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EXPLORING CLIMATE CHANGE TRENDS IN TEMPERATURE AND RAINFALL ACROSS THE SOUTHEASTERN COASTAL AREA OF BANGLADESH

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ABSTRACT

Climate change has become a major concern for scientists all over the world. Bangladesh is considered one of the most vulnerable countries in the world to the negative impact of climate change. Particularly, the coastal part of the country faces a high risk due to the impact of climate and the frequent occurrence of natural disasters, including extreme rainfalls, waterlogging and flash flooding, cyclones, storm surges, and sea-level rise. Therefore, it is essential to explore the trends of climate change in terms of changes in rainfall and temperature in the past decades over the coastal region in Bangladesh. Hence, the aim of the current study is to assess the long-term climate change trends in monthly, seasonal, and annual temperature and rainfall caused by the impact of climate change. Four climate stations located in the southeastern coastal area in Bangladesh, including Cox's Bazar, Teknaf, Hatiya, and Sandwip, are selected. Temperature and rainfall data are collected from the Bangladesh Meteorological Department, and 50 years of data (1950-2023) are used for the analysis. Both statistical and graphical methods are adopted for the analysis of climate change trends, in which the widely applied Mann-Kendall (MK) and Sen's slope (SS) techniques are adopted as the statistical method, whereas the innovative trend analysis (ITA) technique is used as the graphical method. MK, SS, and ITA techniques revealed an overall increasing trend of monthly, annual, and seasonal temperature and rainfall in the study area. The results are statistically significant at the 5% significance level in most cases. Likewise, similar trends are also found in the monthly, annual, and seasonal temperature and rainfall patterns in the study area based on the ITA technique. However, seasonal rainfall trends exhibit both significant and non-significant increasing-decreasing patterns in some cases, demonstrating the most stochastic nature of rainfall in the study area. It is also important to note that MK, SS, and ITA techniques detect similar results of climate change trends in temperature and rainfall. This justifies the viability of using the user-friendly graphical ITA technique in line with the statistical MK and SS techniques for the trend analysis. Thus, it is expected that the findings of the current study could be supportive in planning for the effective climate change adaptation and management policies to address future climate change-induced disasters across the southeastern coastal area of Bangladesh.

Keywords: *Climate change trend; Mann-Kendall Test; Sen's Slope Estimator; Innovative Trend Analysis.*

1. INTRODUCTION

Climate change has emerged as a global threat for mankind. According to the IPCC (2008), the global average temperature could increase by 1.4 to 5.8 °C in 2100 with mean water level rise by 10 cm in next decades (Roth et al., 2018). Bangladesh is expected to experience an increase in average daily temperatures of 1.0˚C by 2030 and 1.4˚C by 2050, indicating the negative outcome of anthropogenic climate change (IPCC, 2014). The IPCC (2023) mentioned in their Sixth Assessment Report (AR6) that anthropogenic activities are the main drivers through the release of greenhouse gases by burning fossil fuels, land-use change, deforestation, and unsustainable energy use that undeniably caused global warming. Rimi et al. (2022) predicted that extreme precipitation events will increase in Bangladesh in the future due to global warming. Ray et al. (2019) mentioned that temperature plays a pivotal role in climate change and works as an indicator of global warming. Girma et al. (2016) mentioned that precipitation is the key factor for affecting the spatial and temporal patterns of water resources. According to New et al. (2001), the amount of precipitation has been increasing globally on average 2% over the last 100 years. Myhre et al. (2019) identified that an increase in relative humidity leads to heavy rainfall and increases the risk of flooding. Mirza et al. (2003) discovered that extreme rainfall could increase the probability of flash floods. Chowdhury & Ward (2007) stated that the El Niño and La Niña phases of the ENSO cycle can lead to increased seasonal shifts in mean extreme precipitation and caused flooding events. Salam et al. (2020) revealed that climate change is expected to increase in temperature and shifting rainfall patterns in Bangladesh, which may potentially impact its water resources, agriculture sectors and public health.

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In recent years, there have been notable shifts in temperature and rainfall patterns that were identified in different parts of the world (An et al., 2023; Kuttippurath et al., 2021; Panda & Sahu, 2019; Prokop & Walanus, 2015; Ray et al., 2019; Umar et al., 2019). Bangladesh is considered more vulnerable to the negative impact of climate change due to its geographical location, low topography, socio-economic conditions, and high population density. Particularly, the coastal part of the country is in severe threat due to the impact of climate change. Climate change poses a severe risk to the region that has already been affected by natural disasters, including extreme rainfalls, waterlogging, flooding, cyclones, storm surges, and sea-level rise (Hossain et al., 2014). The country is expected to have an increase in average daily temperatures of 1.0˚C by 2030 and 1.4˚C by 2050, indicating the impact of anthropogenic climate change (IPCC, 2014). Following the IPCC predictions (IPCC, 2023), the frequency of occurrence of the extreme rainfall is expected to increase in Bangladesh due to the impact of climate change (Rahman and Islam, 2019). It is important to note that the coastal part of the country exhibits an increasing trend in temperature and rainfall as predicted by the IPCC. Hossain et al. (2014) investigated the variability of rainfall in the southwest coastal area of Bangladesh, where they found increasing trends. Rimi et al. (2009) explored the current and future trends in climatic parameters at the local level and the potential impacts of climate change on paddy production in Satkhira, Bangladesh. Climate variability has a severe impact on crop yield variability (Ghose et al., 2021). Rahman et al. (2023) discovered that annual precipitation increased only in the southeastern zone of Bangladesh while the other zones experienced a downfall spanning from 1989 to 2020. They also found in their study that no significant changes were observed in annual maximum temperature, whether in the southeast, northeast, or south-central zones, which showed variations ranging from 0.02 to 0.05°C/year. Hasan & Kumar (2020) revealed that the west coast receives less annual rainfall than the eastern coast by about 100 cm. Therefore, it is essential to explore the trends of climate change in terms of changes in rainfall and temperature in the past decades over the coastal region of Bangladesh.

Numerous studies have been conducted all over the world to explore the climatic trends by using parametric and non-parametric tests (Adarsh & Reddy, 2015; Ali et al., 2019; da Silva et al., 2015; Gajbhiye et al., 2015; Khalil, 2023; Singh et al., 2021). Miró et al. (2022) demonstrated that the trend analysis is an important tool for climate change impact assessment and perceiving past alterations in extreme rainfall and temperature events. According to Onyutha (2016), the best way to get influential information is to use a combined graphical and statistical trend testing methods. Yürekli (2015) stated that the Mann-Kendal (MK) test is the widely used method for detecting increment or decrement trends among the commonly used non-parametric techniques. Jiqin et al. (2023) revealed that Sen's slope (SS) estimator is able to estimate the long-term trend magnitude for time series data. Mullick et al. (2019) applied the pre-whitening approach in addition to MK and SS techniques to explore the trends in temperature and precipitation at 35 stations over Bangladesh for a 50-year period from 1966 to 2015, and in their study, temperature and precipitation showed an upward trend for the overall year except winter season. Sahu et al. (2024) applied the SS estimator for long-term precipitation variability using trend analysis on seasonal and annual time series of 149 stations in Chhattisgarh State, Central India, using 120 years spanning from 1901 to 2020. They revealed that maximum blocks showed decreasing rainfall trends, while some blocks detected increasing trends like Bhopalpattnam, Bijapur, Usur, and Konta. Yacoub & Tayfur (2019) applied the Sen's slope and MK tests for identifying the annual temperature and precipitation trends in Mauritania in Africa during 1970–2013, and they found in their study that temperatures and precipitation time series had shown substantial upward trends. Duhan & Pandey (2013) applied the SS and MK techniques for annual precipitation data in Madhya Pradesh, India, for 102 years (1901–2002), and the results shows a downward trend.

Recently, a graphical method named innovative trend analysis (ITA) technique has been emerged as a useful technique for trend analysis. The ITA graphical technique directly interprets the visual inspection of trend type (increasing, decreasing, or no trend) and then calculates trend slope numerically. Cui et al. (2017) discovered the fact that the ITA technique is very advantageous to detect trends in climatic variables, hydrological parameters, and air pollutants. Öztopal and Sen (2017) used the ITA technique for analyzing the precipitation trend at seven stations in Turkey. Elouissi et al. (2016) applied the ITA method to detect precipitation variability at 25 weather stations in Algeria, and the results revealed that there is a downward trend in the northern region of the Mediterranean Sea coast, whereas an upward trend is found in the south of the Macta basin. Accordingly, researchers adopted the non-parametric ITA technique in addition to the aforementioned statistical (MK and SS estimator) method in numerous scientific studies around the world due to their simplicity in use and easy in trend detection. For example, Nath et al. (2024) combinedly adopted the MK, modified MK, SS estimator, and innovative trend analysis (ITA) methods to assess the long-term trends in annual average rainfall in southeastern region of Bangladesh. Ay & Kisi (2014) applied MK and ITA techniques to investigate the trends of monthly total precipitation in the Black Sea and Central Anatolia regions. Likinaw et al. (2023) utilized the ITA and MK tests to study extreme rainfall trends over three districts in the northwestern highlands of Ethiopia during 1981 to 2018, and they found both upward and downward trends in precipitation series. Sanusi et al. (2021) applied ITA, MK, and SS estimator techniques for daily rainfall trend analysis at two climate stations in Gowa Regency for a 31-year period (1988–2018), and results showed decreasing trends at both stations. Therefore, the objective of the current study is to detect the long-term climate change trends in monthly, seasonal, and annual temperature and rainfall over the southeastern coastal region in Bangladesh using the statistical MK and SS estimator techniques as well as the graphical ITA technique. It is expected that the outcome of the current study could be supportive to the decision makers in planning for adaptive water resource management as well as for future disaster management over the south-eastern coastal area in Bangladesh.

2. METHODOLOGY

The current study focuses on the statistical analysis of the climate change over the southeast coastal region of Bangladesh. Fig. 1 shows the location of the study area. In order to carry out the analysis, four weather stations namely, Cox's Bazar, Teknaf, Sandwip, Hatiya stations, respectively located in the study area, are selected from the region. While selecting the weather stations, it is considered that the station has at least 30 years of available data. In this study, past records of climate data (rainfall and temperature time series) in the study area are analyzed from 1966 to 2023. Accordingly, the trends in rainfall and temperature data in the study area due the impact of climate change are explored using the widely adopted statistical (MK test) and graphical (ITA) methods. The analysis is performed using the XLSTAT and MS Excel software packages.

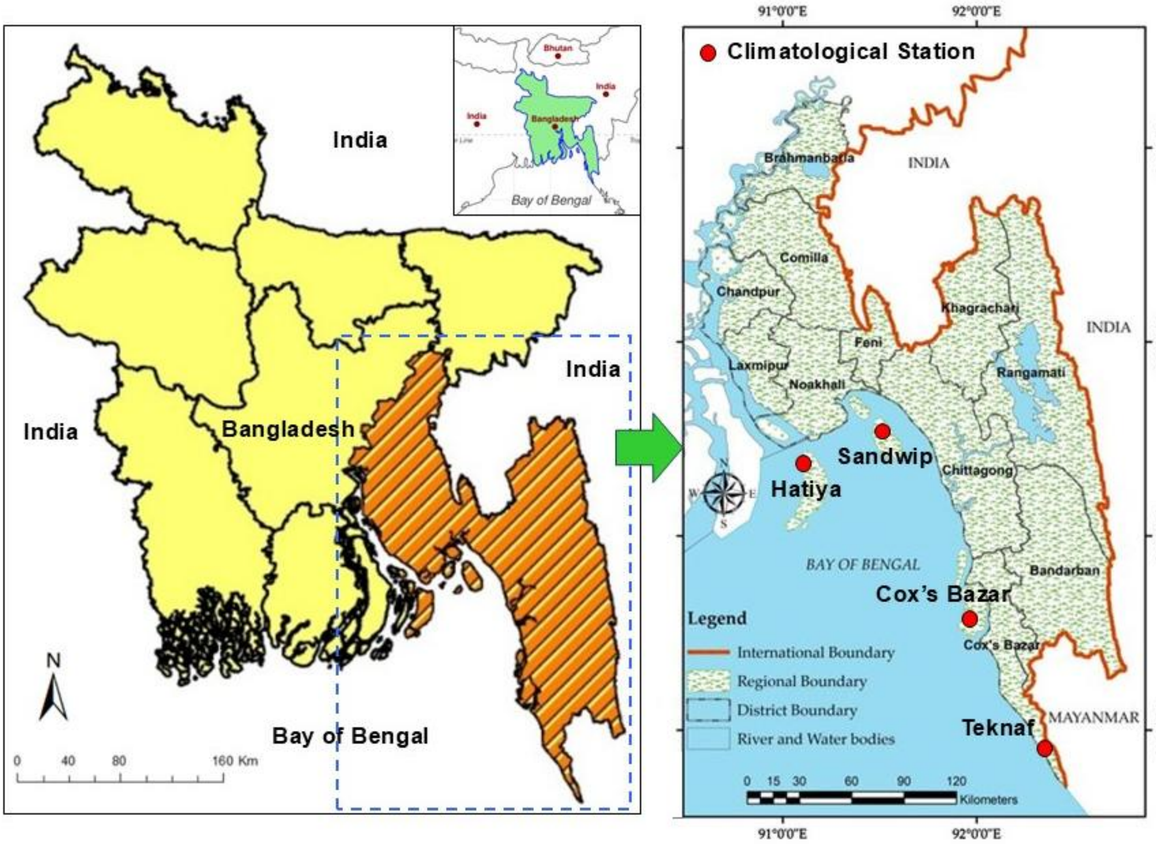

Figure 1: Location of the south-eastern coastal area in Bangladesh with climate stations

2.1 The Study Area and Data Used

Bangladesh is geographically located between 20.57°N - 26.63°N latitude and 88.01°E - 92.68°E longitude. Bangladesh has a hot, humid and tropical monsoon climate which is primarily dominated by seasonal circulations. The southwestern monsoon emerges from the Indian Ocean and carries hot, humid and unstable air (Kamruzzaman et al., 2018). Bangladesh has four distinct seasons: winter (December-February), pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October–November) (Rashid, 1991). The average temperature of the country is about 25.75˚C (Rahman et al., 2018). The annual precipitation of Bangladesh ranges between 1329 mm in the northwest to 4338 mm in the northeast meanwhile the western coast receives lower amount of precipitation (Shahid & Khairulmaini, 2009). The current study has been carried out on four weather stations in the coastal part of Bangladesh inlcuding Cox's Bazar, Teknaf, Sandwip and Hatiya stations, respectively (Fig. 1). The coastal part of the country usually experiences flash floods, cyclonic storm surge and thunderstorms. Hence, it is important to study the statistical analysis of temperature and rainfall time series data to explore the potential climate changes in the coastal part of Bangladesh.

The climate of Bangladesh is highly dominated by the southwest monsoon wind. Climate change has intensified shifts in climatic parameters like temperature and rainfall. The current study aims to detect the long-term monthly, seasonal and annual temperature and rainfall trends over four weather stations namely, Cox's Bazar, Teknaf, Sandwip, Hatiya stations, respectively. Long-term ime series data of temperature and rainfall are collected from the Bangladesh Meteorological Department (BMD). While selecting the weather stations, it is considered that the station has at least 30 years of available data. Table 1 presents summary of the collected data.

Table 1: Summary of collected climate (i.e., temperature and rainfall) data

Station Name	Latitude (Degree)	Longitude (Degree)	Altitude (m)	Data Period
Hatiya	22.36	91.12	4	1966-2023
Sandwip	22.48	91.43	6	1966-2023
Cox's Bazar	21.45	91.97	4	1950-2023
Teknaf	20.87	92.30	5	1977-2023

2.2 Checking of Autocorrelation and Pre-Whitening

In trend analysis of time series data, the main effect is the influence of autocorrelation (Yue et al., 2002). In order to eliminate the autocorrelation effect from the datasets, the lag-1 autocorrelation coefficient r_1 is utilized at a 5% significance level to determine the existence of serial correlation in the time series data. The lag-1 autocorrelation coefficient was estimated by the following Equations:

$$\sum(x_i) = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

Where, $\sum x_i$ defines the mean of sample data and *n* denotes sample size.

$$r_1 = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}\left[x_i - E_{(x_i)}\right] \times \left[x_{(i+1)} - E_{(x_i)}\right]}{\frac{1}{n}\sum_{i=1}^{n} x_i - E(x_i)^2} \tag{2}$$

In order to evaluate the existence of serial correlation, the (r_1) is analyzed at a 95% confidence level using two-tailed tests.

$$r_1[95\%] = \frac{-1 \pm 1.96\sqrt{n-2}}{n-1} \tag{3}$$

The data is examined serially independent when r_1 is concentrated within the significance level; Furthermore, a pre-whitening method is used to omit autocorrelation when there is a significant correlation developed by Yue et al. (2002).

The pre-whitening approach primarily eliminates the lag-1 autocorrelation from the main data *x* at the time t (Yue & Wang, 2002) by the following Equation.

$$x_t' = x_t - r_1 x_{t-1} \tag{4}$$

Where r_1 represent the lag-1 autocorrelation coefficient of sample data.

2.3 Mann-Kendall Trend Test

Mann-Kendall (MK) trend test is widely used to identify the climatic trends of temperature and rainfall time series data (Nath et al., 2024). The following formula is applied to conduct S test statistics of the Mann-Kendall (MK) trend test.

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \text{sign}\left(x_j - x_i\right) \tag{5}$$

In the above formula, n denotes length of dataset meanwhile x_i and x_j indicates temperature and rainfall time series dataset in years. The function sign $(x_j - x_i)$ refers to the values such that the positive and negative sign of the slope indicates the increasing or decreasing trend, respectively.

$$\text{sign}\left(x_j - x_i\right) = \begin{cases} +1 \text{ if } \left(x_j - x_i\right) > 0 \\ 0 \text{ if } \left(x_j - x_i\right) = 0 \\ -1 \text{ if } \left(x_j - x_i\right) < 0 \end{cases} \quad (6)$$

In order to calculate the variance (S), the following equation can be given as.

$$\text{Var}\,(S) = \frac{n(n-1)(2n+5) - \sum_{i-1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \quad (7)$$

Where, n indicates the number of data points following by t_i illustrating the number of ties for i value and m represents the number of tied values. The following equation (Partal & Kahya, 2006) is applied to evaluate the standard statistic (Z) value:

$$Z_{\text{MK}} = \begin{cases} \frac{S-1}{\sqrt{\text{Var}\,(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}\,(S)}} & \text{if } S < 0 \end{cases} \quad (8)$$

According to Sneyer (1990), the null hypothesis (H_0) of no trend is rejected if |Z| > 2.575; |Z| > 1.96 and |Z| > 1.645 at the 1%, 5%, and 10% significance levels, respectively. The positive and negative values of Z_{MK} denotes increasing or decreasing trend.

2.4 Sen's Slope Estimator

Sen (1968) proposed a non-parametric method in order to detect the magnitude of change in a given data series. This is widely known as the sen slope (SS) estimator, which is expressed by Equation (9).

$$\beta = \text{median}\left(\frac{x_j - x_k}{j - k}\right), j > k \quad (9)$$

Where, x_j and x_k demonstrates the values of data points in the time series j and k ($j>k$), respectively. A positive and negative value of β refers to an upward and downward trend in a data series.

2.5 Innovative Trend Analysis

Sen (2012) presented an effective method for trend detection named innovative trend analysis (ITA) technique also known as graphical method. Fig. 2 demonstrates the framework of ITA technique to detect trends in a given data series. As can be seen from the figure, data series is usually divided into two equivalent parts in this technique. Both parts are ranked in ascending order. The first and second half of the data series is then placed on the horizontal axis and the vertical axis of the Cartesian coordinate system. If the data points fall on the 1:1 line, then it indicates that there is no presence of trend in the data. If the data points fall in the upper portion of the 1:1 line, it denotes an increasing trend whereas if the data points fall in the lower portion of the 1:1 line, it indicates a decreasing trend (Şen, 2014; Sen, 2017). In the trend analysis by the ITA technique, the slope of ITA is estimated (Şen, 2012) by Equation (10).

$$B = \frac{1}{n}\sum_{\text{i}=1}^{\text{n}} \frac{10\left(x_j - x_k\right)}{\bar{x}} \quad (10)$$

Where, B refers to the slope of ITA, n indicates the extent of individual sub-series, x_j and x_k shows the values of the consecutive sub-series, and $\bar{x}$ illustrates the mean of the first sub-series (x_k).

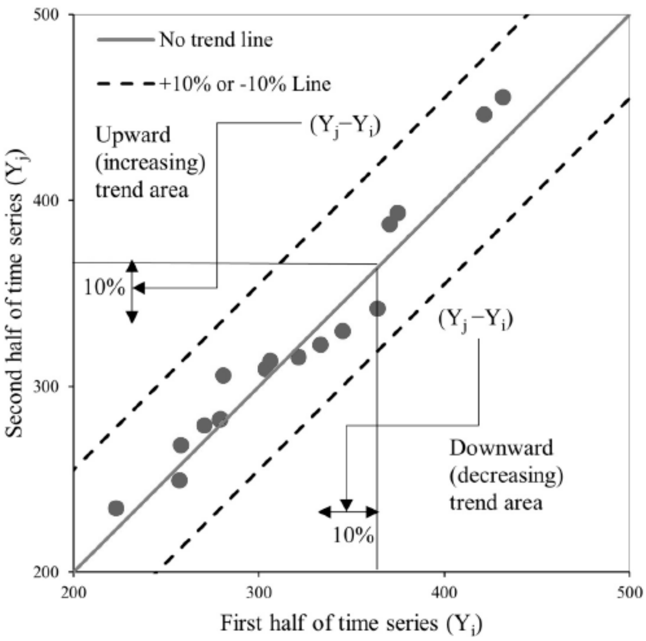

Figure 2: The ITA methodology's illustration with an upward, downward or no trend

3. RESULTS AND DISCUSSION

In the current study, the long-term monthly, seasonal and annual trend of temperature and rainfall time series data for Cox's Bazar, Teknaf, Sandwip and Hatiya stations are explored by applying the statistical (MK and SS) as well as the graphical method (ITA) methods. The findings are discussed in the following sub-sections.

3.1 Analysis of Temperature Trends

The monthly, seasonal and annual trend of temperature and rainfall time series data are calculated applying statistical methods (MK and SS). The graphical method (ITA) is also utilized for annual and seasonal temperature and rainfall time series data over Cox's Bazar, Teknaf, Sandwip and Hatiya stations. The statistical method (MK and SS) results are compared to the estimated results of the graphical (ITA) method. MK, SS and ITA method have been applied with a 5% significance level to assess the significant trends and changes in the long-term monthly, seasonal and annual average temperature trends over the study area. The results of the MK test and SS estimator on all stations are presented in Table 2.

Table 2: Summary of temperature trends over the study area using statistical based MK and SS techniques

Period	Cox's Bazar		Teknaf		Sandwip		Hatiya	
	Z_{MK}	SS	Z_{MK}	SS	Z_{MK}	SS	Z_{MK}	SS
January	5.262 (▲)	0.023 (△)	0.151 (△)	0.001 (△)	-1.645 (▽)	-0.010 (▽)	-0.750 (▽)	-0.005 (▽)
February	6.458 (▲)	0.035 (△)	1.136 (△)	0.007 (△)	0.275 (△)	0.002 (△)	0.013 (△)	4.808 (▲)
March	7.105 (▲)	0.033 (△)	3.077 (▲)	0.019 (△)	1.577 (△)	0.009 (△)	1.446 (△)	0.006 (△)
April	5.853 (▲)	0.027 (△)	2.613 (▲)	0.021 (△)	1.880 (△)	0.012 (△)	2.189 (▲)	0.013 (△)
May	4.181 (▲)	0.019 (△)	3.512 (▲)	0.029 (△)	1.466 (△)	0.010 (△)	3.786 (▲)	0.021 (△)
June	5.781 (▲)	0.023 (△)	4.772 (▲)	0.035 (△)	4.137 (▲)	0.020 (△)	5.019 (▲)	0.024 (△)
July	6.424 (▲)	0.020 (△)	4.412 (▲)	0.021 (△)	3.400 (▲)	0.019 (△)	5.845 (▲)	0.020 (△)
August	6.957 (▲)	0.024 (△)	4.952 (▲)	0.029 (△)	5.087 (▲)	0.022 (△)	6.726 (▲)	0.025 (△)
September	7.391 (▲)	0.023 (△)	5.653 (▲)	0.028 (△)	3.656 (▲)	0.016 (△)	5.838 (▲)	0.026 (△)
October	6.710 (▲)	0.026 (△)	3.986 (▲)	0.026 (△)	2.058 (▲)	0.010 (△)	3.284 (▲)	0.016 (△)
November	6.348 (▲)	0.033 (△)	1.856 (△)	0.015 (△)	-1.335 (▽)	-0.008 (▽)	0.798 (△)	0.005 (△)
December	5.981 (▲)	0.029 (△)	0.653 (△)	0.004 (△)	0.082 (△)	7.008 (▲)	1.163 (△)	0.006 (△)
Pre-monsoon	7.105 (▲)	0.081 (△)	3.796 (▲)	0.068 (△)	2.443 (▲)	0.029 (△)	3.091 (▲)	0.035 (△)
Monsoon	7.901 (▲)	0.092 (△)	6.211 (▲)	0.112 (△)	5.404 (▲)	0.083 (△)	6.856 (▲)	0.099 (△)
Post-monsoon	7.143 (▲)	0.059 (△)	3.465 (▲)	0.044 (△)	0.433 (△)	0.003 (△)	2.127 (▲)	0.021 (△)
Winter	7.210 (▲)	0.085 (△)	0.701 (△)	0.010 (△)	-0.640 (▽)	-0.009 (▽)	-0.509 (▽)	-0.006 (▽)
Annual	8.248 (▲)	0.311 (△)	4.791 (▲)	0.242 (△)	3.435 (▲)	0.122 (△)	4.288 (▲)	0.154 (△)

Note: (▲) = significant increasing trend ($p < 0.05$), (▼) = significant decreasing trend ($p < 0.05$), (△) = non-significant increasing trend, (▽) = non-significant decreasing trend, (—) = no trend, ($p < 0.05$) = the trend is significant at 5% significance level

3.1.1 *Trends in Monthly Average Temperature*

Table 2 presents the statistical trend analysis results of seasonal and annual average temperatures in the study area. The table shows that in Cox's Bazar station, the Z_{MK} trend test results indicate a consecutively significant increasing trend in the long-term monthly average temperature (Tavg) for all the months from January to December. In contrast, the SS estimator displays a non-significant increasing trend for Tavg in all months. In Teknaf station, the Z_{MK} test values for Tavg exhibit a significant increasing trend from March to October (March (3.077), April (2.613), May (3.512), June (4.772), July (4.412), August (4.952), September (5.653), and October (3.986), respectively). Conversely, January (0.151), February (1.136), November (1.856), and December (0.653) demonstrate non-significant increasing trends. Besides, the SS estimator gives a consecutively non-significant increasing trend for all the months. It is also seen from Table 2 that in Sandwip station, the monthly average temperature is significantly increasing from June to October (June (4.137), July (3.40), August (5.087), September (3.656), and October (2.058)), whereas the remaining months also display a non-significant increasing trend. In contrast, the SS estimator observed a significant increasing trend for December (7.008°C/decade). Besides, a non-significant decreasing trend is found in January (-0.01˚C/decade), November (-0.008˚C/decade), February (0.002˚C/decade), March (0.009˚C/decade), April (0.012˚C/decade), May (0.01˚C/decade), June (0.02˚C/decade), July (0.019˚C/decade), August (0. In the Hatiya station, the Z_{MK} results obtained for Tavg indicate a significant increasing trend for April to October (April (2.189), May (3.786), June (5.019), July (5.845), August (6.726), September (5.838), and October (3.284), respectively). While February (0.013), March (1.446), November (0.798), and December (1.163) show a non-significant increasing trend, January (-0.75) identifies a non-significant decreasing trend. In contrast, the SS estimator reveals a significant increasing trend in February (4.808°C/decade), while March (0.006°C/decade), April (0.013°C/decade), May (0.021°C/decade), June (0.024°C/decade), July (0.02°C/decade), August (0.025°C/decade), September (0.026°C/decade), October (0.016°C/decade), November (0.005°C/decade), and December (0.006°C/decade) show a non-significant increasing trend, and January (-0.005°C/decade) gives a non-significant decreasing trend. Thus, it can be concluded from the findings presented in Table 2 that the monthly average temperature in all the stations over the study area is increasing, which could have notable implications for the overall climate in the study area.

3.1.2 *Trends in Seasonal and Annual Average Temperatures*

As can be seen from Table 2, for Cox's Bazar station, the long-term seasonal average temperature (Tavg) for the Z_{MK} test value exhibits a significant increasing trend during the pre-monsoon (7.105), monsoon (7.901), post-monsoon (7.143), and winter (7.210) periods. In contrast, the SS estimator indicates a non-significant increasing trend for the pre-monsoon (0.081°C/decade), monsoon (0.092°C/decade), post-monsoon (0.059°C/decade), and winter (0.085°C/decade) seasons. For the Teknaf station, the Tavg for the Z_{MK} value displays a significant increasing trend during the pre-monsoon (3.796), monsoon (6.211), and post-monsoon (3.465) periods, while the winter season (0.701) reveals a non-significant increasing trend. Additionally, the SS estimator reflects a non-significant increasing trend in the pre-monsoon (0.068°C/decade), monsoon (0.112°C/decade), post-monsoon (0.044°C/decade), and winter (0.01°C/decade) periods. For Sandwip station, the Z_{MK} test value for Tavg indicated a significant increasing trend in the pre-monsoon (2.443) and monsoon (5.404) periods. Conversely, the post-monsoon (0.433) period exhibited a non-significant increasing trend, while the winter (-0.64) period displays a non-significant decreasing trend. The SS results indicated a non-significant increasing trend for the pre-monsoon (0.029°C/decade), monsoon (0.083°C/decade), and post-monsoon (0.003°C/decade) periods, while the winter (-0.009°C/decade) period showed a non-significant decreasing trend. The Z_{MK} test results obtained for Tavg in the Hatiya station indicate a significant increasing trend for the pre-monsoon (3.091), monsoon (6.856), and post-monsoon (2.127) seasons, whereas the winter (-0.509) season shows a non-significant decreasing trend. Conversely, the SS results demonstrate a non-significant increasing trend for the pre-monsoon (0.035˚C/decade), monsoon (0.099˚C/decade), and post-monsoon (0.021˚C/decade), alongside a non-significant decreasing trend for the winter (-0.006˚C/decade) period.

As can also be seen from Table 2, the Z_{MK} test value obtained for the long-term annual average temperature (Tavg) reveals a significant increasing trend (8.248), whereas the SS estimator shows a non-significant increasing trend at a rate of 0.311°C/decade for Cox's Bazar station. For the Teknaf station, the Z_{MK} test result observed a significantly increasing trend (4.791), and the SS estimator reveals a non-significant increasing trend at a rate of 0.242°C/decade. Additionally, the Z_{MK} test result found for annual average temperature gives a significantly increasing trend (3.435), and the SS estimator gives a non-significant increasing trend at a rate of 0.122°C/decade for Sandwip station. Furthermore, the long-term annual average temperature for Hatiya station based on the Z_{MK} test result is found to be a significantly increasing trend (4.288), whereas the SS estimator displays a non-significant increasing trend at a rate of (0.154˚C/decade). Figure 3 shows the trends in long-term seasonal and annual average temperature for the selected stations in the study area based on the statistical methods. The trend analysis results of seasonal and annual average temperatures by the graphical (ITA) methods are shown in Figure

4, which demonstrates similar trends as detected by the statistical methods. Thus, it can be concluded that there is an overall increase in seasonal and annual average temperature, which could have important implications on the climate change adaptation planning and adaptive water resources management in the study area.

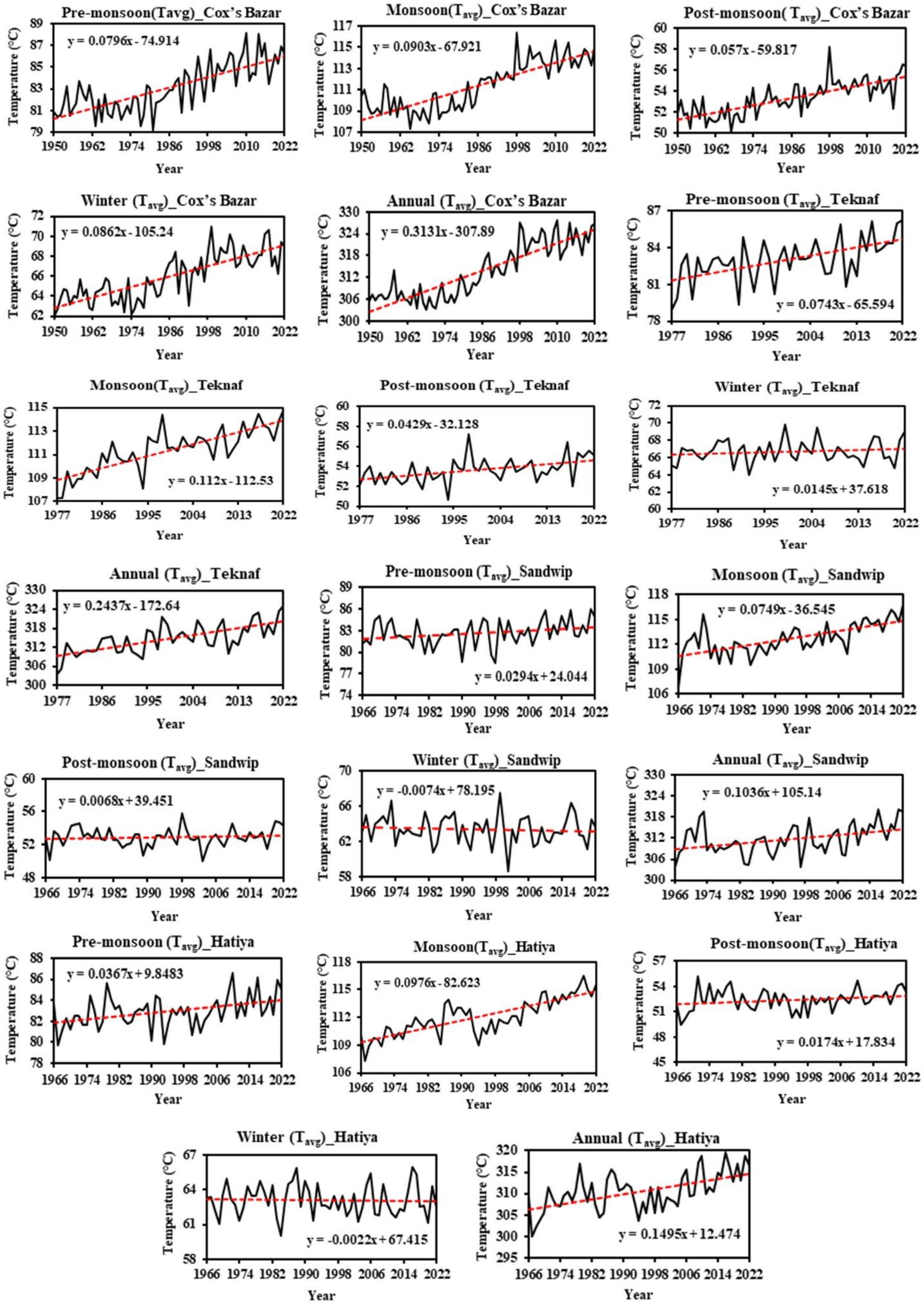

Figure 3: Trends in long-term seasonal and annual average temperatures of Cox's Bazar, Teknaf, Sandwip, and Hatiya stations in the study area based on the statistical method

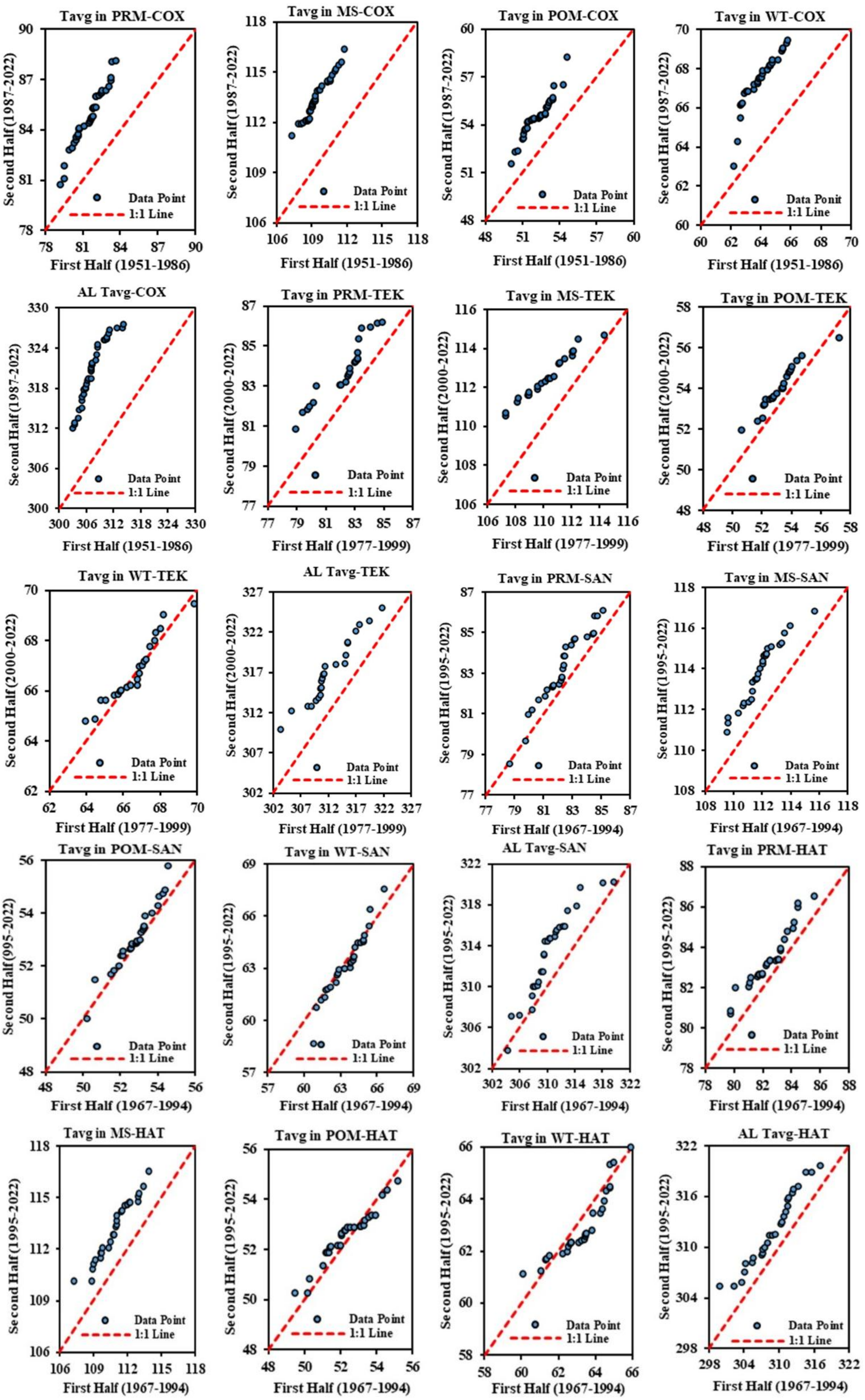

Figure 4: Seasonal and annual temperature trends over the study area using the graphical ITA method (Details of abbreviations used in the plots: PRM: Pre-monsoon, MS: Monsoon, POM: Post-monsoon, WT: Winter, AL: Annual, COX: Cox's Bazar, TEK: Teknaf, SAN: Sandwip, HAT: Hatiya)

3.2 Analysis of Rainfall Trends

The long-term monthly, seasonal and annual rainfall (mm) trend analysis through MK, SS and ITA method have been applied with 95% confidence level over Cox's Bazar (1950-2023), Teknaf (1977-2023), Sandwip (1966-2023) and Hatiya (1966-2023) stations. The results of the MK test and SS estimator on monthly, seasonal and annual rainfall over Cox's Bazar, Teknaf, Sandwip and Hatiya stations are presented in Table 3.

Table 3: Summary of rainfall trends over the study area using statistical based MK and SS techniques

Period	Cox's Bazar		Teknaf		Sandwip		Hatiya	
	Z_{MK}	SS	Z_{MK}	SS	Z_{MK}	SS	Z_{MK}	SS
January	0.605 (△)	0 (—)	0.128 (△)	0 (—)	-0.481 (▽)	0 (—)	0.548 (△)	0 (—)
February	-0.194 (▽)	0 (—)	-1.460 (▽)	0 (—)	-0.849 (▽)	0 (—)	-0.728 (▽)	0 (—)
March	0.816 (△)	0 (—)	0.059 (△)	0 (—)	0.094 (△)	0 (—)	-1.575 (▽)	-0.302 (▽)
April	1.372 (△)	0.400 (△)	-0.900 (▽)	-0.528 (▽)	-1.851 (▽)	-1.759 (▽)	-0.799 (▽)	-0.231 (▽)
May	0.616 (△)	0.600 (△)	0.522 (△)	1.000 (△)	1.214 (△)	1.500 (△)	0.799 (△)	0.765 (△)
June	0.140 (△)	0.214 (△)	-0.275 (▽)	-1.576 (▽)	0.020 (△)	0.051 (△)	1.228 (△)	1.960 (△)
July	-0.424 (▽)	-1.000 (▽)	1.283 (△)	6.417 (▲)	0.617 (△)	2.237 (▲)	1.544 (△)	2.222 (▲)
August	-0.116 (▽)	-0.188 (▽)	0.146 (△)	0.219 (△)	-0.308 (▽)	-0.667 (▽)	0.013 (△)	0 (—)
September	0.541 (△)	0.521 (△)	1.238 (△)	2.714 (▲)	1.422 (△)	2.182 (▲)	-0.094 (▽)	0 (—)
October	-0.387 (▽)	-0.273 (▽)	1.981 (▲)	2.706 (▲)	1.281 (△)	1.500 (△)	3.211 (▲)	3.704 (▲)
November	-0.351 (▽)	0 (—)	-0.781 (▽)	-0.278 (▽)	-0.799 (▽)	-0.044 (▽)	-0.506 (▽)	0 (—)
December	0.933 (△)	0 (—)	0.497 (△)	0 (—)	0.304 (△)	0 (—)	0.098 (△)	0 (—)
Pre-monsoon	1.236 (△)	1.348 (△)	0.137 (△)	0.351 (△)	0.073 (△)	0.194 (△)	0.100 (△)	0 (—)
Monsoon	-0.205 (▽)	-0.808 (▽)	0.467 (△)	2.286 (▲)	0.898 (△)	3.684 (▲)	1.174 (△)	3.737 (▲)
Post-monsoon	-0.424 (▽)	-0.500 (▽)	1.072 (△)	2.286 (▲)	0.637 (△)	0.892 (△)	2.915 (▲)	3.654 (▲)
Winter	0.852 (△)	0.075 (△)	0.435 (△)	0 (—)	-0.316 (▽)	-0.020 (▽)	0.383 (△)	0.026 (△)
Annual	-0.079 (▽)	-0.239 (▽)	0.662 (△)	4.154 (▲)	0.892 (△)	4.767 (▲)	2.194 (▲)	7.833 (▲)

Note: (▲) = significant increasing trend ($p < 0.05$), (▼) = significant decreasing trend ($p < 0.05$), (△) = non-significant increasing trend, (▽) = non-significant decreasing trend, (—) = no trend, ($p < 0.05$) = the trend is significant at 5% significance level

3.2.1 *Trends in Monthly Rainfall*

Table 3 presents the results of statistical trend analysis of monthly average rainfall in the study area. Monthly rainfall trends for the Cox's Bazar station, based on the Z_{MK} test results, indicate a non-significant increasing trend for January (0.605), March (0.816), April (1.372), May (0.616), June (0.14), September (0.541), and December (0.933). Conversely, there is a non-significant decreasing trend for February (-0.194), July (-0.424), August (-0.116), October (-0.387), and November (-0.351). Meanwhile, the SS estimator reveals a non-significant increasing trend for April (0.4 mm/month), May (0.6 mm/month), June (0.214 mm/month), and September (0.521 mm/month), while July (-1 mm/month), August (-0.188 mm/month), and October (-0.273 mm/month) exhibited non-significant decreasing trends. No trend is seen in January, February, March, November, and December. For the Teknaf station, the Z_{MK} test results demonstrate a significant increasing trend in October (1.98). Non-significant increasing trends are observed in January (0.128), March (0.059), May (0.522), July (1.283), August (0.146), September (1.238), and December (0.497). In contrast, February (-1.46), April (-0.90), June (-0.275), and November (-0.781) show non-significant decreasing trends. The SS estimator detects a significant increasing trend in July (6.417 mm/month), September (2.714 mm/month), and October (2.706 mm/month). Additionally, non-significant increasing trends are identified in May (1 mm/month) and August (0.219 mm/month), while non-significant decreasing trends are found in April (-0.528 mm/month), June (-1.576 mm/month), and November (-0.278 mm/month). No trends are detected in January, February, March, and December. The Z_{MK} test results for the Sandwip station reveal a non-significant increasing trend in March (0.094), May (1.214), June (0.02), July (0.617), September (1.422), October (1.281), and December (0.304). A non-significant decreasing trend is observed in January (-0.481), February (-0.849), April (-1.851), August (-0.308), and November (-0.799). Meanwhile, the SS results showed a significant increasing trend for July (2.237 mm/month) and September (2.182 mm/month). Non-significant increasing trends are found in May (1.5 mm/month), June (0.051 mm/month), and October (1.5 mm/month). Non-significant decreasing trends are detected in April (-1.759 mm/month), August (-0.667 mm/month), and November (-0.044 mm/month). No trends are detected for January, February, March, and December. For the Hatiya station, the Z_{MK} test results identified a significant increasing trend in October (3.211). Non-significant increasing trends were observed in January (0.548), May (0.799), June (1.228), July (1.544), August (0.013), and December (0.098). In contrast, non-significant decreasing trends were found in February (-0.728), March (-1.575), April (-0.799), September (-0.094), and November (-0.506). The SS estimator indicated a significant increasing trend for July (2.222 mm/month) and October (3.704 mm/month). Non-significant increasing trends were noted in May (0.765 mm/month) and June (1.96 mm/month), while non-significant decreasing trends were found in March (-0.302 mm/month) and April (-0.231 mm/month). Additionally, no trends are observed for January, February, August, September, November, and December, respectively.

3.2.2 *Trends in Seasonal and Annual Rainfall*

Table 3 presents the results of statistical trend analysis of seasonal and annual average rainfall in the study area. As can be seen from the table, the seasonal rainfall trends for the Cox's Bazar station, as determined by the Z_{MK} test and SS estimator, show a non-significant increasing trend for the pre-monsoon (Z_{MK} = 1.236, Q = 1.348 mm/year) and winter (Z_{MK} = 0.852, Q = 0.075 mm/year). Conversely, the monsoon (Z_{MK} = -0.205, Q = -0.808 mm/year) and post-monsoon (Z_{MK} = -0.424, Q = -0.5 mm/year) seasons exhibit a non-significant decreasing trend. For the Teknaf station, the Z_{MK} test displays a non-significant increasing trend in the pre-monsoon (0.137), monsoon (0.467), post-monsoon (1.072), and winter (0.435). In contrast, the SS estimator identifies a significant increasing trend in the monsoon (2.286 mm/year) and post-monsoon (2.286 mm/year) seasons. The pre-monsoon season exhibits a non-significant increasing trend (0.351 mm/year), while the winter season shows no trend. It is also seen from Table 3 that the seasonal rainfall trend at the Sandwip station, as obtained by the Z_{MK} test, reveals a non-significant increasing trend for the pre-monsoon (0.073), monsoon (0.898), and post-monsoon (0.637), whereas the winter season (-0.316) exhibits a non-significant decreasing trend. Conversely, the SS estimator indicated a significant increasing trend in the monsoon season (3.684 mm/year). Non-significant increasing trends were noted in the pre-monsoon (0.194 mm/year) and post-monsoon (0.892 mm/year) seasons, while the winter (-0.02 mm/year) demonstrates a non-significant decreasing trend. Furthermore, the Z_{MK} test for seasonal rainfall trends at Hatiya station detects a significantly increasing trend during the post-monsoon (2.915) period. Meanwhile, the pre-monsoon (0.1), monsoon (1.174), and winter (0.383) periods exhibited non-significant increasing trends. In contrast, the SS results indicated significant increasing trends in the monsoon (3.737 mm/year) and post-monsoon (3.654 mm/year) seasons. Furthermore, the winter period (0.026 mm/year) shows a non-significant increasing trend, while no discernible trend is found for the pre-monsoon season.

As can also be seen from Table 3, the annual rainfall trend based on the Z_{MK} test value at the Cox's Bazar station indicates a non-significant decreasing trend (-0.079). Additionally, the SS estimator shows a non-significant decreasing trend at a rate of (-0.239 mm/year). In contrast, the Teknaf station's annual rainfall trend, as revealed by the Z_{MK} test result, shows a non-significant increasing trend (0.662), while the SS result identified a significant increasing trend at a rate of (4.154 mm/year). For the Sandwip station, the Z_{MK} test result exhibits a non-significant increasing trend (0.892), and the SS result identified a significant increasing trend at a rate of (4.767 mm/year). Furthermore, the annual rainfall trend for the Hatiya station, as indicated by the Z_{MK} test value, demonstrates a significantly increasing trend (2.194), and the SS estimator detected a significant increasing trend at a rate of (7.833 mm/year). Figure 5 shows the trends in long-term seasonal and annual average rainfall for the selected stations in the study area. The trend analysis results in seasonal and annual average rainfall based on the graphical (ITA) methods are presented in Figure 6, which display similar trends as detected by the statistical methods. Thus, it can be concluded that there is an overall increase in the seasonal and annual rainfall in the study area. It is important to note that seasonal rainfall trends exhibit the increasing-decreasing patterns demonstrating the most stochastic nature of rainfall in the study area.

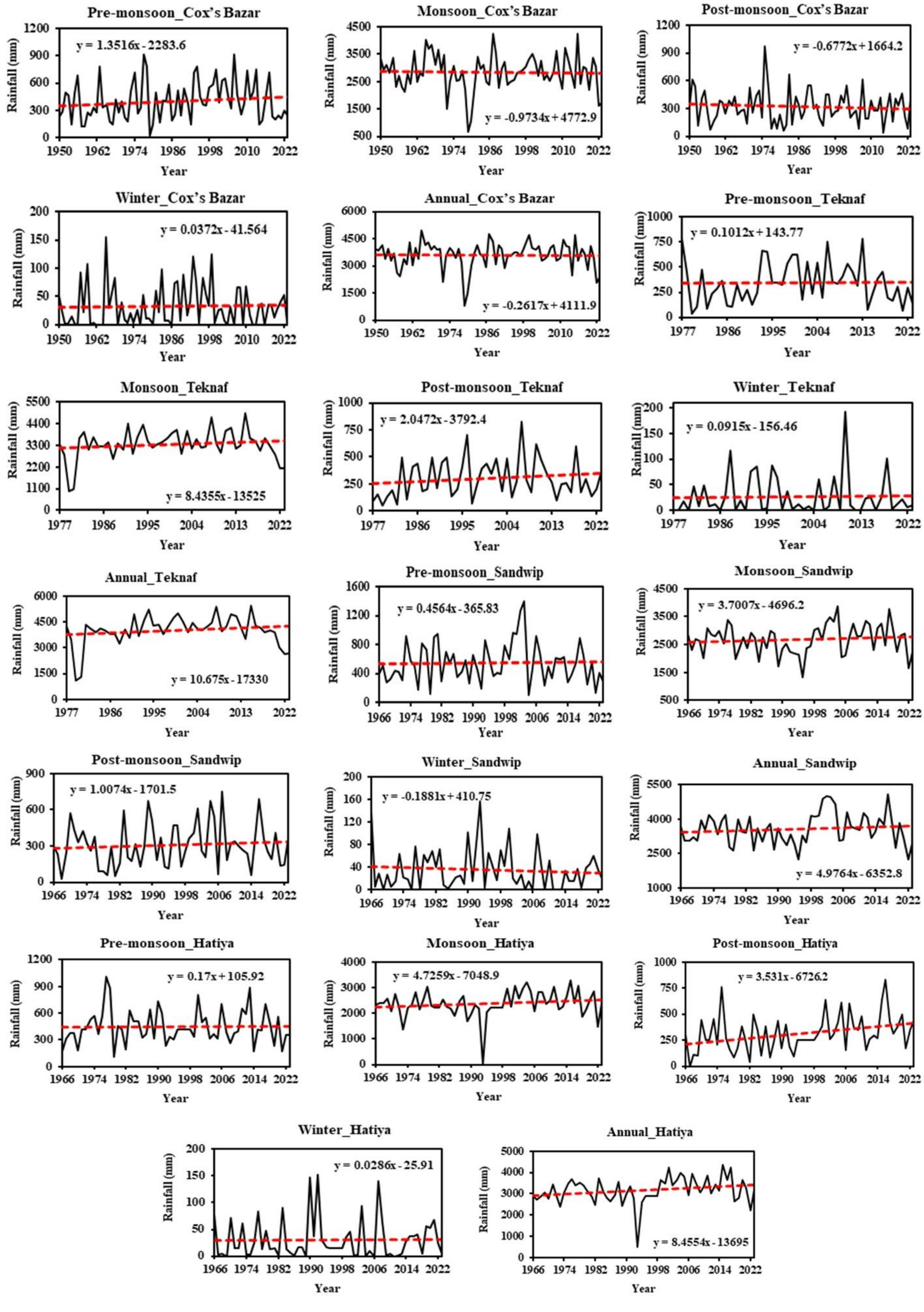

Figure 5: Trends in seasonal and annual rainfall of Cox's Bazar, Teknaf, Sandwip, and Hatiya stations in the study area based on the statistical method

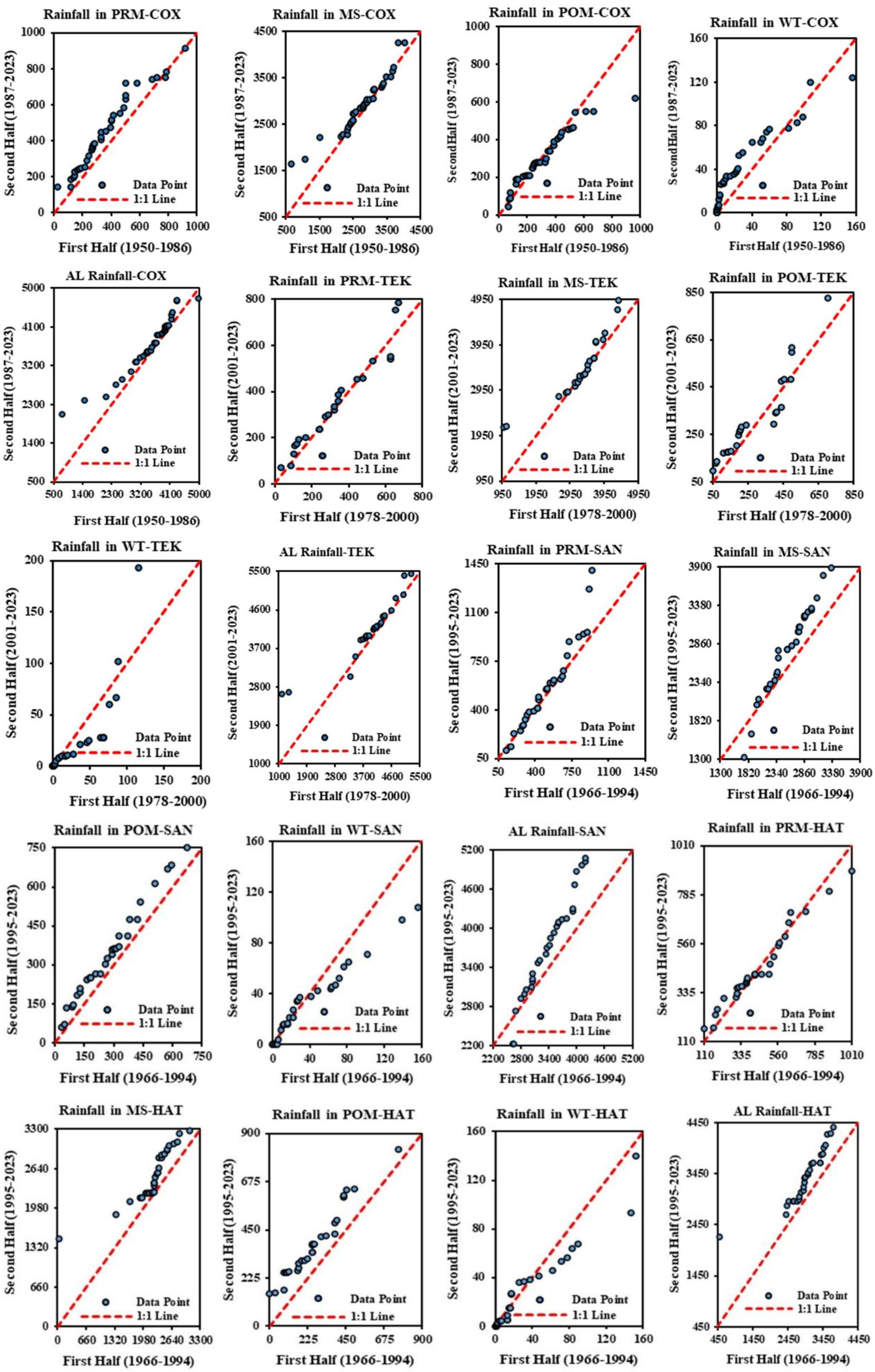

Figure 6: Seasonal and annual rainfall trends over the study area using the graphical ITA method (Details of abbreviations used in the plots: PRM: Pre-monsoon, MS: Monsoon, POM: Post-monsoon, WT: Winter, AL: Annual, COX: Cox's Bazar, TEK: Teknaf, SAN: Sandwip, HAT: Hatiya)

3.3 Comparison of Statistical and Graphical Methods-Based Climate Change Trend Analysis

As detailed in the aforementioned sections, the widely used MK and SS methods are adopted as the statistical methods, whereas the innovative trend analysis (ITA) method is employed as the graphical method in the current study. A comparative analysis of the trend assessment results based on MK, SS, and ITA methods is summarized in Table 4. As can be seen from Table 4, there is an overall increasing trend of seasonal and annual temperatures in all stations of the study area based on both statistical and graphical trend assessment methods. The table also demonstrates that the rainfall trends exhibit the usual stochastic patterns and follow a mixture of increasing and decreasing trends in all the stations in the study area. It is important to note that the seasonal and annual average rainfalls in the study area exhibit an overall increasing trend based on both statistical and graphical methods. Thus, this finding concludes the viability of using the user-friendly graphical ITA technique in line with the statistical MK and SS techniques for the climate change trend assessment and climate change studies in the study area and other similar areas in Bangladesh and all over the world.

Table 4: Comparison of temperature trends based on statistical (MK and SS) and graphical (ITA) methods

Period	Cox's Bazar			Teknaf			Sandwip			Hatiya		
	MK	SS	ITA	MK	SS	ITA	MK	SS	ITA	MK	SS	ITA
Seasonal and Annual Average Temperatures												
Pre-monsoon	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Monsoon	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Post-monsoon	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Winter	↑	↑	↑	↑	↑	↑	↓	↓	↓	↓	↓	↓
Annual	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Seasonal and Annual Average Rainfall												
Pre-monsoon	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	–	↑
Monsoon	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Post-monsoon	↓	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑
Winter	↑	↑	↑	↑	–	↓	↓	↓	↓	↑	↑	↓
Annual	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

Note: '↑' indicates increasing trend, '↓' indicates decreasing trend, '–' indicates no trend

4. CONCLUSIONS

The current study focuses on the assessment of the long-term climate change trends in monthly, seasonal, and annual average temperature and rainfall in the southeastern coastal area of Bangladesh. In order to carry out the trend assessment, four weather stations namely, Cox's Bazar, Teknaf, Hatiya, and Sandwip, are selected. Stations are selected in such a way that the station has at least 30 years of available climate data. Both statistical and graphical methods are adopted for the analysis of climate change trend and compared their performances in trend assessment. The widely applied Mann-Kendall (MK) and Sen's slope (SS) techniques are adopted as the statistical method, while the innovative trend analysis (ITA) technique is employed as the graphical method. The analysis is carried out in the XLSTAT and MS Excel software platforms. Based on the findings of the current study, the following conclusions can be drawn:

- Based on the MK and SS-based statistical trend assessment methods, it is found that there is an overall increasing trend of monthly, seasonal, and annual temperature and rainfall patterns in the study area. The results are statistically significant at the 5% significance level in most cases. This could have important implications on the climate change adaptation planning and adaptive water resources management in the study area.
- Likewise, based on the ITA-based graphical method, similar increasing trends are detected in the monthly, seasonal, and annual temperature and rainfall patterns in the study area based on the ITA technique. This concludes that the user-friendly ITA technique could be a viable option in line with the statistical MK and SS techniques for the climate trend assessment and climate change studies in the study area and other similar areas in Bangladesh and all over the world.
- The results also reveal that seasonal rainfall trends exhibit both significant and non-significant increasing-decreasing patterns in some cases, demonstrating the most stochastic nature of rainfall in the study area. It is expected that the findings of the current study could be supportive in planning effective climate change adaption and management policies to address future climate change-induced disasters across the southeastern coastal area of Bangladesh.

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