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Recent Trends of Meteorological Variables and Impacts on Agriculture in Northwest Bangladesh

J. M. Adeeb Salman Chowdhury,
Md. Abdul Khalek, and Md. Kamruzzaman

Abstract

The study focused on two meteorological variables (rainfall and temperature) and their trend variations from 1960 to 2021. The recorded data was extracted from five regional weather stations in northwest area under Bangladesh Meteorological Department (BMD). By trend analysis, Rajshahi station found the lowest annual average rainfall (1460 mm) and the highest annual average temperature (25.30 °C). The precipitation concentration index (PCI) in the study area described that most of the stations carried varying precipitation concentration (16–20) except Dinajpur station. Linear trend analysis, the nonparametric Mann–Kendall (MK) test, Kendall's tau, Sen's slope estimator, and Spearman's rho (SR) test were used to define whether there were any trend fluctuations and calculate the magnitude of changes at the selected stations. Further, the Sequential Mann–Kendall test was executed to distinguish trend differences and abrupt deviations over time. During the study, Rajshahi station showed the highest significant decreasing trend with the degree of change assessed by Sen's slope estimator which was − 5.50 mm/year. Through cropping seasonal rainfall analysis, it had been observed that only the *Rabi* season (80%) found a declining trend across all stations. According to temperature trend analysis, except for Dinajpur station, all stations showed increasing trends in the annual and seasonal analysis by MK test and SR test. On the other hand, only Bogura and Syedpur stations were found significant at 5% level of significance. The magnitude of change discovered by the Sen's slope estimates varied from − 0.003 to 0.017 °C/year. The *Kharif* season temperature was significantly observed with a positive trend in all stations; however, the *Rabi* and pre-*Kharif* seasons temperature continued to show both increasing and decreasing trends. Furthermore, we checked the time series properties of meteorological data and constructed an appropriate model to forecast next five years based on the previous 60 years' recorded data. The research outcomes will be valuable for the sustainable agronomic growth of the country and reduce agricultural crop vulnerability during drought in the northwest region.

J. M. Adeeb Salman Chowdhury ·
Md.Kamruzzaman (✉)
Institute of Bangladesh Studies,
University of Rajshahi, Rajshahi, Bangladesh
e-mail: mkzaman@ru.ac.bd

J. M. Adeeb Salman Chowdhury
e-mail: asc_2010@cou.ac.bd

Md.Abdul Khalek
Department of Statistics, University of Rajshahi,
Rajshahi, Bangladesh
e-mail: mak.stat09@gmail.com

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Keywords

Trend analysis · Mann–Kendall test · Spearman’s rho test · Sen’s slope estimator · Sequential Mann–Kendall test · ARIMA model · Bangladesh

5.1 Introduction

Climate change has been recognized as a worldwide issue in recent years. Now the global environment is possessed by unpredictable weather conditions resulting in the climate variability and change (Alam et al. 2023). Despite the fact that climate change is a global phenomenon, its effects will not be equally distributed (Shahid and Khairulmaini 2009; Shaw et al. 2013; Karim et al. 2020). According to research, underdeveloped countries are more at risk from the effects of climate change than developed ones. This is mostly due to a poor and constrained capacity to adapt to climate change (Basak et al. 2022; Das et al. 2020a, b, c; Rahman and Lateh 2017). As a developing nation, Bangladesh is particularly in danger due to high climate inconsistency, extreme temperature, huge population density, extreme poverty, unorganized infrastructure, insufficient money supply, and weak educational system (Kamruzzaman et al. 2018). The Intergovernmental Panel on Climate Change (IPCC) report found that precipitation and temperature were identified worldwide significantly, but with varying magnitudes. Every year the nation experiences some sort of disaster, such as floods, droughts, river bank erosion, and cyclones threatening country’s development efforts and resulting poor livelihood and huge agricultural loss (Adams et al. 1998). According to the IPCC (2014), globally the average temperature is increased by 0.85 °C between the year 1880 and 2012, and it will increase 0.3–4.8 °C by 2100 (Karim et al. 2020; Mullick et al. 2019). It is observed that Bangladesh has experienced with a significant amount of precipitation in the monsoon season and less rainfall in other seasons of the year, which also affects the food security and economic growth of the country (Akter and Rahman 2012; Mondol et al. 2018; Rahman et al. 2017; Rahman et al. 2016b; Salam et al. 2020).

Agriculture is heavily relying on country’s economy, but the water constraint (shortage) hinders agricultural production. In our country, agriculture is the most prevalent occupation in rural areas, with approximately 51.88% of people actively involved in agricultural (BBS 2019b). It is a crucial sector contributing 13.82% to the country’s GDP (BBS 2019a). The rural population, roughly 70% of the total, is extremely in danger due to natural disasters (Islam et al. 2019a). Bangladesh is the fourth-largest rice producer in the world, with an annual production of over 34.7 million metric tons. Nearly 80% of all cultivated land (11.7 million hectares) is planted with rice (Mainuddin et al. 2022). Rice is used to make 91% of all food grains and 60% of overall agricultural products (Rahman et al. 2016a, b; Yu et al. 2010).

Despite advancements in technology, such as better crop varieties, irrigation practices, and other sustainable adaptation strategies have established food security, climate conditions still contribute unpredictability to agricultural productivity of the country (Mainuddin and Kirby 2015; Kirby et al. 2015). As a result, rainfall and temperature trend analysis and future prediction have become important subjects of research in Bangladesh, as accurate trend detection directly effects on establishment of long-term food security, an agro-based economy, and infrastructural development. Environmental researchers conduct various types of research to understand the rainfall and temperature patterns of Bangladesh. A number of studies exhibited significant rising or falling trends of temperature and rainfall on a large scale using the MK test, Sen’s slope estimator, and Kendall’s tau (Shahid and Khairulmaini 2009; Zhang et al. 2009; Shahid 2010; Rahman and Lateh 2016; Rahman et al. 2017; Kamruzzaman et al. 2018; Das et al. 2021a, b). Shahid (2010) demonstrated a significant upward trend in annual and pre-season rainfall at 17 rain gauge stations in Bangladesh by using the MK test and Sen’s slope estimator between 1958 and 2007. Similarly, Hossain et al. (2014) perceived rising tendencies in seasonal rainfall variability in the southwest coastal area of

Bangladesh during the years 1948–2007. Rahman and Lateh, (2016) constructed a regression model for trend detection from 1971 to 2010 and forecasting ten-year period of rainfall by the ARIMA method from 34 meteorological stations in Bangladesh. Their findings showed that annual rainfall was forecasted to decline by 153 mm between 2011 and 2020. As a result, almost dry conditions would continue during pre- and post-monsoon season in Bangladesh's northwestern, western, and southwestern regions. Rahman et al. (2017) used 60 years of monthly rainfall data to estimate rainfall trends of selected stations by applying the Mann–Kendall test. Additionally, they found unnoticeable trends in precipitation rather than rising trends for Khulna, Satkhira, Cox's Bazar stations, but they discovered falling trends for Srimongal stations by using the ARIMA approach. Similar types of research were found in hydro-climatic research based on global climate problem (Islam et al. 2021; Kamruzzaman et al. 2018, 2022; Yu et al. 2017).

Although the northwest zone produces huge amount of crops, the agriculture mostly relies on rainwater. In addition, inadequate rainfall, extreme temperature, surface water scarcity, and groundwater depletion for irrigation purposes are common problems in this region (Salam et al. 2020; Karim et al. 2020; Uddin et al. 2020a, 2020b). To address this problem, several studies have been done locally and country-wide to determine future trends. Kamruzzaman et al. (2018) identified the changing rainfall and temperature patterns in different cropping seasons in the NW Bangladesh. Almost identical results were found in different studies on the NW region of Bangladesh (Bariet al. 2016; Rahman et al. 2016a, b). It is traditionally accepted that drought is the outcome of decreasing trends of rainfall and increasing trends of extreme temperature. However, many environmental researchers do not agree with the above statement. To address the issue, many previous studies were conducted based on zone-wise or country-wise methods. However, some limitations have been found in the local and regional studies. The present chapter aims to identifying annual and seasonal trend fluctuations of climatic variables of five meteorological stations (*i.e.*, Bogura, Syedpur, Dinajpur, Rajshahi, and Ishwardi) during 1961–2021 and predicts monthly behavioral change to obtain approximate results. Furthermore, the study looks into the development of agro-economic activities and infrastructure that will strengthen the ability of farmers, policymakers, and researchers to deal with meteorological change.

5.2 Materials and Methods

5.2.1 Area of Study

Sixteen administrative districts, consisting 34,359 km^2 and residing 38 million people, from north and northwest Bangladesh are considered as study area of this research (Uddin et al. 2020a, BBS 2019a). According to Banglapedia (2003), the country belongs to a sub-tropical climate region with hot, humid, and erratic rainfall occurring throughout the year, mostly influenced by monsoon weather as well as pre- and post-monsoon exchanges. The country undergoes three climatic seasons such as (1) the month of November to February known as dry winter season, (2) the month of March to May known as pre-monsoon hot summer season, and (3) lastly the month of June to October regarded as rainy monsoon season (Rashid 1991). In winter season, the mean temperature lies between 18.5 and 21.0 °C, and hot summer season mean temperature ranges from 27.8 to 29.0 °C. The overall annual average rainfall from the northwest to the northeast region is 1329–4338 mm, which indicates that northwest region of Bangladesh receives less amount of rainfall (Shahid and Behrawan 2008; Shahid and Khairulmaini 2009).

During the month of April–May, the average temperature was experienced between 27 and 31 °C in the east and south and west-central portion of the country. However, the western regions of Bangladesh become very hot with a maximum of 40 °C temperature (Shahid 2010; Shahid et al. 2012; Khan et al. 2019). It is experienced that the average maximum temperature of northwest zone goes up to 24 °C in January and 34 °C in June. Meanwhile, the average temperature does not go beyond 27 °C from November to February but exceeds 32 °C from April to October (Bhuyan et al. 2018). The district-wise meteorological stations location is presented in (Fig. 5.1). According to Banglapedia (2003), in our country the agricultural calendar is based on three cropping seasons: *Rabi*, pre-*Kharif*, and *Kharif*. The *Rabi* period, which spans from early November to the end of February, is characterized by a dry climate. The pre-*Kharif* period starts in early March and lasts until the end of June, whereas the *Kharif* begins in the month July and ends in the month October when there is enough moisture from rainfall to support rain-fed or non-irrigated crops (Banglapedia 2003; Kamruzzaman et al. 2018; Shahid and Behrawan 2008).

5.2.2 Data

In this study, Bangladesh Meteorological Department (BMD), Dhaka, has provided rainfall and temperature data from 1960 to 2021. Besides, required and relevant records are retrieved from World Meteorological Organization (WMO), Bangladesh Water Development Board, and online resources from different websites.

5.2.3 Estimation of Missing Data

During study, every station has a number of missing values. Due to the global nature of missing daily temperature and rainfall records, many climatological algorithms have encountered difficulties. There are three broad categories of missing data estimation methods, such as: (a) within-stations, (b) between station, and (c) regression-based (Allen and DeGaetano 2001). The within-stations approach forecasts missing temperatures based on the previous and subsequent days' data. For example, to calculate the missing minimum temperature on *October 1*, the minimum temperatures between *September 30* and *October 2* could be averaged (Oliver 1980).The within-station method is utilized to calculate the daily readings that are lost for a maximum of three days temperature. When more than three days of data are unavailable, regression-based methods should be used. This method uses data from nearby stations. Regression-based approaches are also appropriate, when monthly data is lost, because both monthly and daily data are constructed from this method (Eiseheid et al. 1995). According to Kemp et al. (1983), several regression techniques tend to provide more accurate results compared to other missing data estimation procedures. Multiple imputation techniques are utilized to both daily (Recha et al. 2012) and monthly (Ingsrisawang and Potawee 2012) data for missing rainfall records because the standard error is correctly adjusted for missing data estimation (Enders 2010).

5.2.4 Rainfall Climatological Features

5.2.4.1 Coefficient of Rainfall Variability

The coefficient of rainfall variability CV (%) is determined using the following formula:

$$\mathrm{CV}(\%) = \frac{\sigma}{\mu} \times 100 \tag{5.1}$$

where CV is the coefficient of variation in percentage, μ is the annual average precipitation, and σ is the standard deviation.

5.2.4.2 Precipitation Concentration Index (PCI)

The concentration of rainfall (as major form of precipitation, in the selected study area) variability has been computed by applying the following formula of precipitation concentration index (Oliver 1980; Michiels et al. 1992):

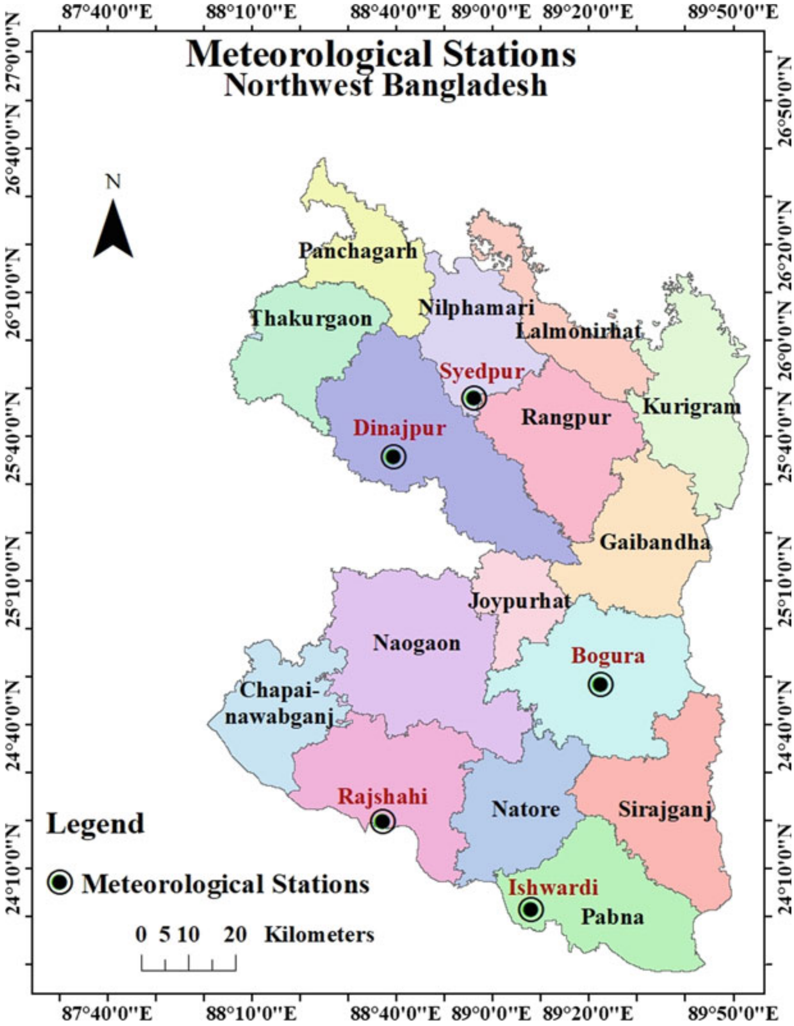

Fig. 5.1 Meteorological stations map in the nothwest region

$$\mathrm{PCI}_{\text{annual}} = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \tag{5.2}$$

PCI represents the monthly precipitation concentration index, and p_i is the monthly precipitation in the month i. It is observed that when PCI values are < 10%, the precipitation concentration should be identical or low precipitation; if PCI value range is 11–15%, it indicates moderate concentration of precipitation; if it ranges 16–20%, then precipitation continues irregularly (Oliver 1980). If a PCI value > 20%, it means that the concentration of precipitation is either high or strongly irregular.

5.2.5 Rainfall and Temperature Trend Analysis

Different statistical techniques and trend detection formula have been implemented for the required study. Mainly descriptive statistical analysis (maximum, minimum, mean/average, standard deviation, and coefficient of variation) has been executed to present the general characteristic of temperature and rainfall time series data.

5.2.5.1 Linear Regression

A popular parametric technique for finding linear trends in time series data is linear regression. It is used to determine the slope of time-dependent meteorological variables (Tabari and Talaee 2011). Positive slope specifies increasing trend and vice versa. The linear monotonic change can be calculated as the following form:

$$y = ax + b \tag{5.3}$$

Here, $a = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sum(x-\bar{x})^2}$ and

$$b = \bar{y} - a\bar{x} \tag{5.4}$$

where y is the dependent variable such as (temperature, rainfall, and humidity) and x is the independent variable (year); a and b are the coefficient of slope and intercept term of the trend line; $\bar{x}$ and $\bar{y}$ are sample means (Rahman and Lateh 2016).

5.2.5.2 Mann–Kendall (MK) Test

The rank-based nonparametric MK (Mann 1945) test is applied as the primary method of trend detection. It is often used to check whether a time series data exhibits a monotonic rising and falling trend. (Das et al. 2021a; Kamruzzaman et al. 2018, 2022; Sa'adi et al. 2019; Rahman et al. 2017). The test statistic *(S)* is identified using the following formula:

$$S = \sum_{K=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \tag{5.5}$$

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} +1, & \mathit{if} \quad (x_j - x_k) > 0 \\ 0, & \mathit{if} \quad (x_j - x_k) = 0 \\ -1, & \mathit{if} \quad (x_j - x_k) > 0 \end{cases} \tag{5.6}$$

Here, S means the trend detection. A rising trend is indicated by a positive value of S and vice versa. When sample size is greater than 10, then the test statistics $\boldsymbol{S}$ is normally distributed, with the following variance (Das et al. 2019):

$$\operatorname{Var}(S) = \frac{[(n(n-1)(2n+5)] - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \tag{5.7}$$

where m represents the total number of tied groups and t_i denotes the size of the *ith* group. The **Z** statistic is calculated using the following equation:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}}, & \text{for } S > 0 \\ 0, & \text{for } S = 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}}, & \text{for } S < 0 \end{cases} \tag{5.8}$$

In general, the positive and negative Z values represent the rising and falling trends, respectively. According to the null hypothesis, there is no trend in records (either accepted or rejected) if the estimated Z value is smaller or greater than the critical value (Das et al. 2021b).

5.2.5.3 Kendall's Tau

Tau (Kendall 1948) assesses the intensity of x and y's monotonic relationship. The Kendall's tau correlation formula is given by,

$$\tau = \frac{S}{n(n-1)/2} \tag{5.9}$$

5.2.5.4 Sen's Slope Estimator

Sen's slope estimator (Sen 1968), which provides the robust estimation of time series, is used to evaluate the degree of change (slope Q) (Das and Bhattacharya 2018; Das et al. 2020b). The estimation slope can be attained from N pairs of data as:

$$Q_i = \frac{x_k - x_j}{k - j}, \qquad i = 1, 2, 3 \ldots N, \quad k > j \tag{5.10}$$

where x_k and x_j represent values of data at k and j times and Q_i is the median slope, respectively.

5.2.5.5 Spearman's Rho (SR) Test

The Spearman's rho (SR) test (Spearman 2010) is another technique that uniformly detects tends and clearly indicates the lack of trends (Das et al. 2020b; Shadmani et al. 2012; Tonkaz et al. 2007; Yue et al. 2002a). According to Yue et al. (2002b), maximum trend test has same strength for long-term data when it comes to detecting monotonic hydrological time series trends. The test statistic D and standardized test statistic Z_{SR} are defined by:

$$D = 1 - \frac{6\sum_{1}^{n}[R(X_i - 1]^2}{n(n^2 - 1)} \tag{5.11}$$

$$Z_{\mathrm{SR}} = D\sqrt{\frac{(n-2)}{(1-D^2)}} \tag{5.12}$$

where R is the ith observation rank order in X_i time series and n is the sample size. The positive values Z_{SR} suggest rising trends and vice versa.

5.2.5.6 Sequential Mann–Kendall (SMK) Test

At the end of any period, it is well known that trend identification using the MK approach does not produce an accurate trend image for entire series. By using the sequential test for each distinct time series, it is possible to identify any fluctuations in the trend during the course of the inquiry (Sneyers 1990). This test establishes 2 series: [i] a progressive series $u(t_i)$ and [ii] a backward series $u'(t_i)$. . There is a statistically noteworthy change point that exists if they cross each other and diverge over predetermined definite threshold value (95% confidence limit). Their intersection point provides an approximate idea of the trend beginning year (Mosmann et al. 2004).

The SMK test is calibrated using rank values. The actual values in the series $(x_1, x_2, x_3 \ldots x_n)$ with the rank value y_i and the magnitudes of y_i $(i = 1, 2, 3\ldots\ldots n)$ are compared with y_j $(j = 1, 2, 3\ldots i-1)$. The cases $y_i > y_j$ are enumerated and indicated for each comparison by $n_{i.}$ Here, t_i is test statistic of SMK test by applying the following formula:

$$t_i = \sum_{j}^{i} n_i$$

The distribution of test statistic t_i has a mean $E(t_i) = \frac{i(i-1)}{4}$ and variance $\mathrm{Var}(t_i) = \frac{i(i-1)(2i+5)}{72}$; then the following formula is employed to obtain the forward sequential results: (Sneyers 1990).

$$u(t_i) = \frac{[t_i - E(t_i)]}{\sqrt{\mathrm{Var}(t_i)}} \tag{5.13}$$

Similar approaches are used to find the backward sequential statistics $u'(t_i)$, which starts at the end of the sequence. Occasionally, the positive and negative trends are canceled by each other in SMK analysis but do not provide a substantial trend turning point (Nalley et al. 2013). This technique was widely used by many researchers to identify trends from the beginning point (Esteban-Parra et al. 1995; Makokha and Shisanya 2010) rather than whole trend detection. Nalley et al. (2013) applied this technique in order to determine the periodicities in the temperature time series.

5.2.5.7 Spatial Distribution Analysis

The Inverse Distance Weighing (IDW) method was employed to evaluate the spatial pattern of trend magnitude (MK test and Sen's slope estimates). This procedure is popular and simple for spatial interpolation (Shahid and Behrawan 2008; Rahman et al. 2017; Kamruzzaman et al. 2018; Islam et al. 2019a, b), and it is very reliable for displaying the spatial analysis of hydro-meteorological records (Praveen et al. 2020). Compared to other interpolation techniques, the IDW method is more effective (Islam et al. 2021). We have used the ArcGIS 10.0 software for performing the IDW method in this study.

5.2.5.8 ARIMA Modeling and Prediction

The ARIMA approach is recognized as a sophisticated and broadly used data analysis technique for forecasting time series (Box and Jenkins 1976). In hydrological research, the ARIMA models are utilized to discover complexity in data series and forecast upcoming scenarios (Dimri et al. 2020; Rahman et al. 2017). Typically, ARIMA model consists of three components: AR is the autoregressive component, MA is the moving average component, and the differencing order (D) integrated with the model both AR and MA. The ARIMA model $(p.d.q)$ includes p = autoregressive term, d = trend term, and q = moving average term. After attaining data stationary, ARIMA method usually proceeds via four major steps: model identification, parameter estimates, model adequacy diagnostics, and forecasting. For the seasonal ARIMA model, notation is like ARIMA $(p, d, q) \times (P, D, Q)S$ where p = non-seasonal autoregressive (AR) order, d = non-seasonal differencing, q = non-seasonal moving average (MA) order, P = seasonal AR order, D = seasonal differencing, Q = seasonal MA order, and S = time span of repeating seasonal pattern. The fitted model performance is based on model selection criteria like log-likelihood, Akaike Information Criteria (AIC), and Bayesian Information Criteria (BIC). For this study, the Box Jenkins technique is implemented to forecast monthly rainfall and temperature data for the following five years based on 1960–2021.

5.3 Results and Discussion

5.3.1 Annual Rainfall Features

Rainfall is not constant across the country. Historically, in our country the northwest region received the least amount of rainfall as compared to the northeast. Around 75% of rainfall happens during the monsoon season (Alamgir et al. 2015). The results in Table 5.1 indicated that the mean annual rainfall ranges from 2171 to 1460 mm with mean value of 1767.80 mm. In 2010, Rajshahi station received the lowest amount of annual rainfall, 792 mm. Meanwhile, Syedpur station received the highest amount of annual precipitation 3748 mm in 1984. Moreover, Syedpur station received a maximum average annual rainfall amount of 2171 mm, whereas the other stations received less than 2000 mm amount of annual rainfall. During study period, the rainfall data was found positively skewed. The coefficient of variation is low in Rajshahi station (19.93%) and high in Ishwardi station (26.12%) which means maximum rainfall variability happened in Ishwardi station. The standard deviation of annual rainfall is high in Syedpur station, with 463.87 mm, and low in Rajshahi station, with 291 mm (Fig. 5.2 a). From the statistical analysis, about 80% stations in the research area were covered by irregular precipitation concentration index (PCI = 16–20), except Dinajpur station that carried a high precipitation concentration, which was more than 20%. Finally, all the stations were found to be positively skewed. The study area's annual rainfall statistics are provided in the following tables (Table 5.1).

5.3.2 Trend Analysis of Annual Rainfall

The MK test result revealed that 40% stations exhibit a positive trend, while the rest of the stations showed negative trend. Moreover, in annual rainfall trend analysis, a positive slope specified increasing amount of rainfall, while a negative slope designated decreasing trends (Table 5.2). According to MK test result *(Z),* Rajshahi station showed the highest amount of significant decreasing trend (− 2.654) at 5% level of significance, followed by Bogura (− 0.176) and Ishwardi (− 0.808), but they were found statistically insignificant. The magnitude of change in annual average rainfall was estimated at the rates of − 5.50, − 0.59, and − 1.71 mm/year at Rajshahi, Bogura, and Ishwardi stations, respectively, but only Rajshahi station showed statistically significant. In contrast, Syedpur and Dinajpur stations found insignificant positive trend, and the degree of

Table 5.1 Descriptive statistics of annual rainfall in the study area (1960–2021)

Stations	Annual rainfall (mm)							
	Min	Max	Mean	CV (%)	SD	Skewness	Kurtosis	$\mathrm{PCI}_{\mathrm{Annual}}$
Bogura	1081	2601	1719	21.92	376.77	0.307	− 0.635	19.47
Dinajpur	920	3179	1906	23.77	453.08	0.395	0.525	20.58
Ishwardi	893	3021	1583	26.12	413.42	1.30	2.530	17.80
Rajshahi	792	2241	1460	19.93	291.00	0.069	0.114	18.16
Syedpur	1231	3748	2171	21.37	463.87	0.905	1.510	19.63

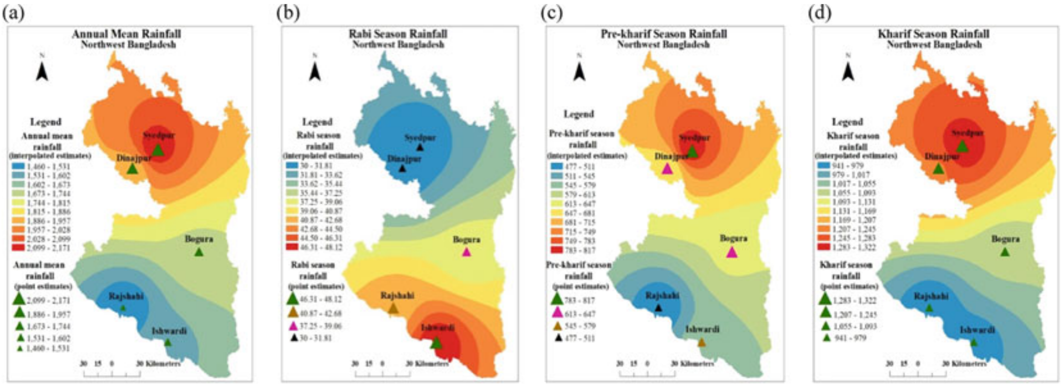

Fig. 5.2 Distribution of **a** Annual average rainfall **b** *Rabi* rainfall **c** Pre-*Kharif* rainfall **d** *Kharif* rainfall

change of these two stations was 3.68 and 2.59 mm/year, respectively. Besides, Kendall's tau revealed a monotonic trend of weak relationships in all stations. The linear regression trends of annual precipitation graph are shown in (Fig. 5.5). The MK test results (Z statistic) and the Sen's estimator of different stations are presented by the spatial distribution analysis (Fig. 5.3a). It is observed that annual average rainfall decreases at the Rajshahi division (Rajshahi, Bogura, and Ishwardi) but increases at the Rangpur division (Dinajpur and Syedpur).

5.3.3 Trend Analysis of Seasonal Rainfall

5.3.3.1 Rabi Season

During the *Rabi* season, the northwest zone received 37.8 mm of annual rainfall, which was significantly less than other parts of Bangladesh. In the study domain, annual average rainfall ranged from 30 mm to less than 50 mm in all stations. According to the regional distribution (Fig. 5.2b) of the *Rabi* season analysis, Dinajpur station found the lowest quantity of annual

Table 5.2 Long-term annual rainfall trend test results

Stations	MK test	Sen's slope	Kendall's tau	SR test
Bogura	− 0.176	− 0.59	− 0.016	− 0.195
Dinajpur	0.692	2.59	0.061	0.501
Ishwardi	− 0.808	− 1.71	− 0.071	− 0.830
Rajshahi	− 2.654*	− 5.50*	− 0.232*	− 2.813*
Syedpur	1.178	3.68	0.103	1.063

* Significant trends at 5% significance level, Sen's slope unit is in mm per year

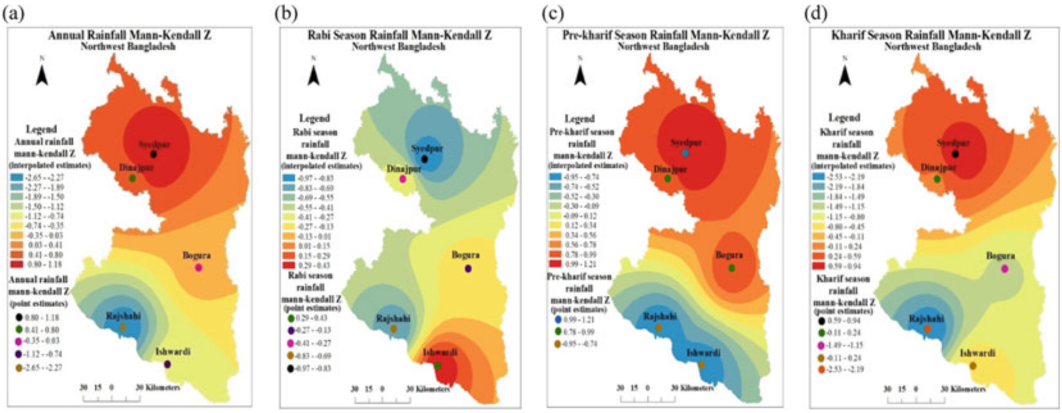

Fig. 5.3 Distribution of *Z* statistics estimates **a** Annual average rainfall **b** *Rabi* rainfall **c** Pre-*Kharif* rainfall **d** *Kharif* rainfall

rainfall (30 mm), whereas Ishwardi station received the highest quantity of rainfall, 48 mm. The standard deviation was high in Rajshahi station (38 mm) and low in Dinajpur station (25.85 mm). Moreover, the coefficient of variation revealed that 95.22% variation occurred in Bogura station, whereas Ishwardi station found low amount of rainfall variation (78.37%). The results of the MK test (*Z* statistics) exhibited that almost all stations shown an insignificant downward trends ranged from − 0.176 to − 0.966 at 95% confidence interval. Analysis of Sen's slope estimations revealed declining trends of 0.029, − 0.034, − 0.167, and − 0.136 mm/year in Bogura, Dinajpur, Rajshahi, and Syedpur, respectively, except Ishwardi station observed at a rate of change 0.107 mm/year (Table 5.3). Spearman rho's test also showed similar trend in all the station that ranged from 0.537 to − 1008. The distribution map of Z statistics and Sen's slope estimates of the *Rabi* season rainfall is depicted in (Fig. 5.3b and 5.4b). The findings of the study exhibited that the northwest region experienced a declining amount of rainfall in the Rabi season, which is particularly harmful for Boro rice production.

5.3.3.2 Pre-Kharif Season

The annual (mean or average) rainfall at different stations, in Bangladesh, in the pre-*Kharif* period was 623 mm, and the standard deviation varied from 153 to 240 mm. The pre-Kharif season rainfall analyses of spatial distribution (Fig. 5.2c) clearly showed that Syedpur station received significant rainfall with 1667 mm. Meanwhile, Rajshahi station found only 96 mm of rainfall in the study period (1960–2021). The northwest region had experienced both rising and falling trends in pre-*Kharif* season. The result derived from different trend analysis test (MK test, Sen's slope, and SR test) points out that 60% of stations showed increasing trend and 40% found insignificant decreasing trend. The MK test outcomes *(Z)* revealed that rainfall varied from − 0.905 (Ishwardi) to 1.208 (Syedpur). The Sen's slope estimates of Bogura, Dinajpur, and Syedpur stations identified insignificant rising trends at a rate of changes 1.73, 1.59, and 1.54 mm/year, respectively, while stations like Ishwardi and Rajshahi achieved insignificant falling trends at a magnitude of change − 0.905 and − 0.954 mm/year, respectively (Table 5.3). Spearman's rank correlation test (SR test) observed the same increasing and decreasing trends for the all stations. The spatial analysis of Z statistics and Sen's slope estimates is displayed in Figs. 5.3c and 5.4c. From above discussion, it is clear that the pre-*Kharif* season rainfall in Bangladesh shows downward trend in the northwest but strongly predicts upward trend in the north.

Table 5.3 Long-term seasonal rainfall trend test results

Stations	Rabi season			Pre-Kharif season			Kharif season		
	MK test	Sen's slope	SR test	MK test	Sen's slope	SR test	MK test	Sen's slope	SR test
Bogura	− 0.176	− 0.029	− 0.147	0.966	1.73	1.008	− 1.227	− 2.18	− 1.432
Dinajpur	− 0.255	− 0.034	− 0.031	0.947	1.59	0.995	0.20	0.50	− 0.007
Ishwardi	0.431	0.107	0.537	− 0.905	− 1.105	− 0.838	− 0.486	− 1.24	− 0.421
Rajshahi	− 0.838	− 0.167	− 0.886	− 0.954	− 1.00	− 0.903	− 2.53*	− 3.80*	− 2.711*
Syedpur	− 0.966	− 0.136	− 1.008	1.208	1.54	1.330	0.94	2.53	0.717

* Significant trends at 5% level, Sen's slope unit is in mm/year

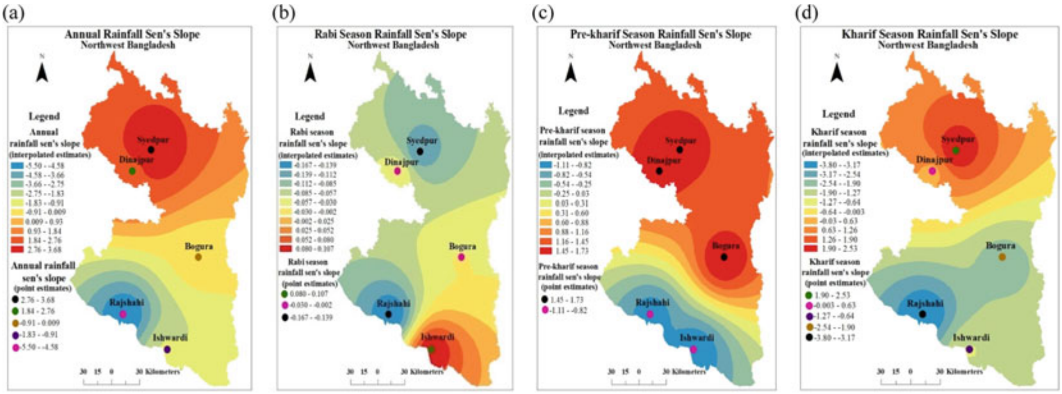

Fig. 5.4 Distribution of Sen's slope estimates **a** Annual average rainfall **b** *Rabi* rainfall **c** Pre-*Kharif* rainfall **d** *Kharif* rainfall

5.3.3.3 Kharif Season

The *Kharif* rainfall is very important for Aman rice production because rice is the main staple food in our country. The average annual rainfall during this season was 1104.8 mm. In this season, Rajshahi station received the least amount of maximum rainfall (1583 mm), and Syedpur station found maximum rainfall (2440 mm). The coefficient of variation is high (29.87%) at Dinajpur station and low (24.98%) at Rajshahi station (Fig. 5.2d). During the month of July to October is considered as the *Kharif* season in our country. In the present study, long-term *Kharif* season was dominated by a mixed rainfall trends in all stations. The MK test and SR test results were detected with same trend directions in the northwest region. From trend analysis, Rajshahi station showed the most significant decreasing trend with − 2.53 at 5% level of significance; on the contrary, Bogura and Ishwardi stations also observed decreasing trend in all trend analysis test, but they were not statistically significant. Moreover, the degree of change obtained by Sen's slope results was − 3.80, − 2.18, and − 1.24 mm/year at Rajshahi, Bogura, and Ishwardi stations, respectively. Dinajpur and Syedpur stations exhibited insignificant positive trends of 0.20 and 0.935 in accordance with the MK test statistic (*Z*), and the magnitude of change assessed by Sen's slope estimates of these two stations was 0.50 and 2.53 mm/year, respectively. According to the SR test results, all stations found a downward trend varied from − 2.711 to 0.717 (Table 5.3). The spatial distribution of MK *(Z)* statistic and Sen's slope estimates of the *Kharif* rainfall trends is shown in (Figs. 5.3d and 5.4d).

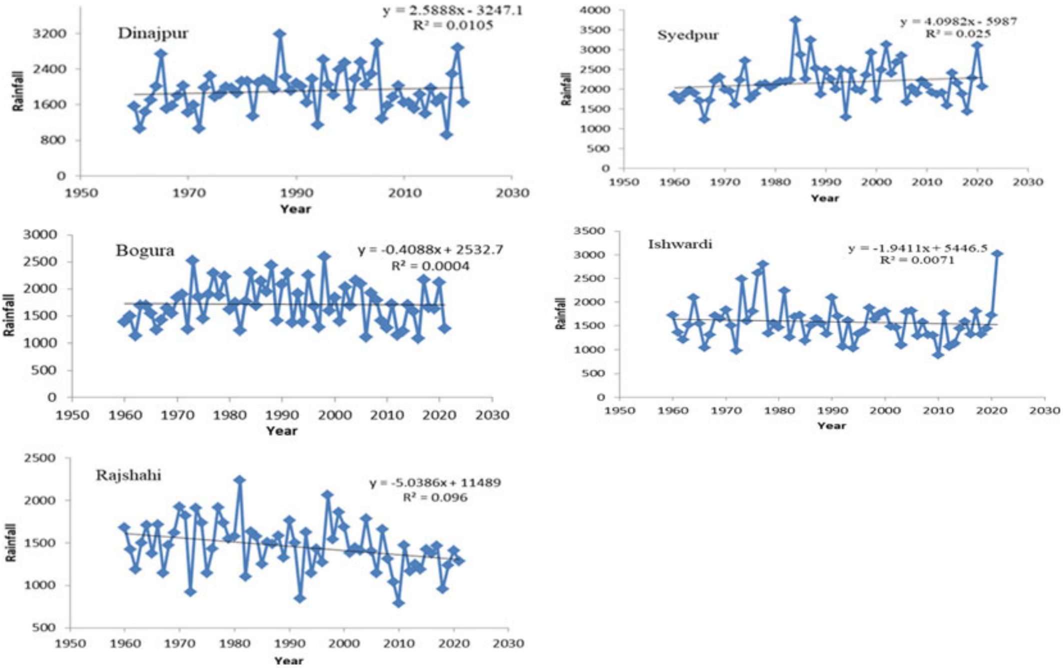

Fig. 5.5 Linear regression trends of annual average rainfall in northwest Bangladesh at five stations during 1960–2021

The linear trend line of yearly rainfall in the northwest region during 1960–2021 is displayed in (Fig. 5.5). The graph indicates that the trend line is decreasing at Bogura, Ishwardi, and Rajshahi stations, while an increasing annual average rainfall at Syedpur and Dinajpur stations.

5.3.4 Annual Temperature Features

The long-term annual mean temperature in the northwest recorded stations was 24.96 °C, and the temperature ranged from 24.30 °C (Syedpur) to 25.30 °C (Rajshahi). Based on historical temperature data, the warmer average extreme temperature varied from 26.57 °C to 25.35 °C, and the cooler average minimum temperature lied between 20.64 °C and 24.67 °C. It was evident that (Table 5.4) along with other descriptive analysis of annual temperature, the standard deviation was high (0.75 °C) at Syedpur station and low (0.31 °C) at Bogura station. The coefficient of variation of temperature data varied from 1.24% to 3.07% at different stations. It means Syedpur station observed maximum temperature variation. The long-term annual mean temperature is shown in (Fig. 5.6a) by spatial distribution analysis. The temperature dataset

Table 5.4 Descriptive statistics of the annual mean temperature of Bangladesh (1960–2021)

Stations	Annual temperature (°C)						
	Min	Max	Mean	CV (%)	SD	Skewness	Kurtosis
Bogura	24.67	26.08	25.24	1.24	0.31	0.613	0.204
Dinajpur	24.10	26.03	24.90	1.75	0.43	0.835	0.521
Ishwardi	24.12	26.26	25.08	1.52	0.38	0.242	1.369
Rajshahi	24.43	26.57	25.30	1.84	0.47	0.856	0.369
Syedpur	20.64	25.35	24.30	3.07	0.75	− 2.504	9.380

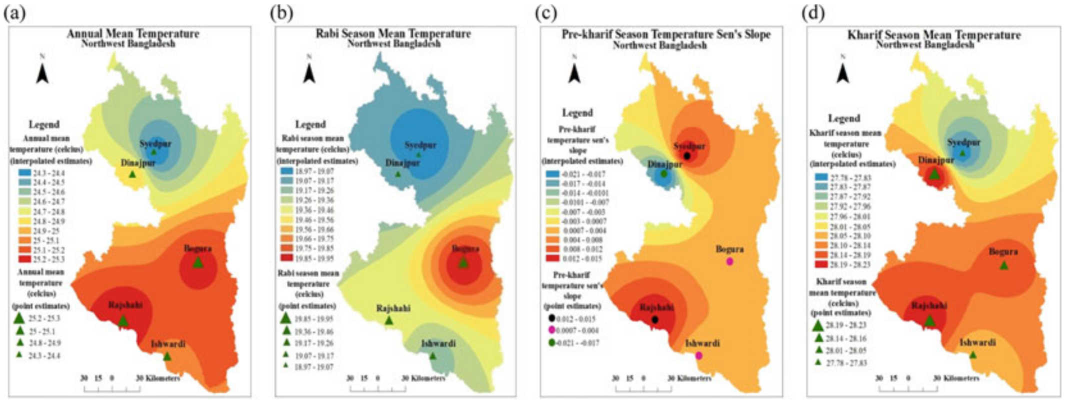

Fig. 5.6 Distributions of **a** Annual average temperature **b** *Rabi* temperature **c** Pre-*Kharif* temperature **d** *Kharif* temperature

was positively skewed in four stations, except Syedpur stations which found negative skewness. Similar results were identified for kurtosis. From the analysis, it is clearly said that the datasets are leptokurtic not mesokurtic.

5.3.5 Trend Analysis of Annual Temperature

The annual mean temperature observed that 80% of the stations displayed an increasing trend, except Dinajpur station which found decreasing trend (Table 5.5). During 60 year period, the highest significant rising trend was found at Bogura and Syedpur stations by the MK test statistic (Z) and SR test, and the magnitude of changes discovered by the Sen's slope estimates were 0.0095 °C/year and 0.017 °C/year, respectively. Ishwardi and Rajshahi stations also presented rising tendencies in annual temperature analysis, but not statistically significant. Apart from that, only Dinajpur station was shown falling trend with the MK test (− 1.014) and SR test (− 1.655), and the rate of change assessed by the Sen's estimates was − 0.003 °C/year. Meanwhile, Kendall's tau received positive relationships over time. The spatial distribution of average annual temperature is displayed in (Figs. 5.7a and 5.8a). Over the years, upward trend of temperature is dominating in this part of the country which will create more dry years and extreme temperature in the future. Linear trend analyses of the long-term annual temperature are shown in (Fig. 5.9).

5.3.6 Trend Analysis of Seasonal Temperature

5.3.6.1 Rabi Season

This season is characterized by the coldest temperature in Bangladesh, generally referred to as winter. The average temperature during *Rabi*

Table 5.5 Long-term annual temperature trend test results

Stations	MK test	Sen's slope	Kendall's tau	SR test
Bogura	4.514*	0.0095*	0.395*	5.040
Dinajpur	− 1.014	− 0.003	− 0.089	− 1.655
Ishwardi	1.451	0.004	0.130	1.390
Rajshahi	1.233	0.004	0.109	1.044
Syedpur	5.674*	0.017*	0.495*	7.259*

* Significant trends at 5% level, Sen's slope unit is in mm per year

season fluctuates from 18.97 to 19.95 °C with an average value 19.32 °C. In this season, the minimum temperature at different stations varied from 16.91 °C (Syedpur) to 18.78 °C (Bogura), and the maximum temperature ranged from 20.60 °C (Syedpur) to 21.52 °C (Rajshahi) (Fig. 5.6b). The coefficient of variation of temperature data varied from 2.51 to 4.16%; i.e., low-temperature variability was found at Bogura station, and high-temperature variability was described at Dinajpur station. The MK and SR test findings indicated that the trend fluctuations were identified by both positive and negative directions. According to the 60 years of historical data, 60% stations (Dinajpur, Ishwardi, and Rajshahi) showed a decreasing trend and 40% stations (Syedpur and Dinajpur) experienced a rising trend with the MK test results or SR test analysis (Table 5.6). The values of MK test statistic (*Z*) ranged from − 0.83 to 2.81. The degree of change evaluated by Sen's slope estimates was − 0.09, − 0.004, and − 0.01 °C/year at Dinajpur, Ishwardi, and Rajshahi stations, respectively, but statistically insignificant (Table 5.6). From the study, only Syedpur station revealed a significant rate of change with 0.014 °C/year. The spatial distribution of MK test statistic (*Z*) and Sen's slope estimates is displayed in (Figs. 5.7b and 5.8b).

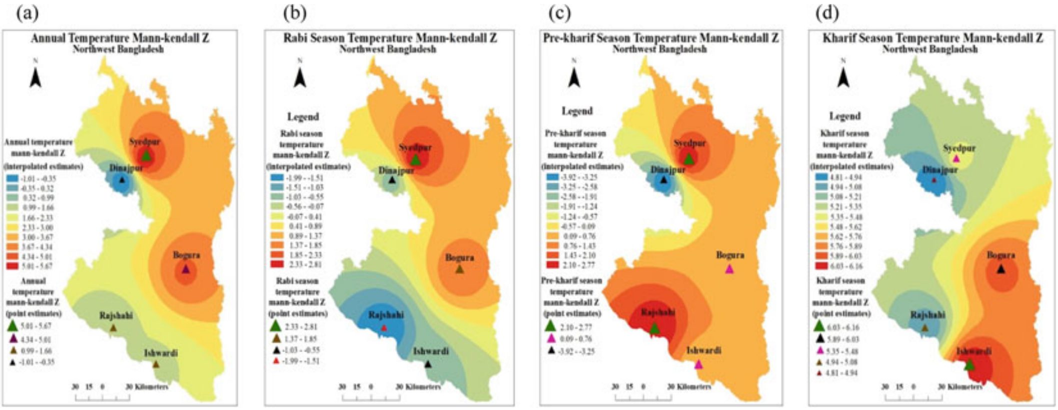

Fig. 5.7 Distributions of *Z* statistics estimates **a** Annual average temperature **b** *Rabi* temperature **c** Pre-*Kharif* temperature **d** *Kharif* temperature

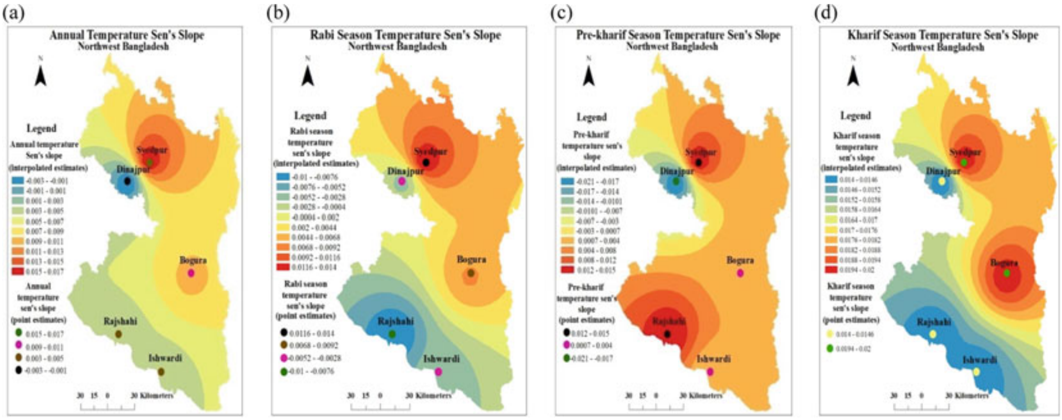

Fig. 5.8 Distribution of Sen's slope estimates **a** Annual average temperature **b** *Rabi* temperature **c** Pre-*Kharif* temperature **d** *Kharif* temperature

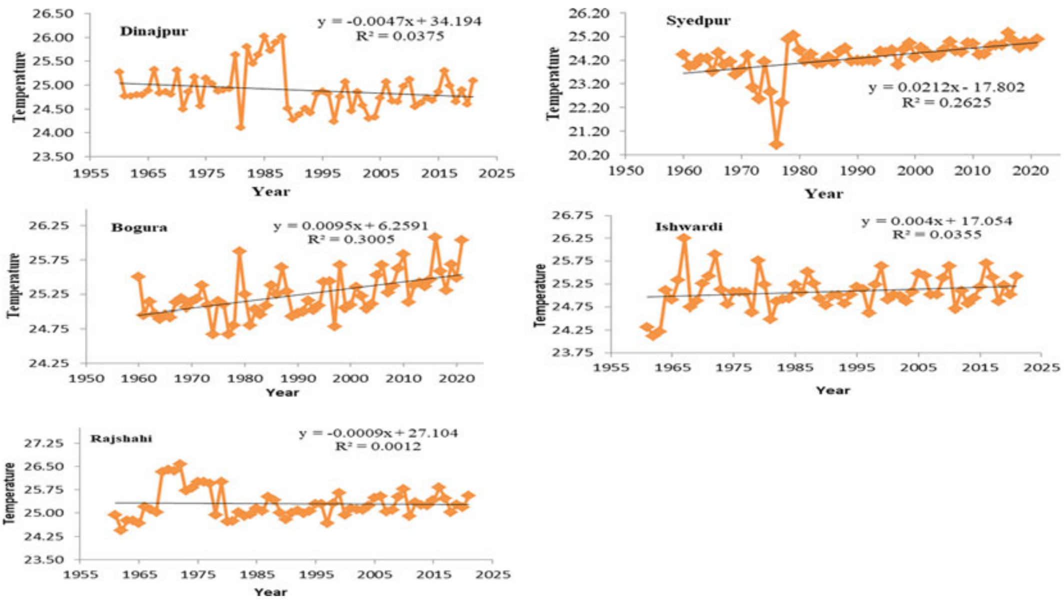

Fig. 5.9 Linear regression trends of annual average temperature during 1960–2021

5.3.6.2 Pre-Kharif Season

During the pre-*Kharif* season temperature analysis, Rajshahi station found average maximum temperature of 30.66 °C, while Syedpur station received 20.68 °C minimum average temperature. The overall average temperature ranged from 26.14 °C to 28.25 °C with a mean value of 27.47 °C. The standard deviation of pre-*Kharif* season temperature varied from 0.63 °C to 1.27 °C, and the CV showed 2.27% at Bogura station and high 4.85% at Syedpur station (Fig. 5.6c). In the study area, 80% of stations observed a strongly positive trend, while 20% station showed negative trend. From trend analysis, Dinajpur, Rajshahi, and Syedpur were statistically significant, but other two stations (Bagura, Ishwardi) were insignificant with increasing trends. Both the MK test and SR test revealed identical result, but only the Rajshahi station showed decreasing trend of − 0.744 in the SR test (Table 5.6). The proportion of change assessed by the Sen's slope estimates ranged from − 0.02 to 0.02 °C/year. However, a station like Dinajpur showed only a significant downward trend at 95% confidence interval, and the magnitude of change was –0.02 °C/year (Table 5.6). The areal dissemination of different stations indicates that in the future temperature trend is more increasing in the northwest region (Figs. 5.7c and 5.8c).

Table 5.6 Long-term seasonal temperature trend test results

Stations	Rabi season			Pre-Kharif season			Kharif season		
	MK test	Sen's slope	SR test	MK test	Sen's slope	SR test	MK test	Sen's slope	SR test
Bogura	1.85	0.007	1.875	0.48	0.003	0.512	5.95*	0.02*	7.542*
Dinajpur	− 0.890	− 0.09	− 1.130	− 3.92*	− 0.02*	− 4.9*	4.81*	0.01*	5.529*
Ishwardi	− 0.834	− 0.004	− 0.799	0.24	0.001	0.227	6.16*	0.01*	8.016*
Rajshahi	− 1.99	− 0.01	− 1.671	2.77*	0.015*	− 0.744	4.96*	0.01*	6.118*
Syedpur	2.81*	0.014*	2.956*	2.77*	0.02*	2.753*	5.41*	0.02*	6.216*

* Significant trends at 5% level, Sen's slope unit is in mm per yer

5.3.6.3 *Kharif* Season

The *Kharif* season, which runs from July through October, is primarily referred to as a rainy season of Bangladesh. The annual average temperature during this time varied from 27.28 °C (Syedpur) to 28.23 °C (Dinajpur), with a mean value of 28.08 °C. The maximum average temperature ranged from 29.33 °C to 29.03 °C, and the minimum average temperature varied from 21.78 °C to 26.70 °C (Fig. 5.6d). The standard deviation of *Kharif* season temperature was low (0.35 °C) at Ishwardi station and comparatively high (1.13 °C) at Syedpur station. Among all the stations, the coefficient of variation was maximum at Syedpur station with 4.08%. Trend analysis of different stations revealed that significant rising trends were found at all five stations, which means the temperature was increased rapidly in the *Kharif* season. The MK test result showed that Ishwardi station experienced the highest positive trend (6.16), while Dinajpur station found the least positive trend (4.81) at 95% confidence interval. Almost similar result was predicted by the SR test analysis. Sen's slope analysis points out that the degree of change varied from 0.01 to 0.02 °C/year with an average 0.014 °C/year (Table 5.6). The spatial map of MK test and Sen's slope estimates is displayed in (Figs. 5.7d and 5.8d) which indicates that significant rising trend continues in the northwest region.

The linear trend analysis during 1960–2021 is displayed in (Fig. 5.9). The graphical analysis indicates that annual average temperature trend lines are decreasing at Dinajpur and Rajshahi stations and increasing at Syedpur, Bogura, and Iswardi stations.

5.3.7 Sequential Mann–Kendall (SMK) Analysis for Annual Rainfall and Temperature

5.3.7.1 Annual Rainfall

The SMK test determines the approximate year where the trend begins at 95% confidence limit. Results from the SMK test revealed that considering $u(t)$ statistics had almost similar to the MK test with decreasing trend at Bogura, Rajshahi, and Ishwardi stations. Here, no,-significant change of points is depicted in Bogura and Ishwardi station, but some abrupt change in annual rainfall was found 15 years ago at Rajshahi station approximately with a significant change point. The rest of the stations (Dinajpur and Syedpur) showed rising trend that starts early year of 1960 to 1965 but noticeable decreasing changes also display after 2004–2005. The SMK plot of different stations in the northwest zone is displayed in (Fig. 5.10).

5.3.7.2 Annual Temperature

The annual temperature analysis of the SMK test exhibited an upward tendency in almost all stations except Dinajpur. From trend analysis, more than one non-significant trend turning points was described at Dinajpur, Ishwardi, and Rajshahi stations, but only Dinajpur station discovered decreasing trend which starts from 1988 to 1990 and it continued till 2020. On the other hand, Rajshahi and Ishwardi stations also found periodic fluctuations between the late 1990s and 2020. A periodic significant upward trend was detected at Bogura and Syedpur stations defining only a trend turning point in the year 2003–2004, and the increment continued. It means that the temperature trend analysis method is dominant after 2003–2004 for Bogura and Syedpur stations. The following Fig. 5.11 represents SMK test analysis trend of annual temperature of different station.

5.3.8 Forecast from ARIMA Models

According to different trend analysis methods, the northwest zone experiences high temperatures and less rainfall throughout the year. The country's economy mostly depends on agricultural production, and about 80% of the population, directly and indirectly, depends on primary economic activities (Kamruzzaman et al. 2018). In our country, the summer monsoon receives the most precipitation, which directly affects our agricultural productivity. Adequate information on total rainfall and temperature characteristics helps our

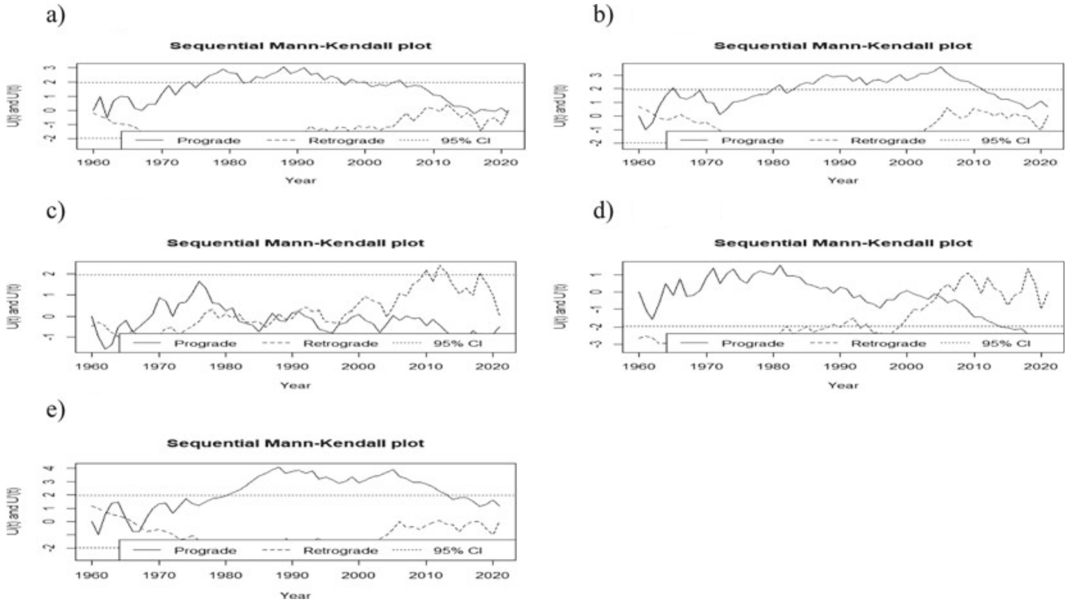

Fig. 5.10 Detection of annual rainfall trends **a** Bogura **b** Dinajpur **c** Ishwardi **d** Rajshahi **e** Syedpur by sequential MK analysis

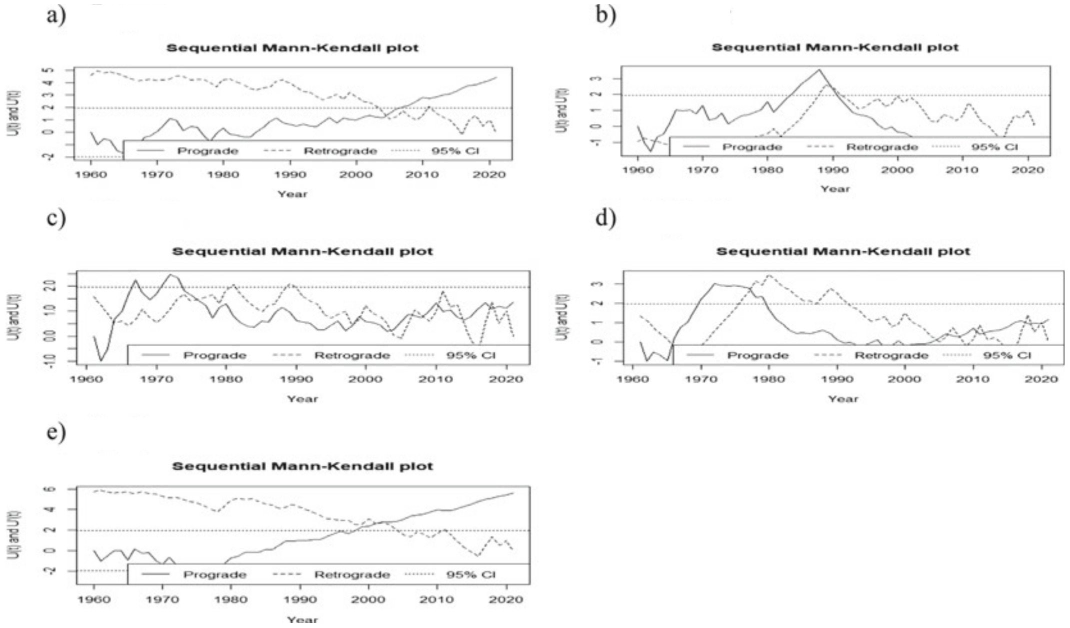

Fig. 5.11 Detection of annual temperature trends **a** Bogura **b** Dinajpur **c** Ishwardi **d** Rajshahi **e** Syedpur by sequential MK analysis

farmers and policymakers to draw a comprehensive picture of the monsoon and dry seasons. Early climate prediction lessens significant crop damage from drought, flood, and other climatic calamities. Moreover, if the total annual rainfall is normal, the intra-seasonal variability, such as early monsoon onset or usual monsoon throughout the year, may cause unavoidable disruption of agricultural activities, hydro-electric power supply, groundwater depletion, or even drinking water supply. The ARIMA technique is applied here to forecast monthly rainfall and temperature data for future five years (60 months) based on sixty years data. Previous years' data is cast-off to articulate the seasonal ARIMA model in determining model parameters.

5.3.8.1 Monthly Rainfall Forecast

Sixty years of monthly rainfall data is analyzed and used to predict future rainfall scenarios. The following table provides the estimated parameters for the ARIMA model of monthly rainfall (Table 5.7).

The station-wise forecasting values of the next five years monthly rainfall of different stations are displayed in (Fig. 5.12). In our study, monthly rainfall varied one station to another due to the diverse geographical locations.

5.3.8.2 Monthly Temperature Forecast

The monthly temperature predictions of all stations are detailed below (Table 5.8). The expected parameters of the ARIMA model for the next five years are based on the previous sixty years data.

It has been detected that the monthly predicting temperature not only fluctuates in one station with a small margin (Fig. 5.13) but also fluctuates from one station to another. Moreover, the temperature has been rising over the years in the northwest zone, and gradually it will increase in the near future also.

5.4 Conclusion

The present chapter elaborates on the latest trends in rainfall variability and temperature during 1960–2021 at five distinguished weather stations in the northwest Bangladesh. The MK test and SR test are equally effective in assessing rainfall and temperature trends. Sen's estimation also gives excellent results, and it is almost identical to the MK test statistic and SR test results. From the recent research work, it is established that the average annual rainfall is 1768 mm and temperature is 24.96 °C. Whereas Syedpur station shows the highest amount of annual average rainfall, Rajshahi station receives the maximum average temperature in the northwest zone. The study findings discover that only Rajshahi station shows maximum significant downward trend of annual rainfall (− 5.50 mm/year), as well as the *Kharif* season (− 3.80 mm/year) also by Sen's estimation. However, other stations represent increasing/decreasing trend by the MK test, SR test, and Sen's slope estimator, but they are not statistically significant. The total rainfall statistic exhibits a substantial change during the research period. These kinds of changes in most of the

Table 5.7 ARIMA models of monthly rainfall data

Station	Month January 1960–December 2021				
	Model	Sigma^2 estimated	Log-likelihood	AIC	BIC
Bogura	ARIMA(0,0,1)(1,1,0)[12]	14,253	− 4540.04	9086.09	9099.87
Dinajpur	ARIMA(0,0,3)(2,1,0)[12]	17,660	− 4618.73	9249.45	9277.0
Ishwardi	ARIMA(1,0,0)(1,1,0)[12]	13,235	− 4513.08	9032.16	9045.95
Rajshahi	ARIMA(1,0,0)(1,1,0)[12] with drift	9365	− 4386.2	8780.4	8798.78
Syedpur	ARIMA(1,0,0)(1,1,0)[12] with drift	21,813	− 4695.41	9398.83	9417.21

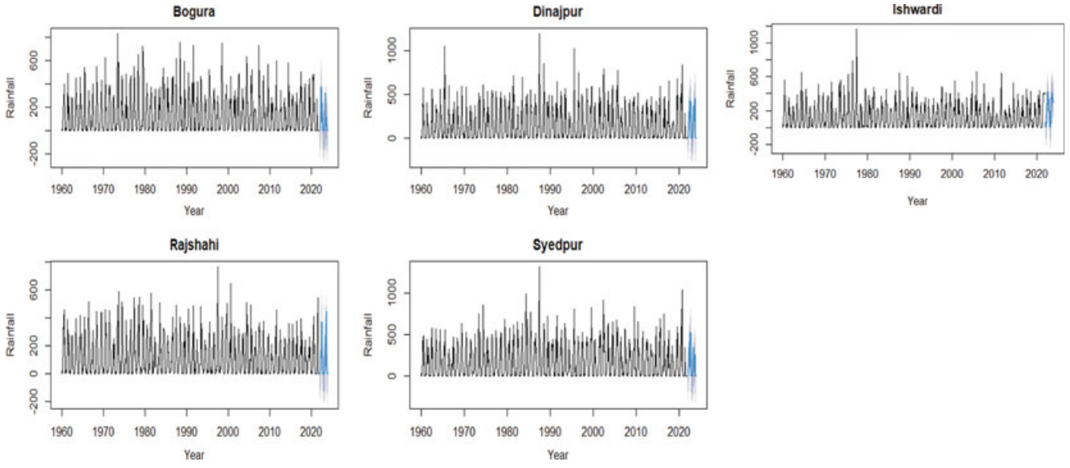

Fig. 5.12 Forecasting monthly rainfall of different stations

Table 5.8 ARIMA models of monthly temperature data

Station	Month January 1960–December 2021				
	Model	Sigma^2 estimated	Log-likelihood	AIC	BIC
Bogura	ARIMA(2,0,2)(2,1,0)[12] with drift	1.103	− 1073.5	2163	2199.76
Dinajpur	ARIMA(0,0,3)(2,1,2)[12]	0.9458	− 1023.63	2063.27	2100.03
Ishwardi	ARIMA(2,0,2)(2,1,2)[12]	0.6953	− 897.94	1813.89	1855.1
Rajshahi	ARIMA(0,0,2)(0,1,1)[12] with drift	0.8151	− 954.94	1919.88	1942.78
Syedpur	ARIMA(0,0,1)(0,1,1)[12] with drift	1.317	− 1146.91	2301.82	2320.2

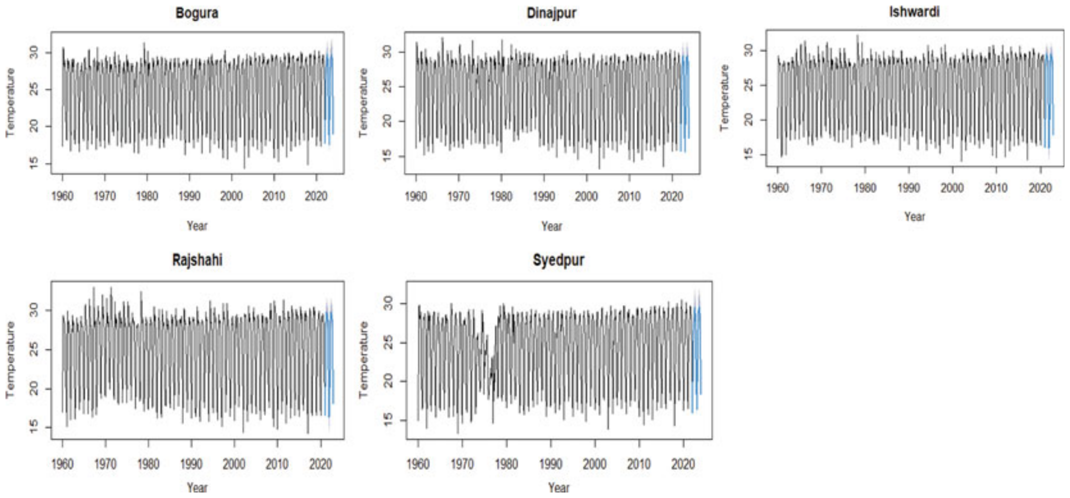

Fig. 5.13 Forecasting monthly temperature of different stations

stations placed the northwest region in danger and increased drought frequency. However, climate variable like temperature also observed an increasing trend 80% of stations, but Dinajpur station reveals a falling trend with a magnitude of change − 0.003 °C/year. From cropping season temperature trend analysis, both upward and downward trends are found during the *Rabi* and pre-*Kharif* seasons. But *Kharif* season shows noteworthy trend of increment at 5% significance level. The degree of change is assessed by Sen's slope estimates which differ from 0.01 to 0.02 °C per year with an average value of 0.014 °C per year. Additionally, SMK analysis has illustrated the starting and turning points of the annual trends. In this chapter, the ARIMA models are used for long-term monthly rainfall and temperature data to forecast future trend in the northwest region. Based on the findings, the information is gathered consistently with the previous studies and will be supportive for farmers, policymakers and researchers on local-scale scheduling on climate change scenarios of the country. Therefore, sustainable adaptation practices are mandatory for agricultural development in the northwest area.

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