

Chapter 2

Spatio-Temporal Changes of Rainfall Pattern Under Changing Climate in West Bengal, India



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Abstract The study of rainfall variability is essential to the environmental researcher as it influences the agricultural-based economy like West Bengal. The primary aim of this research paper is to assess the inconsistent nature of the annual and seasonal rainfall of West Bengal. The 110 years (1901–2010) data of 18 meteorological stations of West Bengal are used in this study. The nonparametric Mann–Kendall (MK), modified Mann–Kendall (mMK), and Sen’s slope estimator (Q) are used to detect the trend and magnitude of the trend. Furthermore, the sub-trends of the data series are estimated using the innovative trend analysis (ITA) method. The percent bias (P_{BIAS}) method is also used to compare the second half with the first half of the data series. The results of the ITA showed Alipore (2.64) and Balurghat ($Q = -2.17$) had a maximum increasing and a decreasing trend in the annual rainfall. On the seasonal, summer (56%) and post-monsoon (100%) seasons are dominated by increasing trends, while decreasing trends dominate monsoon (61%) and winter (56%) seasons. The results of the MK/mMK and P_{BIAS} , more or less similar to the ITA, confirm its reliability for trend detection. The findings of this study can provide a proper way to develop future projects, as it can clarify the reliable information about the rainfall variability throughout the year and can also afford a power of sustain for water resources and agricultural development.

Keywords Rainfall · ITA · MK/mMK · Climate change · Agricultural development

2.1 Introduction

Climate change is an alarming environmental issue in the modern age, responsible for changing the different climatic parameters such as precipitation, temperature,

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humidity, and evapotranspiration (Ahmad et al., 2018; Chen et al., 2017). Such changes have been expanded throughout the world uninterruptedly (Lee & Dang, 2020; Al Mamun et al., 2023). According to the Intergovernmental Panel on Climate Change 2012 (IPCC), climate change is a principal cause of rising extreme weather indices in several parts of the world. Precipitation is one of the essential meteorological variables affected by climate change. The changing precipitation scenario alters numerous crucial sectors of the economy, such as agriculture, irrigation, and transport (Lee & Dang, 2020). It also influences the flood and drought events, generates a considerable difference between the water supply and water requirement, eventually affecting the entire hydrological system at global and local scales (Jain et al., 2013; Wu et al., 2013). However, the spatial and temporal consistency of rainfall widely varies worldwide (Sa'adi et al., 2019), predominantly affecting the spatial distribution of water resources (Dore, 2005; Wu & Qiana, 2017; Alam et al., 2023). India receives about 80% of annual precipitation from the South Asian summer monsoon (Sravani et al., 2021). But the changing nature of the environment is vastly hindering agricultural production and water resources management systems, which is immensely affecting the agricultural-based economy of India (Gosain et al., 2006; Kalra et al., 2008; Lal, 2000; Lee & Dang, 2020; Mukherjee, 2017; Pal et al., 2015; Patle & Libang, 2014). Hence, some essential and accurate information concerning long-term precipitation trends is necessary to get an idea about any region's water resources (Sun et al., 2018).

Numerous studies have been conducted on rainfall variability at regional, national, and global scales using parametric and nonparametric approaches (e.g., Mann–Kendall test, Sen's slope estimator, Spearman's rho, linear regression, etc.) (Pingale et al., 2014). Most of the studies based on MK or mMK test revealed rainfall in India show both positive and negative trends for monthly, seasonally, and annually (Bhutiyani et al., 2010; Gadgil et al., 2007; Joshi & Kumar, 2006; Kumar & Jain, 2011; Mondal et al., 2012; Mandal et al., 2021a, b). The methods used in these studies are generally for trend detection, and it requires some assumptions regarding the data, such as independence from autocorrelation and normality distribution (Singh et al., 2021). To overcome this problem, Şen (2012) has proposed a newly trend analysis technique, i.e., innovative trend analysis (ITA), which many researchers have used successfully in their area of study (Ay & Kisi, 2015; Cui et al., 2017; Kisi & Ay, 2014; Saplıoğlu et al., 2014). This new method can analyze the different time series data by identifying sub-trends from the graphical representation, which is impossible in the MK test (Kisi & Ay, 2014; Wu & Qian, 2017). In addition, the ITA method has universal contextually compared to MK or mMK test (Mandal et al., 2021).

West Bengal is India's most popular agricultural-based state. The livelihood pattern of most of the people of West Bengal relies on an agro-based economy. So, timely occurrences of adequate rainwater are significant for the inhabitants as proper growth of crops entirely depends on rainwater. However, the state's agricultural system is hampered regularly due to its divergence rainfall. The irrigation facility is also directly or indirectly dependent on sufficient rainwater. According to Pal et al. (2015), the entire state experienced varied and inadequate rainfall, which utterly affects agricultural production. Similarly, the tea industry of the Dooars region

is threatened by the massive changes in precipitation and temperature as such industries near the Darjeeling district have been struck by the increased temperature and decreased rainfall in the last 20 years (Mallik & Ghosh, 2021). On the other hand, as it is situated in the adjacent vicinity of the Bay of Bengal, it experiences tremendous low pressure arise from this ocean, creating heavy rainfall and producing extreme floods, especially in the Sundarbans region (Nandargi & Barman, 2018). Therefore, the present study on the long-term variation of precipitation and its trends in West Bengal will be most significant for forecasting climatological disasters (flood and droughts) and water resources management (Ghosh et al., 2009).

The principal aim of the present work is to find out the spatial and temporal variation of rainfall trends (1901–2010) at annual and seasonal scales using MK, mMK, and Sen's slope estimator. Additionally, the ITA method has been used to analyze the rainfall characteristics with its sub-trend of the data series. The ITA has also been used to justify the results of the MK or mMK test. P_{BIAS} identifies the percentage of increasing and decreasing trends of the second half of the entire period concerning the first half. Therefore, the present study exhibited the potentiality of comprehensive statistics to better understand the rainfall distribution patterns over space and time.

2.2 Materials and Methods

2.2.1 Study Area

West Bengal situated between $21^{\circ}31'$ and $27^{\circ}13'14''$ north latitudes and $85^{\circ}45'20''$ and $89^{\circ}53'$ east longitudes having a unique landscape with heterogeneous relief features. The northern part is enclosed with the mountain ranges. In contrast, the western segment is covered with the plateau region, while the broad plain is situated in the central part. On the other hand, the coastal area with a deltaic formation is concentrated in the southern section of West Bengal. The countries of Bangladesh delimit it in the eastern region, Nepal and Bhutan in the north-eastern segment, and the Indian states of Odisha existed in the southward's direction, Jharkhand, Bihar occupied the western section, Sikkim and Assam situated in the northeast corner of the West Bengal (Fig. 2.1). Based on the latitudinal extension, the northern province of West Bengal confines in the temperate belt due to the Tropic of Cancer passing 6 km north of Nabadwip. The southern segment lies in the tropical belt. But this part obtains an ample amount of rainfall as the prevailing marine climate decreased the extreme hot condition. Excluding the mountainous belt of Darjeeling and Jalpaiguri, the whole state experiences a tropical monsoon with warm wet weather. Besides this, the western part of West Bengal, characterized by the plateau region, has practiced significantly less rainfall and temperature variation. On the other hand, marine effects in the coastal area have experienced a moderate and pleasant climate.

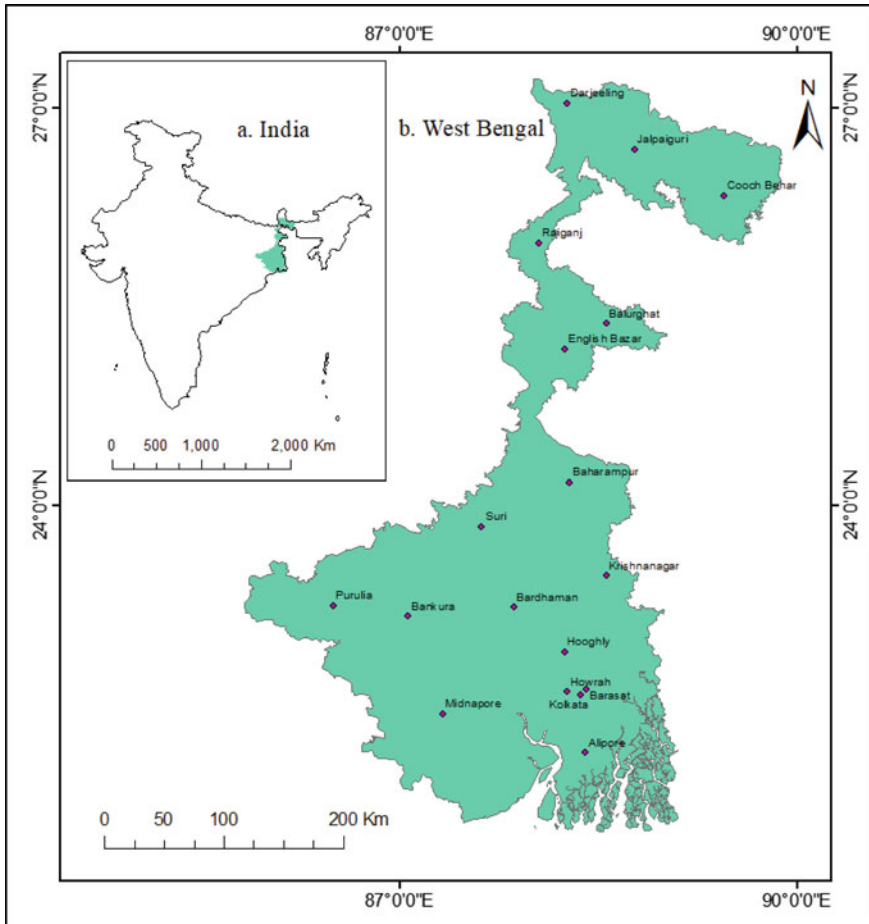


Fig. 2.1 Study area **a** India, **b** West Bengal with rain gauge stations

2.2.2 Data Sources

The present research work applied three popular trend analysis statistics (MK, mMK, and Sen's slope estimator) and the autocorrelation function to identify the inconsistency in the precipitation trends from 1901 to 2010. Moreover, the ITA method was also used to examine the variant precipitation at 18 climatological stations throughout the state and compare its consequences with MK, mMK, and Sen's slope estimator test. On the other hand, the exclusive method of Percent Bias is also used to detect the percentage of the inconsistency of the second half of the entire series in relation to the first half. For the above analysis, the required data of 18 meteorological stations of West Bengal for the year 1901–2010 have been taken from the India-water portal.

2.2.3 Autocorrelation Function

In 1999, Von Storch and Navarra recommended that, at first, the entire series should be pre-whitened to reject the serial relationship from the series. After that, the MK test should be applied. These research works integrate this proposal in both the MK test and Sen's slope estimator test.

The trends of sample data which are probably significant (m_1, m_2, \dots, m_n) are examined with the subsequent measures:

- (1) At first calculate the lag-1 serial correlation coefficient, which is represented by P_1 . The given equation evaluated the lag-1 serial correlation coefficient of sample data of m_i

$$P_1 = \frac{\sum_{i=1}^{N-1} (M_i - \bar{M})(M_{i+1} - \bar{M})}{\sum_{i=1}^N (M - \bar{M})}, \quad (2.1)$$

$$E(m_i) = \frac{1}{n} \sum_{i=1}^n m_i. \quad (2.2)$$

In the above equation, $E(m_i)$ denotes the sample data with the mean value and n represented as the sample size.

- (2) If the result of P_1 is characterized with a non-significant trend at a 5% level; subsequently, the statistical test of MK test and Sen's slope estimator is used.
- (3) If the result of P_1 is characterized with the significant trend, then at first apply the MK and Sen's slope estimator test; afterward, the time series of 'pre-whitened' might be acquired by $(m_2 - p_1 m_1, m_3 - p_1 m_2, \dots, m_n - p_1 m_{n-1})$

The natures of the test have highly influenced the significance level of the critical value of p_1 , whether it may one-tailed test or a two-tailed test. In a one-tailed test, the alternative hypothesis is usually that the true p_1 is more significant than '0'. But in the case of a two-tailed test, the alternative hypothesis is that the true p_1 is different from '0' (zero), with no particular positive or negative result. By the following formula, the limits of the probability of an independent series for p_1 can be presented (Anderson, 1942) as

$$p_1 = \begin{cases} \frac{-1+1.645\sqrt{n-2}}{n-1}, & \text{one tailed test} \\ \frac{-1\pm 1.96\sqrt{n-2}}{n-1}, & \text{two tailed test} \end{cases}, \quad (2.3)$$

where

n denotes the sample size.

The one-tailed test is most appropriate if there are several causes to assume positive autocorrelation—otherwise, the two-tailed examination is considered more suitable.

2.2.4 Method of Innovative Trend Analysis (ITA)

In 2012, Sen offered a newly statistical test of trend analysis, i.e., innovative trend analysis. This method splits an entire series into equal two fragments, independently arranged in rising order. Afterward, the first sub-series (X_i) is sited on the horizontal (X) axis, and the second sub-series (Y_i) is sited on the vertical (Y) axis in a Cartesian coordinate system which is two-dimensional. The actual nature of these two concerns sub-series specifies with no trend. On the other hand, the dots of the scatter plot diagram establish on a 1:1 line (45°). The points positioned on the upward side of the 1:1 line demonstrated that the time series had experienced a rising trend. In contrast, the opposite part of the points placed under the 1:1 line indicates a decreasing order of trend. The different absolute values of y and x positioned at the horizontal and vertical axis represent the distance from the 1:1 line (Şen, 2014). Thus, it can conduct to measure the trend of any time series. And the average disparity indicated the general trend. On the other hand, the average variation must standardize as it compares the trends of two sequences with varying magnitude. In favor of direct comparison, the chief task is to multiply 10 with the indicator to achieve a similar result of the MK test and Sen's slope estimator. Subsequently, the indicator of ITA is expressed as follows:

$$\beta = \frac{1}{n} \sum_{i=1}^n \frac{10(Y_i - X_i)}{\mu}, \quad (2.4)$$

where β symbolizes a trend indicator with the positive value specify a trend of increasing order, and the negative value indicated the trend with decreasing order. On the other hand, the total number of observations of all sub-series expresses by n . X_i and Y_i represent as the mean value of the observed data in the first sub-series and second sub-series. The symbol μ is the average of the first sub-series.

2.2.5 Mann–Kendall (MK) Test

Kendall (1938); Kendall and Gibbons (1975) and Mann (1945) invented the nonparametric statistics of the MK (Mann–Kendall) test. This technique is more suitable and well recognized in identifying the trends pattern in the meteorological and hydrological time series (Chaouche et al., 2010; Cui et al., 2017; Das et al., 2020a, b, c). In this test, H_0 denotes the null hypothesis, representing the independent nature of the data, and haphazardly distributes as it has no significant trend. And H_1 , another hypothesis, has the monotonous trend. The statistical test k is equated

$$k = \sum_{s=1}^{n-1} \sum_{r=s+1}^n \text{sign}(x_r - x_s), \quad (2.5)$$

where n th value denotes the number of total observations, x_s and x_r are the s th and r th ($r > s$) observations in the time series. On the other hand, $\text{sign}(x_r - x_s)$ denotes the sign function explained as follows:

$$\begin{aligned} \text{Sign}(x_r - x_s) &= +1 \text{ if } x_r - x_s > 0 \\ &= 0 \text{ if } x_r - x_s = 0 \\ &= -1 \text{ if } x_r - x_s < 0 \end{aligned} \quad (2.6)$$

When the n th value is higher than ten (10), then the distribution of k has experienced an average trend (Kendall & Gibbons, 1975). The formula of $\text{VAR}(S)$, i.e., the variance of S , is

$$\text{VAR}(S) = \frac{1}{18} \left\{ N(N-1)(2N+5) - \sum_{l=1}^g G_l(G_l-1)(2G_l+5) \right\}. \quad (2.7)$$

The above equation N denotes the number of groups of tied, G_l means as some ties of extent l . The statistic K as the standard regular test applies for perceived a significant trend which is represented as

$$\tau = \frac{K}{D}, \quad (2.8)$$

where

$$D = \sqrt{\frac{1}{2}N(N-1) - \frac{1}{2} \sum_{l=1}^g G_l(G_l-1)} \sqrt{\frac{1}{2}N(N-1)}. \quad (2.9)$$

The assessment of (K) and $\text{VAR}(S)$ applies to computed the suitable measurement of Z is implemented when $n > 10$ (Gilbert, 1987)

$$Z = \begin{cases} \frac{K-1}{\sqrt{\text{VAR}(S)}}, & \text{if } K > 0 \\ 0, & \text{if } K = 0 \\ \frac{K+1}{\sqrt{\text{VAR}(S)}}, & \text{if } K < 0 \end{cases} \quad (2.10)$$

The standardized Z value follows a normal distribution and also characterizes by the variance of '1' and the average of '0'. It has been used to determine the significant trend level (Das et al., 2019).

2.2.6 Modified Mann–Kendall Test

The modified MK (mMK) test is applied when the autocorrelation coefficient of the given data is significant at lag-1 to avoid the serial dependency in the concerned series (Basak et al., 2021; Das et al., 2021a). The VAR(S) can evaluate with the help of the given formula:

$$\text{VAR}(S) = \left(\frac{N(N-1)(2N+5)}{18} \right), \left(\frac{N}{N_e^*} \right) \quad (2.11)$$

For autocorrelated data, the correlation factor $\left(\frac{N}{N_e^*} \right)$ is fix as follows:

$$\left(\frac{N}{N_e^*} \right) = 1 + \left(\frac{2}{N^3 - 3N^2 + 2N} \right) \sum_{j=1}^{N-1} (N-j)(N-j-1)(N-j-2)p_e(f). \quad (2.12)$$

$p_e(f)$ signifies the autocorrelation between observational ranks, which can access as follows:

$$p_e(f) = 2 \sin\left(\frac{\pi}{6} p_e(f)\right). \quad (2.13)$$

2.2.7 Sen's Estimator Method

This nonparametric test (Sen, 1968) is generally applied to perceive the magnitudes of the trend pattern of the time series data. It also uses it to compute the changes that happen per unit time. The trend slope has increased or decreased appearances in the seasonal and annual time series (Das and Bhattacharya, 2018). With the help of the following equation, the slope of N can be first evaluated.

$$Q_i = \frac{x_r - x_s}{r - s}, \quad i = 1, 2, \dots, N, \quad r > s, \quad (2.14)$$

x_r and x_s symbolize the data's values at time r and s ($r > s$) from the above equation. A positive Q_i value stands for a rising trend, whereas a negative Q_i value stands for a declining trend.

Sen's slope estimator test has broadly applied in hydrological time series and meteorological time series (Tabari & Marofi, 2011; Yue & Hashino, 2003).

2.2.8 Percent Bias

In the present study, the percent bias method is used to determine the percentage change in rainfall between the first and second half of the time series, (Mandal et al., 2021b; Das et al., 2021b).

$$\text{PBIAS} = 100 - \sum_{i=1}^n \frac{Y_i}{X_i} \times 100, \quad (2.15)$$

where (PBIAS) represents Percent bias, n represents the entire length of individual sub-series; X_i and Y_i are signified as the value of observed data in the first and second sub-series, respectively, with a positive score indicating an inclining trend and negative score indicating a declining trend in respect of first sub-series.

2.3 Results and Discussion

2.3.1 Exploratory Statistics

The study area has experienced a varying mean annual rainfall of 1281.60–2420.10 mm with a mean value of 1595.31 mm during the hydrological period of 1901–2010. The highest mean rainfall is observed at Jalpaiguri (2420.10 mm \pm 17.61), higher than the state's average rainfall. In contrast, the lowest mean rainfall is found at Purulia (1281.60 mm \pm 23.24). The mean annual rainfall of 28% of the stations has exceeded the state's average annual rainfall. The study area has a sharp gradient from the west to the north-eastern region with an increasing trend. (Table 2.1). Moreover, the standard deviations (SD) of annual rainfall varied from 210.14 mm (Krishnanagar) to 429.33 mm (Raiganj), whereas coefficient of variation (CV) values range from 14.61 mm (Krishnanagar) to 29.80 mm (Raiganj station). The CV slope represents a sharp gradient from the eastern part to the western part of West Bengal with an increasing trend.

2.3.2 Autocorrelation Effect on Rainfall

Autocorrelation plots for the seasonal and annual rainfall distribution of 18 weather stations have been presented in Fig. 2.2. The analysis is conducted to check the randomness and periodicity among the rainfall time series. From the analysis, it is found that both positive and negative serial correlations characterize the annual and seasonal rainfall except post-monsoon. At the same time, the post-monsoonal rainfall has experienced only positive serial correlations (Fig. 2.2e). Additionally, the

Table 2.1 Descriptive statistics of the annual rainfall of West Bengal

Stations	Lat	Long	Mean	SD	CV	Skewness	Kurtosis
Bankura	23.16	87.06	1412.50	212.85	15.07	0.57	1.09
Bardhaman	23.23	87.86	1415.37	217.99	15.40	0.67	0.72
Suri	23.84	87.62	1387.00	233.56	16.84	0.56	0.46
Cooch Behar	26.34	89.45	2172.21	346.75	15.96	1.07	2.20
Balurghat	25.37	88.56	1484.00	225.57	15.20	-0.13	-0.21
Darjeeling	27.04	88.26	2156.30	359.48	16.67	1.09	2.54
Howrah	22.60	88.26	1601.10	269.65	16.84	0.45	-0.11
Hooghly	22.90	88.25	1526.90	254.69	16.68	0.55	0.11
Jalpaiguri	26.68	88.77	2420.10	426.21	17.61	1.45	3.34
Kolkata	22.57	88.36	1585.70	273.37	17.24	0.54	-0.01
English Bazar	25.18	88.25	1382.99	210.45	15.22	0.14	-0.22
Midnapore	22.43	87.32	1578.73	241.93	15.32	0.50	0.28
Baharampur	24.18	88.28	1401.53	215.53	15.38	0.36	0.22
Krishnanagar	23.47	88.56	1438.45	210.14	14.61	0.38	0.58
Barasat	22.62	88.40	1601.60	265.13	16.55	0.42	-0.17
Purulia	23.25	86.50	1281.60	297.84	23.24	-1.91	8.11
Alipore	22.14	88.40	1428.80	270.26	18.92	0.56	0.24
Raiganj	25.98	88.05	1440.70	429.33	29.80	-2.34	5.84

Krishnanagar for annual rainfall and Darjeeling for post-monsoon rainfall showed the weakest and strongest serial correlations in the study period. On the other hand, entire stations have no evidence of the significant negative serial correlations seasonally. Surprisingly, all the stations except for Kolkata have experienced a significant positive serial correlation in the post-monsoon season (Fig. 2.2e). Similarly, Cooch Behar in the monsoon season and Jalpaiguri in the winter have experienced a significant positive serial correlation (Fig. 2.2d, b).

2.3.3 Annual and Seasonal Trend by ITA

Analysis of annual and seasonal precipitation trends using ITA is presented in Figs. 2.3 and 2.4a. The results obtained from ITA showed more than 50% of the stations had a decreasing trend. The decreasing trends are observed in the Bankura, Bardhaman, Suri, Darjeeling, Balurghat, English Bazar, Baharampur, Purulia, and Raiganj weather stations distributed over the whole West Bengal. At the same time, Cooch Behar, Howrah, Hooghly, Jalpaiguri, Kolkata, Midnapore, Krishnanagar, and Barasat showed an increasing trend. This rising trend has occurred from north to

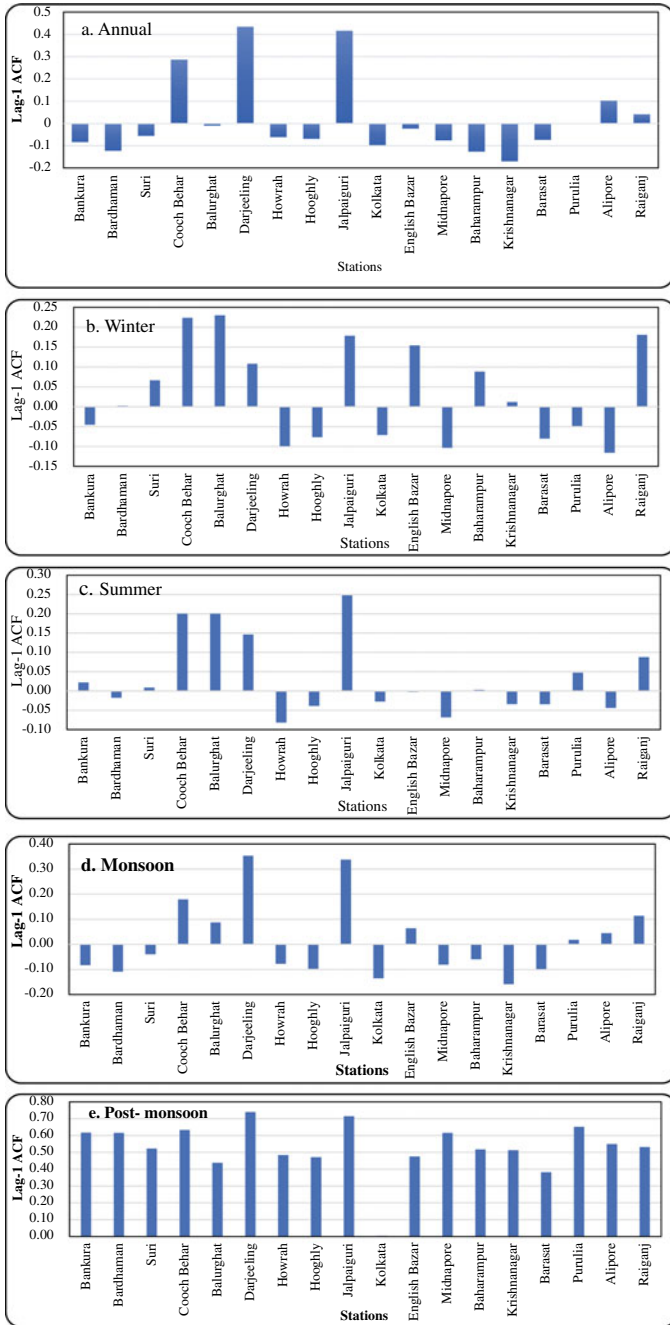


Fig. 2.2 Lag-1 autocorrelation function of the stations **a** annual rainfall, **b** winter rainfall, **c** summer rainfall, **d** monsoonal rainfall, and **e** post-monsoonal rainfall

southward to the Murshidabad station and from the south to north direction up to Krishna Nagar and Birbhum (Fig. 2.4a.).

On the other hand, the summer season showed a decreasing trend of 4.44% of the stations covering the Middle East to the southwest part of West Bengal. In contrast, the remaining stations have acquired an increasing trend with the slope direction

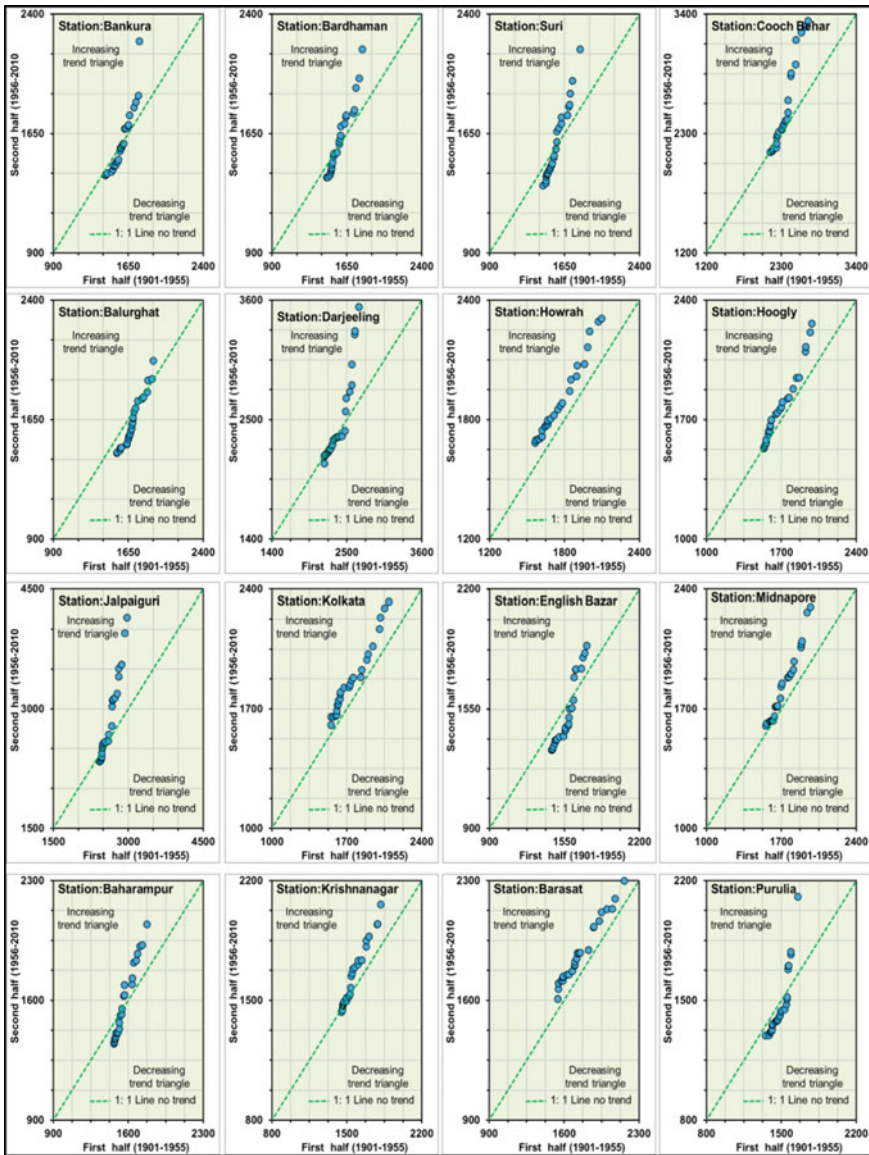


Fig. 2.3 ITA of the annual rainfall of the selected stations

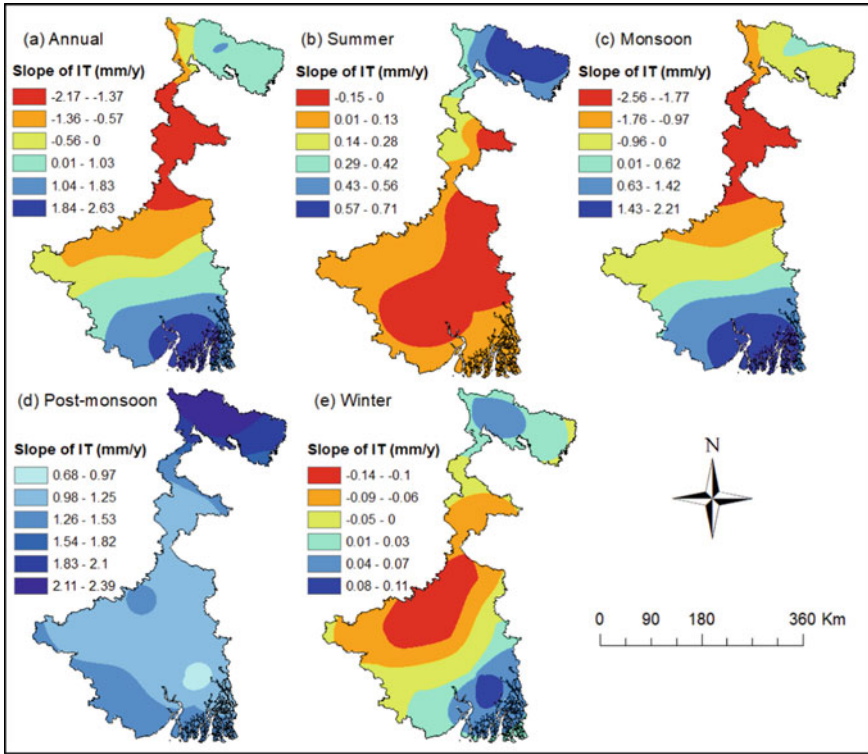


Fig. 2.4 Spatial distribution of slope of the ITA **a** annual, **b** summer, **c** monsoon, **d** post-monsoon, and **e** winter

from north to south. In the monsoon period, about 39% of stations obtained a rising trend with the gradient from north to the south except the central part, which ultimately practiced a declining trend. However, the Cooch Behar is considered a trendless station in the monsoon season. The post-monsoon season has experienced an increasing trend, which is the source of the flood in West Bengal. In addition, more than half (55.55%) of the stations in the winter season have shown a decreasing trend. In all season except for post-monsoon, Bardhaman, Balurghat, and Baharampur have shown a decreasing trend, whereas Cooch Behar, Jalpaiguri, Kolkata, and Alipore, showed no decreasing trend in all seasons, positioned in the extreme north and southern segment. Conversely, Darjeeling is the only weather station with a decreasing trend in the monsoon and the annual rainfall series. In contrast, Howrah showed a decreasing trend only in the summer season. Furthermore, the descending trend is observed over Hooghly and Midnapore weather stations in the summer and winter seasons, respectively. At the same time, a similar result receives by Krishna Nagar in the summer, monsoon, and winter series, and Barasat in only the summer season (Fig. 2.4).

2.3.4 Annual and Seasonal Trend by MK/mMK Test

Table 2.2 and Figs. 2.5, 2.6 represent the result of the annual and seasonal rainfall trends, using the MK, mMK, and Sen's slope estimator. From the annual rainfall trend, it is found that about 27.8% of weather stations are statistically significant ($P < 0.05$). However, the significant decreasing (80%) trends are dominated the study area for annual rainfall. Only one station, i.e., Alipore, has experienced a significant increasing trend, located in the southern segment of this state. Significant decreasing tendencies have been observed in the central part of West Bengal. Raiganj has experienced a maximum rate of decreasing trend (-3.1 mm/year). This negative trend has also been gradually increased toward southern and northern West Bengal (Fig. 2.5a). Mukherjee (2017) and Pal et al. (2015) have also found the same consequence in their research regarding the significant rising trend of West Bengal.

The distributional pattern of rainfall at different seasons has also been experienced wide variation. Such as out of 18 stations, three (16.66%) stations in summer, five (27.8%) in monsoon, and one (5.55%) in post-monsoon season, are statistically significant at a 5% significant level. Significant ($P < 0.05$) positive trend in the summer season has been noticed in Cooch Behar, Darjeeling, and Jalpaiguri, situated in the northern part of the study area. Whereas, in the post-monsoon season, only English Bazar in Malda district showed a significant increasing trend. On the other hand, in the monsoon season, a significant ($P < 0.05$) positive trend has been observed at Alipore, located in the southern part of West Bengal. Still, a significantly decreasing trend at a 0.05% significant level has been found at four stations of Balurghat, English Bazar, Baharampur, and Raiganj. The English Bazar of Malda district has obtained the highest decreasing trend and the rate of -1.88 mm/year (Fig. 2.6).

2.4 Percent Bias

P_{BIAS} is the most recently introduced method that divided the entire rainfall series of 110 years into two sub-series, i.e., the first series extended from 1901 to 1955 and the second series extended from 1956 to 2010. It represents the percentage of inconsistent nature of the rainfall of the second series in comparison with the first series. The results of the P_{BIAS} show that about 44.44% of stations of annual rainfall have experienced an increasing trend, located mainly in the southern and extreme northern parts. However, the rest of the stations have acquired a declining trend. The most robust decreasing trend in the second half has been noticed at the station of Balurghat (Fig. 2.7). Besides this, in the summer season, seven meteorological stations, situated in the southern and Middle Eastern part of West Bengal, have attained a decreasing trend in the second half concerning the first half. At the same time, the rest of the stations have shown an increasing trend, with the maximum in Jalpaiguri and the minimum in Bankura (Fig. 2.7).

Table 2.2 Results of the MK, mMK test statistics Z, Sen's slope estimators Q for annual and seasonal rainfall time series (1901–2010)

Season Statistics	Annual		Summer		Monsoon		Post-monsoon		Winter	
	Z	Q	Z	Q	Z	Q	Z	Q	Z	Q
Bankura	-0.28	-0.21	0.26	0.051	-0.28	-0.184	1.22	0.175	-0.71	-0.055
Bardhaman	-0.86	-0.52	-0.09	-0.019	-1.11	-0.652	1.49	0.247	-1.07	-0.086
Suri	-1.25	-0.883	0.7	0.128	-1.86	-1.143	1.92	0.339	-1.39	-0.12
Cooch Behar	1.35	1.206	2.67*	0.872	0.83	0.632	1.21	0.25	1.06	0.054
Balurghat	-2.23*	-1.54	-0.37	-0.06	-2.84*	-1.81	1.91	0.36	-0.92	-0.05
Darjeeling	0.91	0.89	2.12*	0.58	0.47	0.64	0.66	0.14	0.33	0.02
Howrah	1.22	1.03	-0.59	-0.13	1.02	0.72	1.79	0.51	-1.16	-0.1
Hooghly	-0.02	-0.02	-0.44	-0.1	0.04	0.03	1.43	0.32	-1.04	-0.09
Jalpaiguri	1.57	1.92	2.98*	0.93	1.28	1.26	0.35	0.07	1.23	0.06
Kolkata	1.64	1.18	-0.29	-0.06	1.92	1.19	0.91	0.16	0.17	0
English Bazar	-1.9	-1.22	0.93	0.16	-3.06*	-1.88	2.30*	0.43	-1.14	-0.06
Midnapore	1.48	1.1	0.13	0.03	1.45	0.82	1.37	0.32	-0.99	-0.09
Baharampur	-2.15*	-1.45	-0.8	-0.16	-2.20*	-1.45	1.78	0.33	-1.78	-0.12
Krishnanagar	0.06	0.05	-0.39	-0.11	-0.15	-0.07	1.54	0.27	0.29	0.02
Barasat	1.47	1.12	0.23	0.04	1.11	0.82	1.41	0.39	0.32	0.03
Purulia	-2.18*	-1.52	0.69	0.11	-1.03	-0.65	0.87	0.12	-1.62	-0.16
Alipore	3.35*	2.63	0.54	0.12	3.03*	1.98	1.89	0.51	0.3	0.03
Raiganj	-3.90*	-3.1	0.73	0.13	-2.62*	-1.52	0.96	0.16	-0.41	-0.02

Z, normalized test statistics; Q, Sen's slope per decade

*Statistically significant trends at the 5% significant level

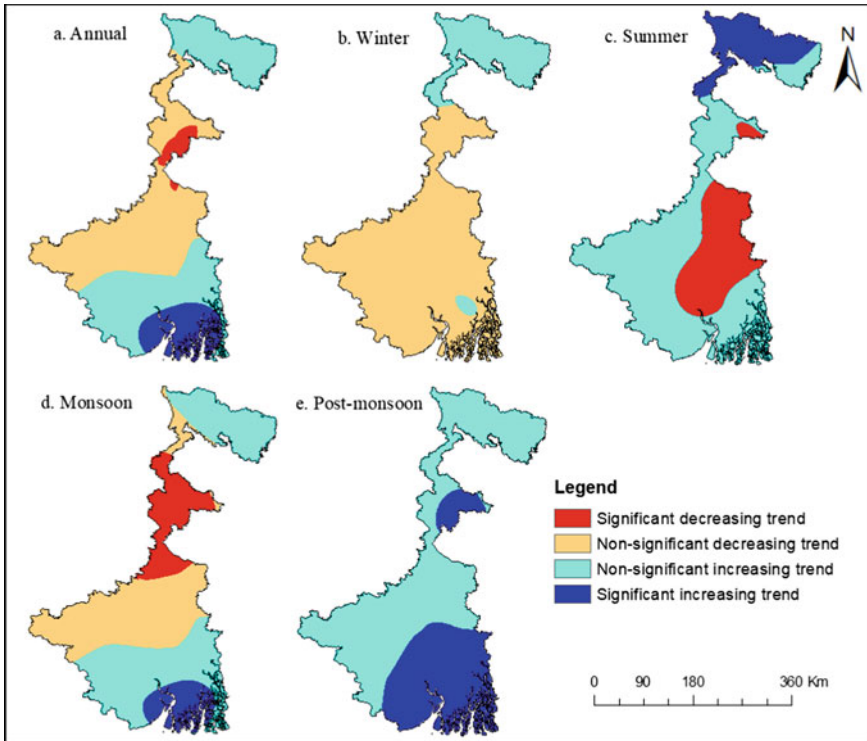


Fig. 2.5 Spatial distribution of trend of different stations **a** annual rainfall, **b** winter rainfall, **c** summer rainfall, **d** monsoonal rainfall, and **e** post-monsoonal rainfall

2.5 Comparisons Between the Trend Analysis Methods

The reliability of the recently introduced ITA method is estimated by comparing its result with the result of Z statistic, i.e., MK/mMK, and Sen's slope for annual and seasonal rainfall, is presented in Fig. 2.8. The comparative assessment of these three methods has been conducted by quadrantal analysis. Figure 2.8a, b shows the scattered plots of ITA slope and the Z statistics of MK/mMK and ITA and Sen's slope. These two scatter plots represent the maximum points (97%) drop inside the first and third quadrants. From this, it is identified that the general agreement has prevailed in these three methods. The remaining 3% points fall in the 4th quadrants, showing a discrepancy in the rainfall trend, revealing insignificant magnitudes. The results show a robust statistical relationship between the ITA slope and the Z of MK/mMK and ITA slope with Sen's slope. Therefore, the reliability of these three methods of trend identification affirms that the ITA is more efficient and dependable as it can easily evaluate the trend of the hydrological and meteorological time series data at low, medium, and high values through the diagrammatical presentations (Wu & Qian, 2017).

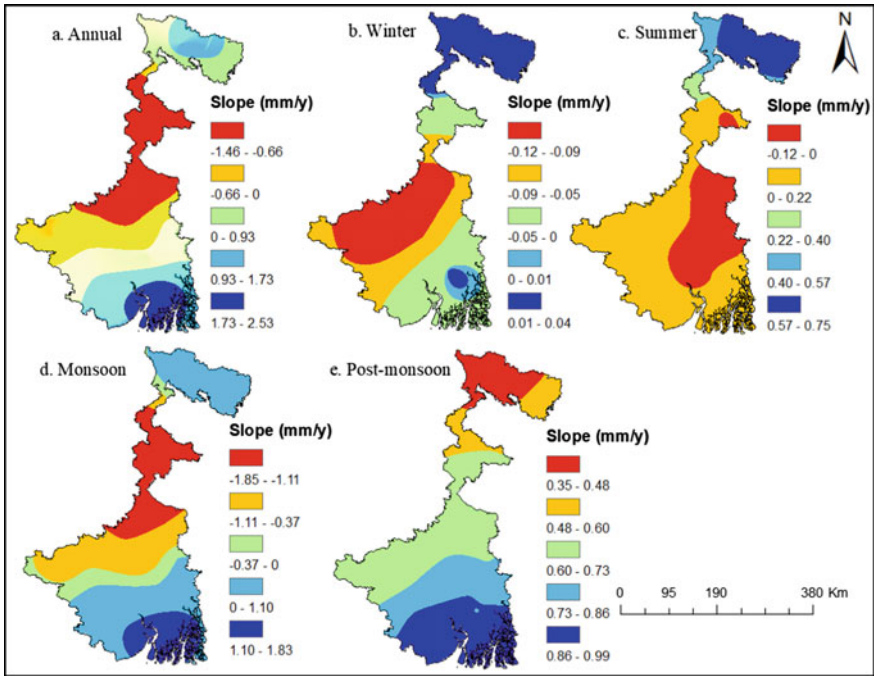


Fig. 2.6 Magnitude of change of different stations **a** annual rainfall, **b** winter rainfall, **c** summer rainfall, **d** monsoon rainfall, and **e** post-monsoon rainfall

2.6 Discussion

The present work investigates the inconsistent nature of rainfall on the annual and seasonal scale over West Bengal. The state is situated adjacent to the vicinity of the Bay of Bengal, experiencing great vagaries in the monsoonal and annual rainfall. Hence, the state's climate is affected by wet monsoonal air streams blow from the south to the southeast Bay of Bengal during the monsoon season. So, West Bengal's water resources entirely depend on the summer monsoon precipitation, which carries the moisture from the Bay of Bengal and the Arabian Sea. This season the mountainous region and foothills of the Himalayas and the Sundarbans of West Bengal received more rainwater. The low pressure over the southern part of West Bengal is responsible for heavy rainfall, causing massive floods in the Sundarbans region (Nandargi & Barman, 2018). Also, the middle part of the state is characterized by the flood-prone area, which is the primary source of agricultural practices. Although, the quantity of summer monsoon rainfall decreased due to high temperatures throughout the state due to the summer solstice. Recently, West Bengal has suffered from the declining trend of monsoonal rainfall and the inclining trend of post-monsoonal rainfall (Pal et al., 2015; Mukherjee, 2017).

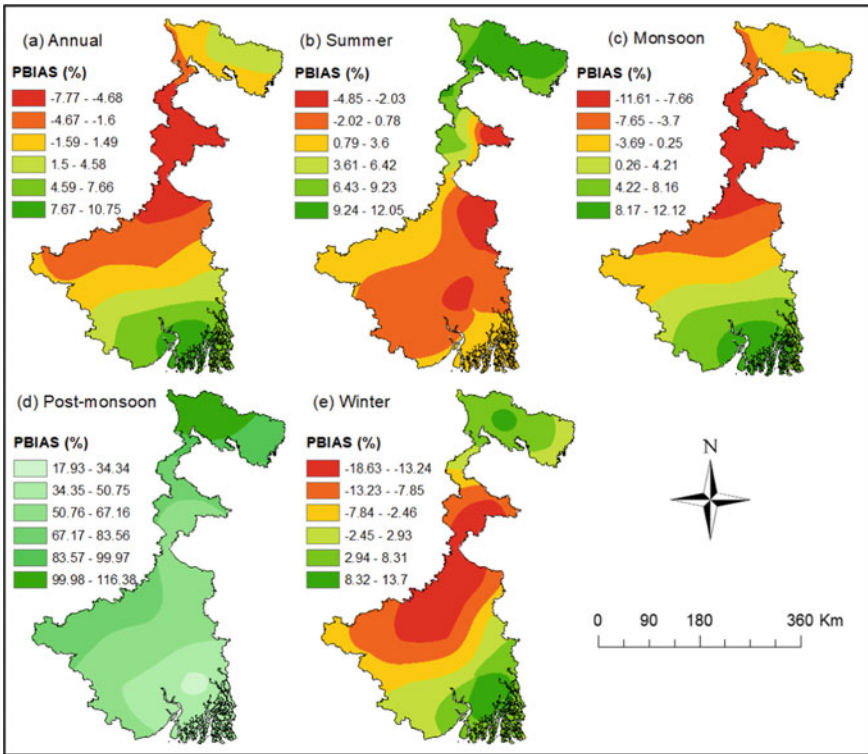


Fig. 2.7 Spatial distribution of P_{BIAS} of a annual, b summer, c monsoon, d post-monsoon, and e winter

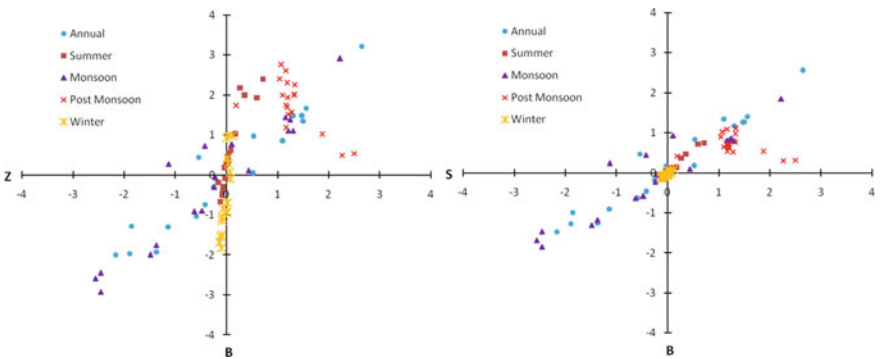


Fig. 2.8 Comparison of a Z statistic and innovative trend and b Sen's slope and innovative trend

Most of the stations of North Bengal experienced an inclining trend in the pre-monsoon period, whereas most of all stations in South Bengal have shown the opposite result. Therefore, it is clear that North Bengal is more suitable for boro cultivation than South Bengal. However, it is impossible without the use of an irrigation facility. The Malda district has shown an insignificant declining trend in the annual rainfall, representing a curious rain incidence. Therefore, agricultural activities suffered from an inadequate water supply; however, the agricultural lands are transformed into mango orchards due to their suitable environmental condition (Mukherjee, 2017). Likewise, the increasing rainfall trend in the post-monsoon in the study area apart from North Bengal has become anxiety for the flood prospects and crop defeat. Therefore, the agricultural land is facing water staging, and hence, the pre-harvested crops become damaged. The declined rainfall throughout the post-monsoonal series has affected the harvest of Kharif crops as it causes a severe loss of yield. Such an unpredictable trend is very much consideration for the economy of the entire West Bengal. According to Mukherjee (2017), the economy of West Bengal is purely agro-based, and rice is considered the principal crop.

2.7 Conclusion

The present work has investigated the inconsistent nature of annual and seasonal rainfall of West Bengal using ITA, MK/mMK, percent bias, and Sen's slope. The study also assessed the ITA's reliability by comparing its result with the Z statistic of MK/mMK and Sen's slope estimator. By analyzing the rainfall trend using the method mentioned above, it can be said that all the methods are more or less the same in terms of finding the significant trend. On the other hand, the climate changes impact has been significantly noticed in the study area's annual and seasonal rainfall pattern. Therefore, measuring future water accessibility at diverse spatio-temporal scales is obligatory as water demand is continuously increasing due to increasing population and agricultural and industrial purposes. The findings of this study provide a proper way to develop future projects as it explained the rainfall variability accurately, which can support many engineers and practitioners to construct the desirable infrastructures for managing the vulnerable conditions of floods and droughts hazards. Moreover, understanding the rainfall variability is also very effective for agricultural production. It will also help the local water management authorities to construct a wise and rational plan to satisfy and overcome all the challenges in the state in the context of rainfall change.

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