**ORIGINAL ARTICLE**

# Assessment of long-term variability in rainfall trends over Damodar River Basin, India

**Pradeep Kumar Mahato[1] · Kesheo Prasad[1] · Pabitra Ranjan Maiti[1]**

## Abstract

Understanding rainfall is vital for analyzing river basins as it is an integral part of its hydrological cycle. This paper has focused on examining annual and seasonal precipitation variation from the year 1901 to 2021 along with maximum and minimum temperatures from the year 1951 to 2021 within the Damodar River Basin. Serial dependence is determined initially by calculating lag-1 autocorrelation coefficient on the time series dataset before removing impacts of serial correlation by applying pre-whiteness processing ahead of conducting Mann–Kendall tests. The non-parametric Mann–Kendall test alongside Sen's slope estimator have helped ascertain extreme precipitation and temperature presence and size magnitudes while Sequential Mann–Kendall (SQMK) tests have aided us in detecting sudden change within these trends. The average annual maximum and minimum temperatures have exhibited declining and increasing trends, according to a careful review of the data, the maximum and minimum temperature during the monsoon have shown an increasing tendency. The annual and monsoon rainfall are both trending downward by – 0.582 mm/year and – 0.355 mm/year, respectively. While the annual minimum temperature showed an increasing trend (0.0028 °C), the annual maximum temperature for the observed time showed a low warming or falling trend of (– 0.0019 °C). At a 5% level of significance, the annual minimum temperature result was found to be statistically significant, but the annual maximum temperature trend result was not. The SQMK approach demonstrates periodic trend fluctuation, which is particularly apparent during the pre-monsoon and monsoon season. This investigation makes use of a thorough examination of the shifting trends in rainfall patterns seen in hydro-meteorological data collected within the Damodar River Basin. The results of this study have a great deal of promise for use in managing water resources and promoting sustainable agriculture in the basin's environs.

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**Graphical Abstract**
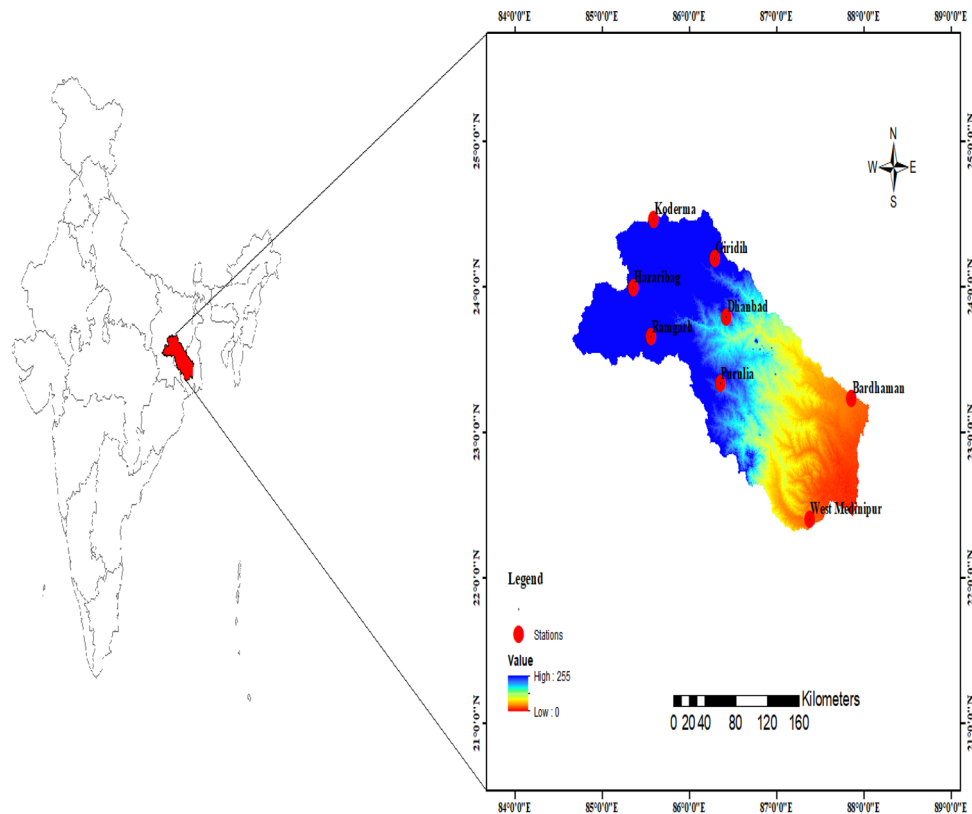


**Keywords** Non-parametric analysis · Trend. Sequential Mann–Kendall · Climatic variables · Pre-whitening

## Introduction

A long-term shift in climatic variables and weather patterns is termed Climate Change. Due to anthropogenic activities, there are drastic shifts in the earth's climate. According to the Intergovernmental Panel on Climate Change (IPCC 2013), anthropogenic activities are the predominant factors causing a rise in average temperature by 0.89 °C from 1901 to 2012. Also, the sea surface temperature (SST) continuously rises at an average rate of 1.4 °F per decade. It has adversely affected the increasing trend. So, the problem of food and water scarcity faced by those nations will be more pronounced in the future. The region of Asia–Pacific has already been substantially affected by the precipitation and temperature pattern.

Furthermore, to assess the impacts of climate change, trend analysis of hydro-meteorological data layout important information (Subash et al. 2011; Chen and Georgakakos 2014; Darand et al. 2015; Kishore et al. 2016; Sharma and Saha 2017; Umar et al. 2022). The effect of climate change brings significant hydrological changes, like increasing and decreasing trends of rainfall and temperature. The

above-stated changes can harm the friable environment of Damodar basin and its surroundings and can cause damage to Jharkhand's and West Bengal's economies by affecting the horticulture and tourism sectors.

Analysis of precipitation and temperature from the last decades at different Spatio-temporal scales is one of the significant issues (Mariam et al. 2021). Research puts an essential role in solving problems like uncertainties in data (Singh and Sontakke 1999). Several studies have been carried out throughout the world to detect a trend in hydro-meteorological datasets (Yin et al. 2010; Kumar and Jain 2011; Wang et al. 2013; Suryavanshi et al. 2014; Sushant et al. 2015; Gajbhiye et al. 2016; Nikzad Tehrani et al. 2019; Ekwueme and Agunwamba 2021; Gupta et al. 2021; Mahato et al. 2021; Zakwan and Ahmad 2021). The previous studies provide a sustainable solution to the various problems related to agriculture and irrigation and are also beneficial for managing the river basin (Watson 2004).

In a recent study, the variability of climatic parameters over the Damodar River basin, in India, has been analyzed by a non-parametric test for detecting trends in the time series is Mann–Kendall test (Mann 1945; Kendall 1975).

However, very few studies have been done on the Damodar basin, followed by the statistical analysis of rainfall and temperature trends. Although at the regional level in India, several studies have been conducted and found that significant decrease in precipitation and temperature trend over Madhya Pradesh (Duhan and Pandey 2013; Kundu et al. 2015); Chattisgarh (Meshram et al. 2017) Gomti River Basin (Abeysingha et al. 2014). At the same time, there is an insignificant decreasing trend of rainfall detected in the Cauvery River basin (Sushant et al. 2015) and a significant decreasing trend seen in annual and monsoon throughout the Damodar River basin (Sharma and Saha 2017).

In light of the above-mentioned studies, the present study identified long-term hydroclimatic changes by applying the MK test, Sen's slope method, and the sequential Mann–Kendall test. The current work has selected eight major stations to analyze hydro-climatic variables in the Damodar River Basin. Moreover, the research on the Damodar basin has gained impetus due to minimal research accompanying the trend analysis. Any changes in the hydroclimatic data may cause floods (Ghosh and Mistri 2015) studied hydrodynamic modeling to identify flood vulnerability zones in the lower Damodar river basin. This research will provide valuable information in predicting future trend pattern and helps out to put effective management of water resources under the influence of Climate Change.

## Materials and methods

### Description of the study area

The study area selected for this research work is Damodar River Basin (DRB) lies in the states of Jharkhand and West Bengal and is also called "*Sorrow of Bengal*". It rises in the southeast corner of the hills of the Chottanagpur Plateau of Palamau district of Jharkhand at an elevation of 1366 m. It joins the Hugli River 48 km south of Kolkata with a length of 575 km and it covers a drainage area of 41,965.49 sq km. The present study considers eight major regions: Dhanbad, Bardhamna, Koderma, Hazaribag, Ramgarh, Purulia, Giridih, and West Medinipur, respectively. The study area is located in central north-east, India (Fig. 1). The latitude and longitude of Damodar River Basin lie between 21 44' to 24 25'N and 84 35' to 88 20'E of the country. Usri, Barakar, and the Kasai are the major tributaries of the Damodar River, while Barakar, Konar, Jamunia, and Nunia are the left tributaries, and Sali is the right tributaries (West Bengal).

### Dataset

Rainfall data on a daily basis for 121 years from (1901–2021) and temperature maxima-minima for 71 years

from (1951–2021) of eight weather stations of the Damodar River basin were obtained from the India Meteorological Department (IMD) Pune, website (http://www.imdpune.gov.in) to examine spatial and temporal variability in the rainfall data series. IMD is a centrally funded agency responsible for collecting meteorological observation data, weather prediction, and seismology. The data from eight weather stations were used in the study shown in Fig. 1 and converted the time series dataset into annual and seasonal for all stations, and the trend analysis of precipitation and temperature was considered for the following climatic variables. Interpolation techniques (Inverse Distance Weighting) were employed for a few weather stations whose data were found missing. Four climatological seasons 1. Pre-monsoon (summer) season (March–May), 2. Monsoon (rainy) season (June–September), 3. Post-monsoon season (October–November), and winter season (December–February) are considered for statistical analysis.

## Methodology

The step-wise procedure adopted to ascertain the long-term temporal and spatial variability in climatic variables is included in Fig. 2. For the analysis of rainfall and temperature trend pattern was carried out for all stations in the basin, a non-parametric test has been performed as it is distribution-free and also used for non-normal variables. In contrast, some assumptions followed in the parametric test about the parameters of the data distribution. Lag-1 autocorrelation is implemented to check the serial correlation before applying the MK test. The pre-whitening process has removed positive serial correlation from time-series data prior to the trend test. To manifest the fluctuations in the analysis of trends, the SQMK test was conducted. Sen's slope estimator has been used to calculate the magnitude of the trend and the MK test was used when the autocorrelation in data was found insignificant. R software (version 10.8) was applied to determine the significant results at a 95% confidence interval. Statistical methods of the following sections are discussed below in detail. The detailed description and mathematical insights for the above methodologies have been elaborated further.

### Autocorrelation

The relationships present in the time series data has been checked by Lag-1 autocorrelation (Anderson 1942). These phenomena are called serial correlation or lagged correlation. The coefficient of lag-1 autocorrelation is simply correlation coefficient of the first observations $N$–1, $X_k$, $k = 1, 2, 3 \ldots, N - 1$ and the next observations, $X_{k+1}$, $k = 2, 3, \ldots, N$. The correlation between $X_k$ and $X_{k+1}$ is given by
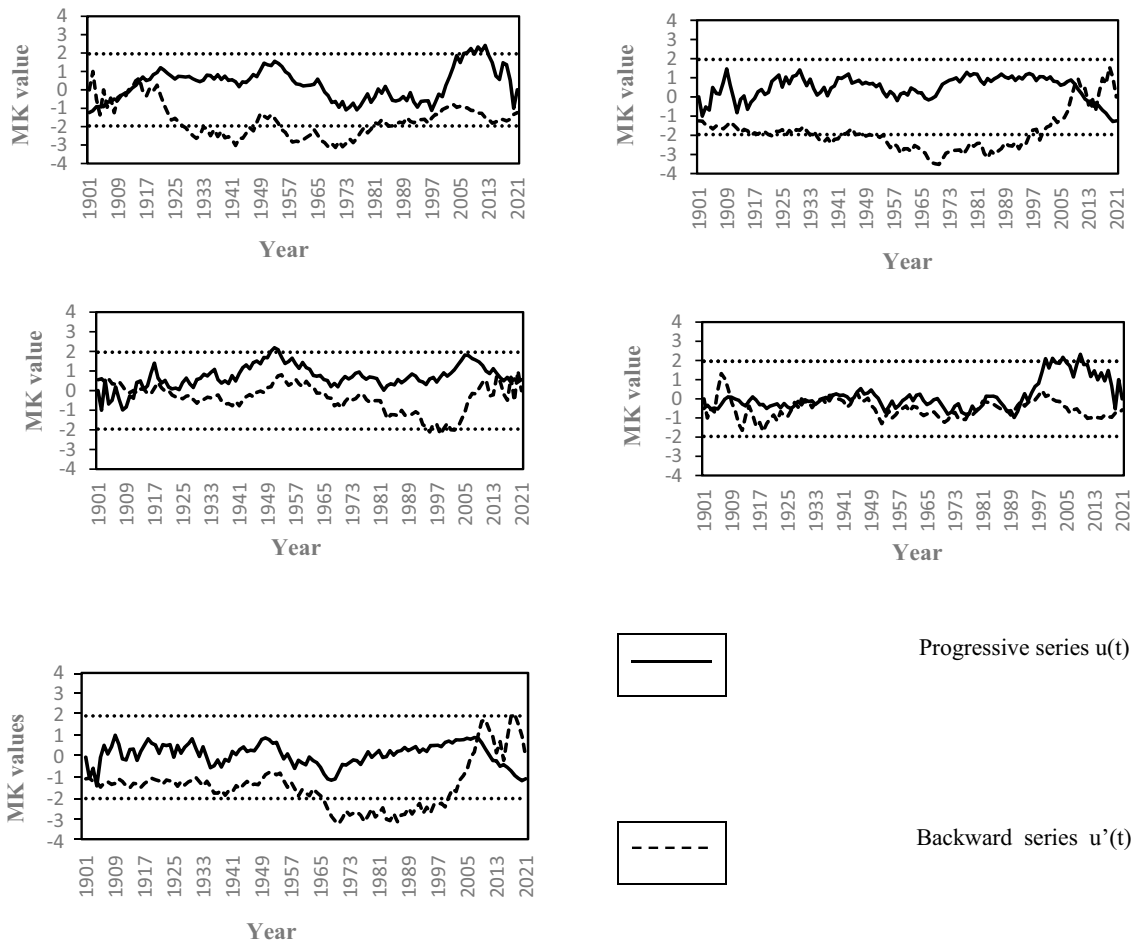
**Fig. 1** Study area map showing the location of stations in Damodar River Basin. **a** Pre-Monsoon. **b** Monsoon

$$r_1 = \sum_{k=1}^{N-1} (X_k - X)(X_{k+1} - X) \div \sum_{k+1}^{N} (X_k - X), \quad (1)$$

where $X = \sum_{k=1}^{N} X_k$ is the overall mean.

The lag-1 autocorrelation coefficient $r_1$ is tested for its significance. The probability limits on the correlogram of an independent series of the two-tailed test are given below.

$$r_1 = \frac{\sqrt{N-k-1}}{N-k}, \quad (2)$$

where $N$ is the sample size and k is the lag.

The data are assumed to be serially independent if the value of $r_1$ lies inside the confidence interval, and if $r_1$ lies outside the confidence interval means the presence of serial correlation in the data series. However, the present study carried out to check serially correlated data up to lag-3 were estimated.

### Pre-whitening test

Before applying the MK test, the pre-whitening procedure was applied to remove the effect of serial correlation present in the time series data. This method was proposed by Kulkarni and Storch (1995). If the existence of serial correlation found in the time series dataset, it rejects the null hypothesis of no trend, it should be accepted. Pre-whitening with the MK test (Yue et al. 2002) was implemented to detect a significant trend with sufficient serial correlation in the present study. Suryavanshi et al. (2014) also used the same method. The different steps followed for a pre-whitening procedure.

**Step 1.** Methodology proposed by Theil (1950) and Sen (1968), estimated from sample data to find the slope ($\beta$) of the trend. By dividing each values of the original sample data ($X_t$) with the sample mean $E(X_t)$ to make it unitized for conducting the analysis of the trend (Yue et al. 2002). Following this approach, the mean of each dataset becomes one and the property remains unchanged of the original dataset.
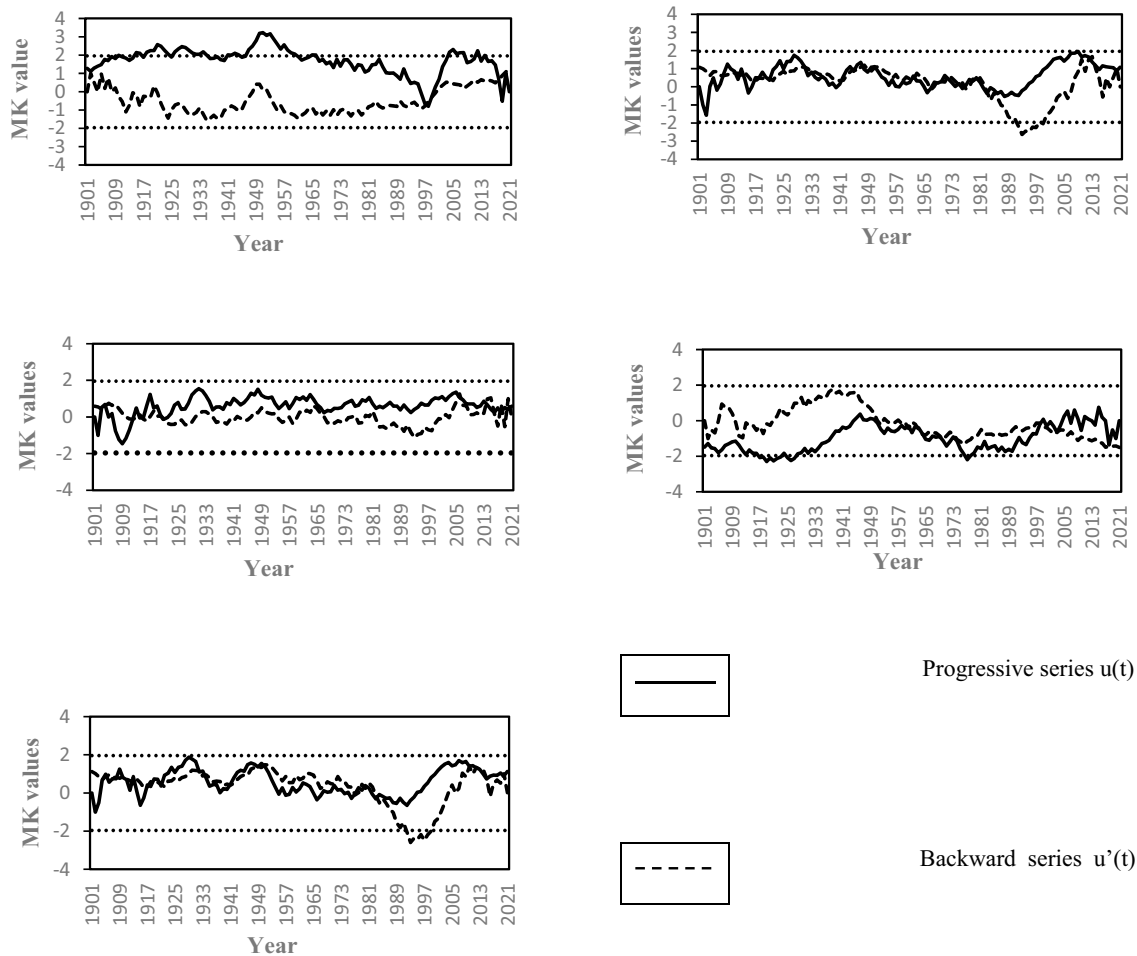
**Fig. 2** Fluctuations in precipitation levels for annual and seasonal data in the Bardhaman region by analyzing both the progressive series $u(t)$ and backward series $u'(t)$

Conducting a trend analysis is not necessary if the slope is almost zero. If the slope is other than zero, it is assumed to be linear and sample data detrended by

$$X_t' = X_t - T_t = X_t - \beta \times t. \tag{3}$$

**Step 2.** The coefficient of serial correlation ($r_1$) of the detrended series were calculated using Eq. (2). The sample data would be considered serially independent if $r_1$ shows significantly differ from zero and the MK test may directly apply in sample data. Otherwise, it is deemed to be serially correlated and can be removed by

$$Y_t' = X_t' - r_1 X_{t-1}'. \tag{4}$$

The pre-whitening procedure after de-trending the series is termed trend-free pre-whitening (TFPW) and an MK test is applied to assess the significance of the trend.

## Mann–Kendall trend test

The Mann–Kendall trend test is a non-parametric method introduced by Mann (1945), and Kendall (1975) used to analyze precipitation trends in the present study. It is frequently used to detect a significant trend in hydrologic data series (Liang et al. 2010; Diop et al. 2018; Wu et al. 2018; Zakwan and Ara 2019; Al-Hasani 2021) However, the non-parametric method is less sensitive to outliers, does not depend on data distribution, and has the advantage of being robust. (Chevuturi et al. 2018). The null hypothesis $H_o$ means no significant trend in the time series dataset, while $H_a$ alternative hypothesis means the presence of a trend in the data series in the MK test. The rejection of the null hypothesis of a substantial trend in the data series is defined by Eq. 4 to compute the Mann–Kendall Statistics ($S$)

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i), \tag{5}$$

where $n$ is the length of the dataset, $X_i$ is ranked from $i = 1$, 2, 3…$n-1$, and $X_j$ ranked from $j = i + 1$, 2.

$$sgn(\varphi) = \begin{cases} 1 \ldots if\, \varphi > 0 \\ 0 \ldots if\, \varphi = 0 \\ -1 \ldots if\, \varphi < 0 \end{cases}. \tag{6}$$

The direction of the trend is indicated by S value. A negative value indicates a decreasing trend, while a positive value shows an increasing trend. For the sample size $n \geq 8$, the test statistic S is normally distributed with mean zero and its variance as follows:

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+1) - \sum_{t=1}^{m} t_k(t_k - 1)(2t_k + 5)\right], \tag{7}$$

where $m$ is the number of tied groups and $t_k$ is the size of $i$th group. The given formula can calculate the standardized MK test statistics ($Zmk$):

$$\begin{cases} S - \frac{1}{\sqrt{Var(S)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ S + \frac{1}{\sqrt{Var(S)}} \text{ if } S < 0 \end{cases} \tag{8}$$

The positive value of $Zmk$ indicates an upward trend, while the negative value signifies a decreasing trend. The value of $Z\frac{\alpha}{2}$ is less than $Zmk$, it is considered a significant trend, where $\alpha$ indicates the level of significance and the null hypothesis is rejected.

### Sen's slope estimator test

Sen's slope ($\beta$) method is a non-parametric method known as Sen's estimator (Sen 1968) used to determine the magnitude of a linear trend of the data set developed (Theil 1950) and (Sen 1968). The slopes ($S_i$) for all data pairs are first calculated by

$$Si = \frac{Xj - Xk}{j - k} \text{ for all } i = 1, 2, 3 \ldots N \tag{9}$$

where $X_j$ and $X_k$ are data values at times $j$ and $k$ ($j > k$). The median of $N$ values of $Si$ is known as Sen's estimator of slope and can be calculated as:

$$\beta = S_{N+1/2} \text{ if } N \text{ is odd} \tag{10}$$

$$\beta = \frac{1}{2}\left(S_{n/2} + S_{n+2/2}\right) \text{ if } N \text{ is even} \tag{11}$$

A positive value of $\beta$ indicates an upward trend and a negative value of $\beta$ shows a downward trend in the time series.

### Sequential Mann–Kendall test

MK test was used to identify trends and does not give the overall view of a trend at any closing time period (trend structure) of the whole time series. SQMK test was applied in the time series to check the fluctuation in the trend. The sequential series $u(t)$ and backward series $u'(t)$ are obtained from Sequential Mann–Kendall Rank Statistics (SMKRS) was used to determine the changing pattern of trend along with time (Partal and Kahya 2006). The sequential series $u(t)$ is similar to the $Z_{MK}$ value and fluctuations shown in sequential series with respect to the zero level. Trends have been observed as statistically significant when the two series cross each other and surpasses beyond a specified threshold value. (Tabari et al. 2011). Consistently, the trend is not always positive and negative, so SQMK graphs (Makokha and Shisanya 2010) can detect a more significant trend. The sequential version of MK statistic on time series $x_i$ detects change points in long-term time series. The sequential Mann–Kendall test is computed using ranked values, $y_i$ of the original in the analysis ($X_1$, $X_2$, $X_3$,…,$X_n$). The magnitudes of $y_i$ ($i = 1, 2, 3, \ldots, n$) are compared with $y_j$, ($j = 1, 2, 3, \ldots, i-1$). The cases where $y_i > y_j$ are countable for each comparison and indicated as $n_i$. A statistic $t_i$ can be defined as:

$$t_i = \sum_{1}^{i} n_i. \tag{12}$$

The mean and variance of the test statistic is estimated by:

$$E(t) = i(i-1)/4$$
$$Var(t_i) = [i(i-1)(2i+5)]/72 \tag{13}$$

The sequential value u(t) can be determined by:

$$u(t) = t_i - E(t)/\sqrt{var(t_i)}. \tag{14}$$

The same procedure was applied for data series from the end to determine $u'(t)$ (backward series).

### Proportionate change/Relative change

The equation of proportionate change (PC) was used for the calculation of different climatic parameters as follows: ShiftehSome'e et al. (2012)

$$PC = \frac{n \times \beta}{|y|} \times 100, \tag{15}$$

where $n$ is the length of the time period, $\beta$ is the median of the slope of time series data and $y$ is the absolute average value of the time series.

## Results and discussions

Statistical analysis of trends of several climatic variables (rainfall, temperature maxima- minima) over DRB was analyzed in different time scales to (annually and seasonally) to recognize the hydrological features of the basin. First, in this case, the station exhibits significant persistence, then the effect of serial correlation is eliminated by pre-whitening of the time series dataset before trend analysis at a significance level of 5%.

### Temporal variability in rainfall

Time series data of rainfall for the period (1901–2021) were analyzed seasonally and annually for eight weather stations located in DRB such as Bardhaman, Dhanbad, Giridih, Hazaribag, koderma, Purulia, Ramgarh and West-Medinipur. The coefficient of serial correlation for lag1($r_1$), ZMK trend value along its significance, the median of slope ($\beta$), intersection point and proportionate change has been carried out for rainfall which is presented in Table 1. Before applying the MK test, we have checked the serial correlation and it revealed that no significant serial correlation was observed across the stations in pre-monsoon but showed a little value of persistence with a noteworthy downward trend. In the case of monsoon season shows a positive correlation coefficient with a decreasing trend. No significant persistence with an increasing trend was observed whole basin during post-monsoon whereas no significant persistence with a significant decreasing trend during the winter season was perceived by study stations. Median of slope or magnitude of the trend is calculated by Sen's slope estimator annually and seasonally as represented in Table 1. The decreasing trends in monsoon precipitation ranged between 0.527 mm/year for Bardhaman station and 0.81 mm/year in Giridih, 0.26 mm/year in Hazaribag, 1.36 mm/year for the station Koderma, 0.85 mm/year for Ramgarh station, while the increasing trends were observed 0.75 mm/year for the station of Dhanbad, 0.01 mm/year in Purulia and 0.21 mm/year at West-Medinipur station. This shows that an overall declining trend of rainfall (– 0.35) mm/year was observed in monsoon season and 0.58 mm/year declined annually. The SQMK statistics are used for determining the approximate year of the starting of a significant trend. The graphical representations of SQMK sequential series $u(t)$/progressive series and backward series $u'(t)$ presented in Figs. 3 and 4. It is derived from a forward analysis illustrated by a solid line and a backward analysis demonstrated by a dashed line

of MK rank correlation and the confidence interval at a 5% significant level of sequential MK represented by a horizontal dashed line as shown in Figs. 3 and 4. If they cross each other and diverge beyond their specific threshold value, then there is a statistically significant trend. For example, the two graphs of stations Bardhaman and Dhanbad from the study region are plotted in Figs. 3 and 4, respectively. From Figs. 3 and 4, It can be concluded that several times forward series and backward series crosses each other in all the seasons, however, two significant turning point were identified in the year 1902 in monsoon and 2005, 1969 annually for station Bardhaman. Although in case of pre-monsoon and post-monsoon exhibited significant turning points in the year 1917 and 1935. No significant turning points were identified in winter and post-monsoon season but in the monsoon season 1987 is the year of approximate trend occurs. Annually two significant turning points were found in 1921 and 1987, while in pre-monsoon significant turning points occurred in the year 1905.

The results of the trend analysis showed a decline in nature and episodic fluctuations of rainfall trend in most of the cases. The declining trend of rainfall is in agreement with other studies that also found rainfall in decrement in annual as well as monsoon rainfall over the Damodar basin (Sharma and Saha 2017), Sindh river basin (Gajbhiye et al. 2016), and Madhya Pradesh (Kundu et al. 2015) which exist in different parts of India.

Percentage change was also calculated for all seasons. For annual precipitation, all weather stations exhibit negative percent change except Dhanbad and Purulia which showed positive change in percentage. The maximum negative percent change was found at Koderma (– 10.90) while the minimum was at West-Medinipur (– 0.45). For monsoon season maximum negative percent change occurred at Ramgarh (– 10.54) and minimum (– 0.23) at station Purulia.The cause of variability in rainfall pattern may be due to several factors such as North Atlantic Sea Surface Temperature (SST), Equatorial SE Indian Ocean SST, East Asian mean sea-level pressure. As per Singh and Oh (2007) and Roxy and Tanimoto (2007), the regional warming of SST over the Indian Ocean is likely to impact the Indian monsoon circulations and thereby reduce the precipitation over northeast India covering the state of Jharkhand and West Bengal in which DRB flows through. The declining nature of trends of precipitation during the monsoon season which directly affects the water requirement of Industrial zone and agricultural purposes also.

### Temporal variability in maximum temperature

Maximum temperature was analyzed seasonally and annually for the period of 71 years (1951–2021) in all study stations such as Bardhaman, Dhanbad, Giridih, Hazaribag,

**Table 1** Analysis of statistical parameter for rainfall for selected station

| Seasons | Pre-monsoon | Monsoon | Post-monsoon | Winter | Annual |
|---|---|---|---|---|---|
| Bardhaman | | | | | |
| $r_1$ | 0.032 | − 0.010 | 0.042 | 0.100 | 0.003 |
| ZMK | − 1.933 | − 0.81 | 0.105 | − 0.11 | − 1.21 |
| $\beta$-value | − 0.331 | − 0.52 | 0.018 | − 0.006 | − 0.87 |
| PC | − 25.26 | − 8.02 | 11.93 | − 17.50 | − 9.05 |
| Intercept | 224.04 | 1090.5 | 112.04 | 45.51 | 1472 |
| Trend | Decreasing | Decreasing | Increasing | Decreasing | Decreasing |
| Dhanbad | | | | | |
| $r_1$ | 0.13 | 0.02 | − 0.05 | − 0.10 | 0.04 |
| ZMK | 1.26 | 1.25 | 1.005 | − 1.44 | 1.427 |
| $\beta$-value | 0.191 | 0.75 | 0.18 | − 0.093 | 0.964 |
| PC | 21.17 | 11.05 | 26.048 | − 54.97 | 11.20 |
| Intercept | 94.99 | 1003.2 | 90.46 | 47.19 | 1235.8 |
| Trend | Increasing | Increasing | Increasing | Decreasing | Increasing |
| Giridih | | | | | |
| $r_1$ | 0.060 | 0.044 | 0.022 | 0.0255 | 0.0802 |
| ZMK | 0.396 | − 1.25 | 0.224 | − 2.074 | − 1.427 |
| $\beta$-value | 0.058 | − 0.81 | 0.033 | − 0.127 | − 0.930 |
| PC | − 2.209 | − 8.706 | − 2.799 | − 75.627 | − 9.752 |
| Intercept | 86.362 | 1021.9 | 99.05 | 49.25 | 1256.6 |
| Trend | Increasing | Decreasing | Increasing | Decreasing | Decreasing |
| Hazaribag | | | | | |
| $r_1$ | 0.120 | 0.052784 | 0.066298 | 0.01147 | 0.148592 |
| ZMK | − 0.486 | − 0.441 | 0.676 | − 3.185 | − 1.059 |
| $\beta$-value | − 0.065 | − 0.265 | 0.113 | − 0.291 | − 0.667 |
| PC | 5.5593 | − 1.418 | 12.246 | − 78.893 | − 3.9578 |
| Intercept | 78.485 | 1074.2 | 90.757 | 69.458 | 1359.2 |
| Trend | Decreasing | Decreasing | Increasing | Decreasing | Decreasing |
| Koderma | | | | | |
| $r_1$ | 0.193 | 0.299 | 0.154 | 0.137 | 0.470 |
| ZMK | − 0.05 | − 2.26 | 0.36 | − 3.069 | − 2.46 |
| $\beta$-value | − 0.008 | − 1.362 | 0.05 | − 0.21 | − 2.25 |
| PC | 20.56 | − 14.62 | 1.305 | − 95.72 | − 10.90 |
| Intercept | 56.79 | 1030.6 | 81.94 | 58.35 | 1836 |
| Trend | Decreasing | Decreasing | Increasing | Decreasing | Decreasing |
| Purulia | | | | | |
| $r_1$ | 0.109 | 0.018 | 0.036 | − 0.057 | − 0.02 |
| ZMK | 1.812 | 0.011 | 0.488 | − 1.194 | 0.262 |
| $\beta$-value | 0.250 | 0.011 | 0.095 | − 0.083 | 0.163 |
| PC | 31.509 | − 0.233 | 9.393 | − 58.00 | 1.489 |
| Intercept | 101.36 | 1072.1 | 100.25 | 56.559 | 1330.3 |
| Trend | Increasing | Increasing | Increasing | Decreasing | Increasing |
| Ramgarh | | | | | |
| $r_1$ | 0.174 | 0.104 | 0.056 | 0.114 | − 0.002 |
| ZMK | 0.221 | − 1.498 | 0.107 | − 3.158 | − 1.633 |
| $\beta$-value | 0.034 | − 0.853 | 0.024 | − 0.238 | − 1.106 |
| PC | 28.61577 | − 10.5437 | 5.0767 | − 92.4118 | − 9.39752 |
| Intercept | 75.587 | 1092.9 | 91.036 | 62.171 | 1321.7 |
| Trend | Increasing | Decreasing | Increasing | Decreasing | Decreasing |
| West-Medinipur | | | | | |
| $r_1$ | 0.100 | − 0.004 | 0.052 | − 0.028 | − 0.025 |

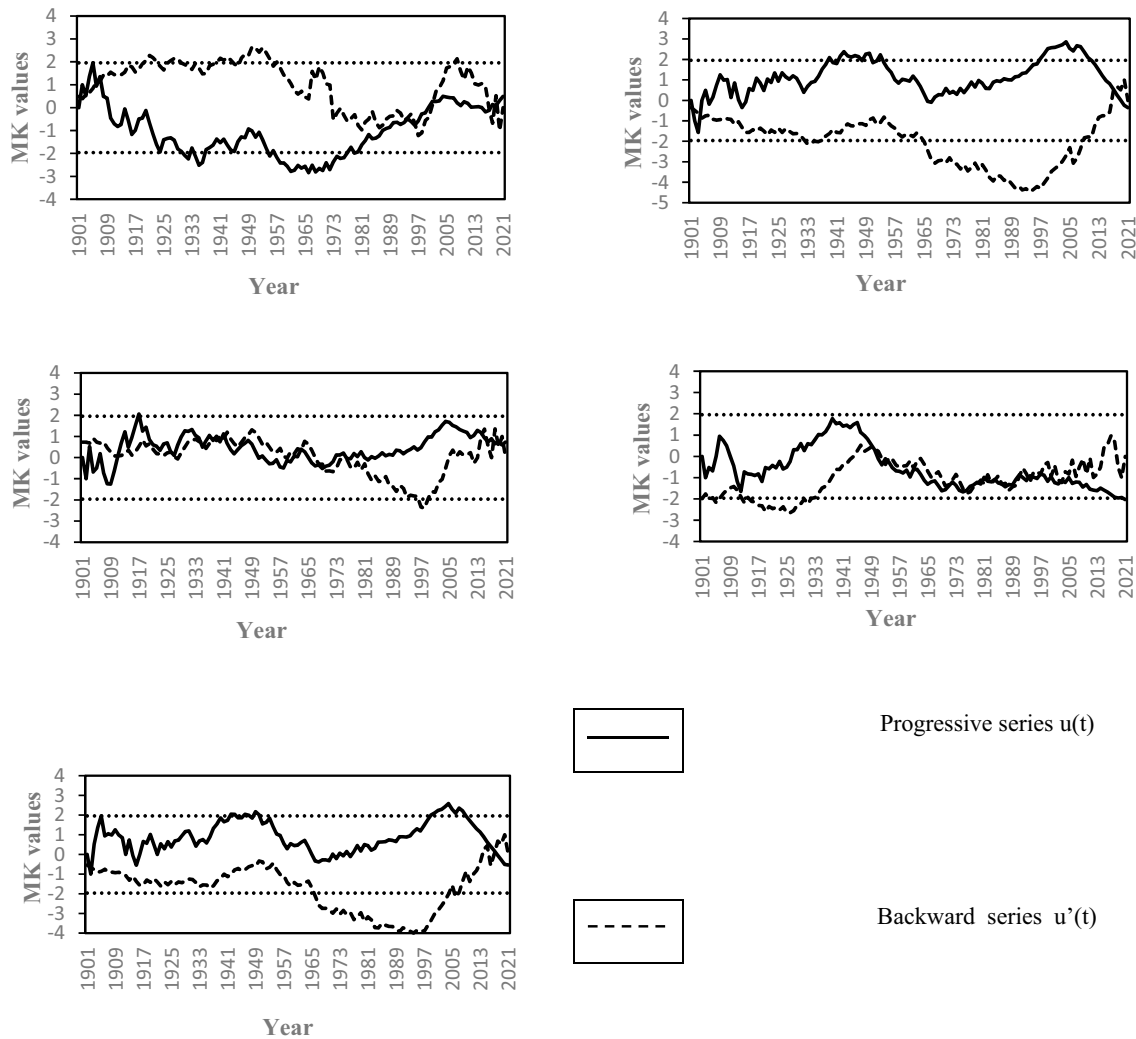| Seasons | Pre-monsoon | Monsoon | Post-monsoon | Winter | Annual |
|---|---|---|---|---|---|
| ZMK | − 1.583 | 0.293 | 0.665 | − 0.804 | 0.042 |
| β-value | − 0.399 | 0.210 | 0.147 | − 0.058 | 0.036 |
| PC | − 22.52 | 1.7533 | 21.401 | − 17.354 | − 0.456 |
| Intercept | 247.13 | 1169.6 | 124.91 | 49.662 | 1591.3 |
| Trend | Decreasing | Increasing | Increasing | Decreasing | Increasing |

**Table 1** (continued)



**Fig. 3** Fluctuations in precipitation levels for annual and seasonal data in the Dhanbad region by analyzing both the progressive series $u(t)$ and backward series $u´(t)$

Koderma, Purulia, Ramgarh and West-Medinipur. The coefficient of serial correlation for lag-1 ($r_1$), the ZMK trend value and its significance, median of slope ($β$), intersection point and proportionate change have been carried out for maximum temperature and are presented in Table 2. The study area has revealed that no persistence with a negative significant trend in pre-monsoon, whereas during monsoon season persistence with a significant trend was observed.

However, a noteworthy persistence with a significant increasing trend was found in post-monsoon and a negative significant decreasing trend in winter. The magnitude of percentage change is maximum in post-monsoon (3.07) and minimum is observed in the monsoon season (2.41), while maximum negative occurred in pre-monsoon (− 4.38) and minimum in the winter season (− 4.28). The graphs of two stations, Bardhaman and Dhanbad from the study region
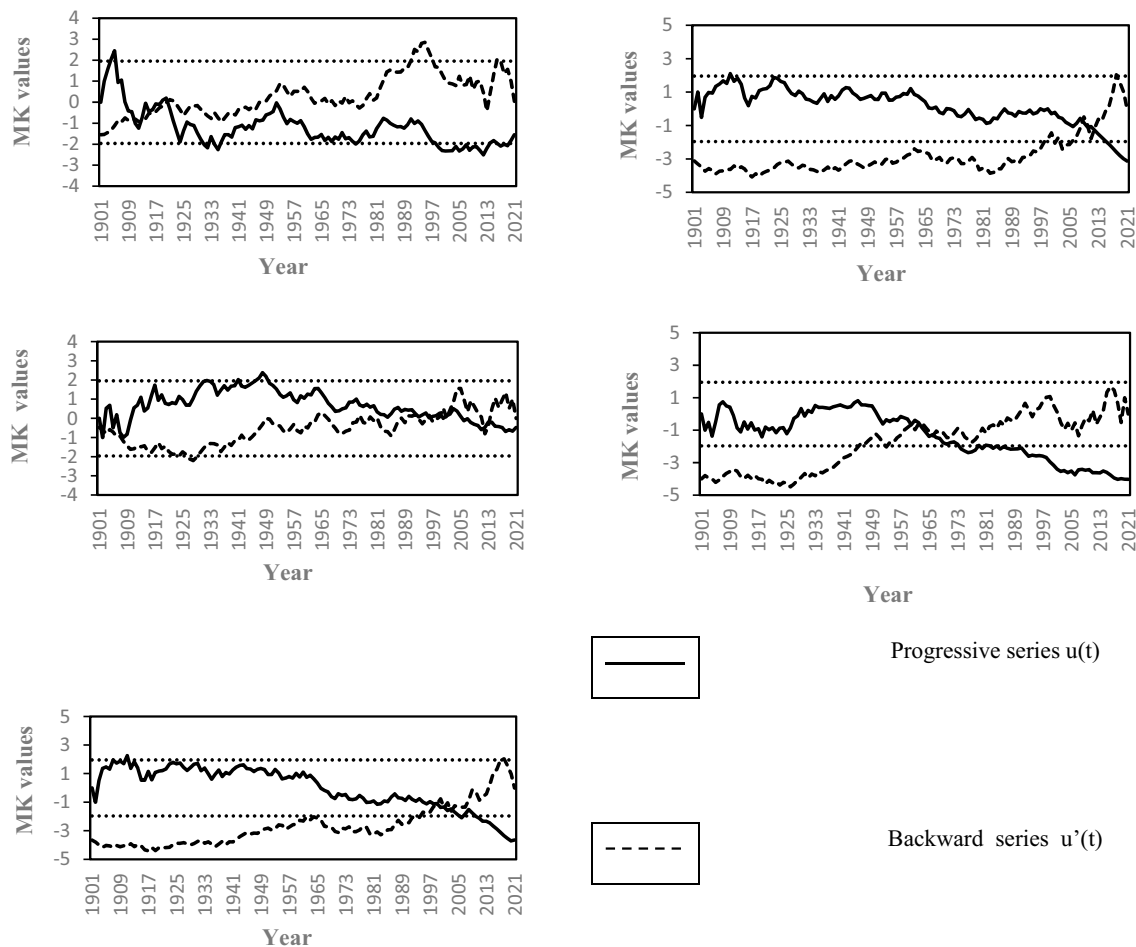
**Fig. 4** Fluctuations in maximum temperature for annual and seasonal data in the Bardhaman region by analyzing both the progressive series $u(t)$ and backward series $u'(t)$

are plotted in Figs. 5 and 6 as example, respectively. The progressive series $u(t)$ and backward series $u'$(t) of SQMK in graphical format are displayed in Figs. 5 and 6 for maximum temperature which have multiple intersection points. When examining the trace corresponding to $u(t)$ and $u'(t)$ found that the turning point/change point occurred in the year 2015 in the monsoon season of Bardhaman station while several turning points traced annually in the year 1954, 1955, 1989, 2015 and 2018 out of which 1989 is the year in which significant turning points exhibited. In the case of Dhanbad station observed that several fluctuations or approximate trend occurred annually in the year 1953, 1957, 1961,1964, 1970, 1972–1977, 2015 and 2019, while in the monsoon season approximate turning point in 2015–2017. The result of trend analysis of maximum temperature is a significant trend with a decrease in nature of magnitude (− 0.40 °C) in pre-monsoon season and (− 0.031 °C) in winter. Monsoon and Post-monsoon show a significant increasing trend with a magnitude of 0.02 C and 0.01C. The maximum annual temperature decreases by − 0.002 °C in the whole basin.

## Temporal variability in minimum temperature

The coefficient of serial correlation for lag-1 ($r_1$), the ZMK trend value with its significance, the median of slope ($\beta$), intersection point and proportionate change was carried out for minimum temperature between 1951 and 2021 presented in Table 3. Pre-monsoon exhibits a substantial persistence and insignificant decreasing trend; however, monsoon, post-monsoon and winter show a positive trend. The magnitude of the trend is maximum in post-monsoon and minimum in pre-monsoon. The proportionate change value for minimum temperature is quite low for all stations. From the study region, the graphs of Bardhaman and Dhanbad are plotted in Fig. 7 as example. The SQMK statistics derived from the progressive series $u(t)$ and backward series $u'$(t) of the MK rank correlation, represented in Fig 7. The results indicated that an increasing trend was observed in all seasons except pre-monsoon which exhibited a decreasing trend. Significant turning point was observed in 2005 in annual while 2016 in monsoon season for Bardhaman station. Several

**Table 2** Analysis of statistical parameter for maximum temperature for selected stations

| Seasons | Pre-monsoon | Monsoon | Post-monsoon | Winter | Annual |
|---|---|---|---|---|---|
| Bardhaman | | | | | |
| $r_1$ | − 0.0176 | 0.0730 | 0.2101 | 0.1181 | 0.086 |
| ZMK | − 3.1668 | 2.0947 | 1.6479 | − 3.851 | − 1.896 |
| $\beta$-value | − 0.0540 | 0.0274 | 0.0139 | − 0.045 | − 0.005 |
| PC | − 5.9323 | 2.5283 | 2.7391 | − 6.589 | − 1.732 |
| Intercept | 111..25 | 132.52 | 61.341 | 82.38 | 32.291 |
| Trend | Decreasing | Increasing | Increasing | Decreasing | Decreasing |
| Dhanbad | | | | | |
| $r_1$ | − 0.058 | 0.034 | 0.2068 | 0.0370 | 0.038 |
| ZMK | − 2.749 | 1.548 | 1.7472 | − 2.7598 | − 1.330 |
| $\beta$-value | − 0.046 | 0.023 | 0.0146 | − 0.0379 | − 0.003 |
| PC | − 5.136 | 2.193 | 2.7575 | − 5.0035 | − 1.3313 |
| Intercept | 111.46 | 130.95 | 60.058 | 80.746 | 31.935 |
| Trend | Decreasing | Increasing | Increasing | Decreasing | Decreasing |
| Giridih | | | | | |
| $r_1$ | − 0.0504 | 0.0675 | 0.1355 | 0.0859 | 0.020 |
| ZMK | − 3.0179 | 2.3031 | 1.5288 | − 3.524 | − 1.45 |
| $\beta$-value | − 0.0539 | 0.0320 | 0.0117 | − 0.0489 | − 0.004 |
| PC | − 5.9526 | 3.1231 | 2.3815 | − 7.1136 | − 1.685 |
| Intercept | 110.47 | 130.88 | 60.034 | 79.552 | 31.745 |
| Trend | Decreasing | Increasing | Increasing | Decreasing | Decreasing |
| Hazaribag | | | | | |
| $r_1$ | − 0.01026 | − 0.1351 | 0.1699 | 0.05551 | 0.1147 |
| ZMK | − 1.9755 | 0.0397 | 2.0649 | − 1.0324 | − 0.6651 |
| $\beta$-value | − 0.0334 | 0.0005 | 0.0174 | − 0.0132 | − 0.0018 |
| PC | − 3.6169 | 0.7323 | 3.5200 | − 1.3845 | − 0.2718 |
| Intercept | 110.47 | 130.88 | 60.034 | 79.552 | 31.745 |
| Trend | Decreasing | Increasing | Increasing | Decreasing | Decreasing |
| Koderma | | | | | |
| $r_1$ | − 0.0138 | 0.0852 | 0.0681 | − 0.008 | 0.097 |
| ZMK | − 1.8564 | 2.5017 | 2.4024 | − 1.647 | 0.079 |
| $\beta$-value | − 0.031 | 0.0371 | 0.0191 | − 0.0242 | 0.0002 |
| PC | − 3.256 | 3.6301 | 3.757 | − 3.484 | 0.2318 |
| Intercept | 109.92 | 130.57 | 58.904 | 76.141 | 31.294 |
| Trend | Decreasing | Increasing | Increasing | Decreasing | Increasing |
| Purulia | | | | | |
| $r_1$ | − 0.058 | 0.034 | 0.2068 | 0.0370 | 0.038 |
| ZMK | − 2.749 | 1.548 | 1.7472 | − 2.7598 | − 1.330 |
| $\beta$-value | − 0.046 | 0.023 | 0.0146 | − 0.0379 | − 0.003 |
| PC | − 5.136 | 2.193 | 2.7575 | − 5.0035 | − 1.3313 |
| Intercept | 111.46 | 130.95 | 60.058 | 80.746 | 31.935 |
| Trend | Decreasing | Increasing | Increasing | Decreasing | Decreasing |
| Ramgarh | | | | | |
| $r_1$ | − 0.010 | − 0.0348 | 0.1699 | 0.0555 | 0.114 |
| ZMK | − 1.975 | 0.73462 | 2.0649 | − 1.0324 | − 0.665 |
| $\beta$-value | − 0.033 | 0.01036 | 0.0174 | − 0.0132 | − 0.001 |
| PC | − 3.616 | 1.49631 | 3.5200 | − 1.3845 | − 0.271 |
| Intercept | 109.89 | 128 | 58.163 | 78.101 | 31.18 |
| Trend | Decreasing | Decreasing | Increasing | Decreasing | Decreasing |
| West-Medinipur | | | | | |
| $r_1$ | − 0.0212 | 0.1776 | 0.1730 | 0.0143 | 0.04709 |

**Table 2** (continued)

| Seasons | Pre-monsoon | Monsoon | Post-monsoon | Winter | Annual |
|---|---|---|---|---|---|
| ZMK | − 1.7025 | 2.6159 | 1.9904 | − 2.5563 | − 0.21344 |
| $\beta$-value | − 0.02392 | 0.034523 | 0.01502 | − 0.03187 | − 0.00059 |
| PC | − 2.43087 | 3.450982 | 3.179336 | − 4.29801 | 0.115102 |
| Intercept | 105.79 | 129.44 | 60.693 | 82.4 | 31.527 |
| Trend | Decreasing | Decreasing | Increasing | Decreasing | Decreasing |
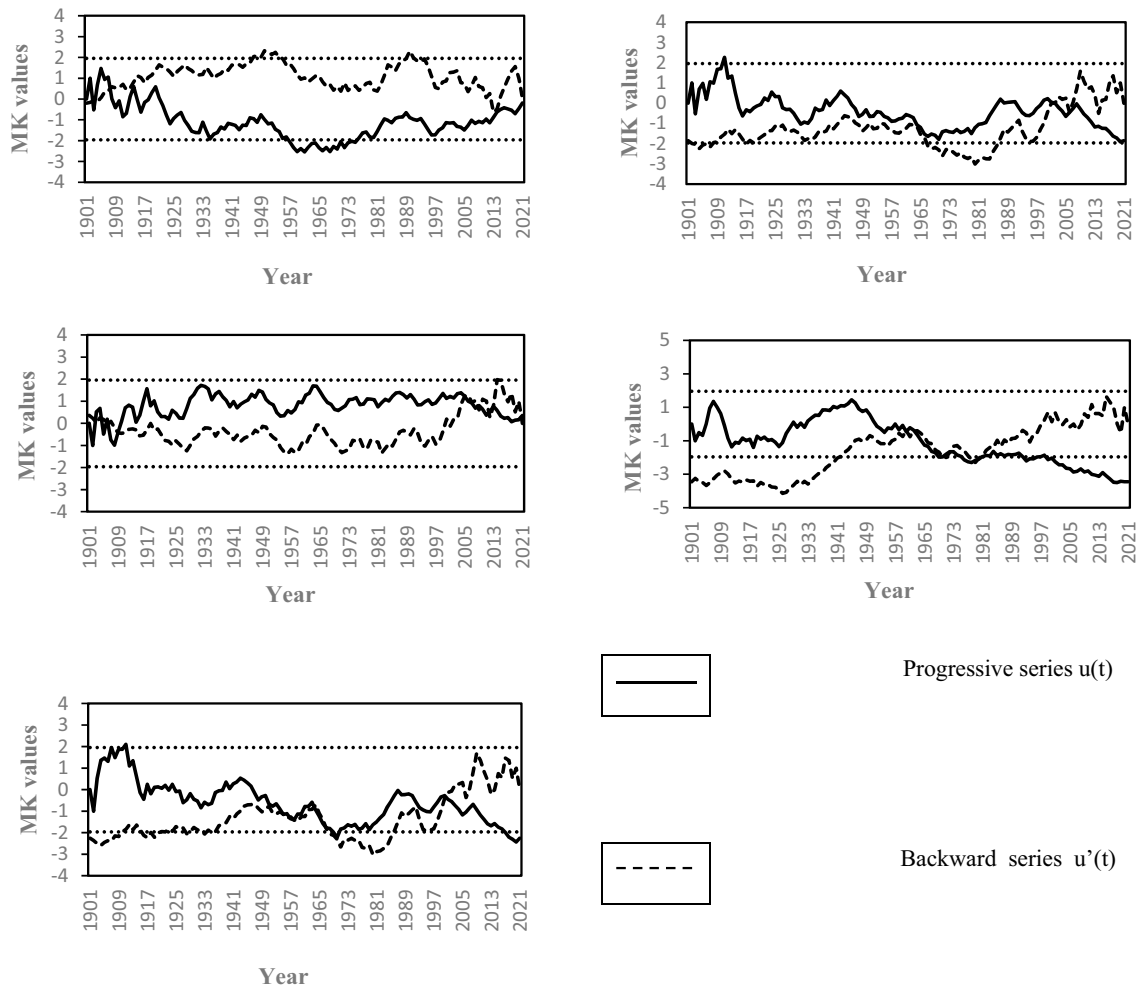


**Fig. 5** Fluctuations in maximum temperature for annual and seasonal data in the Dhanbad region by analyzing both the progressive series $u(t)$ and backward series $u'(t)$

turning points occurred in the year 2002, 2003, 2011 and 2012 for Dhanbad station. Although in monsoon season trend turning points/change point were observed in 2009–10 and 2014–2016. The average minimum temperature shows an increasing trend with a magnitude of 0.002 °C annually while 0.007 °C seasonally. The minimum temperature exhibit in pre-monsoon and maximum in monsoon. Apart from increasing minimum temperature pattern may lead to water scarcity in the basin area and impact rabi crops accordingly.

## Spatial variability of climatic variables

The spatial distribution of the long-term Mann–Kendall value (ZMK) of the annual time series dataset for the period of 121 years of precipitation and 71 years for temperature maxima- minima is illustrated in Fig. 7. The color variations shown in the map for the studied stations is according to the *ZMK* value. The *ZMK* value varies from − 2.4 to 1.4 for precipitation signifies that decreasing trend whereas the temperature increases with the ZMK value − 0.5 to 2.7 in
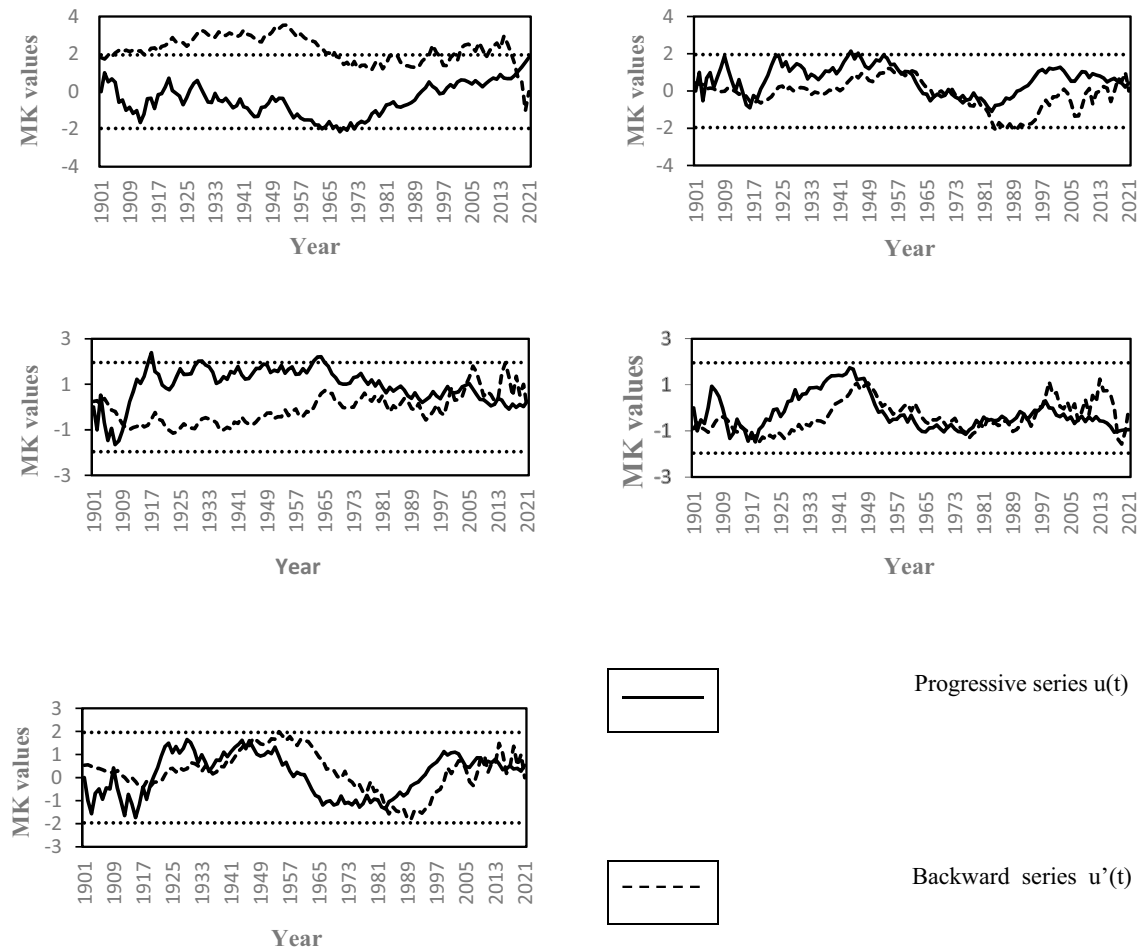
**Fig. 6** Fluctuations in minimum temperature for annual and seasonal data in the Bardhaman region by analyzing both the progressive series *u*(*t*) and backward series *u*′(*t*)

the case of minimum temperature and decreasing in maximum temperature with the *ZMK* value – 1.8 to 0.07. The arrow sign indicates an increasing or decreasing trend as the upward arrow sign demonstrates an increasing trend while downward arrow for decreasing trend. Significant trend is indicated by a diamond symbol which depends upon *ZMK* values. Overall, it can be concluded that a decrease in rainfall has occurred over the entire time period. The color spectrum shows the color from blue (negative ZMK values) to red (positive ZMK values) with intermediate color followed by cyan, green and yellow. The spatial distribution map of rainfall and maximum temperature illustrates decreasing trend, whereas an increasing trend demonstrated in minimum temperature (Fig. 8). The findings of this study of spatial maps of rainfall and temperature will help in accessing the zones severely affected due to rising trend of maximum temperature and decreasing trend of rainfall that help government personal to provide relief instantly. The further increasing trend may severely affect crop production under warmer climate as arid and semi-arid regions could

experience severe water stress due to a due to decline in soil moisture with an increase in high temperature.

## Conclusion

This study has analyzed three predetermined climatic variables, namely rainfall, maximum temperature and minimum temperature in the DRB, India were systematically explored. Eight weather stations were selected for trend analysis based on daily rainfall data (1901–2021), and daily temperature data maxima-minima (1951–2021), respectively. The effect of persistence has been removed prior to the statistical approach for trend analysis. Trend analysis has been done for seasonal and annual time series. Rainfall in this region is a dominating factor for the hydrological features of the basin. Several studies have been carried out in recent decades to investigate rainfall trends in the DRB (Sharma and Saha 2017). Analysis of a trend for an extended period would help to understand the behavior of the trend

**Table 3** Analysis of statistical parameter for minimum temperature for selected station

| Seasons | Pre-monsoon | Monsoon | Post-monsoon | Winter | Annual |
|---|---|---|---|---|---|
| **Bardhaman** | | | | | |
| $r_1$ | 0.167073 | 0.65080 | 0.31683 | 0.292971 | 0.556 |
| ZMK | 0.20847 | 2.7201 | 2.9087 | 1.092 | 2.620 |
| $\beta$-value | 0.00317 | 0.0309 | 0.0266 | 0.012 | 0.006 |
| PC | 0.669972 | 3.51138 | 7.73379 | 3.78664 | 3.4597 |
| Intercept | 66.689 | 98.888 | 38.059 | 37.28 | 20.07 |
| Trend | Increasing | Increasing | Increasing | Increasing | Increasing |
| **Dhanbad** | | | | | |
| $r_1$ | 0.15877 | 0.49968 | 0.2510 | 0.212637 | 0.418 |
| ZMK | − 0.4368 | 2.5712 | 1.9755 | 0.61549 | 1.737 |
| $\beta$-value | − 0.0060 | 0.0256 | 0.0188 | 0.00738 | 0.003 |
| PC | − 0.96457 | 2.55318 | 5.91962 | 1.718769 | 2.0002 |
| Intercept | 66.676 | 98.297 | 36.747 | 36.421 | 19.845 |
| Trend | Decreasing | Increasing | Increasing | Increasing | Increasing |
| **Giridih** | | | | | |
| $r_1$ | 0.35624 | 0.6497 | 0.2691 | 0.355656 | 0.6309 |
| ZMK | − 0.0198 | 1.5983 | 2.1443 | 0.8934 | 1.8167 |
| $\beta$-value | − 0.0004 | 0.0220 | 0.0191 | 0.0115 | 0.0064 |
| PC | − 1.0044 | 1.9091 | 6.1601 | 1.83697 | 1.7505 |
| Intercept | 66.455 | 99.571 | 37.215 | 36.029 | 19.939 |
| Trend | Decreasing | Increasing | Increasing | Increasing | Increasing |
| **Hazaribag** | | | | | |
| $r_1$ | 0.24120 | 0.3876 | 0.14943 | 0.2676 | 0.416143 |
| ZMK | − 1.9557 | 0.0694 | 1.1913 | 0.019 | − 0.3970 |
| $\beta$-value | − 0.0205 | 0.0003 | 0.010 | 0.0002 | − 0.0009 |
| PC | − 3.52752 | − 0.0873 | 3.7343 | − 0.8141 | − 0.56503 |
| Intercept | 65.512 | 96.972 | 34.925 | 34.270 | 19.307 |
| Trend | Decreasing | Increasing | Increasing | Increasing | Decreasing |
| **Koderma** | | | | | |
| $r_1$ | 0.46876 | 0.614656 | 0.26734 | 0.41973 | 0.58368 |
| ZMK | − 1.0424 | − 0.4665 | 0.3772 | − 0.4963 | − 0.5956 |
| $\beta$-value | − 0.0123 | − 0.0051 | 0.0032 | − 0.0048 | − 0.0019 |
| PC | − 2.8638 | − 0.8094 | 0.91932 | − 2.40545 | − 1.38023 |
| Intercept | 63.492 | 89.903 | 35.441 | 43.57 | 19.367 |
| Trend | Decreasing | Decreasing | Increasing | Decreasing | Decreasing |
| **Purulia** | | | | | |
| $r_1$ | 0.158 | 0.499 | 0.251 | 0.212 | 0.418 |
| ZMK | − 0.436 | 2.571 | 1.975 | 0.615 | 1.737 |
| $\beta$-value | − 0.006 | 0.025 | 0.018 | 0.0073 | 0.0035 |
| PC | − 0.96457 | 2.5531 | 5.9196 | 1.7187 | 2.0002 |
| Intercept | 66.676 | 98.297 | 36.747 | 36.421 | 19.845 |
| Trend | Decreasing | Increasing | Increasing | Increasing | Increasing |
| **Ramgarh** | | | | | |
| $r_1$ | 0.241 | 0.387 | 0.149 | 0.267 | 0.416 |
| ZMK | − 1.955 | 0.069 | 1.191 | 0.019 | − 0.397 |
| $\beta$-value | − 0.020 | 0.0003 | 0.0105 | 0.0002 | − 0.000 |
| PC | − 3.5275 | − 0.0873 | 3.7343 | − 0.8141 | − 0.5650 |
| Intercept | 65.512 | 96.972 | 34.925 | 34.27 | 19.307 |
| Trend | Decreasing | Increasing | Increasing | Increasing | Decreasing |
| **West-Medinipur** | | | | | |
| $r_1$ | 0.155041 | 0.60245 | 0.24191 | 0.303786 | 0.523129 |

| Seasons | Pre-monsoon | Monsoon | Post-monsoon | Winter | Annual |
|---|---|---|---|---|---|
| ZMK | 0.42687 | 3.0377 | 2.5414 | 0.62542 | 2.7002 |
| $\beta$-value | 0.00699 | 0.0321 | 0.0239 | 0.00768 | 0.0062 |
| PC | 0.903466 | 3.165236 | 6.705372 | 2.696337 | 3.03988 |
| Intercept | 72.126 | 103.38 | 41.206 | 43.627 | 21.695 |
| Trend | Increasing | Increasing | Increasing | Increasing | Increasing |

**Table 3** (continued)
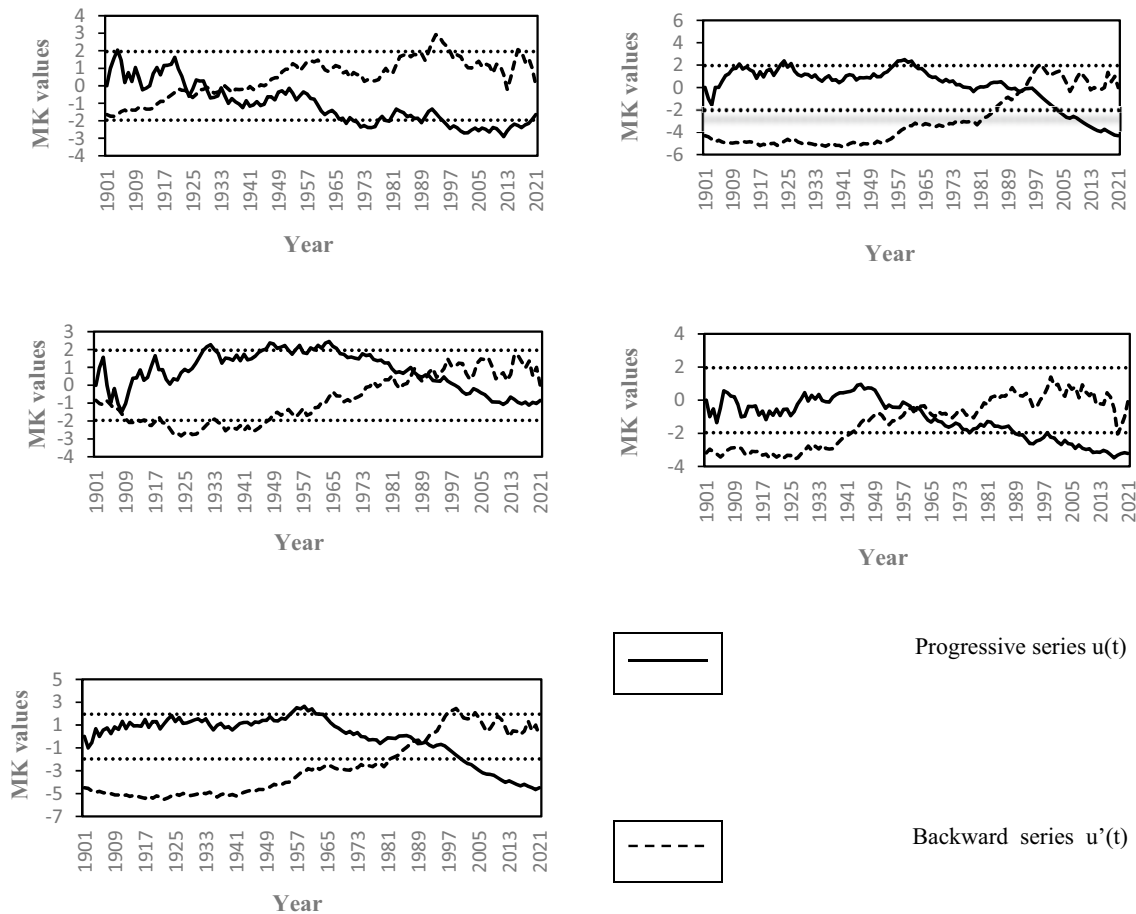


**Fig. 7** Fluctuations in minimum temperature for annual and seasonal data in the Dhanbad region by analyzing both the progressive series $u(t)$ and backward series $u'(t)$

better. It would provide helpful information for planning, developing and managing water in any area or region. The variables of Climate, particularly rainfall and temperature responsible for the hydrological process. A decreasing trend was found over the basin annually, as most of the stations exhibit an insignificant decreasing trend except post-monsoon season. The magnitude of rainfall declined annually ranges from – 2.2 to 0.96 mm/year and – 1.3 to 0.7 mm/year in the monsoon season over the Damodar River basin. A significant decreasing trend was observed in the winter season – 0.13 mm/year, while a decreasing trend in the case of pre-monsoon with a magnitude of – 0.03 mm/year and

an increasing trend of 0.08 mm/year in the post-monsoon season. Although in the case of maximum temperature insignificant decreasing trend was observed annually and a significant increasing trend was detected in the monsoon season. The magnitude of maximum temperature declined annually – 0.002 °C and an increasing trend of magnitude of 0.02 °C/year in the monsoon season, while pre-monsoon and winter also exhibited a decreasing trend of magnitude – 0.04 °C/year and – 0.03 °C/year, but post-monsoon season shows decreasing trend 0.01 °C/year. The increasing trend was perceived in almost all the seasons except pre-monsoon in minimum temperature. A significant trend was seen in
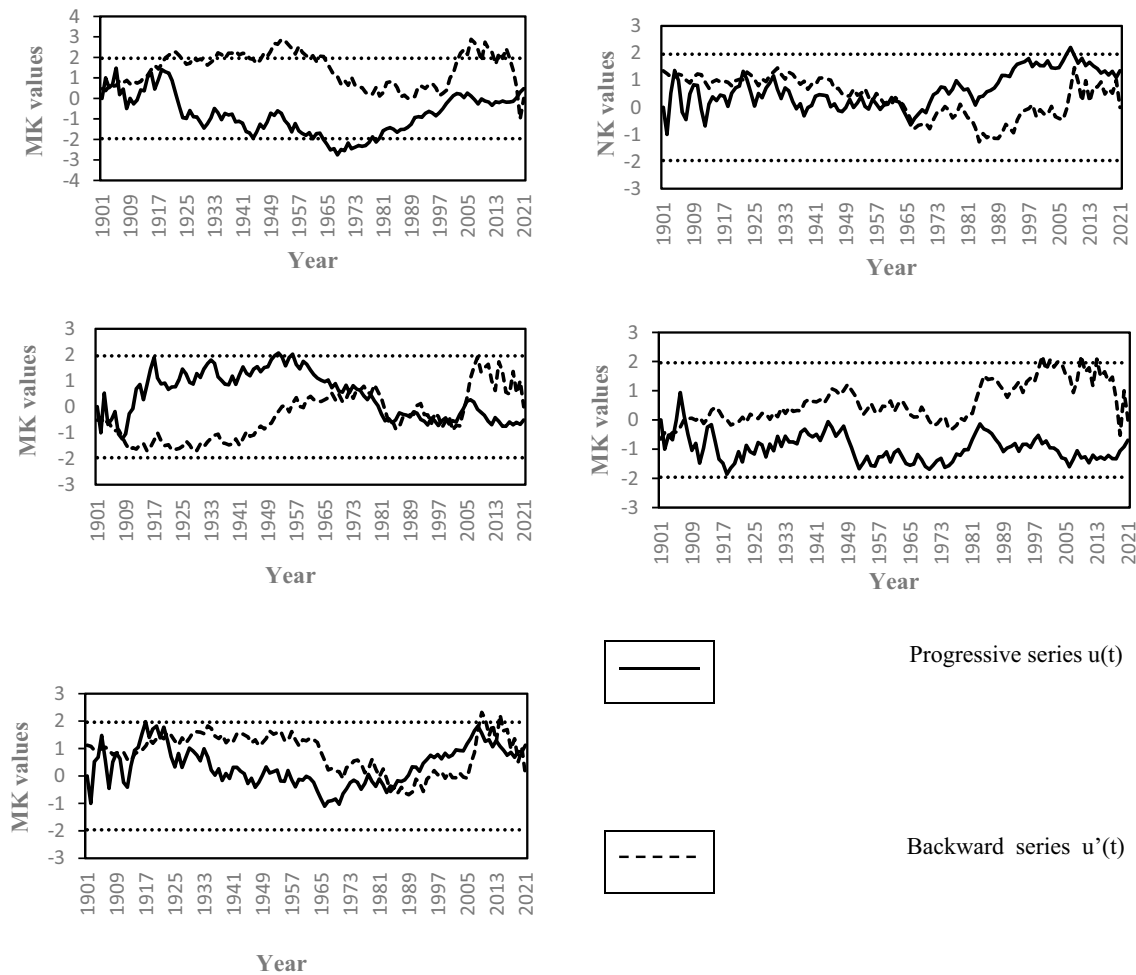
**Fig. 8** Spatial distribution of trend (ZMK values) from 1901 to 2021 for precipitation and 1951–2021 for maximum and minimum temperature of the weather stations for climatic variable **a** precipitation **b** maximum temperature and **c** minimum temperature respectively in Damodar River basin, India

post-monsoon with a magnitude of 0.01 °C/year. The pattern of minimum temperature is increasing in nature in monsoon, post-monsoon, winter and annually. The increasing trend in annually and monsoon season are 0.002 °C/year and 0.01 °C/year, respectively.

The results of the sequential Mann–Kendall test revealed that periodic fluctuations in almost all the stations both monsoon and annual. It also points out the abrupt changes and approximate year of trend beginning. The decrease in rainfall can impact the area of water resources and the agriculture sector. The growth of Kharif crops (May–October) may be affected due to a decreasing trend in seasonal rainfall. Planners need to integrate the basin's changing climate and water resources management. As the basin comes in the area of Jharkhand and West Bengal the state of India, where most people depend on rainfall. Based on research done in this paper,

the future scope includes the land and land cover changes and aerosol trend for determining the probable reasons for decreasing rainfall in the basin area. So, water policymakers and agricultural planners should consider better water techniques.

**Data availability** Data can't be made publicly available; readers should contact the corresponding author.

## Declarations

**Conflict of interest** The authors declare no conflict of interest.

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