studies have been confined to detecting meteorological data trends and are spatially incomplete. Henceforth, the use of interpolation techniques, including Inverse distance weighting (IDW) and Ordinary kriging (OK), to analyse the spatial variability of meteorological data is essential for mapping the spatial distribution of the detected trends. This analysis is crucial for implementing suitable adaptive strategies in agricultural practices and water resources management within the river basin (Eshete *et al.,* 2022). The variogram technique is commonly used in geo-statistics to explain the spatial structure of identified variables. It is used to predict the amount and intensity of rainfall across the basin based on meteorological data. The deterministic IDW technique is based on the theory that two points will have similar characteristics as they approach each other. Conversely, ordinary kriging offers an unbiased estimation of variables by spatially correlating all available data by applying different semi-variogram. The spatial variability of rainfall and temperature was evaluated by employing IDW and OK (Xu *et al.,* 2022). Caloiero *et al.* (2021) employed IDW and OK for monthly rainfall data, New Zealand. They found worse accuracy of the IDW rainfall map than the OK technique.

Numerous researchers studied the trend analysis of rainfall and temperature at the country, state, district, and regional levels. However, very few studies have been carried out at the river basin level, especially in eastern India. Sharma *et al.* (2016) conducted an analysis of changes in precipitation pattern and temperature levels in eastern India by employing various trend detection techniques. They found that certain parts of eastern India indicate a positive (+) trend, whereas certain parts indicate a negative (-) trend of precipitation and temperature. A negative relationship between rainfall and maximum temperature (T_{max}) was noted in eastern India. Pastagia and Mehta (2022) employed an innovative trend analysis (ITA) technique on rainfall data for arid regions of India. They found an upward trend for the winter, a downward trend for both pre- and post-monsoon and no trend for the annual season. Xu *et al.* (2022) employed MK test and OK technique to evaluate the rainfall and temperature time series in Beijing, China. They found the downward trend in precipitation and upward trend in temperature. Worku *et al.* (2019) employed the M-K test and Sen's slope for rainfall and temperature trend analysis of a watershed in Basona Worena District, Addis Ababa. The MK test indicated that the trends in seasonal and annual rainfall exhibited significant variability, while the minimum temperature (T_{min}) and T_{max} increased at different rates.

This article employed the IDW and OK interpolation technique to enhance the station data in the SRB over a period of 30 years.

2 | MATERIALS AND METHODS

2.1 | Study Area

Sakri river basin (SRB) is lies between 24°26'2" - 25°14'35" N latitude and 85°29'34" - 86° 8'59” E longitudes (Fig. 1). The coverage area of the SRB is approximately 1,745 km^2, having inhabitants of about 71,09,559 with 36,52,779 males and 34,56,780 female in 2011. The SRB is characterized by a variety of bio-physical conditions and a wealth of cultural traditions. It region is marked by a varied topography, a reduction in forest cover, persistent drought conditions, irregular and unpredictable rainfall patterns, poor ground-water levels, high soil erosion, and a limited capacity of the soil to store water. The lack of safe disposal of surface runoff, drying of tanks & wells, and poor soil and water conservation (SWC) measures lead to insufficient agricultural and allied activities, unemployment and acute poverty in the watershed. Despite good rainfall, the agricultural productivity in the watershed is very poor because of the undulating terrain, unavailability of irrigation infrastructure, and poor SWC measures. The SRB covers the five most populated districts of eastern India.

Climatic condition in the upper part of the SRB varies from humid to sub-humid tropical monsoon, whereas in the

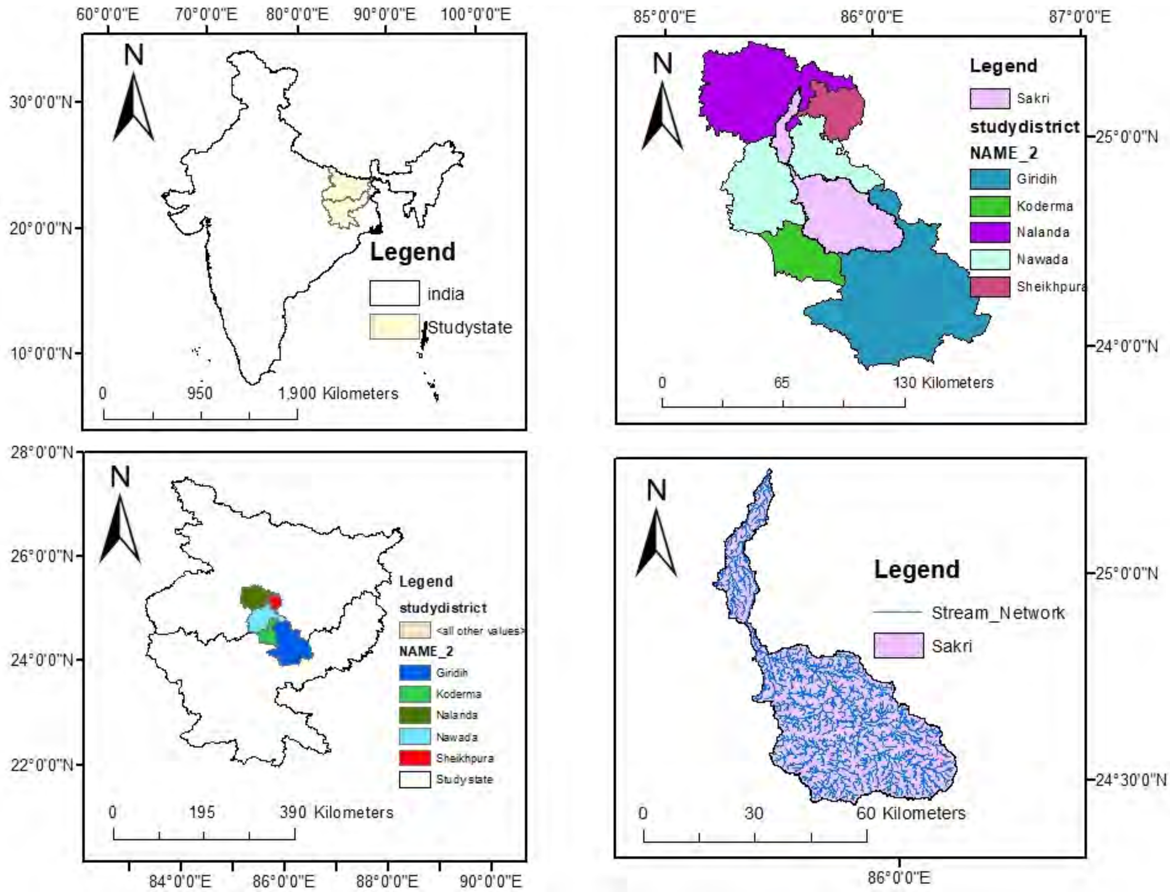

FIGURE 1 Location map of the Sakri basin

lower part, they range from humid to sub-tropical. The topographical variations of the SRB vary from > 300 m above sea level (MSL) over the upper part to < 150 m (MSL) in the lower part (Fig. 2).

The upper part of the SRB cultivates a variety of crops, predominantly utilizing an agroforestry system, while subsistent agriculture serves as a backbone of the region's economy. The upper part of the SRB engages in mixed agricultural practices, including agriculture and livestock production. The lower part of the SRB mainly grows cereal crops, pulses, oilseeds and vegetables throughout the year, with minimal areas under agroforestry. The major crops in the basin are cereal crops, i.e., rice, wheat, maize, oilseeds, pulses and vegetables. The hydro-meteorological condition of the SRB is significantly affected by the monsoon (June-September). Therefore, in the upper part of the basin dug wells, ponds, and tanks are used as sources of irrigation. In the lower part, due to the presence of a canal system, the area irrigated by canals, tube wells, and wells.

2.2 | Data Sources and Acquisition

In the present study utilized time series data of rainfall at different scales (monthly, seasonal, and annual) spanning the past 30 years (1991-2020), which was obtained from the Indian Meteorological Department (IMD) and the National Aeronautics and Space Administration (NASA) POWER website. There are 4 meteorological stations: Nalanda (25.333° N, 85.630° E), Nawada (24.870° N, 85.530° E), Koderma (24.439° N, 85.540° E) and Giridih (24.206° N, 86.314° E) in the Sakri basin (Fig. 3). We downloaded and used precipitation and temperature data from the dataset for this study.

2.3 | Data Analysis Methods

The current study investigated the spatial and temporal variability of seasonal and annual rainfall including winter, monsoon, pre- and post-monsoon periods alongside temperature variations including (T_{min} and T_{max}). The trend analysis was conducted by employing M-K test and SSE, at a confidence level of 95% (p<0.05). The annual rainfall data was derived from the monthly rainfall. Seasonal rainfall for each season was calculated by aggregating the corresponding monthly rainfall totals. To conduct trend analysis, NP M-K test and SSE were employed. Because of parametric tests necessitate adherence to normal distribution assumptions, this study utilized the NP test to detect trends.

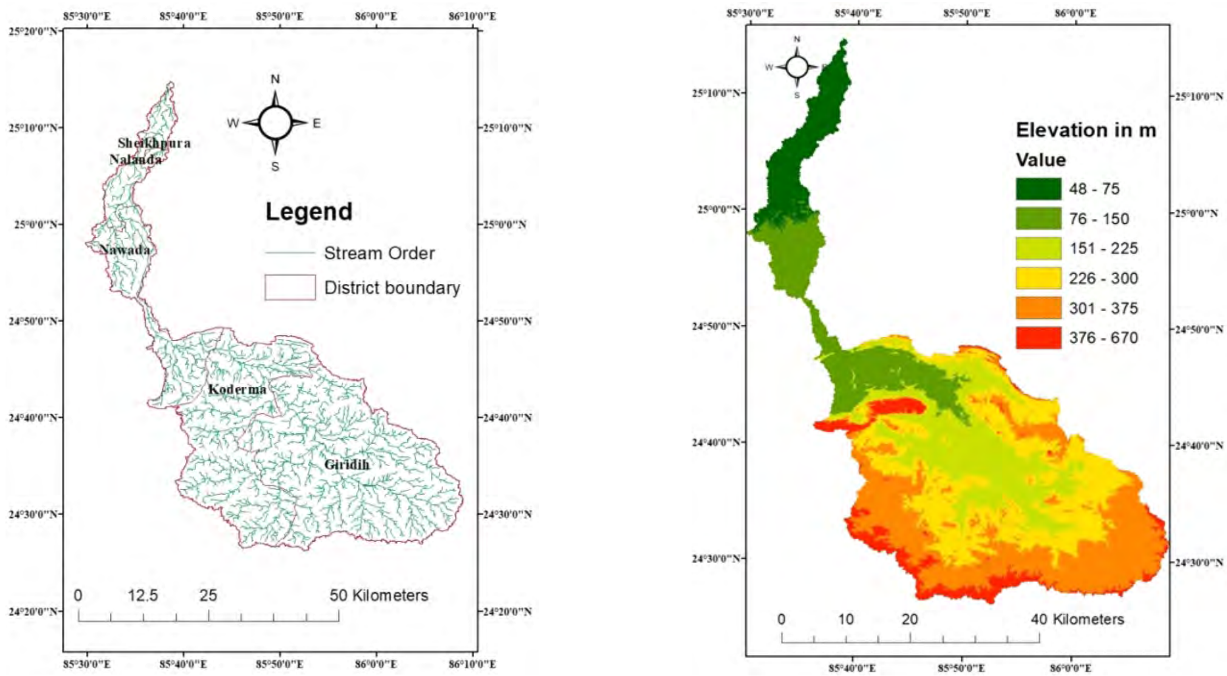

FIGURE 2 Stream order and topographic map of the Sakri Basin

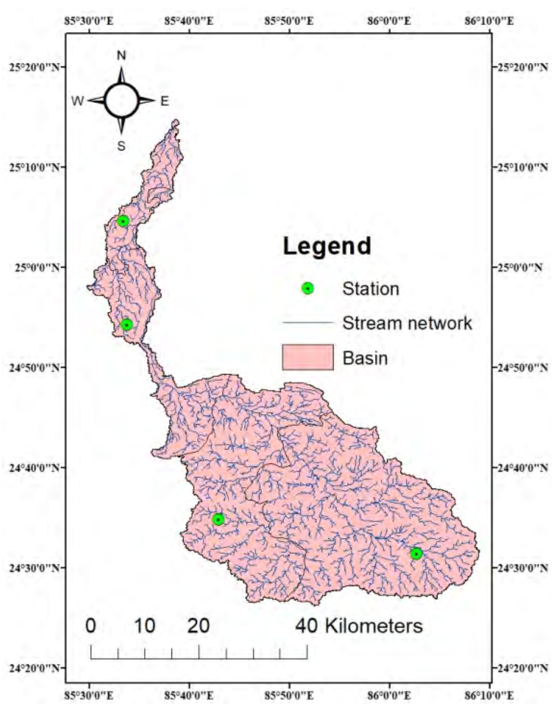

FIGURE 3 Meteorological station map in the Sakri basin

Seasonal and annual patterns of climatic variables (1991-2020) were employed to investigate the uniform climatic zones within the research area. The patterns in temporal rainfall time series, alongwith the time series of T_{min} and T_{max}, were identified through the application of a linear regression model. The flow diagram of the methodology is depicted in Fig. 4. The study employed the M-K test to evaluate the importance of the observed trends. Trends for each climatic region were derived by applying a mask corresponding to the area of the climatic region.

The following indicators were calculated:

Inter-annual monthly rainfall: The monthly rainfall for the same month across various years.

Annual rainfall: Addition of monthly rainfall from January to December.

Seasonal rainfall: Addition of monthly rainfall for winter (January-February), pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October-December) periods.

Monthly maximum rainfall: Maximum rainfall recorded within a month.

The weighted average rainfall was calculated on a monthly, seasonal and annual basis.

The average seasonal and annual temperature was calculated for each district in the SRB.

The annual average T_{min} and T_{max} was calculated for each district in the SRB.

2.4 | Trend Analysis

2.4.1 | Mann-Kendall's test

It is commonly employed to identify consistent upward or downward trends in climatological and hydrological time

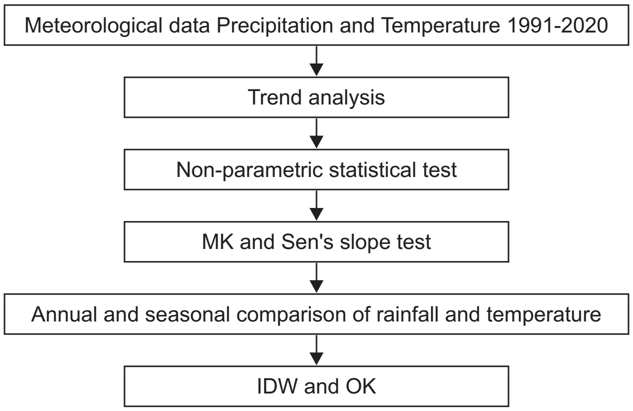

FIGURE 4 Flow chart diagram illustrating the methodology

series data (Mann, 1945; Kendall, 1975), and it has been performed using XLSTAT 2023 software (https://www.xlstat.com/en/). It evaluates whether there is upward, downward or stable trend on the hydro-meteorological data for each of the chosen stations. It is a NP test, and uses following statistic:

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} \mathrm{sgn}(X_J - X_K) \qquad ...(1)$$

Where, X_K and X_J represent the sequential data values of the time series for the years I and J, respectively, where J is greater than K and n denotes the total length of dataset. An positive (+) S value signifies an upward trend, whereas and a negative (-) value signifies a downward trend within the data series.

Let sign $(X_J - X_K)$ denotes an indicator function that assumes the values of 1, 0, or -1 based on the sign of $(X_J - X_K)$ can be expressed as:

$$\text{sign } (X_J - X_K) = \begin{Bmatrix} 1 \; if \; X_J - X_K > 0 \\ 0 \; if \; X_J - X_K = 0 \\ -1 \; if \; X_J - X_K < 0 \end{Bmatrix} \qquad ...(2)$$

The variance of S (σ^2) can be expressed as:

$$\sigma^2 = \left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5) \right\} / 18 \qquad ...(3)$$

Where, n represents the total number of data points in time series, p denotes the count of tied groups within dataset, and t_j signifies the quantity of data points found in the j^{th} tied group.

The test statistics, Z is expressed as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var\,(S)}} & if \quad S < 0 \end{cases} \qquad ...(4)$$

The null hypothesis (H_0) represents the data are independent and exhibit a normal distribution. Conversely, the alternative hypothesis (H_A) suggests that data display a monotonic trend, either decreasing or increasing. The test statistic Z serves as an indicator of trend. A (+) value of Z signifies an upward trend, whereas (-) value of Z signifies a downward trend.

2.4.2 | Sen's slope estimator test and percentage change

It is commonly employed to assess the extent of a trend within a time series. It calculates both the intercept and the slope (or steepness) of the trend in the time series (Sen, 1968). To estimate the slope (amount of annual change) of an existing trend, a NP method (Sen's slope, β) was used and performed using XLSTAT 2023 software. A (+) value of Sen's slope signifies an upward (or increasing) trend, whereas a (-) value indicates a downward (or decreasing) trend within the time series. The percentage of change (% Δ) is calculated by equation (5)

$$\%\,\Delta = \frac{\beta \text{ * length of period}}{\text{Mean}} \qquad ...(5)$$

2.5 | Geo-statistical Analysis

In present study, the spatial distribution and trends of seasonal & annual rainfall, and temperature by utilizing interpolation techniques such as IDW and OK within the ArcGIS 10.5 software environment.

The fundamental principal underlying both techniques is the premise that points in close proximity exhibit greater correlations and similarities compared to those that are farther apart. The IDW technique is the most effective when applied to areas with uniformly distributed points. The value of inverse distance estimate is presented in eq. 6.

$$Z(x) = \sum_{i=1}^{n} \lambda_i Z\,(xi) \qquad ...(6)$$

The term $Z(x)$ represent the inverse distance estimate at the specified estimation location, while n represent the total number of sample points. The variables λ_i indicates the weights allocated to each sample point x_i, and $Z(x_i)$ indicates to the conditioning data associated with those sample points.

Ordinary kriging (OK) provides an estimate for an unsampled location by calculating the weighted average of nearby observed points within a defined area. The weight (correlation between squared differences of paired samples and their respective distances) is determined by the spatial structure variables of a semi-variogram.

Ordinary kriging estimate was calculated using the equation (7).

$$Z(x_0) = \sum_{i=1}^{n} \lambda_i Z(xi) \quad ...(7)$$

Where $Z(x_0)$ represent the predicted estimate, λ_i indicates the unknown weight associated with the measured value of point pairs at the i^{th} position, $Z(x_i)$ indicates the value of point pairs at the i^{th} position, and n signifies the total number of measured values of points pairs.

3 | RESULTS AND DISCUSSION

3.1 | Seasonal and Annual Rainfall Patterns

The analysis of rainfall data shows the long-term average annual rainfall over a 30 years period in the SRB was 1074 mm. Nevertheless, as illustrated in Table 1, the average annual rainfall varies between 984 and 1230 mm. The minimum rainfall (984 mm) recorded in the lower part of the basin, Nalanda, while the maximum rainfall (1230) was noted in the upper part of basin at Giridih. The standard deviation (SD) of 195.62 and 204.05 mm and CV of 19.87% and 16.58% were observed at lower and upper reach of the basin, respectively (Table1). This suggests that the regions with low annual rainfall exhibit a high coefficient of variability in rainfall. The average monthly rainfall for the basin, derived from data collected at four stations over a 30-year period, indicates that the basin experiences its peak average maximum rainfall in July, while November and December recorded the lowest rainfall amount.

The proportion of seasonal rainfall relative to the annual average rainfall exhibits varying value. During the rainy season, the average rainfall amount to 899.71 mm with all meteorological stations recording over 800 mm of rainfall annually during this season. The highest average monsoon rainfall was noted in Giridih (1003 mm), while Koderma followed with a total of 908 mm. The greatest and least proportions of monsoon rainfall occurrence to the overall average annual total were recorded in Nalanda (85%) and Giridih (81.54%), respectively (Table 1). Conversely, the occurrence of pre-monsoon rainfall to the annual total was significant in Giridih (9%), while it is relatively small in Nawada (6.5%), followed by Koderma (6.53%) and Nalanda (6.78%). In contrast, the occurrence of post-monsoon rainfall to the annual total was significant in the Giridih (7.25%), while it is relatively small in Nalanda (5.63%), followed by Koderma (6.7%) and Nawada (6.12%).

3.2 | Spatial Distribution of Rainfall and Temperature

The distribution of rainfall, as well as temperature trends, has been analyzed using the IDW and OK techniques. These techniques have been employed to depict the distribution of seasonal and annual rainfall and temperature across the study period from 1991 to 2020, as shown in Fig. 5 and 6. The spatial distribution assessed using the IDW technique revealed distinct regions associated with low or high rainfall and temperature values.

The annual rainfall for the SRB is reported to be 1074 mm, accompanied by a SD of 183. Consequently, the distribution of rainfall across the basin was calculated to be 17%. This indicates that distribution of rainfall within the basin is relatively low.

Figure 5 and 6 illustrate a general trend of increasing of the annual average rainfall from the northern region of Nalanda to the southern region of Giridih. Additionally, it is evident that the south eastern (SE) region of Giridih experiences the highest annual average rainfall. The variability ranges from <1050 mm in the northern region (Nalanda) to >1200 mm in the SE region (Giridih). The main reason is that the meteorological stations located near the hills and plateau regions, such as Giridih and Koderma, receive significantly more rainfall compared to those situated in lower elevation or plain regions.

The most significant rainfall distribution during the monsoon was recorded in the southern and SE regions of the basin. Conversely, the northern region experiences comparatively lower rainfall. Throughout the monsoon season, the southern and SE regions receive a greater volume of rainfall than other regions. Nonetheless, the noticeable decline in rainfall from the SE to the northern region of the basin around the seasons.

The distribution of T_{max} and T_{min} over a 30 year period is presented in Fig. 7 and 8. The highest annual T_{max} (36.39°C) was recorded in the northern region of Nalanda, exceeding the comparatively lower annual T_{max} of 34.53°C recorded in the southern and SE region of Giridih by 1.86°C. The CV between the T_{max} and T_{min} revealed the T_{min} coefficient of variation in Giridih and Koderma, compared with the T_{max} in the same area in the year 1991-2020.

TABLE 1 Seasonal & annual mean rainfall (mm) and coefficient of variation (%) from 1991-2020

Station	Annual		Winter		Pre-monsoon		Monsoon		Post-monsoon	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Giridih	1230.13	16.58	27.07	76.17	110.78	42.43	1003.06	17.92	89.217	72.44
Koderma	1080.07	15.36	26.70	81.67	72.91	43.13	907.99	16.58	72.45	72.57
Nawada	999.62	16.71	24.38	83.92	65.28	48.38	848.08	18.32	61.88	73.25
Nalanda	984.41	19.87	22.48	84.01	66.75	54.64	839.71	21.77	55.47	74.55

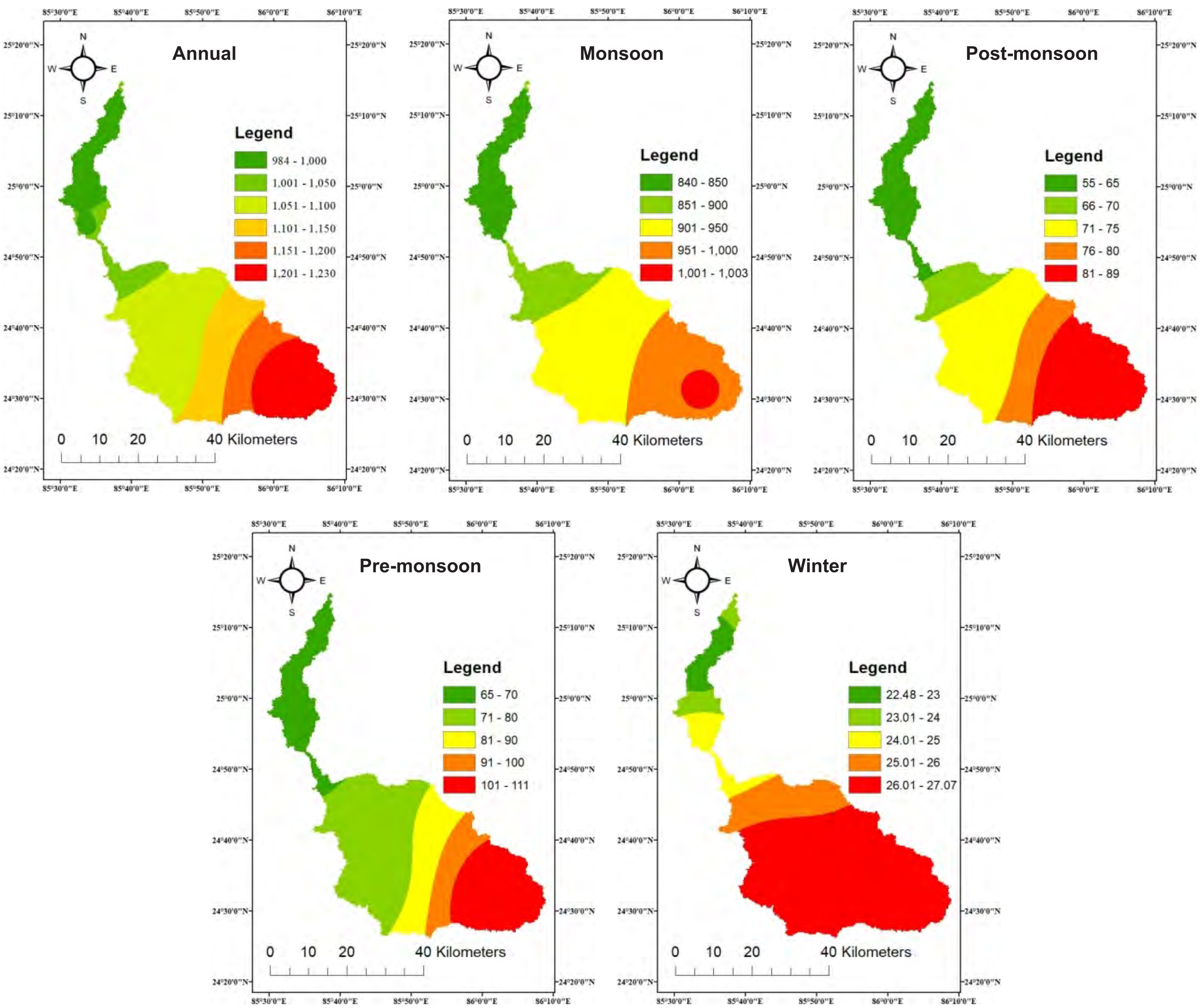

FIGURE 5 Annual and seasonal rainfall interpolated using inverse distance weighting (IDW) method

3.3 | Trend Analysis

3.3.1 | Rainfall trend analysis

The M-K test results were utilized to evaluate the spatiotemporal trends of variables from 1991 to 2020 in the SRB. Similarly, Sen's slope (β) and percentage change (% Δ) were employed to evaluate the magnitude and variations of these variables. The findings of the M-K test, β and % Δ in rainfall are presented in Table 2. The trends observed on a seasonal and annual basis, as well as the rate of change rate, differs significantly from one location to another. The trend result indicates the average seasonal and annual rainfall increase (upward trend), decrease (downward trend), and zero (no) trend for all four stations in the basin.

Accordingly, annual rainfall shows an upward trend in all basin stations. All stations have an insignificant increase at $p<0.05$. From these, an insignificant upward trend has been observed at Giridih (7.63 mm/year), Koderma (4.64 mm/year), Nawada (2.51 mm/year), and Nalanda (2.26 mm/year) with a % Δ of 2.27, 1.57, 0.92, and 0.84, respectively.

A significant upward trend was observed in all stations Giridih (3.25 mm/year), Koderma (1.71 mm/year), Nawada (1.57 mm/year) and Nalanda (2.14 mm/year) with % Δ of 2.69, 2.16, 2.22 and 2.95, respectively, during the pre-monsoon season (Table 2). Conversely, stations in Giridih (2.36 mm/year), Koderma (1.98 mm/year) and Nawada (1.17 mm/year) shows an insignificant downward trend during monsoon season with a % Δ of 0.29, 0.27 and 0.17, respectively, while Nalanda (0.28 mm/year) shows an insignificant downward trend with a % Δ of -0.04 during the monsoon season at $p<0.05$ and these results were relatively

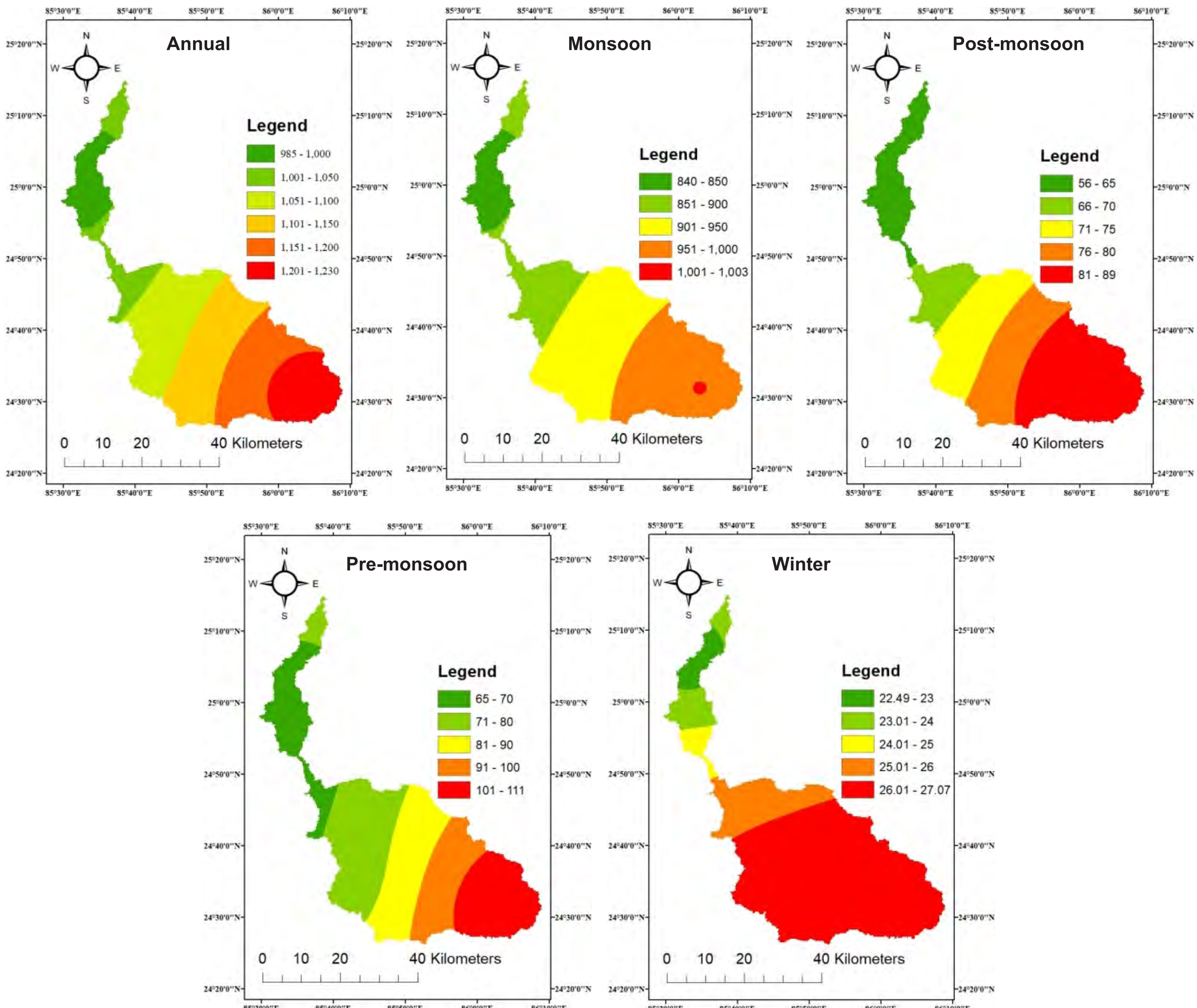

FIGURE 6 Annual and seasonal rainfall interpolated using ordinary kriging (OK) method

consistent (Padhiary *et al.,* 2020). In the post-monsoon season, Giridih exhibits show an insignificant upward trend, whereas other stations exhibit an insignificant downward trend. Throughout the winter season within the river basin, all stations indicate an insignificant increase in rainfall. A similar study conducted by Jeet *et al*. (2017) in the drought-prone BRB, India, indicates an insignificant ($p<0.05$) upward and downward trend in winter season rainfall. Rainfall patterns and trends over the past 30 years have shown similarities between monsoon and annual rainfall, with the exception of Nalanda. This suggests that monsoon rainfall significantly contributes to the total annual rainfall across all stations. This will help in the water management planning in the future to improve land and water productivity of the river basin and to meet the food requirements of the living population.

3.3.2 | Maximum temperature

Employing the same methodology for seasonal and annual rainfall, monthly T_{max} trend for the 30-year period from 1991–2020 was examined across the SRB. May records the highest temperature (47.31°C), followed closely by June (47.20°C) and April (46.17°C). In contrast, December is the month with lowest temperature (24.15°C), succeeded by January (24.93°C) and November (26.69°C). A significant negative trend of T_{max} was detected in the pre-monsoon month of May at all stations except Nalanda. At Nalanda station, an insignificant negative trend was detected. A significant positive trend was detected in the monsoon month of September at all stations except Koderma. At Koderma station, an insignificant increase was detected. The significant decreasing magnitude of monthly T_{max} was assessed in May at Giridih (-0.09°C/year), Koderma (-

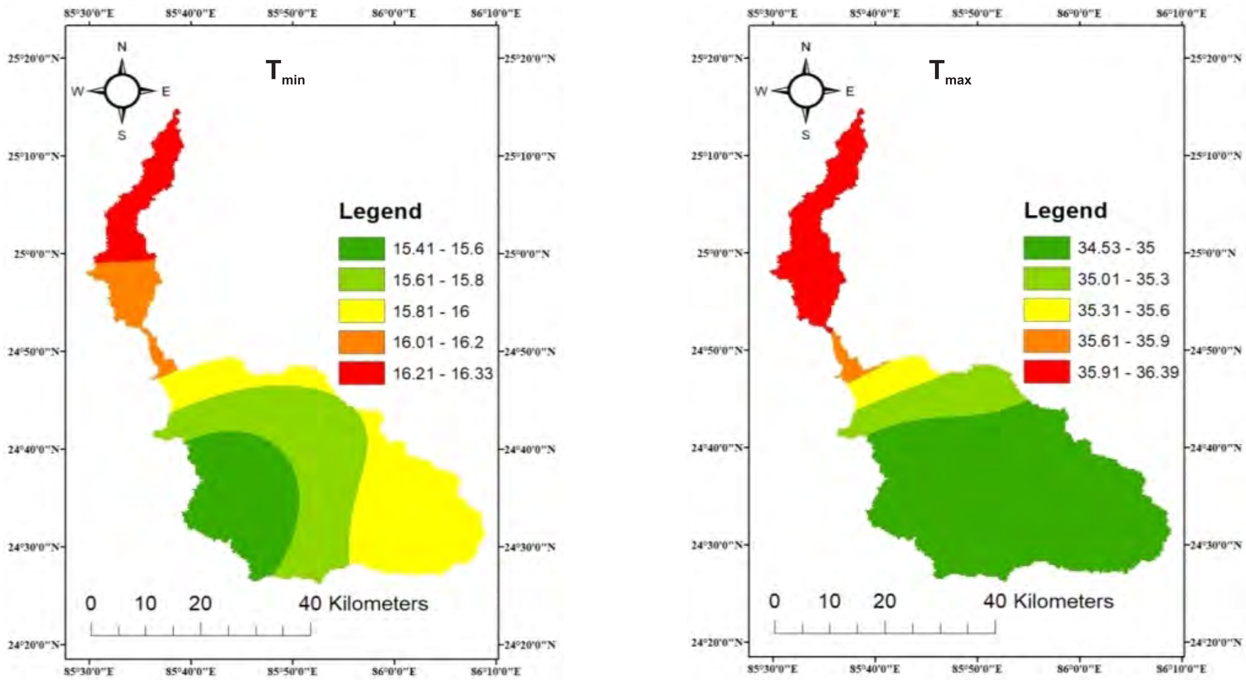

FIGURE 7 Spatial distribution of minimum and maximum temperature using inverse distance weighting (IDW) method

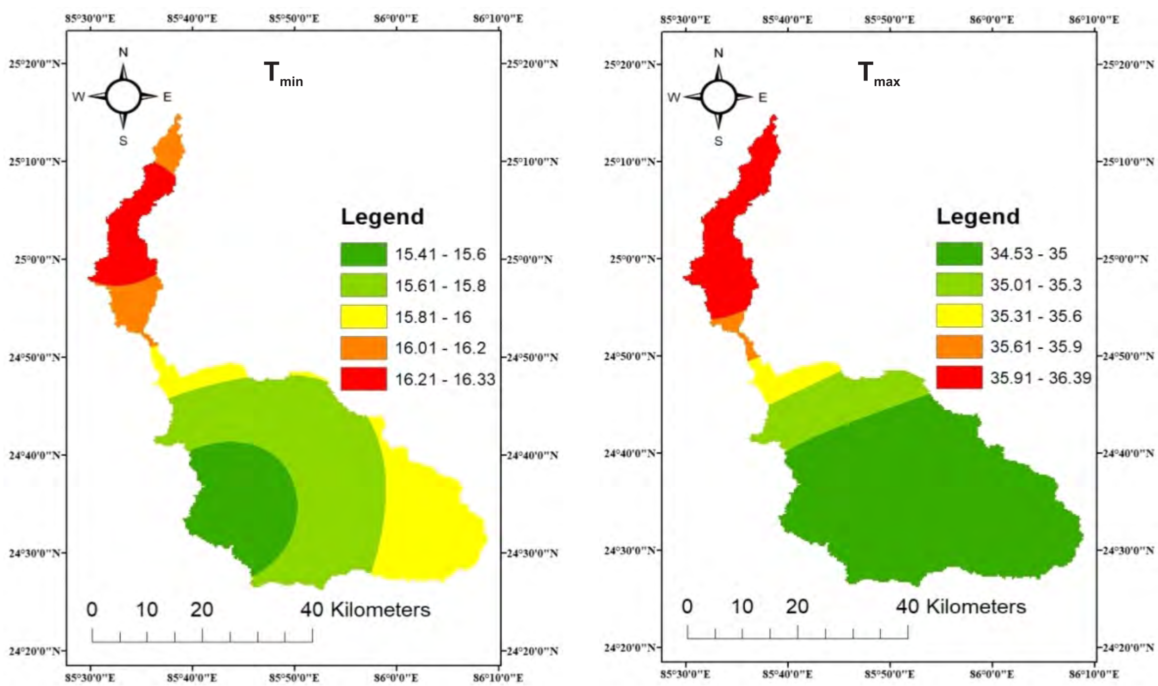

FIGURE 8 Spatial distribution of minimum and maximum temperature using ordinary kriging (OK) method

TABLE 2 Trend analysis of annual and seasonal rainfall of Sakri basin (1991-2020)

Station	Annual			Winter			Pre-monsoon			Monsoon			Post-monsoon		
	Z_{mk}	β	% Δ	Z_{mk}	β	% Δ	Z_{mk}	β	% Δ	Z_{mk}	β	% Δ	Z_{mk}	β	% Δ
Giridih	1.67	7.63	2.27	0.32	0.10	0.22	3.46*	3.25	2.69	1.07	2.36	0.29	0.07	0.05	0.057
Koderma	1.35	4.64	1.57	0.32	0.14	0.31	2.64*	1.71	2.16	0.74	1.98	0.27	-0.49	-0.26	-0.33
Nawada	0.79	2.51	0.92	0.43	0.19	0.47	2.39*	1.57	2.22	0.54	1.17	0.17	-0.57	-0.50	-0.75
Nalanda	0.36	2.26	0.84	0.25	0.101	0.27	2.60*	2.14	2.95	-0.04	-0.28	-0.04	-0.43	-0.51	-0.84

**indicates a significance level of 5%.*

TABLE 3 Trend analysis of monthly maximum temperature and percentage change of Sakri basin (1991-2020)

(a) Z value of MK test

Station	Jan Z_{mk}	Feb Z_{mk}	March Z_{mk}	April Z_{mk}	May Z_{mk}	June Z_{mk}	July Z_{mk}	Aug Z_{mk}	Sep Z_{mk}	Oct Z_{mk}	Nov Z_{mk}	Dec Z_{mk}
Giridih	-1.50	-0.27	-0.87	-1.85	-3.57*	-0.48	-1.17	1.38	1.97*	1.14	-0.82	-0.34
Koderma	-1.17	-0.15	-0.31	-2.19*	-2.87*	-0.46	-0.88	0.19	2.33	1.28	-1.36	-0.44
Nawada	-1.31	0.54	-0.15	-1.77	-2.29*	-0.54	-1.09	-0.46	3.06*	0.83	-1.87	-0.92
Nalanda	-1.78	0.07	-0.22	-1.51	-1.65	-0.85	-1.26	-0.27	2.30*	0.49	-1.67	-0.92

**indicates a significance level of 5%.*

(b) Magnitude (β) and percentage change (% Δ) of MK test and sen's slope

Station	Jan		Feb		Mar		Apr		May		June		July		Aug		Sep		Oct		Nov		Dec	
	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ
Giridih	-0.05	-0.06	-0.01	-0.01	-0.02	-0.02	-0.07	-0.05	-0.09	-0.06	-0.03	-0.02	-0.04	-0.04	0.02	0.02	0.02	0.02	0.02	0.02	-0.02	-0.02	0.00	-0.01
Koderma	-0.04	-0.04	-0.01	0.00	-0.01	-0.01	-0.07	-0.05	-0.06	-0.04	-0.01	-0.01	-0.04	-0.03	0.01	0.01	0.02	0.02	0.02	0.02	-0.04	-0.04	-0.01	-0.01
Nawada	-0.04	-0.05	0.02	0.01	0.00	0.00	-0.06	-0.04	-0.05	-0.03	-0.03	-0.02	-0.06	-0.05	-0.01	-0.01	0.03	0.03	0.02	0.02	-0.06	-0.06	-0.03	-0.03
Nalanda	-0.05	-0.06	0.01	0.00	-0.01	-0.01	-0.04	-0.03	-0.04	-0.03	-0.05	-0.03	-0.08	-0.06	-0.01	-0.01	0.04	0.03	0.01	0.01	-0.08	-0.08	-0.03	-0.03

0.06°C/year), and Nawada (-0.05°C/year) with a percentage change of -0.09, -0.06 and -0.05, respectively. It was also observed in April at Koderma (-0.07°C/year) with a % Δ of -0.07%. A significantly increasing magnitude of T_{max} is assessed in September at Giridih (0.02°C/year), Nawada (0.03°C/year) and Nalanda (0.04°C/year) with a % Δ of 0.02%, 0.03% and 0.03%, respectively, at $p<0.05$. Conversely, an insignificant increasing/decreasing monthly T_{max} was observed at all stations. The increase in T_{max} in the future changing clmatic scenario in the eastern India river was also reported by Padhiary *et al.* (2020). Details of Z_{mk} value, β and % Δ for T_{max} and T_{min} are presented in Table 3(a) and 3(b).

A comprehensive analysis of the intensity and distribution of rainfall, as well as T_{max} and T_{min} extremes, is crucial for assessing impacts and planning adaptations for extreme weather events. It is recommended that the forthcoming evaluations of spatiotemporal phenomena, taking into account climate changing scenarios, be conducted on different temporal sclaes within the Sakri basin. Such assessments would significantly help in the effective preparation and supervision of water resources in the context of a changing scenarios of climate in the SRB of India.

3.3.3 | Minimum temperature

The T_{min} exhibits a significantly upward trend in April across all stations except Giridih in the SRB. A significant increase in T_{min} was also observed in August at Giridih and Nalanda. The highest recorded monthly T_{min} exhibited a significant increase in Nawada and Nalanda (0.08°C/year), corresponding to % Δ of 0.12% and 0.13%, respectively. The lowest recorded monthly T_{min} was observed in Giridih (0.02°C/year) corresponding to % Δ of 0.03%, which is statistically significant at $p<0.05$. A significant positive β was noted in April at Koderma (0.06°C/year), Nawada (0.08°C/year) and Nalanda (0.08°C/year) corresponding to % Δ of 0.09%, 0.12% and 0.13%, respectively. It was also observed in August at Giridih (0.02°C/year) and Nalanda (0.03°C/year) corresponding to % Δ of 0.03% and 0.03%, respectively. Conversely, an insignificant increasing / decreasing monthly T_{min} was observed at all stations across the seasons, at $p<0.05$. Similar results were documented by Kumar *et al.* (2016) in their analysis of climatic trends in Jharkhand, India. The Z_{mk} value, β and % Δ acquired from the MK test over the annual timeframe for all stations are presented in Table 4 (a) and (b).

4 | CONCLUSIONS

Sakri basin is an agriculturally dominated river basin in eastern India, playing a significant role in the state's export-oriented economy. Comprehending the distribution of rainfall and temperature within the river basin is essential for the effective supervision of land and water resources. The results of the study reveal significant variations in seasonal and annual rainfall, as well as trends observed over an extended time series, characterized by differing levels of rainfall variability. The M-K test was employed to identify trends in these climatic variables alongwith the assessment of the magnitude of Sen's slope, whereas the spatial distribution was evaluated by IDW and OK techniques. Results of rainfall trend showed that monsoonal and annual rainfall is increasing in the basin. Thus, the SRB has enormous potential to harvest rainfall. Still, due to undulating terrain in the upper reach and poor SWC measures, the most of water drained out. Therefore, it is recommended that water storage capacity and groundwater recharge be increased by developing suitable water harvesting structures or reviving existing structures in the basin. It was detected that the maximum monthly temperature is decreasing and minimum temperature, increasing in the

TABLE 4 Trend analysis of monthly minimum temperature and percentage change of Sakri basin (1991–2020)

(a) Z value of MK test

Station	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}	Z_{mk}
Giridih	-0.75	-0.80	-0.53	0.82	-1.09	-0.44	-0.73	2.16*	1.50	0.80	1.51	-1.68
Koderma	-0.90	-0.51	-0.34	2.02*	-0.58	0.03	-0.14	1.87	1.34	0.49	1.27	-1.80
Nawada	-0.09	-0.44	-0.27	1.97*	-0.75	0.46	-0.20	1.38	1.27	0.88	1.12	-1.67
Nalanda	-0.20	-0.31	-0.03	2.18*	-0.54	1.43	-0.46	2.23*	1.17	1.22	1.17	-1.44

**indicates a significance level of 5%.*

(b) Magnitude (β) and percentage change (% Δ) of MK test and sen's slope

Station	Jan		Feb		Mar		Apr		May		June		July		Aug		Sep		Oct		Nov		Dec	
	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ	β	% Δ
Giridih	-0.02	-0.14	-0.03	-0.11	-0.02	-0.06	0.03	0.04	-0.03	-0.04	-0.01	-0.01	-0.01	-0.01	0.02	0.03	0.04	0.05	0.02	0.04	0.05	0.15	-0.05	-0.25
Koderma	-0.02	-0.14	-0.02	-0.08	-0.01	-0.03	0.06	0.09	-0.02	-0.02	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.04	0.01	0.02	0.03	0.10	-0.05	-0.28
Nawada	0.00	-0.01	-0.02	-0.07	-0.01	-0.02	0.08	0.12	-0.02	-0.02	0.02	0.02	0.00	0.00	0.01	0.02	0.03	0.04	0.03	0.05	0.05	0.13	-0.04	-0.21
Nalanda	0.00	-0.02	-0.01	-0.04	0.00	-0.01	0.08	0.13	-0.02	-0.02	0.04	0.05	0.00	0.00	0.03	0.03	0.03	0.04	0.05	0.09	0.05	0.14	-0.05	-0.23

SRB. The evaluation of recent trends within the SRB is essential for addressing the drought conditions experienced over the past decade in future scenarios. This assessment is significant for informing policy decisions, resource management and planning. Additionally, it acts as a valuable resource for planning future agriculture practices and climate-related research in the nation.

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DATA AVAILABILITY STATEMENT

The data generated or analysed during this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare there is no conflict.

AUTHOR'S CONTRIBUTION

Conceptualization, P.J. and A.K.S.; data collection, P.J., P.K.S. and A.K.S.; methodology, P.J., A.U. and P.K.S.; resources, A.D. and A.U.; investigation, P.J. and A.K.S.; validation, P.J. and D.S.; writing-original draft preparation, P.J. and P.K.S.; writing-review and editing, P.J., A.U., A.K.S., D.S., P.K.S and P.K.S.; visualization, P.K.S. and A.D.; supervision, P.J.; project administration, A.D. and A.U. All authors have read and agreed to the published version of the manuscript.

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