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# PANTNAGAR JOURNAL OF RESEARCH

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# Evaluating Long-Term rainfall and temperature trends across the Shipra River basin

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**ABSTRACT:** This study examines the long-term trends in seasonal and annual rainfall, and temperature patterns across the Shipra River Basin in Madhya Pradesh, Central India, utilizing high-resolution gridded rainfall data spanning from 1901 to 2020 for rainfall and 1951 to 2020 for temperature. The primary aim was to evaluate changes in rainfall dynamics through the application of both parametric and non-parametric statistical tools, including the Mann-Kendall trend test, Sen's Slope estimator. The findings revealed a positive trend in monsoon and annual rainfall at a rate of +1.12 mm/year and 1.06 mm/year, respectively. In contrast, pre-monsoon, post-monsoon, and winter rainfall exhibited statistically non-significant declining trends with rate of –0.020 mm/year, –0.010 mm/year, and –0.030 mm/year, respectively. Temperature trend analysis (1951–2020) revealed statistically significant increases in annual maximum and minimum temperatures at rates of +0.006 °C/year and +0.006 °C/year, respectively. These findings highlight the emergence of hydroclimatic imbalance in the basin, necessitating the adoption of climate-resilient agricultural practices, sustainable water resource planning, and further integration of climate projection models for informed adaptation strategies.

**Key words**: Mann-Kendall Test, Parametric, Rainfall, Temperature, Trend Analysis

Rainfall constitutes a vital climatic element, with variations in its patterns exerting direct or indirect influences on agricultural production, human lifestyles, water resource management, and the function and structure of ecosystems (Kumar and Gautam, 2014). Numerous scientific investigations have substantiated alterations in rainfall patterns attributable to climate change (CC). For instance, a study by Trenberth *et al.* (2014) identified an intensification of extreme rainfall events across various global regions, including North America, Europe, and parts of Asia. Similarly, research by Sheffield *et al.* (2012) demonstrated that abrupt shifts in precipitation patterns have exacerbated water stress in several areas, notably the Mediterranean and the southwestern United States. In recent decades, significant transformations in the global climate, marked by unexpected shifts in temperature and rainfall patterns, have become evident. These changes bear considerable implications for the social lifestyle and economy of rural populations, who predominantly depend on agriculture as their principal source of income. Their reliance on seasonal monsoons and environmental sustainability further accentuates the potential impact of these climatic variations (Nadeau *et al.*, 2022). Various studies conducted globally have documented changes in rainfall patterns over different temporal scales (Das *et al.*, 2022).

In recent years, India has encountered substantial challenges due to climate change (CC), which have notably impacted its forests (El Kasri *et al.*, 2021) and agricultural sector (Kumar and Gautam, 2014). Between 1951 and 2015, the nation experienced a decline in rainfall, coupled with an increase in mean, maximum, and minimum temperatures at rates of 0.15, 0.15, and 0.13/ °C, respectively (Krishnan *et al.*, 2022). Given the critical dependence of India's economy and food security on timely rainfall (Abrol and Gupta, 2019), numerous studies have investigated the variability of regional and seasonal rainfall. Research conducted by Kumar *et al.* (2010), Machiwal *et al.* (2017), and Katzenberger *et al.* (2021) underscores both spatial heterogeneity and the recent intensification of extreme rainfall events, particularly in the northeastern and southern regions. In Gujarat, Shah *et al.* (2021) documented a reduction in the number of rainy days and average monsoon rainfall. Similar declining trends have been observed in Uttarakhand (Banerjee *et al*., 2020) and across central and western peninsular India (Sam *et al*., 2020). In Madhya Pradesh, rainfall trends exhibit regional variation: East Madhya Pradesh demonstrates significant monsoon declines (Yadav and Singh 2023), whereas areas such as Bundelkhand and Betul exhibit high variability or statistically insignificant changes (Som and Dey 2022; Sharma *et al*., 2021). These alterations in rainfall patterns pose critical risks to water availability and agricultural productivity, highlighting the urgent need for climate resilience initiatives.

A limited number of studies have examined the seasonal variations and trends in rainfall and temperature patterns in Central India using long-term gridded data. This study presents a comprehensive analysis of the temporal variability and trends of rainfall and temperature, which is crucial for understanding the regional impacts of climate change on Central India. The primary objective of this research, utilizing long-term IMD gridded data, is to assess the trends and magnitude of seasonal (Monsoon, Pre-Monsoon, Post-Monsoon, and Winter) and annual rainfall and temperature in Shipra River basin. The parametric linear regression method as well as Non-parametric Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975), and Sen's Slope estimator have been employed for trend analysis.

## MATERIALS AND METHODS

### Study Area

The present study was conducted in the Shipra River basin, a significant waterway in the state of Madhya Pradesh, India. The Shipra, also referred to as the Kshipra, originates in the Kakri-bardi Hills of the Vindhya Range, north of Dhar, and traverses the Malwa Plateau before joining the Chambal River. This river holds sacred significance for Hindus, akin to the Ganges, and the term "Shipra" is often associated with purity, chastity, or clarity of mind, emotions, and body. The sacred city of Ujjain is located on the eastern bank of the river. The Simhastha fair (Kumbh Mela) is held every 12 years to honor the annual celebrations of the river goddess Shipra, during which numerous Hindu shrines along the riverbanks are visited. The Shipra River is situated at an average altitude of 553 meters above mean sea level (MSL). The region is characterized by fertile soil, gentle slopes, and moderate rainfall. The latitudinal and longitudinal extent of the basin lies between 23°56′41" and 22°27′36" North latitude and 76°13′32" and 75°24′27" East longitude, encompassing a catchment area of 5624 square kilometers. The total course of the river is approximately 190 km, flowing through the Ujjain, Indore, and Dewas districts of the state before ultimately conferencing with the Chambal River near the Kalu-Kher village. The primary tributaries of the Shipra River include the Khan River near Ujjain and the Ghambir River near Mahidpur. The index map of the Shipra basin indicating its location is presented in Figure 1.

Historically, the river exhibited perennial characteristics; however, it now experiences drought periods lasting 5 to 6 months annually. The Shipra's water, once traditionally used for potable purposes, is no longer suitable for consumption. Nevertheless, it continues to fulfill industrial and agricultural needs. The Shipra sub-basin is characterized by a sub-humid climate with distinct tropical dry and wet seasons. The study area's average annual precipitation ranges from 440 mm to 1932 mm, with monsoon rainfall varying between 399 mm and 1854 mm over the period from 1901 to 2020. The basin receives substantial precipitation during the monsoon months (June to September). The region's mean monthly maximum temperature ranges from 31°C to 34°C, while the mean monthly minimum temperature varies between 18°C and 20°C during the study period (1951 to 2020). The primary crops cultivated in the Shipra River basin area include soybean and sorghum as Kharif crops, wheat and gram as Rabi crops, and sunflower as the Zaid crop.

### *Rainfall and Temperature Data*

The high-resolution gridded datasets for rainfall and temperature were sourced from the India

Meteorological Department (IMD), Pune (https://www.imdpune.gov.in/). The gridded rainfall data are available in two formats, namely Binary and NetCDF, with resolutions of 0.25°×0.25° and 1°×1°, respectively (Pai *et al*., 2014). In this study, the rainfall analysis was conducted using the Binary format at a finer resolution of 0.25°×0.25° for the period from 1901 to 2020. In contrast, the gridded maximum and minimum temperature data, available for the period from 1951 to 2020, are provided in both Binary and NetCDF formats at a 1°×1° resolution. Consequently, to derive the maximum and minimum temperature series, the daily gridded temperature data were downloaded in Binary format at a 1°×1° resolution for the period from 1951 to 2020. It is noteworthy that these datasets are freely accessible and regularly updated by the IMD to incorporate recent rainfall and temperature measurements from an ever-increasing number of automatic weather stations and rain gauges, thereby enhancing the accuracy of rainfall and temperature estimates across the country.

The raw data of rainfall and temperature in the binary format were downloaded from IMD website (https://www.imdpune.gov.in/). Further, in order get daily/monthly series, the Python script developed by Lekshmi *et al*. (2022), was employed for the extraction of data series in (.csv) format; and then converted to excel sheet for further analysis. The downloaded data were arranged on monthly, seasonal, and annual time scales to understand the variation of rainfall and temperature in the basin. Four seasons were defined as follows: pre-monsoon (March to May), monsoon (June to September), post-monsoon (October-November) and winter (December to February).

***Trend Analysis***

Trend analysis is a widely utilized technique, extensively employed by researchers over the past two decades to examine variations in hydro-meteorological variables. To evaluate trends in climatic parameters, such as rainfall and temperature, within the study area, both parametric (regression analysis) and non-parametric statistical methods have been applied. Non-parametric statistical tests are particularly suitable for data that do not follow a normal distribution, as they are less sensitive to outliers compared to parametric tests. Among non-parametric tests, the Mann-Kendall

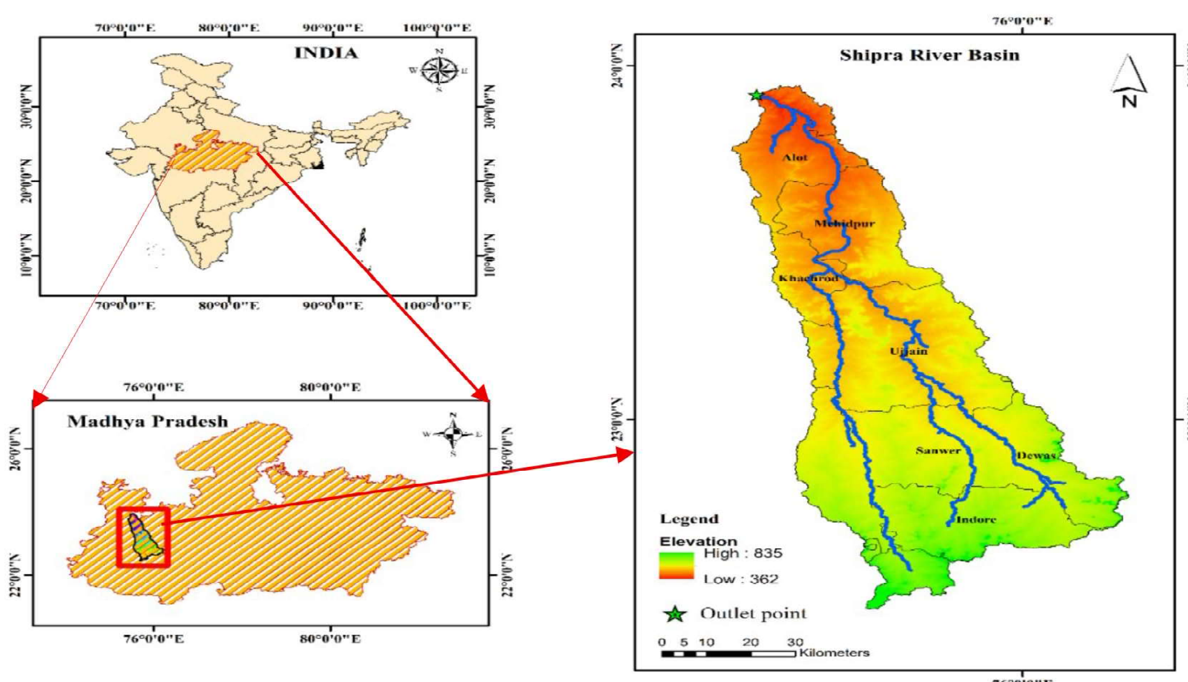


**Fig. 1: Location map of Shipra basin**

(MK) test is the most widely accepted, as endorsed by the World Meteorological Organization (WMO) for analyzing trends in hydro-meteorological time series.

**Linear Regression Test**

To detect the trend of long-term and short-term rainfall series over the entire basin, the linear regression method was used. Simple linear regression analysis is a parametric approach that is often used to detect trends in time series data (Malik and Kumar, 2020). The linear regression technique can be mathematically expressed as given in Eq. (1):

$$y = \theta + mX \tag{1}$$

where, y is the dependent variable, X is the independent variable, *m* represent the slope of the line, and $\theta$ is the intercept.

In this study, the rainfall trend was carried out on the long-term as well as short-term series for seasonal and annual scales. According to the World Meteorological Organization (WMO), defines the classical climate period as a 30-year period for the analysis. To determine the short-term trend, the 1901-2020 time series was subdivided into four consecutive classical 30-year periods such as, series-1(1901-1930), series-2 (1931-1960), series-3 (1961-1990), and series-4 (1991-2020).

**Mann-Kendall (MK) Test**

The Mann-Kendall (MK) test, as developed by Mann (1945) and Kendall (1975), is one of the most widely utilized non-parametric tests for detecting significant trends in meteorological and hydrological time series data. This test is suitable for non-autocorrelated data and does not require assumptions of normality or homogeneity of variance. As the test compares medians rather than means, it is less affected by one or two outliers in the data. The Mann-Kendall test statistic (S) is represented as Eq. (2):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(X_j - X_i\right) \tag{2}$$

where, n is the number of observations, $X_i$ is the rank for i^th^ observations, $X_j$ is the rank for j^th^ observations in the time series and sgn(X) is the sign function and can be defined as Eq. (3):

$$sgn\left(X_j - X_i\right) = \begin{Bmatrix} 1 & for\ X > 0; \\ 0 & for\ X = 0; \\ -1 & for\ X < 0; \end{Bmatrix} \tag{3}$$

When n ≥ 10, the test statistic S is assumed to be asymptotically normally distributed with zero mean i.e., (E(S)=0) and the variance ($V_S$) can be calculated as Eq. (4):

$$V_S = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i (t_i - 1)(2t_i + 5)}{18} \tag{4}$$

where, p is the number of tied groups and $t_i$ is the number of data values in the $i^{th}$ tied group (i=1,2,3…n).

A tied group is a set of sample data having the same value. After the calculation of variance ($V_s$) of the time series data, the Mann-Kendall statistics ($Z_{MK}$) can be calculated as Eq. (5):

$$Z_{MK} = \begin{Bmatrix} \frac{S-1}{\sqrt{V_S}} & for\ S > 0; \\ 0 & for\ S = 0; \\ \frac{S-1}{\sqrt{V_S}} & for\ S < 0; \end{Bmatrix} \tag{5}$$

The null hypothesis ($H_0$) implies that there is no trend in the time series and the alternate hypothesis ($H_1$) indicates significant trend over the data. Thus, in two-sided condition, the $H_0$ and $H_1$ are tested at one significance levels of (α) i.e., α=10% significant level with Z=±1.645; α= 5% significant level with Z=±1.96; or α=1% significant level with Z=±2.54. If $\pm Z_{MK} > \pm Z_{\alpha/2}$, then $H_0$ is rejected and $H_1$ is accepted. A positive ($Z_{MK}$) value indicates an increasing trend while a negative ($Z_{MK}$) value indicates a decreasing trend in the time series.

**Sen's Slope Estimator**

The magnitude of the trend is assessed using the slope estimator methods proposed by Sen (1968). Sen's slope estimator is a non-parametric, linear slope estimator that is particularly effective for monotonic data. It is capable of calculating both the slope (i.e., the linear rate of change) and the intercept according to Sen's method. A positive slope value (Qi) signifies an 'upward trend' (increasing values over time), whereas a negative slope value (Qi) signifies a 'downward trend' (decreasing values over time). Generally, the slope (Qi) of a trend in a sample of N pairs of data can be estimated as shown in Eq. (6):

$$Q_i = \frac{X_j - X_k}{j - k} \quad \text{for i= 1, 2…N,} \tag{6}$$

where, $X_j$ and $X_k$ are the data values at times j and k (for all k< j), respectively.

If there is only one datum in each time-period, then $N = \frac{n(n-1)}{2}$ and if there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$, where n is the total number of observations.

The N values of $Q_i$ are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as Eq. (7):

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]}, & if\ N\ is\ odd \\ \frac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2}, & if\ N\ is\ even \end{cases} \tag{7}$$

The $Q_{med}$ sign reflects data trend reflection i.e., (increasing or decreasing) trend, while its value indicates the steepness of the trend.

## Percentage Change in Mean

Some trends may not be evaluated to be statistically significant while they might be of practical interest, and vice versa (Yue and Hashino, 2003). Even if a climate change component is present, it does not need to be detected by statistical tests at a satisfactory significance level. The percentage change in mean is calculated by its approximation with linear trend. Thus, change percentage is equal to the median slope which is multiplied with the length of the period and then the whole was divided by the corresponding mean value in percentage (Yue and Hashino, 2003). The percentage change is computed by the following formula given in the Eq. (8).

$$\text{Percentage change (\%)} = \frac{Q_I \times l}{\overline{X}} \tag{8}$$

where,

$Q_i$ is Slope magnitude (Sen's slope value), $l$ is total length of the year, and $\overline{X}$ is mean value.

## RESULTS AND DISCUSSION

***Trend analysis of rainfall using Linear Regression***

The regression analysis as given in Figures 2 to 6 presented the seasonal and annual rainfall trends of the Shipra River basin based on the seasonal and annual time series. Figure 2 presents linear trends in pre-monsoon seasonal rainfall across the basin over time. The graph shows multiple trendlines with regression equations and $R^2$ values indicating trend strength. The black and gray lines show annual rainfall variations. From 1901 to mid-1920s, there was a slight rainfall increase with low $R^2$ (0.0455). Between 1931-1960, the trend was nearly flat (0.0285x - 40.086, $R^2$ = 0.0002). A decline occurred from 1961-1990 (-0.3594x + 721.67, $R^2$ = 0.059), while 1991-2020 showed a weak positive trend (0.1561x - 300.33, $R^2$ = 0.0085). The findings indicated that the pre-monsoon rainfall variability was mainly influenced by external climatic factors rather than linear trends. Figure 3 shows monsoon seasonal rainfall trends across the basin from 1901-2020, with multiple trendlines and high $R^2$ values indicating strong statistical relationships. The early period (1901–1930) shows an increasing trend (0.3898x - 0.0722, $R^2$ = 0.9064), followed by steeper rises in 1931-1960 (0.4832x + 0.0799, $R^2$ = 0.9401) and 1961-1990 (0.4431x + 0.0743, $R^2$ = 0.8811). The recent period (1991–2020) maintains this positive trend (0.4506x - 0.0787, $R^2$ = 0.9046). The high $R^2$ values suggest strong correlation between time and increasing monsoon rainfall, indicating gradual precipitation rise potentially due to climatic shifts. These trends demonstrate consistent increases in monsoon rainfall over time, suggesting ongoing climatic or hydrological changes in the basin.

Similarly, Figure 4 depicts the long-term and short-term linear trends of post-monsoon season rainfall across the entire basin from 1901 to 2020. The graph reveals significant inter-annual variability, with fluctuations in post-monsoon rainfall over different periods. The trendlines for each period indicate varying tendencies, with low $R^2$ values, suggesting weak correlations. The early period (1901–1930)

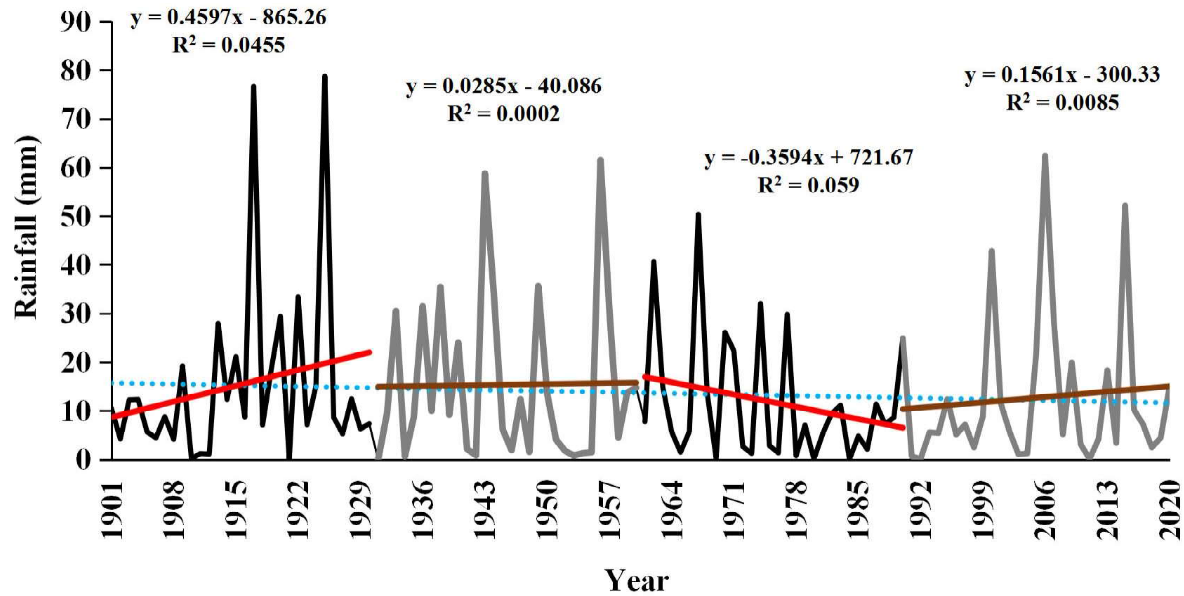


Fig. 2: Long term and short-term linear trend of pre-monsoon seasonal rainfall

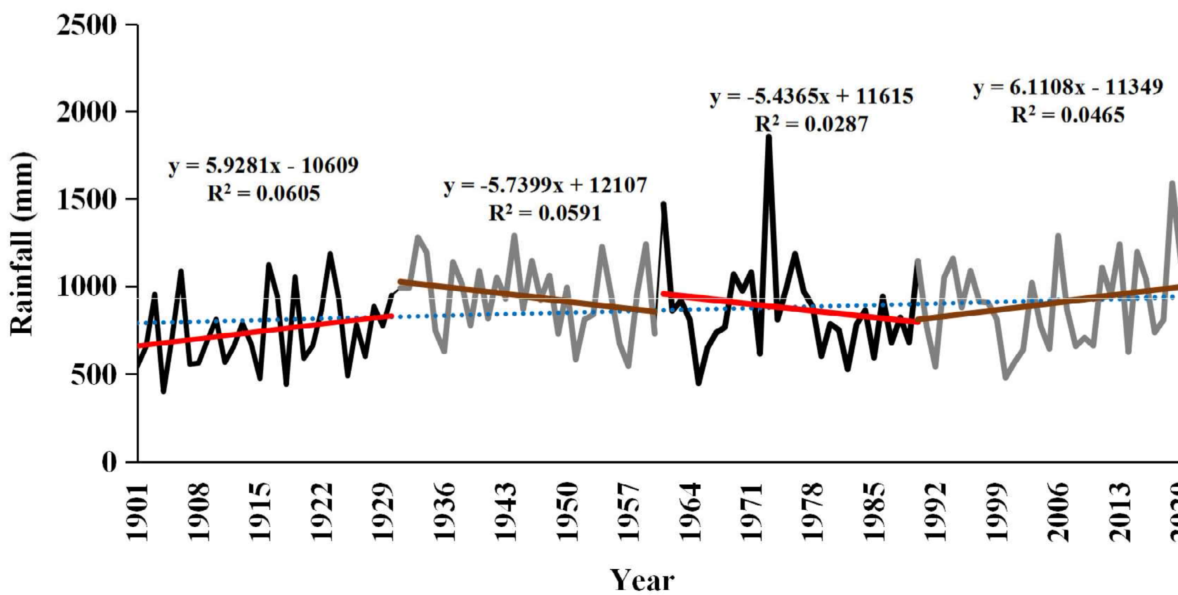


Fig. 3: Long term and short-term linear trend of monsoon seasonal rainfall series

**Table 1: Seasonal and annual rainfall trend over the entire basin**

| Time series | $Z_{MK}$ value | Sen's slope | Change % | Trend |
|---|---|---|---|---|
| Pre-monsoon | -0.88 | -0.04 | -17.54 | Insignificant decrease |
| Monsoon | 1.65[a] | 1.12 | 15.55 | Significant increase |
| Post-monsoon | -0.04 | -0.01 | -2.78 | Insignificant decrease |
| Winter | -1.61 | -0.03 | -22.26 | Insignificant decrease |
| Annual | 1.53 | 1.06 | 13.57 | Insignificant increase |

Note: Bold values a, b and c show the 10%($Z_{10\%}$=±1.64), 5% ($Z_{5\%}$ = ±1.96) and 1% ($Z_{1\%}$= ±2.58) significant level of trend

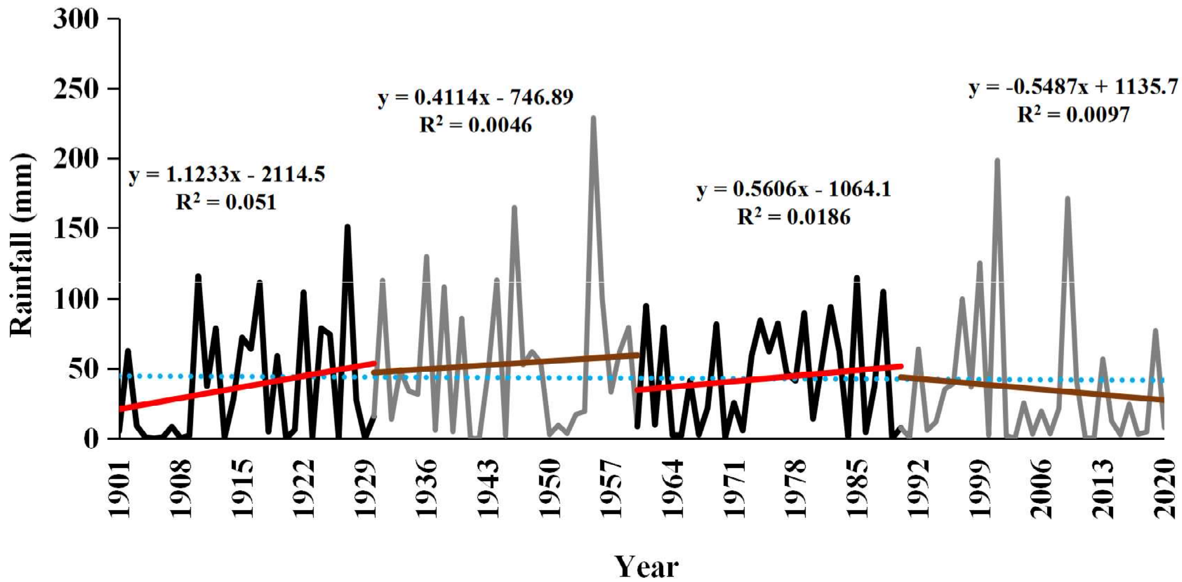


**Fig. 4: Long term and short-term linear trend of post-monsoon seasonal rainfall**

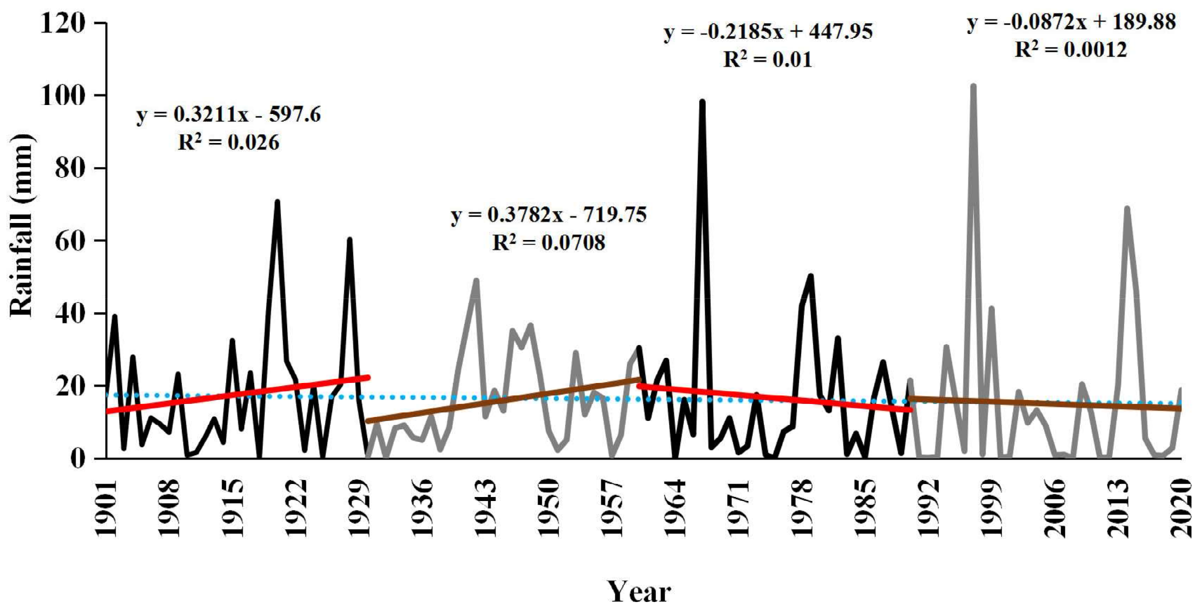


**Fig. 5: Long term and short-term linear trend of winter seasonal rainfall**

**Table 2: Results of MK test and Sens slope (°C/year) based on seasonal and annual maximum temperature series during 1951 to 2020**

| Season | $Z_{MK}$ value | Sen's slope | Change % | Trend |
|---|---|---|---|---|
| Pre-monsoon | 3.792[c] | 0.013 | 4.35 | Significant increase |
| Monsoon | 1.399 | 0.005 | 1.09 | Insignificant increase |
| Post-monsoon | 1.136 | 0.006 | 1.31 | Insignificant increase |
| Winter | -0.537 | -0.003 | -0.70 | Insignificant decrease |
| Annual | 1.946[a] | 0.006 | 1.29 | Significant increase |

Note: Bold values a, b and c show the 10% ($Z_{10\%}$=±1.64), 5% ($Z_{5\%}$ = ±1.96) and 1% ($Z_{1\%}$= ±2.58) significant level of trend

**Table 3: Seasonal and annual trend analysis of minimum temperature series based on MK test and Sens slope (°C/year) during 1951 to 2020**

| Season | $Z_{MK}$ value | Sen's slope | Change % | Trend |
|---|---|---|---|---|
| Pre-monsoon | 1.886[a] | 0.007 | 2.34 | Significant increase |
| Monsoon | 1.501 | 0.002 | 0.65 | Insignificant increase |
| Post-monsoon | 2.383[b] | 0.014 | 5.83 | Significant increase |
| Winter | 0.923 | 0.003 | 1.48 | Insignificant increase |
| Annual | 2.504[c] | 0.006 | 2.24 | Significant increase |

Note: Bold values a, b and c show the 10%($Z_{10\%}$=±1.64), 5% ($Z_{5\%}$ = ±1.96) and 1% ($Z_{1\%}$= ±2.58) significant level of trend

exhibits a positive trend (1.1233x - 2114.5, $R^2$ = 0.051), followed by a substantially weaker increasing trend from 1931 to 1960 (0.4114x - 746.89, $R^2$ = 0.0046). A slightly stronger increase is observed in 1961–1990 (0.5606x - 1064.1, $R^2$ = 0.0186), while the most recent period (1991–2020) demonstrates a declining trend (-0.5487x + 1135.7, $R^2$ = 0.0097). The overall trends suggest a weak increase in post-monsoon rainfall during the early decades, followed by a slight decline in recent years, potentially influenced by changing climatic conditions or regional hydrological dynamics. However, the low $R^2$ values indicate that post-monsoon rainfall variability is predominantly governed by external climatic and atmospheric factors rather than exhibiting a strong linear trend.

Figure 5 presents the long-term and short-term linear trends in winter seasonal rainfall across the entire basin from 1901 to 2020. The graph reveals significant fluctuations in winter rainfall over various periods, with trendlines indicating diverse tendencies. The initial period (1901–1930) shows a slight increase in rainfall (0.3211x - 597.6, $R^2$ = 0.026), followed by a more pronounced rising trend between 1931 and 1960 (0.3782x - 719.75, $R^2$ = 0.0708). However, the subsequent periods demonstrate a declining trend, with 1961–1990 exhibiting a negative slope (-0.2185x + 447.95, $R^2$ = 0.010) and 1991–2020 showing a further decrease (-0.0873x + 189.88, $R^2$ = 0.0012). The low $R^2$ values across all periods indicate that the trends are weak, suggesting that winter rainfall variability is

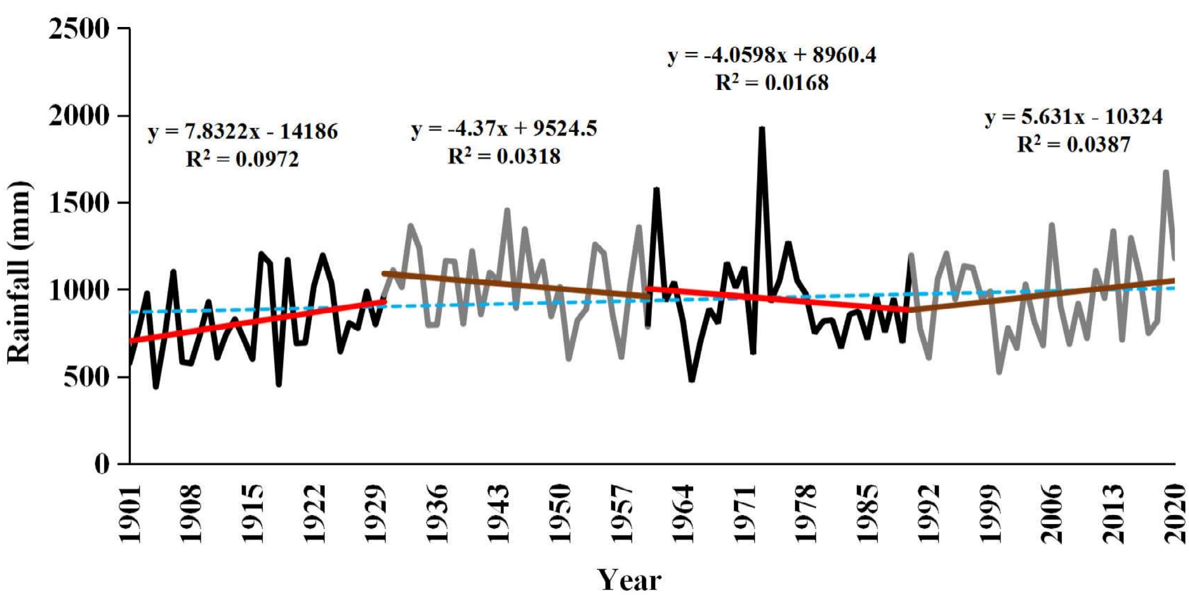


**Fig. 6: Long term and short-term linear trend of annual rainfall series**

predominantly influenced by external climatic factors rather than a strong linear pattern. Overall, the findings suggest an initial increase in winter rainfall, followed by a declining trend in recent decades, potentially attributable to changing atmospheric circulation patterns or regional climatic shifts.

Figure 6 illustrates the long-term and short-term linear trends in annual rainfall across the entire basin from 1901 to 2020. The trend analysis reveals significant fluctuations in annual rainfall patterns over different periods. The early period (1901–1930) demonstrates a positive trend (7.8332x - 14186, $R^2$ = 0.0972), indicating an increasing rainfall pattern. However, between 1931 and 1960, the trend reverses, exhibiting a declining tendency (-4.37x + 9524.5, $R^2$ = 0.0318). The period 1961–1990 also displays a negative slope (-4.0598x + 8960.4, $R^2$ = 0.0168), suggesting continued decline. Notably, the most recent period (1991–2020) indicates a positive trend (5.631x - 10324, $R^2$ = 0.0387), implying a slight recovery in rainfall.

Despite these fluctuations, the low $R^2$ values suggest that annual rainfall variations are predominantly influenced by external climatic factors rather than a strong linear pattern. Overall, the analysis highlights periodic shifts in rainfall trends, with an initial increase, mid-century decline, and a slight rise in recent decades, potentially associated with climate variability and regional hydrological changes.

***Trend analysis of rainfall using Mann-Kendall (MK) Test***

The seasonal and annual $Z_{MK}$ statistics computed from 1901 to 2020 years rainfall data over the entire basin is presented in Table 1. For the seasonal analysis, it was observed that the $Z_{MK}$ statistics varied from -1.61 to 1.65 for different seasons having a minimum value for the winter season and maximum value for the monsoon season. The result showed that the monsoon season observed a significant increasing trend at 10% significance level, while other seasons did not show any significant trend. The lowest magnitude of the trend was observed (-0.03 mm/year) for the winter season and highest for the monsoon season (1.12 mm/year). Further, a non-significant increasing trend was observed in annual rainfall.

As can be seen from Table 1, the percentage change in the trend was increased in case of annual and monsoon rainfall time series; however, the percentage change in trend was decreased in case of pre-monsoon, post-monsoon and winter seasons.

***Temperature (°C) Trend Analysis Using Mann-Kendall Test***

**Maximum temperature trend analysis**

The seasonal and annual trends of maximum

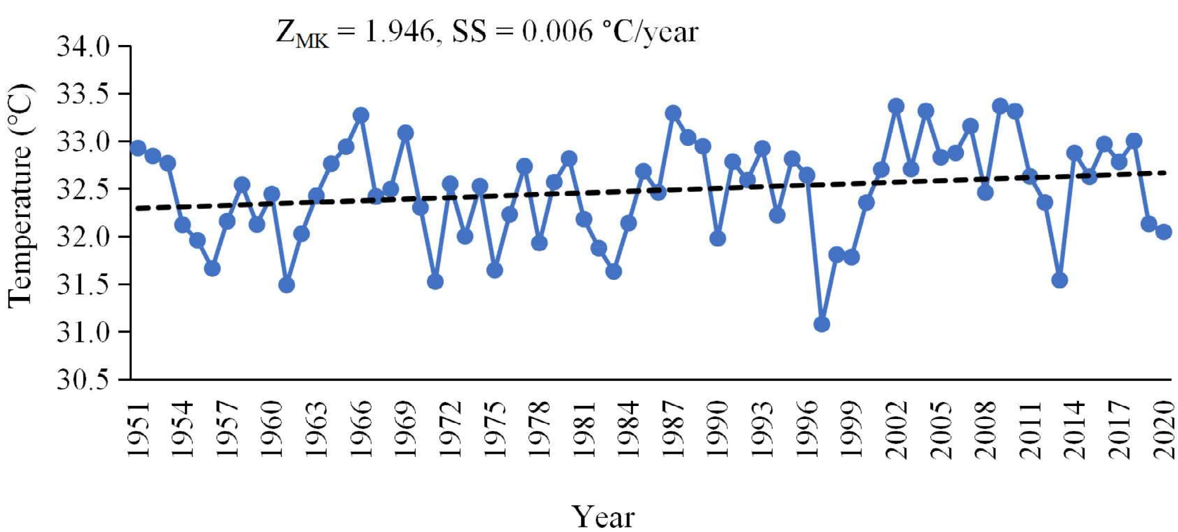


**Fig. 7: Trend of annual maximum temperature series**

temperature data were calculated, and the results obtained are shown in the Table 2. It was observed that the $Z_{MK}$ statistics varied from -0.537 to 3.792 for different seasons having the minimum value for the winter season and maximum for the pre-monsoon. Among the four seasons, only the pre-monsoon maximum temperature series indicated a significantly increasing trend, whereas monsoon and post-monsoon series depicted a non-significant increasing trend. However, the winter season indicated a non-significant decreasing trend. The lowest magnitude of the trend was observed for winter series (-0.003 °C/year) and the highest for pre-monsoon series (0.013 °C/year).

Figure 7 depicts the trend in the annual maximum temperature series from 1951 to 2020. The Mann-Kendall test statistic (ZMK = 1.946) and the slope statistic (SS = 0.006 °C/year) indicate a statistically significant upward trend in annual maximum temperatures. Although interannual variations are evident, the overall trend suggests a warming pattern, which may have implications for climate change, thermal stress, and environmental sustainability in the region.

***Minimum temperature trend analysis***

The result of seasonal and annual trend of minimum temperature series is shown in the Table 3. It was observed that the $Z_{MK}$ statistics varied from 0.923 to 2.383 for different seasons having the minimum value for the winter season and maximum value for the post-monsoon season. It was observed that the pre-monsoon and post-monsoon seasons for minimum temperature series showed a significantly increasing trend at 10% and 5% significant level, respectively. However, monsoon and winter seasons indicated a non-significant increasing trend. The lowest magnitude of the Sen's slope estimator was observed for monsoon season (0.002°C/year), while for other seasons the magnitude varied between 0.003 to 0.014 °C/year. Further, the annual minimum temperature series observed a positive $Z_{MK}$ value (2.504), showed a significantly increasing trend, and having a magnitude of (0.006 °C/year).

Figure 8 illustrates the trend in the annual minimum temperature series from 1951 to 2020. The Mann-Kendall test statistic ($Z_{MK}$ = 2.504) and the slope statistic (SS = 0.006 °C/year) demonstrate a statistically significant upward trend in annual minimum temperatures. This finding suggests a gradual increase in nocturnal or cold-season temperatures, which may have implications for agricultural practices, water resource management, and overall climate resilience by reducing frost

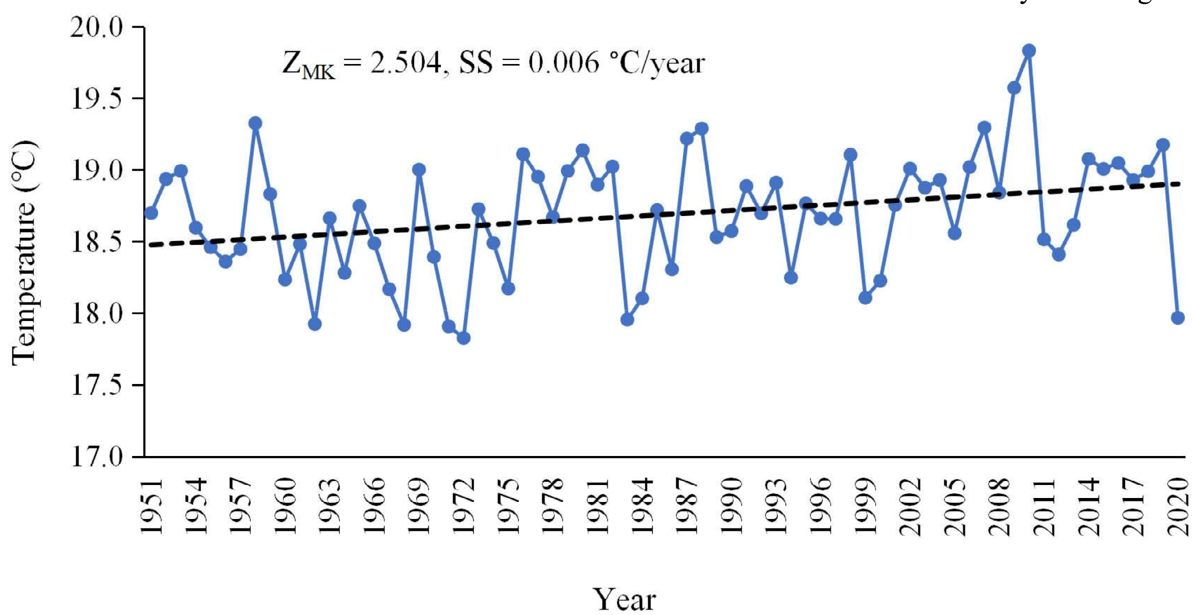


**Fig. 8: Trend of annual minimum temperature series**

events and altering thermal comfort parameters.

## CONCLUSION

This study conducts a comprehensive temporal analysis of rainfall and temperature trends in the Shipra River Basin, Madhya Pradesh, India, utilizing long-term IMD gridded data and robust parametric and non-parametric statistical methods. The analysis identifies pronounced seasonal variability, particularly during the pre-monsoon, post-monsoon, and winter periods, while annual and monsoon rainfall patterns remain relatively stable. A modest yet consistent increasing trend in monsoon rainfall (1.12 mm/year) was observed, which may facilitate early crop sowing and groundwater recharge. However, other seasons, exhibit overall decreasing trends, posing risks to agricultural sustainability and water security. Concurrently, temperature trends from 1951 to 2020 indicate statistically significant warming in both minimum and maximum values, particularly during the pre-monsoon and annual periods, intensifying evapotranspiration and further stressing water resources. The seasonal minimum temperature found to have an increasing trend in pre-monsoon, post-monsoon, and annual seasons. These findings collectively indicate an emerging hydroclimatic imbalance, driven by climate change and land use pressures, underscoring the urgent need for climate-resilient agricultural practices, enhanced water resource management, and policy interventions. The study recommends region-specific adaptation strategies, including rainwater harvesting, improved watershed management, and enhanced seasonal monitoring systems, while also advocating for future research that integrates high-resolution climate projections, soil moisture dynamics, and socio-economic vulnerability to support informed, sustainable development planning in the basin.

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## DATA AVAILABILITY STATEMENT

The data pertaining to rainfall and temperature utilized in this study were procured from the India Meteorological Department (IMD), Pune, and are accessible in a gridded format (0.25° × 0.25° for rainfall and 1° × 1° for temperature) *via* the IMD's official data portal: https://www.imdpune.gov.in/.

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