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Detection of changes and trends in climatic variables in Bangladesh during 1988–2017

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Abstract

Due to the importance of climatic variability, an assessment detecting the changes and trends has been carried out over different time series of major climatic variables from the records of meteorological stations over Bangladesh from 1988–2017. Linear regression, the Mann-Kendall test, and Sen's slope method were used to analyze the significant trends and magnitude of the variables' changes, while the Pearson and Spearman rho correlation test have been applied to correlate between the variables. The results show that the average monthly maximum temperature (T_{max}) and minimum temperature (T_{min}) have increased significantly by 0.35 °C/decade and 0.16 °C/decade, respectively. However, the increase in T_{max} is comparatively higher than T_{min} and caused significant increases in the monthly temperature range (MTR) at a higher rate in winter than in the monsoon season. The trend patterns of T_{max}, T_{min}, and MTR reveal that most of the regions of the country (especially the south-eastern and north-eastern) have been colder during winter and hotter during the monsoon. In contrast, the wind speed (WS) has decreased significantly all over the country and decreased by a higher rate in the north-western (NW) region (monsoon, 0.60 and annual, 0.51 kt/

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decade) than other regions, while the monsoonal and annual precipitation have decreased by 87.35 mm/decade and 107 mm/decade, respectively. The monsoonal T_{max} and T_{min} (0.47 °C/decade and 0.38 °C/decade, respectively) have increased significantly in the NW; consequently, this region has been warmed by 0.27 °C/decade. The increase in temperature and decrease in WS may cause a decrease in rainfall in the NW region. Humidity changes are not significant except in the monsoon season across the country. Precipitation, WS, and humidity are negatively correlated with the temperature variables. The declination of WS may influence the rising trend in temperature and the falling trend in precipitation and humidity, suggesting the need for further advanced study on the negative effects of climate change in Bangladesh.

Keyword: Environmental science

1. Introduction

Climate change is a major modern issue that has attracted significant attention from governments as well as the public throughout the world. Global surface temperature has been increasing day by day since the last few decades of the 19th century as a result of increasing the emission of greenhouse gases caused by worldwide urbanization, large-scale combustion of fossil fuels, human intervention and land use changes (IPCC, 2002; Liang, 2013; Jaiswal et al., 2015). From the 1950s onward, many types of research have been conducted to identify climate change, revealing that huge amounts of ice have melted and the sea level has risen because of the warming of the atmosphere and ocean (Hartmann and Tank, 2013; IPCC, 2013). The concentration of greenhouse gases has increased, which causes an increase in land and sea surface temperature and changes the patterns of precipitation, sea level rise and intensification of El Nino (Basak et al., 2013; Raihan et al., 2015; Jaiswal et al., 2015; Yu et al., 2016; Islam and Nursey-Bray, 2017). In the 12th session, IPCC, 2013 has observed that the combined global land and sea surface temperature has increased by 0.89 °C (0.69 °C−1.08 °C) during 1901−2012 and by about 0.72 °C (0.49 °C−0.89 °C) during 1951−2012, and the atmospheric burden of well-mixed greenhouse gases has increased from 2005 to 2011 (IPCC, 2001; Hartmann and Tank, 2013; Yu et al., 2016). The average rising annual temperature has occurred from June to August due to the temperature anomalies in both hemispheres (Lugina et al., 2006). Bangladesh is one of the countries that is most vulnerable to extreme climate change and its effects around the world (Ali, 1999; Shahid, 2011; Islam and Nursey-Bray, 2017; Vij et al., 2018). IPCC (2001) has distinguished Bangladesh as a risky country due to climate change, where many natural disasters such as high temperature, flood, cyclone, drought, saline water intrusion, sea-level rise, and heavy monsoon downpours are very common phenomena (Titumir and

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Basak, 2012; Basak et al., 2013). Due to the historical climate change, Bangladesh's seasonal cycle has changed from six seasons to three, which can be primarily characterized by a hot summer, a shrinking winter, and medium to heavy rains during the monsoon season (Denissen, 2012).

The variation in temperature, precipitation, humidity and wind speed due to climate change during the past decades has intensified various problems around the world as well as Bangladesh. Currently, many studies have focused on climate change all over the world, and researchers from most countries are finding solutions to lessen the negative effect of climate change, but Bangladesh has not yet advanced in this field. Although a number of studies have been found on temperature variability in Bangladesh (Jones, 1995; Singh, 2001; Shahid, 2010b, 2011; Shahid et al., 2012; Basak et al., 2013; Raihan et al., 2015), no analysis has been carried out so far on the most important climatic variables or covered the entire area of the country, and the focus has largely been on individual climate variables in most cases. Besides these, most studies have highlighted the daily maximum and minimum temperature variables before the year 2008, even without considering all the records of the meteorological stations. Shahid (2010b) and Shahid et al. (2012) reported that the temperature has increased extensively in the last fifty years (1961−2008). Compared to the summer, the winter is warming more and the winter and pre-monsoonal diurnal temperature range in Bangladesh has decreased; however, the temperature range has increased in the monsoon season. In contrast, Shahid and Khairulmaini (2009), and Shahid (2010a) concluded that the precipitation has increased slightly based on the analysis dataset of about 50 years before 2007. Raihan et al. (2015) also identified that the daily maximum temperature in south-eastern Bangladesh has increased significantly during the last few years with a decrease in both daily minimum and mean temperature. Basak et al. (2013) and Shahid et al. (2012) used only the temperature and precipitation data and showed that the temperature has significantly increased mainly in monsoonal months. Besides these reports, Warrick et al. (1994), Karmakar and Shrestha (2000), and Debsarma (2002) provided an estimation of temperature and precipitation over Bangladesh, while Chowdhury and Debsharma (1992), and Mia (2003) calculated the changes in temperature based on the historical data analysis of some selected stations. Only a few studies have been found on rainfall trends and extremes, though some studies have described rainfall patterns over the country (Ahmed and Karmakar, 1993; Hussain and Sultana, 1996; Kripalani et al., 1996; Rahman et al., 1997; Ahmed and Kim, 2003; Islam and Uyeda, 2008). Primarily, no research has been found that focused on the changes in the variables with monthly maximum and minimum temperature as well as wind speed in the different climatic sub-regions of the country using very recent data, though a study was found on the assessment of the monthly maximum and minimum temperature associated with other variables in neighboring India (Jaiswal et al., 2015).

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In this study, we have attempted to build upon a steadily increasing number of theoretical and experimental studies of the climate factors such as temperature, relative humidity, precipitation and wind speed to assess their change during 1988−2017 in Bangladesh according to the data. Therefore, extensive statistical analysis was performed using meteorological data, and a historical climate change trend was found in the climatic sub-regions as well as the entire country. The main objective of this study is to explore the coherent trend of related climate variables in order to explain their changes in the time series and comprehensible correlation during the last 30 years. The dramatic climate change over the country is also a part of the focus of this study.

1.1. The climate of Bangladesh

Geographically, Bangladesh extends from 20°34′N to 26°38′N latitude and from 88°01′E to 92°41′E longitude. It is a South Asian developing country, located in the tropical monsoon region, and its climate is characterized by fairly marked seasonal variation with high temperature, heavy rainfall, and frequently high humidity (Rashid, 1991; Banglapedia, 2014). The most noticeable features of its climate are the reversal of the wind circulation system of the south Asian subcontinent through the year, that is why four distinct seasons can be recognized in Bangladesh: (i) winter from December to February, (ii) pre-monsoon from March to May, (iii) monsoon or rainy season that lasts from June through September and (iv) the post-monsoon season from October to November (Shahid and Khairulmaini, 2009; Banglapedia, 2014). The hottest month is May, when the average temperature varies from 27 °C in the east and south to 31 °C in the west-central part of the country, whereas the temperature sometimes increases up to 40 °C in the western regions (Islam, 2003; Shahid et al., 2012; Banglapedia, 2014). The cold winter air of northwestern India passes through the country, which loses much of its intensity and reaches the northwestern corner of the country in January, making it the coldest month wherein the temperature varies from 17 °C in the northwestern and northeastern parts to 20−21 °C in the coastal area (Banglapedia, 2014). However, in late December to early January, the minimum temperature in the extreme north-western and north-eastern part of the country falls within 4 °C of the freezing point (Banglapedia, 2014). More than 75% of the rainfall occurs in the monsoon season in Bangladesh and is caused by weak tropical depressions carried from the Bay of Bengal into the inland by the wet monsoon winds (Shahid, 2010a). The average rainfall ranges from 1400 mm in the west to 4400 mm in the east with a gradient of 7 mm/km from the west to the east of the country (Islam, 2003; Shahid and Khairulmaini, 2009). The average relative humidity for the whole year ranges from 70.5% to 78.1% (Banglapedia, 2003; Shahid, 2010a); however, the least humid months are March to April (with a recorded low of 57%) over most of the western part and January to March (∼58.5%) over the eastern area of the country (Banglapedia, 2014). The

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seasonal reversals between summer and winter are the primary characteristics of atmospheric pressure and wind in Bangladesh. The southerly component (flowing from the south, southwest or southeast) dominates the wind direction in Bangladesh during the summer season; however, variable wind directions have been observed during the transition seasons (in spring and autumn). The monsoonal winds are stronger (4.32−8.64 knots) than winter winds (1.62−3.24 knots), while a mean pressure of 1,020 millibars was measured in January and 1,005 millibars was recorded from March to September (Banglapedia, 2014).

2. Materials and methods

Meteorological data including the monthly maximum and minimum temperature, daily average temperature (measured by the dry bulb thermometer of a hygrometer), relative humidity, total precipitation and wind speed over the last 30 years (Jan. 1988−Dec. 2017) were collected from the Bangladesh Meteorological Department (BMD). The collected data were recorded by the 35 climatic stations distributed across the country (Fig. 1).

There is a significant difference in the intensity of seasons in different parts of the country. Based on the overall climatic conditions, Bangladesh can be divided into seven distinct zones (Rashid, 1991; Khatun et al., 2016), which are illustrated in Fig. 1 by different colors and symbols; their subsidiary stations are listed in Table 1. To evaluate climate change in the different climatic regions of Bangladesh and to facilitate the discussion, the different stations in the same region have been considered a single station. The northern part of the northern region (region C) and the north-western area (region D) are considered the same region because no individual climate station has been set up yet in region C. The records of the data cover the period continuously with a few exceptions, since a few stations were not established at the beginning of the period and several others were suspended from data recording for a certain period (see Table 1 for details). Therefore, the missing values (day or month) of different parameters have been neglected. The monthly maximum and minimum temperature (°C) is the highest and lowest temperature recorded in a certain calendar month, respectively, and the monthly temperature range (°C) is the difference between the monthly maximum and minimum temperature in a month. Monthly relative humidity (in %) and wind speed (in knots, kt) is the average value of the days throughout the whole month, while monthly precipitation (in millimeters, mm) is the total rainfall occurring throughout the month.

Monthly, seasonal and annual averages were calculated for the entire climate variables. No attempt has been made to substitute missing values of the daily observation (though the missing value problem has been solved by averaging the parameters of another station at the same region), and averages were calculated without the missing

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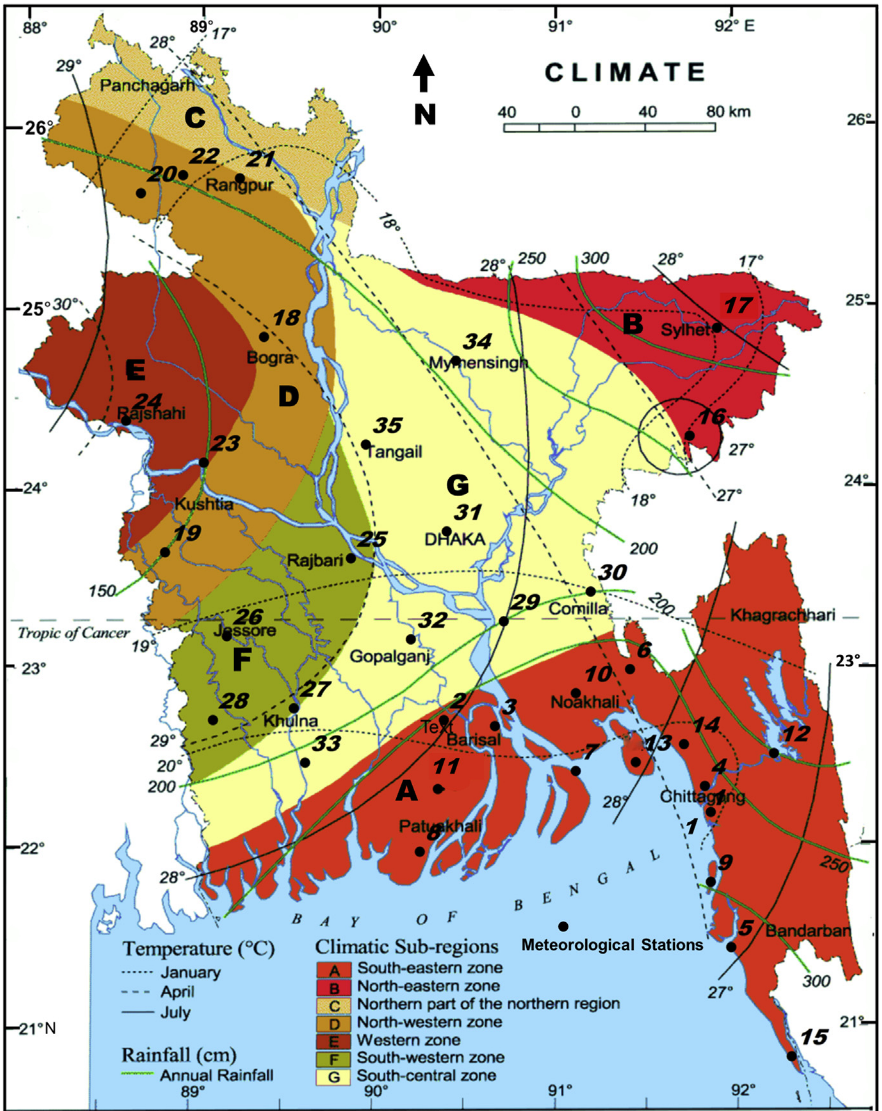

Meteorological Stations, Bangladesh

1. Ambagan (Ctg); 2. Barisal; 3. Bhola; 4. Chittagong; 5. Cox`s Bazar; 6. Feni; 7. Hatia; 8. Khepupara; 9. Kutubdia; 10. M.Court; 11. Patuakhali; 12. Rangamati; 13. Sandwip; 14. Sitakunda; 15. Teknaf; 16. Srimangal; 17. Sylhet; 18. Bogra; 19. Chuadanga; 20. Dinajpur; 21. Rangpur; 22. Saidpur; 23. Ishurdi; 24. Rajshahi; 25. Faridpur; 26. Jessore; 27. Khulna; 28. Satkhira; 29. Chandpur; 30. Comilla; 31. Dhaka; 32. Madaripur; 33. Mongla; 34. Mymensingn; 35. Tangail

Fig. 1. Climatic sub-regions of Bangladesh associated with the location of 35 meteorological stations (modified after Rashid, 1991 and Banglapedia, 2014).

values; therefore, the number of used observations (n) varied between stations and variables (Table 1). The spatial distribution of the climatic variables was prepared for mapping using the geo-statistical analysis tool of ArcMap 10.2 by obtaining their average values over the period. A linear regression test was applied to determine the

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Table 1. Information about the meteorological data observed and stations. Latitude and longitude are given in decimal degrees, elevation in meters. The climate sub-regions illustrated in Fig. 1 are denoted as A, B, C, D, E, F and G (Khatun et al., 2016).

Climatic Region	Meteorological station	Latitude (DD)	Longitude (DD)	Elevation (m)	Period covered					
					Maximum Temperature, T_{max}	Minimum Temperature, T_{min}	Daily average Temperature, $T_{ave.}$	Precipitation, P_T	Relative Humidity, H_R	Wind speed, WS
South-East (A)	Ambagan (Ctg)	22.3500	91.8170	5.20	1999–17	1999–17	1999–17	1999–17	1999–17	1999–17
	Barisal	22.7170	90.3670	4.00	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Bhola	22.6830	90.6500	5.00	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Chittagong	22.3500	91.8170	5.50	1988–02, 2008–17	1988–02, 2008–17	1988–02, 2008–17	1988–03, 2008–17	1988–02, 2008–17	1988–02, 2008–17
	Cox's Bazar	21.4520	91.9640	3.70	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Feni	23.0000	91.4000	8.00	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Hatia	22.4330	91.1000	4.00	1988–96, 2000–17	1988–96, 2000–17	1988–96, 2000–17	1988–94, 1999–17	1988–17	1988–17
	Khepupara	21.9830	90.2330	9.00	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Kutubdia	21.8170	91.8500	7.00	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	M.Court	22.8670	91.1000	6.00	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Patuakhali	22.3330	90.3330	3.00	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Rangamati	22.5330	92.2000	68.9	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Sandwip	22.4830	91.4330	6.00	1988–02, 2004–17	1988–02, 2004–17	1988–02, 2004–17	1988–02, 2004–17	1988–02, 2004–17	1988–02, 2004–17
	Sitakunda	22.5830	91.7000	10.0	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Teknaf	20.8460	92.3000	6.00	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
North-East (B)	Srimangal	24.3000	91.7330	23.0	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17
	Sylhet	24.9000	91.8830	32.0	1988–17	1988–17	1988–17	1988–17	1988–17	1988–17

(*continued on next page*)

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Table 1. (*Continued*)

Climatic Region	Meteorological station	Latitude (DD)	Longitude (DD)	Elevation (m)	Period covered					
					Maximum Temperature, T_{max}	Minimum Temperature, T_{min}	Daily average Temperature, $T_{ave.}$	Precipitation, P_T	Relative Humidity, H_R	Wind speed, *WS*
Northern of North Region (C) and North-West (D)	Bogra	24.8500	89.3670	20.0	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Chuadanga	23.6500	88.8170	12.0	1989−17	1989−17	1999−17	1989−17	1989−17	1989−17
	Dinajpur	25.6500	88.6830	37.0	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Rangpur	25.7330	89.2330	34.0	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Saidpur	25.7500	88.9170	39.0	1991−17	1991−17	2000−17	1991−17	1991−17	1991−17
West (E)	Ishurdi	24.1500	89.0330	14.0	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Rajshahi	24.3830	88.6000	23.0	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
South-West (F)	Faridpur	23.6170	89.8500	9.00	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Jessore	23.1840	89.1610	6.10	1988−17	1988−17	1988−17	1988−17	1988−17	1988−98, 2000−17
	Khulna	22.7830	89.5330	4.00	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Satkhira	22.7170	89.0830	6.00	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
Mid-South (G)	Chandpur	23.2670	90.7000	7.00	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Comilla	23.4330	91.1830	9.00	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Dhaka	23.7670	90.3830	7.00	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Madaripur	23.1670	90.1830	13.0	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Mongla	22.4794	89.5948	1.80	1989−17	1989−17	1991−17	1991−17	1989−17	1989−17
	Mymensingn	24.7170	90.4330	18.0	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17
	Tangail	24.2500	89.9330	10.2	1988−17	1988−17	1988−17	1988−17	1988−17	1988−17

significance and relationship between climatic variables and time series in the observations (Sneyers, 1990; Blender et al., 2003; Raihan et al., 2015). The Mann-Kendall test and Sen's slope methods were applied to determine the trend and the magnitude of changes, respectively. Pearson and Spearman's rank (Spearman's rho) correlations were also used to correlate the variables. To evaluate the significance of the analysis, the confidence level of ≥90% was used as the threshold. Statistical analysis of the data was performed with the SPSS Statistics 22 package (SPSS, USA) and R software (3.4.3). The following statistical methods have been used in the present study.

2.1. Mann-Kendall test

The Mann-Kendall test is a non-parametric test that does not require normally distributed data and has low sensitivity to abrupt breaks due to inhomogeneous time series. This test has been widely recommended for public application by the World Meteorological Organization and has been used to evaluate trends in climatic, hydrological, water resource, and other kinds of data (Mitchell et al., 1996; Tabari et al., 2011; Jaiswal et al., 2015). Each value in the series is compared with others in this test, which is always performed in sequential order, and the initial value of the Mann-Kendall statistics is assumed to be zero, indicating no trend. Here, S is incremented by 1 when a data point from the later time period is higher than a data point from an earlier time period and vice-versa. The final value of S is calculated by the net result of those increments and discernment yields. If $x_1, x_2, x_3, \ldots, x_i$ represent n data points where x_j represents the data point at time j, then S can be written as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_k\right) \tag{1}$$

Where n is the total length of data, x_j and x_k are two generic sequential data values, and function $sign(x_j - x_k)$ assumes the following values:

$$sign(x_j - x_k) = 1, \text{ if } x_j - x_k > 0$$

$$= 0, \text{ if } x_j - x_k = 0$$

$$= -1, \text{ if } x_j - x_k < 0$$

The probability associated with S and the sample size, n, is then computed to statistically quantify the significance of the trend. Normalized test statistic Z (z-test) is performed as follows:

$$Z = \frac{S-1}{\sqrt{var(S)}}, \text{ if } S > 0$$

$$= 0, \text{ if } S = 0$$

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$$= \frac{S+1}{\sqrt{var(S)}}, \text{ if } S < 0 \tag{2}$$

The null hypothesis of no trend is rejected if $|Z|>2.575$, $|Z|>1.96$, and $|Z|>1.465$ at the 99%, 95%, and 90% significance level, respectively. For example, the trend is rising if $Z > 1.465$, falling if $Z <$ -1.465 and no trend if -1.465 $< Z <$ 1.465 at 90% significance level (More details in Sneyers, 1990).

2.2. Sen's slope method

Sen's slope method is better than the linear regression, as it involves computing slopes for all the pairs of ordinal time points and then using the median of these slopes as an estimate of overall slope (Shahid et al., 2012). If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple nonparametric procedure (Sen, 1968). This means that in the case of continuous monotonic increasing and a decreasing function of time, *f(t)* is defined as:

$$f(t) = Qt + B \tag{3}$$

Where Q is the slope and B is a constant. To get the slope, Q in the equation, first the slopes of all data pairs are calculated by,

$$Q' = (x_{t'} - x_t)/(t' - t) \tag{4}$$

Where, Q' = Slope between the points of $x_{t'}$ and x_t

$x_{t'}$ = data measurement time at t'

x_t = data measurement time at t

Sen's estimator of the slope is simply given by the median slope,

$$Q = Q'_{(N+1)/2} \text{ if N is odd}$$

$$= \left\{Q'_{(N+1)/2} + Q'_{(N+2)/2}\right\}/2 \text{ if N is even} \tag{5}$$

Where the number of calculated slopes is N. A $100(1-\alpha)$ % two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution (Drápela and Drápelová, 2011).

2.3. Pearson correlation test

In statistics, the Pearson correlation coefficient, *r,* is a measure of the linear correlation between two variables X and Y. The value of 'r' is defined as $-1 \le r \le 1$, where 1 is a total positive linear correlation, 0 represents no linear correlation, and -1

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indicates an entirely negative linear correlation (Pearson, 1895; Rodgers and Nicewander, 1988; Stigler, 1989). It is widely used in the sciences and denoted as:

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}} \quad (6)$$

Where x_1, x_2, x_3,…,i_n and y_1, y_2, y_3,…,y_n represent the individual data value of X and Y variables respectively.

2.4. Spearman's rho test

Spearman's rho test is also a non-parametric test and is one of the important tests widely used for studying a population that takes on ranked order values of the variables. If there is no trend and all observations are independent, then all rank ordering is equally likely (Shahid et al., 2012; Jaiswal et al., 2015). In this test, the difference between order and rank (d_i) for all observations x_1, x_2, $x_{3,\ldots,}x_n$ can be used to compute the Spearman's ρ, variance $Var(\rho)$ and test statistic (Z) using the following equations:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)} \quad (7)$$

$$\mathrm{Var}\,(\rho) = \frac{1}{\mathrm{n} - 1} \quad (8)$$

$$Z = \frac{\rho}{\sqrt{Var(\rho)}} \quad (9)$$

The value of ρ is defined as $-1 \leq \rho \leq 1$ in which $\rho > 0$ and $\rho < 0$ represent positive and negative correlations, respectively, where the significance is tested by the Z-statistic.

3. Results and discussion

The analysis of climate change reveals the changes in climatic variable time series in Bangladesh during the period of 1988−2017. The results of the statistical analysis of the climatic variables and their changes and trends in the time series are discussed in the following sections.

3.1. Climatic variables characteristics

The descriptive statistics of monthly maximum temperature (T_{max}) and minimum temperature (T_{min}), monthly temperature range (MTR), daily average temperature, total precipitation, relative humidity, and wind speed (WS) are summarized in

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Table 2. The spatial distribution of the average T_{max}, T_{min}, MTR and daily average temperature (°C), yearly total precipitation (mm), relative humidity (%) and WS (kt) as well as the monthly distribution of temperature (T_{max}, T_{min} and their mean associated daily average temperature) and precipitation (with monthly percentages) are depicted in Fig. 2.

3.1.1. Temperature

The average T_{max} is highest in the pre-monsoon season (May) and lowest in the winter season (January), whereas the average T_{min} is highest in the monsoon season and lowest in the winter season (Fig. 2h). T_{max} is higher in the south-western part (regions D, E, and F) but lower in the northern (region C) and southeastern part of the country than the other regions (Fig. 2a). On the other hand, T_{min} is lower in the northwestern part (region E, and northwestern parts of regions C and D) than the south-western part (lower part of region A, i.e., most of the coastal areas) (Fig. 2b), and the daily average temperature is higher in the southern part than the northern part of the country (Fig. 2c). The average MTR is lower in the monsoon season than the winter season (Fig. 3b), and it ranges from 10.53 ± 0.61 °C in July to 20.58 ± 1.67 °C in February during this period (Table 2, Fig. 3b). Moreover, MTR is lower in the coastal area and higher in the upper land area (Fig. 2d), which is consistent with the spatial distribution of the diurnal temperature range (DTR) of Shahid et al. (2012) as well as being close to the distribution of the DTR of Geerts (2003), Jackson and Forster (2010)**.** Similarly, the DTR and MTR distribution are also lower in coastal than the upper land areas, perhaps due to the influence of the marine environment (Jackson and Forster, 2010). In the upper land area, the MTR is comparatively higher in the north-western areas (regions C, D, E, and F) but lower at some locations of south-eastern zones (region A) (Fig. 2d). Throughout all of Bangladesh, MTR is observed to be higher in winter and lower during the monsoon (Fig. 3b), which may be caused by excessive overcast and rainfall over the country (Shahid et al., 2012). In fact, the average T_{max} and daily average temperature were increased by 1.16 °C and 0.47 °C, respectively, but the average T_{min} has been decreased by 0.40 °C from 1988−2017.

3.1.2. Precipitation

Using data from 35 stations, the average total annual precipitation is 2429.27 ± 269.59 mm, with the maximum at 2861.55 mm and the minimum at 1848.53 mm from 1988−2017 (Table 2). The highest precipitation has been observed in June (19.26% of the total yearly rainfall) and lowest in December (0.30%; Fig. 2i). Most of the rainfall occurs in the monsoon season (71.22%), which is similar to the observation of Shahid (2010a), and very little rainfall (∼1.5%) occurs in the winter season (Fig. 4). According to Ahmed and Kim (2003), Shahid and

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Table 2. Monthly, seasonal and annual descriptive statistics of different climatic variables in Bangladesh.

Month/ Season	Maximum temperature (°C)			Minimum temperature (°C)			Monthly temperature range (°C)			Daily average temperature (°C)			Precipitation (mm)			Relative humidity (%)			Wind speed (kt)		
	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min
Jan	28.68 ± 0.65	30.26	27.24	8.90 ± 1.05	10.36	6.23	19.78 ± 1.0	22.71	18.45	18.06 ± 0.76	19.53	16.31	7.14 ± 9.71	39.89	0.00	77.04 ± 2.40	81.18	71.58	2.94 ± 0.35	3.86	2.35
Feb	31.78 ± 1.37	34.36	28.36	11.19 ± 1.19	13.71	9.09	20.58 ± 1.67	23.25	16.97	21.49 ± 0.88	23.62	19.72	21.90 ± 19.51	75.76	0.06	72.52 ± 2.47	76.71	67.29	3.31 ± 0.52	4.82	2.45
Mar	35.45 ± 1.02	37.37	33.56	15.07 ± 1.28	17.93	12.50	20.38 ± 1.42	23.01	17.43	25.52 ± 0.89	27.20	23.39	48.74 ± 42.99	145.47	3.12	70.90 ± 3.15	76.67	65.55	3.71 ± 0.61	4.96	2.76
Apr	36.68 ± 1.13	39.64	34.63	18.93 ± 1.04	21.01	15.88	17.76 ± 1.07	19.79	16.04	28.13 ± 0.91	29.59	25.68	108.81 ± 59.27	282.34	18.65	74.98 ± 2.62	78.88	68.86	4.05 ± 0.73	5.72	2.69
May	36.71 ± 0.85	38.22	34.93	20.78 ± 0.69	22.73	19.01	15.93 ± 0.87	17.42	14.05	28.76 ± 0.65	29.74	27.63	276.18 ± 91.95	511.26	151.11	79.28 ± 1.91	83.31	75.94	3.97 ± 0.79	5.58	2.86
Jun	35.80 ± 0.76	37.30	34.20	22.78 ± 0.46	23.59	21.57	13.03 ± 0.79	14.15	10.97	28.71 ± 0.51	29.82	27.84	469.19 ± 121.83	724.65	235.58	84.48 ± 1.49	87.32	81.17	3.84 ± 0.71	5.53	2.69
Jul	34.51 ± 0.54	35.45	33.12	23.98 ± 0.49	24.74	23.06	10.53 ± 0.61	11.86	8.78	28.38 ± 0.30	29.09	27.80	531.33 ± 134.67	832.20	326.49	86.37 ± 1.18	88.50	84.31	3.68 ± 0.59	4.78	2.79
Aug	34.71 ± 0.64	36.00	33.33	24.09 ± 0.39	24.80	23.29	10.61 ± 0.73	12.35	9.43	28.53 ± 0.31	29.08	27.88	402.14 ± 107.79	658.26	159.77	85.73 ± 1.26	88.12	83.71	3.52 ± 0.55	4.48	2.56
Sep	35.01 ± 0.66	36.37	33.93	23.58 ± 0.49	24.32	22.42	11.42 ± 0.63	12.85	10.26	28.35 ± 0.35	28.88	27.66	332.48 ± 90.01	652.74	176.97	85.48 ± 1.05	87.76	82.70	3.31 ± 0.49	4.03	2.40
Oct	34.68 ±	35.86	33.73	20.27 ±	22.45	18.27	14.41 ±	16.57	11.92	27.20 ±	28.26	26.26	196.19 ±	401.06	46.70	83.19 ±	85.52	80.00	3.02 ±	3.85	2.14

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Table 2. (*Continued*)

Month/ Season	Maximum temperature (°C)			Minimum temperature (°C)			Monthly temperature range (°C)			Daily average temperature (°C)			Precipitation (mm)			Relative humidity (%)			Wind speed (kt)		
	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min	Mean ± SD	Max	Min
	0.56			1.14			1.17			0.44			89.02			1.49			0.52		
Nov	32.58 ± 0.75	34.11	30.76	14.99 ± 1.05	17.03	13.00	17.59 ± 1.25	19.99	15.43	23.69 ± 0.59	25.24	22.61	35.03 ± 44.21	185.22	0.09	79.02 ± 1.73	82.74	74.00	2.65 ± 0.37	3.48	2.07
Dec	29.45 ± 0.62	30.60	27.99	10.93 ± 1.09	13.07	8.91	18.52 ± 1.13	20.51	16.52	19.60 ± 0.69	21.09	17.93	7.36 ± 12.28	48.79	0.00	78.59 ± 2.31	83.14	73.00	2.64 ± 0.32	3.21	2.13
Winter	29.95 ± 0.63	31.27	28.49	10.34 ± 0.65	11.47	8.98	19.63 ± 0.69	21.18	18.41	19.73 ± 0.56	20.90	18.81	36.70 ± 28.41	128.47	0.37	76.03 ± 1.61	78.98	72.95	2.97 ± 0.36	3.79	2.40
Pre-Monsoon	36.28 ± 0.77	38.09	34.66	18.26 ± 0.60	19.91	17.06	18.00 ± 0.66	19.48	16.81	27.47 ± 0.58	28.61	26.18	433.28 ± 119.03	665.69	215.68	75.05 ± 1.76	78.47	70.80	3.91 ± 0.63	4.92	2.96
Monsoon	35.01 ± 0.42	35.70	34.04	23.61 ± 0.33	24.08	22.85	11.40 ± 0.37	12.19	10.64	28.49 ± 0.24	28.87	28.06	1738.72 ± 230.81	2238.97	1343.59	85.52 ± 0.64	86.81	84.24	3.58 ± 0.54	4.47	2.80
Post-Monsoon	33.66 ± 0.59	35.00	32.60	17.68 ± 0.80	19.62	16.04	15.98 ± 0.88	17.73	14.50	25.49 ± 0.53	27.20	24.68	231.13 ± 92.33	408.38	59.61	81.25 ± 1.17	83.94	79.08	2.84 ± 0.40	3.48	2.11
Annual	37.55 ± 0.77	39.79	36.05	8.71 ± 0.88	9.88	6.23	28.96 ± 1.07	31.31	27.23	25.56 ± 0.30	26.38	25.06	2429.27 ± 269.59	2861.55	1848.53	79.83 ± 0.68	81.15	77.78	3.35 ± 0.45	4.12	2.64

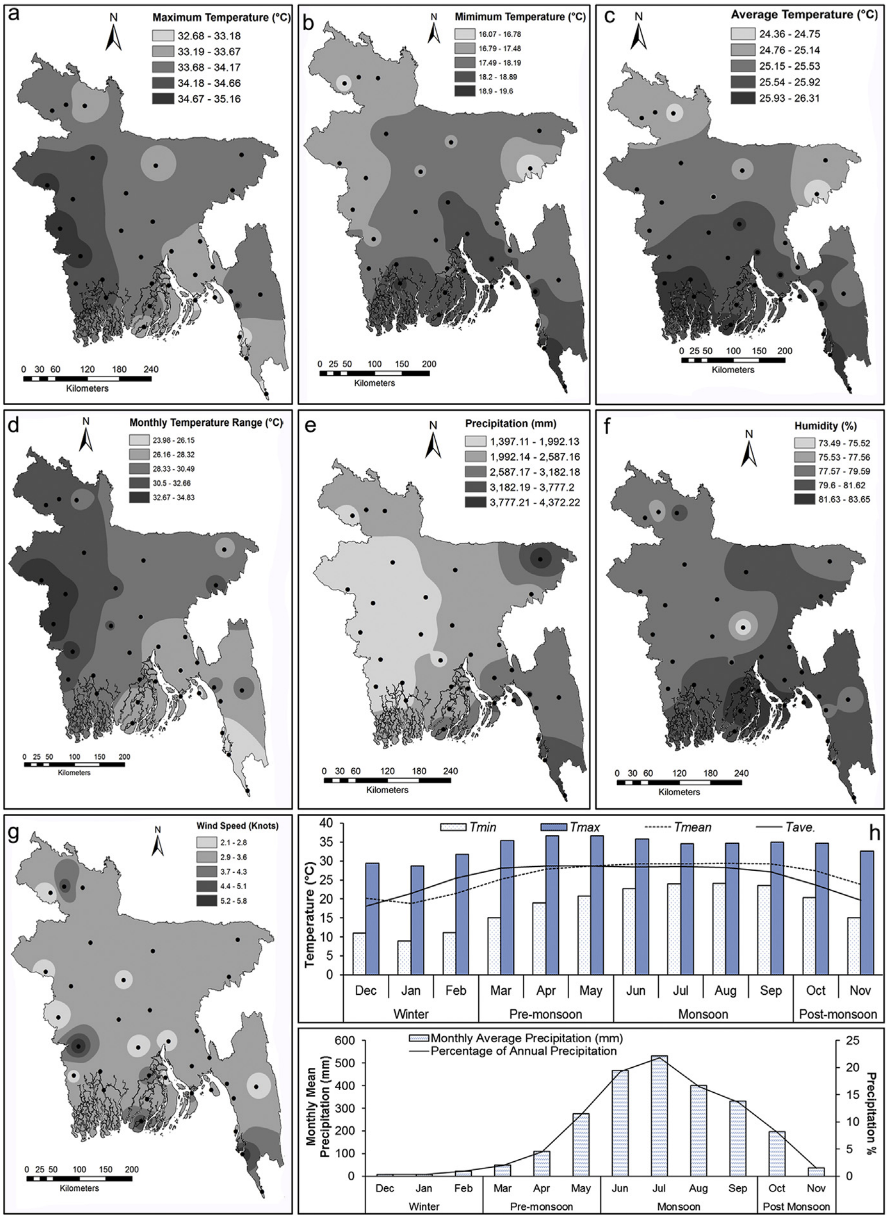

Fig. 2. Spatial distribution of average (a) monthly maximum temperature, (b) monthly minimum temperature, (c) daily average temperature, (d) monthly temperature range, (e) total annual precipitation, (f) relative humidity, and (g) wind speed; (h) monthly and seasonal distribution of maximum (T_{max}) and minimum (T_{min}) temperature associated with their mean (T_{mean}) and daily average temperature ($T_{ave.}$), and (i) precipitation of Bangladesh during the period of 1988−2017. The black dots on the spatial distribution maps are the location of meteorological stations.

Khairulmaini (2009), Shahid (2010a) and Shahid et al. (2012), the tropical depressions (also known as monsoon depressions) in the Bay of Bengal are the main precursor for the rainfall in Bangladesh during the summer monsoon season, which move from the Bay of Bengal toward the monsoon trough and produce enormous amounts of rainfall.

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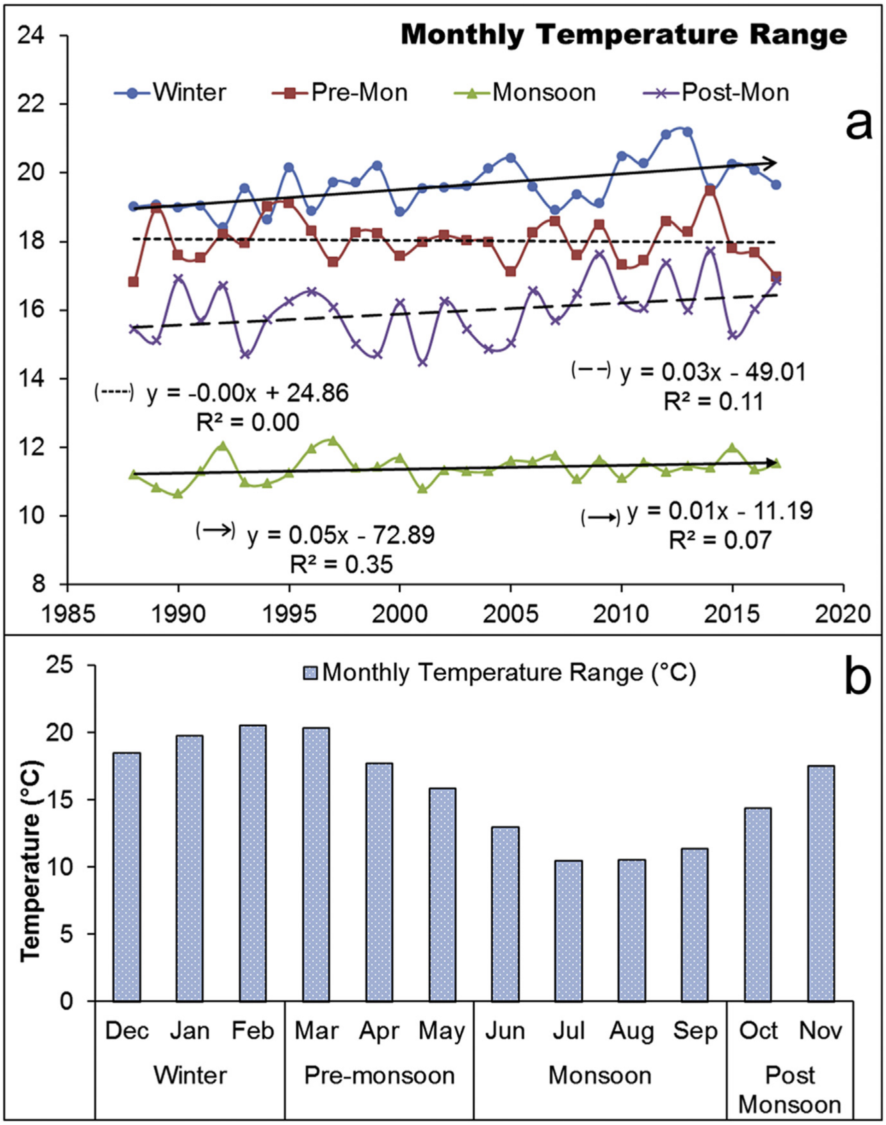

Fig. 3. (a) Seasonal trends in monthly temperature range (MTR) and (b) the seasonal and monthly distribution of average MTR during the period of 1988−2017.

The main explanation for the declining rainfall in the northwest and west part of Bangladesh may be due to the moisture content loss of the monsoon depressions from the Bay of Bengal (Ahmed and Kim, 2003; Shahid and Khairulmaini, 2009). Furthermore, the rainfall has increased in the northeast of Bangladesh because of the additional uplifting effect of the Meghalaya plateau (Shahid and Khairulmaini, 2009). Less precipitation occurs in the west and northwest regions (regions C, D, E, and F) than the north-eastern (region B) and south-eastern (i.e. north-eastern part, region A) regions of the country (Fig. 2e). Shahid and Khairulmaini (2009), Shahid (2010a) and Shahid et al. (2012) reported that the rainfall in Bangladesh varies from ∼1500 mm in the west to more than ∼4000 mm in the east, which is also consistent with this study.

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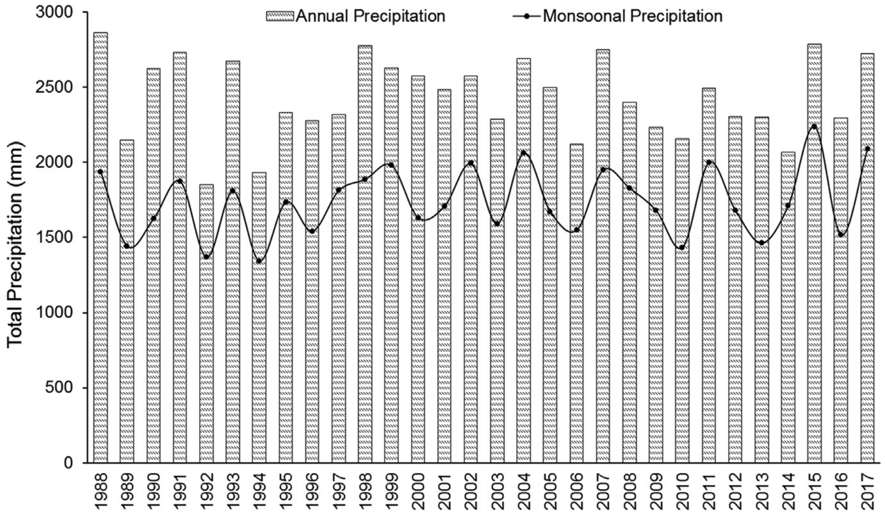

Fig. 4. Total annual precipitation distribution with the monsoonal rainfall in Bangladesh from 1988 to 2017.

3.1.3. *Relative humidity*

The relative humidity over the country ranges from 70.90% (March) to 86.37% (July) with a yearly average value of 79.83% (Table 2). In monsoon season, the humidity is higher (about 85.52%) than the other seasons (and is lower in the pre-monsoon season, ~75.05%). The south-eastern and north-eastern parts (regions A and B) are a higher-humidity area of the country (Fig. 2f). This could be due to greater water vapor content in the air of the coastal area and may be associated with the increasing temperature of these regions.

3.1.4. *Wind speed*

The average annual WS is 3.35 ± 0.45 kt, with a maximum of 4.12 kt and minimum of 2.64 kt (Table 2). The highest WS was recorded in April (4.05 kt) and the lowest in January (2.64 kt). The average maximum WS has detected a maximum in the pre-monsoon (3.91 kt) and minimum in the post-monsoon (2.84 kt) seasons. The overall WS has decreased across the country during the last thirty years (Fig. 2g). In 1988, the average WS was 4.03 kt, which decreased to 2.68 kt in 2016. Wind is partly a result of a contrast in temperature, such as a strong cold front between low and high latitudes, and there are various reasons for the WS to decrease at a considerable rate. Several researchers have concluded that the atmospheric and tropical circulations have weakened during the last few decades (e.g. Vecchi and Soden, 2007; Gastineau and Soden, 2009; You et al., 2010; Bichet et al., 2012; Mika, 2013; Rummukainen, 2013; Saha et al., 2017).

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3.2. Trend analysis

Linear regression, Mann-Kendall, and Sen's slope tests have been applied to determine the significant trends in the different meteorological variables associated with time series during the period. The test results of Mann-Kendall's trend analysis of the monthly, seasonal and yearly (region-wise) climatic variables were applied to determine the significant trend in the time series. Sen's slope and linear regression test were used to determine the magnitude of the change and find out the confidence level, respectively (Table 3).

i. In region A, T_{max} shows a rising trend in most of the seasonal series; however, no significant trend is observed in the annual series. According to the (Sen's) slope values, the T_{max} has risen significantly through the time series during all of the seasons. In contrast, T_{min} does not show any significant trend in most of the seasons except the monsoon; however, a small decrease is observed in the annual series (0.20 °C/decade). The annual MTR has increased by 0.56 °C/decade, whereas the seasonal rising rate is higher in winter (0.66 °C/decade) than the monsoon season (0.12 °C/decade). Additionally, the daily average temperature has risen significantly by 0.14 °C/decade and 0.14 °C/decade in the annual and monsoon series, respectively. Besides these factors, the precipitation and humidity have slightly decreased, though they do not show any significant trend. The WS has decreased at a higher rate in both seasonal and annual series (0.53 kt/decade) at a 99% confidence level.

ii. The T_{max} in region B shows a rising increasing trend in winter, monsoon, and post-monsoon and annual series by 0.71, 0.33, 0.45 and 0.29 °C/decade, respectively; however, the T_{min} has increased by 0.33 °C/decade only in the monsoon season. The significant ascending trend of the MTR has been observed in winter (0.70 °C/decade) and post-monsoon (0.68 °C/decade) seasons, while the daily average temperature has increased significantly in monsoon and annual time series. The precipitation and humidity have decreased in most of the seasonal and annual time series (except the post-monsoon season). This decline in WS is very significant in the monsoon season.

iii. A significant increasing trend has been found in T_{max} during winter, monsoon and annual series, and in T_{min} during pre-monsoon and monsoon season in regions C and D. The daily average temperature has also increased in the monsoon, post-monsoon and in annual series by 0.25 °C, 0.28 °C and 0.20 °C/decade, respectively; however, no significant trend exists in MTR. Precipitation and humidity show descending trends in the monsoon season at a decreasing rate of 120 mm/decade and 0.70%/decade, respectively. Additionally, the WS in the seasonal and annual series demonstrates a decreasing trend.

iv. In region E, the monsoonal T_{max} and T_{min} have increased by 0.60 °C/decade and 0.46 °C/decade, respectively. The MTR exhibits a significant decreasing trend

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Table 3. Monthly, seasonal and annual trends for different climatic variables in the different regions of Bangladesh. Values in the table are calculated by Sen's slope test which changes per decade.

Region	Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Pre-Mon	Monsoon	Post-Mon	Annual
South-East (A)	T_{max}	0.56**	0.71*	0.46	0.35	0.47**	0.44**	0.39**	0.31	0.45*	0.35**	0.36	0.38*	0.55**	0.43**	0.35**	0.40**	0.22
	T_{min}	-0.09	-0.10	0.20	0.26	0.13	0.18	0.28*	0.13	0.25**	-0.11	-0.08	-0.43	-0.16	0.17	0.22**	0.04	-0.20
	T_{range}	0.58*	0.73**	0.23	0.17	0.33	0.21*	0.02	0.16	0.09*	0.43	0.54	0.72*	0.66**	0.23	0.12**	0.45*	0.56*
	$T_{ave.}$	-0.06	0.12	0.12	0.20	0.24	0.26*	0.09	0.11	0.14*	0.10	-0.15	0.01	-0.01	0.21	0.15**	0.03	0.14*
	P_T	0.00	-7.19*	-6.26	-19.46	-4.76	7.87	45.01	42.99	19.52	-3.18	-7.91	-0.06	-13.46*	-6.62	125.02	-16.11	19.46
	H_R	0.37	-1.79*	-0.79	0.00	-0.54	-0.37	0.08	0.03	0.09	0.13	0.23	1.08**	0.08	-0.48	-0.07	0.24	-0.19
	WS	-0.44**	-0.47**	-0.63**	-0.63**	-0.81**	-0.73**	-0.66**	-0.60**	-0.41**	-0.46**	-0.34**	-0.38**	-0.46**	-0.67**	-0.59**	-0.40**	-0.53**
North-East (B)	T_{max}	0.47	0.81**	0.38	0.10	0.15	0.12	0.21	0.29	0.55*	0.50**	0.40	0.78	0.71**	0.30	0.33**	0.45**	0.29
	T_{min}	0.33	-0.18	0.08	0.33*	0.20	0.33	0.44**	0.20*	0.35*	-0.02	-0.23	-0.33	-0.02	0.26	0.33**	-0.17	-0.05
	T_{range}	0.40	1.13**	0.42	-0.36	0.02	0.00	-0.17	0.06	0.07	0.57	0.78*	0.83*	0.70**	-0.02	0.03	0.68*	0.25
	$T_{ave.}$	-0.09	0.18	0.18	-0.04	0.13	0.10	0.25*	0.14	0.28*	0.27*	-0.10	0.10	0.02	0.12	0.21**	0.13	0.18**
	P_T	0.00	-6.25	-12.06	62.50	26.67	13.75	-62.00	69.21*	21.50	-20.00	-3.29	0.00	-10.00	72.50	-38.54	-25.36	-30.33
	H_R	0.00	-1.56*	-1.19	0.63	-0.50	0.00	-0.83*	0.00	-0.58	-1.25**	-0.77	0.64	-0.15	-0.83	-0.56	-0.91**	-0.38
	WS	-0.17	-0.25	-0.22	-0.38*	-0.56**	-0.40**	-0.37*	-0.28**	-0.36**	-0.41**	-0.41*	-0.38*	-0.29*	-0.32**	-0.42**	-0.45*	-0.36**
Northern of North Region (C) and North-West (D))	T_{max}	0.10	0.53	-0.07	-0.22	0.01	0.32	0.50**	0.20	0.34	0.40*	-0.03	0.27	0.37*	-0.07	0.33**	0.20	0.29
	T_{min}	0.08	-0.07	0.47	0.53*	-0.02	0.16	0.26*	0.28**	0.56**	0.08	0.16	-0.37	-0.05	0.36**	0.30**	0.27	-0.16
	T_{range}	-0.04	0.62	-0.52	-0.91*	-0.09	0.20	0.20	-0.12	-0.28	0.36	-0.21	0.52	0.36	-0.37	0.02	0.06	-0.04
	$T_{ave.}$	-0.33	0.09	0.14	0.06	0.25	0.33**	0.22*	0.13	0.40**	0.26*	0.10	-0.04	-0.13	0.15	0.25**	0.28*	0.20**
	P_T	-1.80	-1.91	2.43	7.38	1.20	-23.75	-31.13	14.33	-60.2**	3.50	-0.84	0.00	-5.29	8.68	-120.70*	-8.70	-130.0
	H_R	1.53*	0.42	1.90	1.67	-0.35	-0.75*	-0.70	-0.32	-0.83*	-0.09	0.40	2.28**	1.62**	1.05	-0.70**	0.13	0.40
	WS	-0.31**	-0.42**	-0.47**	-0.51**	-0.48**	-0.57**	-0.30**	-0.30**	-0.32**	-0.27*	-0.30**	-0.20**	-0.31**	-0.50**	-0.38**	-0.32**	-0.35**
West (E)	T_{max}	0.02	0.75	0.08	-0.50	-0.50	0.54	0.67**	0.56**	0.54**	0.42*	-0.05	0.25	0.32	-0.22	0.60**	0.16	-0.43
	T_{min}	0.17	0.19	0.18	0.79**	0.45	0.26	0.41**	0.43**	0.61**	0.10	0.03	-0.24	0.07	0.50*	0.46**	0.06	0.18
	T_{range}	0.00	0.36	-0.25	-1.46*	-0.95	0.18	0.33	0.21	-0.21	0.26	-0.10	0.45	0.33	-0.70*	0.17	0.15	-0.22

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Table 3. (*Continued*)

Region	Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Pre-Mon	Monsoon	Post-Mon	Annual
	$T_{ave.}$	-0.14	0.14	0.19	0.00	0.19	0.39**	0.29**	0.23**	0.36**	0.11	-0.14	-0.17	-0.13	0.21	0.28**	0.09	0.14*
	P_T	0.36	-5.63*	1.09	10.00	-17.22	-25.77	-16.36	13.70	-36.67	-1.75	-1.67	0.00	-7.50	-1.18	-54.00	-11.23	-103.93
	H_R	1.82**	0.45	1.60	2.50	0.00	-0.94*	-0.80*	-0.38	-0.71	0.00	0.14	2.03**	1.67**	1.19	-0.64**	0.36	0.48
	WS	-0.30**	-0.45**	-0.50**	-0.70**	-1.09**	-1.07**	-0.83**	-0.68**	-0.75**	-0.48**	-0.38**	-0.42**	-0.40**	-0.77**	-0.83**	-0.40**	-0.64**
South-West (F)	T_{max}	0.07	0.31	-0.05	0.12	0.09	0.56**	0.29*	0.43**	0.36*	0.40**	0.05	0.18	0.13	0.11	0.37**	0.27	-0.07
	T_{min}	0.25	-0.14	0.03	0.63**	0.20	0.22	0.33*	0.45**	0.64**	0.00	0.17	0.06	0.08	0.42*	0.38**	0.26	-0.22
	T_{range}	-0.10	0.25	0.12	-0.75	-0.04	0.44	-0.08	-0.02	-0.40	0.54	-0.21	0.04	0.09	-0.22	0.06	0.04	0.00
	$T_{ave.}$	-0.11	0.00	0.05	0.27	0.32*	0.32**	0.13	0.19*	0.36**	0.19	-0.09	0.00	-0.10	0.21	0.24**	0.18	0.18**
	P_T	0.00	-7.27	-3.61	-9.70	-14.08	-15.83	37.14	14.55	11.53	-15.19	-1.11	0.00	-11.82	-31.56	59.17	-23.02	-46.47
	H_R	1.15*	-0.48	-0.02	-0.21	-1.50**	-1.25**	-0.31	-0.46	-1.07**	-0.50	0.00	1.52**	1.01*	-0.56	-0.80**	-0.31	-0.28
	WS	-0.40**	-0.32**	-0.68**	-0.88**	-1.05**	-0.97**	-0.74**	-0.63**	-0.52**	-0.39*	-0.25*	-0.37**	-0.42**	-0.80**	-0.73**	-0.38*	-0.59*
Mid-South (G)	T_{max}	0.19	0.38	0.06	-0.03	0.31*	0.51**	0.39**	0.28	0.43*	0.37**	0.16	0.38*	0.32*	0.17	0.39**	0.33**	0.19
	T_{min}	0.11	0.02	0.17	0.29	0.03	0.02	0.15	0.16	0.27**	-0.04	0.14	-0.28	-0.08	0.21	0.14*	0.07	-0.13
	T_{range}	0.20	0.43	-0.04	-0.54	0.32	0.55**	0.27	0.05	0.10	0.41	0.23	0.42	0.35**	-0.11	0.26**	0.39	0.29
	$T_{ave.}$	-0.15	0.09	0.08	0.13	0.28	0.21*	0.11	0.08	0.24**	0.14	-0.08	-0.09	-0.14	0.23	0.14**	0.06	0.13
	P_T	-0.29	-11.29**	-11.79	-6.90	-29.40	-3.33	20.71	30.95	0.17	-20.45	-3.01	0.00	-12.83**	-53.95	39.46	-30.10	-78.72
	H_R	1.31	-0.91	-0.20	0.60	-1.02*	-0.59	-0.27	-0.08	-0.41	-0.29	-0.16	1.46*	0.90*	-0.36	-0.36*	-0.14	-0.08
	WS	-0.22**	-0.34**	-0.50**	-0.68**	-0.93**	-0.79**	-0.67**	-0.58**	-0.47**	-0.35**	-0.21**	-0.29**	-0.31**	-0.71**	-0.61**	-0.27**	-0.49**
All Regions	T_{max}	0.27*	0.59*	0.18	0.16	0.22	0.41**	0.38**	0.35*	0.41**	0.41**	0.18	0.32*	0.39**	0.21	0.37**	0.36**	0.35**
	T_{min}	0.10	-0.13	0.22	0.43	0.12	0.16	0.28**	0.22*	0.38**	-0.01	-0.02	-0.32	-0.10	0.25	0.25**	0.11	0.16*
	T_{range}	0.25	0.63	0.21	-0.43	0.11	0.26	0.08	0.05	-0.06	0.41	0.27	0.47	0.42**	-0.06	0.13	0.33	0.20**
	$T_{ave.}$	-0.16	0.06	0.04	0.13	0.24	0.28*	0.15*	0.13	0.23**	0.17	-0.06	-0.06	-0.13	0.20	0.19**	0.07	0.14*
	P_T	-0.29	-9.10*	-6.27	-7.31	-7.65	-2.98	22.91	33.36	-5.69	-10.08	-5.20	-0.37	-4.01*	-6.48	13.37	-9.56	-32.59
	H_R	1.04	-0.86	-0.14	0.74	-0.74	-0.62	-0.31	-0.08	-0.38	-0.06	0.00	1.20*	0.73	-0.10	-0.37*	0.03	-0.03
	WS	-0.34**	-0.38**	-0.53**	-0.63**	-0.84**	-0.76**	-0.64**	-0.56**	-0.42**	-0.39**	-0.30**	-0.35**	-0.38**	-0.68**	-0.60**	-0.36**	-0.51**

* Significant at 95% level of confidence.

** Significant at 99% level of confidence. T_{max} maximum temperature, T_{min} minimum temperature, *MTR* monthly temperature range, $T_{ave.}$ daily average temperature, P_T total precipitation, H_R relative humidity, *WS* wind speed.

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in the pre-monsoon season (0.70 °C/decade), but the increasing rate in annual series is not significant. The daily average temperature has slightly risen in the monsoon and annual time series. Precipitation and humidity show a falling trend in the monsoon season by 54 mm/decade and 0.64%/decade, respectively. The trend of WS declines in the all-time series, with the highest rate (0.83 kt/decade) in monsoonal periods.

v. The T_{max} in monsoon and T_{min} in both the pre-monsoon and monsoon seasons have a significant ascending trend in region F. The rising trend of the daily average temperature is significant during monsoon and annual series; however, the trend in MTR is not significant. Moreover, there is no significant trend for precipitation, but a monsoonal falling trend for humidity exists; however, WS dropped significantly during seasonal and annual series.

vi. In region G, T_{max} increased in the winter, monsoon and post-monsoon seasons by 0.32 °C, 0.39 °C, and 0.33 °C/decade, respectively. The T_{min} and the daily average temperature have increased in the monsoon season. The trend pattern of MTR indicates that the rising rate of MTR is higher in winter than in the monsoon season. Similarly, the humidity shows a rising trend in winter associated with precipitation, which falls in the pre-monsoon, monsoon and post-monsoon seasons. This could be due to the extensive irrigation development in this region (Nasrin, 2009). The trend of WS is downward in all the time series by a significant rate.

The T_{max} increased in most regions in the country during winter (and post-monsoon in some cases) and during the monsoon season. On the other hand, the T_{min} tended to decrease during the winter season, whereas it increased significantly during the monsoon season. However, monsoonal T_{max} increases at a higher rate than the rate of T_{min}. Therefore, the MTR increased at a higher rate during winter compared to the monsoon season. Based on the trend analysis of T_{max}, T_{min} and MTR, most of the regions of the country (especially regions A and B) are colder during winter and hotter during the summer monsoon season. The average warming rate in regions A and B is higher than the other regions, and their respective rates are 0.28 °C/decade and 0.33°C/decade in monsoonal months and 0.30 °C/decade and 0.37 °C/decade in the annual series at a 99% confidence level. Additionally, the monsoonal T_{max} and T_{min} (0.47 °C/decade and 0.38 °C/decade, respectively) also increased significantly in the north-western regions (regions C, D, and E); therefore, these areas have been warmed by 0.27 °C/decade. The monsoonal precipitation increased somewhat in region A; however, it declined in region B associated with the north-western regions (regions C, D, and E). The monsoonal humidity also decreased because of the increase in temperature and decrease in precipitation in those regions. WS decreased dramatically all over the country and declined at a higher rate in the north-western regions (monsoon, 0.60 and annual, 0.51 kt/decade) than other regions, and the monsoonal and annual precipitation have decreased by 87.35 mm/decade and 107

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mm/decade, respectively. The overall monsoonal wind circulation speed has intensely declined across the country, and the rate of decrease is notably higher (0.65 kt/decade) in the north-western area (regions C, D, E, and F) of the country. In addition, the precipitation occurred in the north and north-western regions of the country due to the monsoon depressions, and the WS is the main driving force that advances the depressions to the north. As the WS also declined over the area, the depressions cannot pass through the northern area. Besides, the moisture content of depressions tends to decrease during their passage through the inland regions; resulting in a decrease in rainfall in the north-western regions (Ahmed and Kim, 2003; Shahid and Khairulmaini, 2009; Shahid, 2010a). Bari et al. (2016) have also identified a decreasing trend in monsoonal and annual rainfall in most of the northern or north-western regions of Bangladesh. Furthermore, both T_{max} and T_{min} have increased in the western and north-western regions, and these areas have been warming significantly, especially in the monsoon season, by 0.27 °C/decade. As a result, flooding, drought, and falling underground water levels are common climatic effects in north-western Bangladesh.

Considering the overall observations, a significant increase in the average seasonal and annual T_{max} has been observed across the country (Table 3, Figs. 5a and 6a). However, no significant change has been observed for T_{max} in pre-monsoon periods, which causes a slight decrease in MTR (Fig. 3a). The increase in T_{max} and decrease in T_{min} have caused the increase in MTR by a significant rate (0.42 °C/decade) in the winter season across the country (Figs. 5a and b). Due to this increase, T_{max} and T_{min} are close in value during the monsoon and post-monsoon seasons, though the

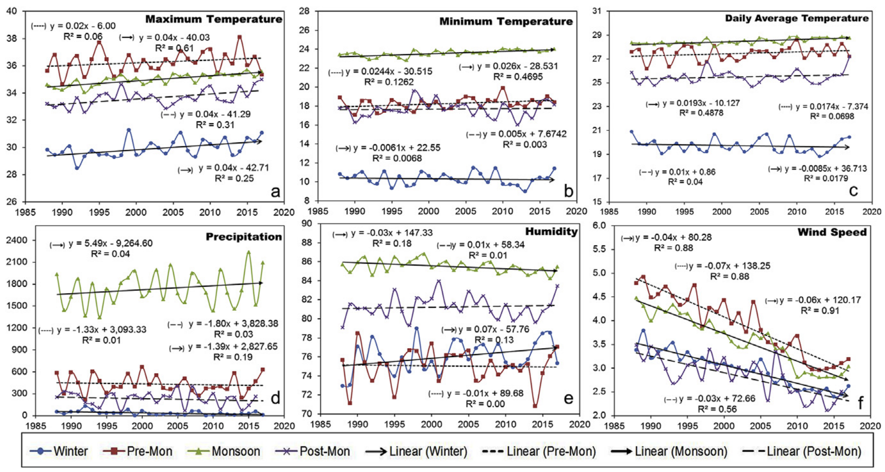

Fig. 5. The seasonal trend in (a) monthly maximum temperature, (b) monthly minimum temperature, (c) daily average temperature, (d) total annual precipitation, (e) relative humidity, and (f) wind speed. The regression equation and R^2 value are indicated by the same indicator of the trend line for the different season. In the figure, pre-mon and post-mon mean the pre-monsoon and post-monsoon season, respectively. The units are degree centigrade (°C) for temperature, millimeter (mm) for precipitation, percentage (%) for humidity and knot (kt) for wind speed along the y-axis.

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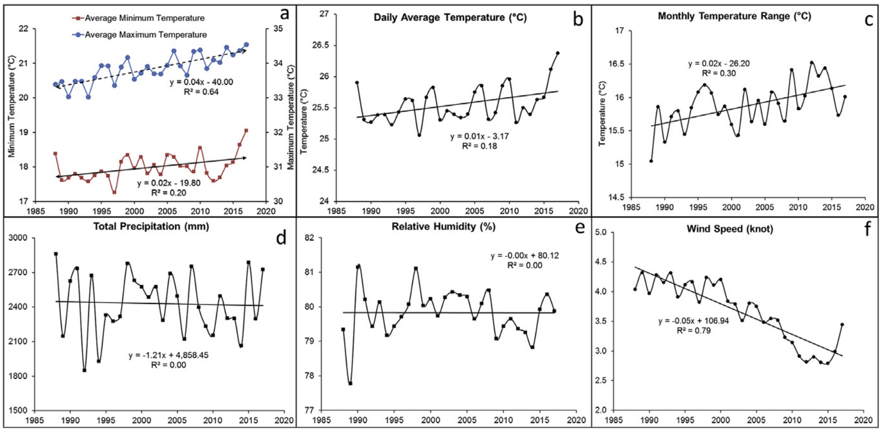

Fig. 6. Annual trend in (a) monthly maximum and minimum temperature, (b) daily average temperature, (c) monthly temperature range, (d) annual precipitation, (e) relative humidity, and (f) wind speed. The units are degree centigrade (°C) for temperature, millimeter (mm) for precipitation, percentage (%) for humidity and knot (kt) for wind speed along the y-axis.

increase in MTR is not significant (Table 3). The daily average temperature has also increased by a significant rate during the monsoon season; however, the rate of increase is not significant during the other seasons. Although the total precipitation during winter, pre-monsoon, and post-monsoon seasons has decreased slightly, the rising monsoonal trend is not very significant (Fig. 5d). Relative humidity has increased in winter but decreased in pre-monsoon and monsoon seasons (Fig. 5e). The monsoon and pre-monsoonal WS has decreased more rapidly across the country (Fig. 5f). Generally, temperature variables have indicated an increasing trend; however, there is no significant change in annual precipitation and humidity, whereas WS has decreased intensely over the country during the selected period (Fig. 6).

The temperature of Bangladesh has increased significantly over the last few decades; the increase in daily minimum temperature is more than the maximum temperature (Shahid et al., 2012). Meanwhile, monthly maximum temperature has increased significantly; however, monthly minimum temperature has shown a tendency to decrease across the country during the last thirty years. Therefore, seasonal analysis of temperature shows more winter warming compared to summer warming in Bangladesh, which is consistent with Shahid et al. (2012). The MTR has increased more in winter than in the monsoon season from 1988−2017, which is caused primarily by excessive cloudiness in the summer monsoon season. Herein, the MTR is the difference between T_{max} and T_{min} in a distinct calendar month, which has a strong positive correlation ($r = 0.83$, $p < 0.001$ at a 99% confidence level) with the difference in daily maximum and minimum temperature and the diurnal temperature range (DTR). Several studies have documented the inverse relationship between DTR and cloud cover (Karl et al., 1993; Dai et al., 1997, 1999; Travis et al., 2004; Zhou et al., 2009; Jackson and Forster, 2010; Rai et al., 2012). The excessive cloud cover

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provides the resistance to heat radiation. As a result, the increase in cloud cover tends to decrease the maximum temperature, whereas its net effect on the daily minimum temperature is comparatively minor because of the reflection of sunshine by the clouds to the surface, which causes the increase in temperature even after sunset, thereby increasing the minimum temperature. Besides these effects, clouds also enhance downward long-wave radiation, which increases the minimum temperature, and consequently, the DTR decreases (Karl et al., 1993; Dai et al., 1997, 1999; Zhou et al., 2009; Rai et al., 2012). We note that clouds are at a minimum (10%) during winter across almost the entire country and then increase up to 60% by the end of the pre-monsoon, reach 85−90% during the summer monsoon, and finally return to a minimum in winter in Bangladesh after dropping to 25−50% in the summer monsoon (Banglapedia, 2003; Shahid et al., 2012). This pattern can thus be considered the main reason for the increase in MTR in winter compared to the monsoon season.

The climate of Bangladesh is primarily monsoon-driven, and therefore, the precipitation is mainly concentrated in the monsoon season, with about 70−80% of total rainfall occurring during this time. Although there is no significant change in average precipitation across the country, a monsoonal decrease is found in some regions, especially in north or north-western areas (regions B, C, D, and E). This may be due to the increase in temperature variables and the significant decrease in WS. There are likely some reasons for the increasing trend of humidity, such as increases in temperature or increases in the wetness of the land surface. The average annual relative humidity tended to decrease across the country. Therefore, the combined effect of the increase in temperature and decrease in humidity on potential evapotranspiration is observed to be negative rather than positive (Climate Change Cell, 2009; Nasrin, 2009). However, humidity during winter and the post-monsoon season shows a rising trend (Fig. 5e). Through the last three decades, especially in the dry season (November−May), the irrigation has increased significantly, causing higher increases in humidity. Additionally, irrigation development for rice cultivation (along with coastal shrimp aquaculture) using standing water on land as contributed greatly to the increase in humidity in Bangladesh (Mondal et al., 2013). On the contrary, the average annual WS dropped by 1.53 kt during the last three decades at a 99% confidence level ($p < 0.0001$). Studies show that the near-surface WS projections for the Indian sub-continent have decreased significantly in the monsoon time in which there was an ∼1−5% WS decrease in the Indo-Gangetic Basin and an ∼3% decrease in the Gangetic West Bengal and adjoining Bangladesh (Saha et al., 2017). Vecchi and Soden (2007) concluded that the greenhouse effect might have an important role to play in the weakening of atmospheric and tropical circulations in the past few years. Several studies (Jacobson and Kaufman, 2006; Xu et al., 2006; Zhao et al., 2006; Chan and Lee, 2011; Bichet et al., 2012; Saha et al., 2014) have shown that the WS has decreased in different parts of the world.

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In the past few decades, the decreasing frequencies of extreme wind events have been an important feature in and around the tropics in relation to global warming (Gastineau and Soden, 2009; Rummukainen, 2013; Mika, 2013). Thus, decreasing WS or changing the wind circulation near the surface may be a cause of temperature rise and rainfall reduction (especially in the north) in Bangladesh.

3.3. Correlation among the variables

Pearson's correlation is a parametric correlation test that has been applied to examine whether there is any linear correlation between any of the two variables used for this study. The total precipitation and humidity are negatively correlated with T_{max} and MTR in all distinct regions of the country (Table 4). The WS shows a negative correlation with temperature variables, suggesting that the WS has decreased with the increase in temperature in most of the regions of the country (except regions C and D). In contrast, the precipitation, humidity, and WS have a positive correlation with T_{min}. It is also apparent that humidity remains correlated positively with precipitation but negatively with MTR, as it is increasingly associated with T_{max} in the dataset.

Spearman rho's test has been used to show the monotonic relationship between the temperature variables and precipitation, humidity and WS (Table 5). Based on the rho values, total precipitation is negatively correlated with T_{max} during winter and the pre-monsoon season in all the distinct regions; however, T_{max} has a positive correlation with precipitation during the monsoon season in regions A and F and a negative correlation in regions B, C, D and E. In the north and north-west part of the country (regions C, D and E), significant negative correlations of temperature with precipitation and WS (including region F as well) have been detected, which indicates that the precipitation has decreased because of an increase in temperature. The monsoonal precipitation shows a positive significant correlation with temperature in region A but negative correlation in region B, whereas there is no significant relationship between monsoonal precipitation and the temperature variables in other regions. Annual average MTR and T_{max} have a significant negative correlation with precipitation in Bangladesh. MTR is correlated negatively with precipitation in winter, pre-monsoon and post-monsoon, but positively in the monsoon season in most of the regions. Seasonal humidity is negatively correlated with T_{max} and MTR in most of the regions. The change in WS shows a negative correlation with T_{max} and MTR, suggesting that the increase in T_{max} and MTR may cause a decrease in WS. Different studies have also found that the changes in precipitation or WS are negatively correlated with the temperature variables (Verdecchia et al., 1994; Geerts, 2003; Shahid, 2010a, 2010b; Jhajharia and Singh, 2011; Shahid et al., 2012; Raihan et al., 2015).

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Table 4. Summary of Pearson correlation coefficient between the climatic variables for individual regions.

Climatic Region	Variable	T_{max}	T_{min}	*MTR*	$T_{ave.}$	*PT*	*HR*	*WS*
South-East (A)	T_{max}	1.00						
	T_{min}	-0.23	1.00					
	MTR	0.61*	-0.67*	1.00				
	$T_{ave.}$	0.20	0.20	0.05	1.00			
	PT	-0.33	0.10	-0.27	0.06	1.00		
	HR	-0.17	0.22	-0.36	-0.05	0.33	1.00	
	WS	-0.23	0.24	-0.41*	-0.31	0.00	0.32	1.00
North-East (B)	T_{max}	1.00						
	T_{min}	-0.11	1.00					
	MTR	0.60*	-0.75*	1.00				
	$T_{ave.}$	0.22	0.14	-0.09	1.00			
	PT	-0.32	-0.05	-0.2	-0.03	1.00		
	HR	-0.56*	0.22	-0.39*	-0.41*	0.29	1.00	
	WS	-0.3	0.02	-0.14	-0.10	0.33	0.2	1.00
Northern of North Region (C) and North-West (D)	T_{max}	1.00						
	T_{min}	-0.09	1.00					
	MTR	0.61*	-0.65*	1.00				
	$T_{ave.}$	-0.18	0.17	-0.22	1.00			
	PT	-0.06	0.24	-0.23	-0.05	1.00		
	HR	-0.57*	0.06	-0.55*	0.06	0.38*	1.00	
	WS	0.27	0.22	0.12	-0.46*	0.29	-0.39*	1.00
West (E)	T_{max}	1.00						
	T_{min}	0.17	1.00					
	MTR	0.58*	-0.54*	1.00				
	$T_{ave.}$	0.08	0.28	-0.12	1.00			
	PT	-0.35	-0.12	-0.3	-0.34	1.00		
	HR	-0.62*	-0.13	-0.39*	0.01	0.47*	1.00	
	WS	0.21	-0.03	0.00	-0.36*	0.28	-0.35	1.00
South-West (F)	T_{max}	1.00						
	T_{min}	0.11	1.00					
	MTR	0.63*	-0.59*	1.00				
	$T_{ave.}$	0.13	0.2	0.03	1.00			
	PT	-0.23	0.11	-0.35	-0.05	1.00		
	HR	-0.45*	0.12	-0.41*	-0.37*	0.41*	1.00	
	WS	-0.05	0.06	0.09	-0.37*	0.05	0.09	1.00
Mid-South (G)	T_{max}	1.00						
	T_{min}	0.23	1.00					
	MTR	0.36*	-0.66*	1.00				
	$T_{ave.}$	0.34	0.19	-0.12	1.00			
	PT	-0.34	-0.2	-0.31	-0.04	1.00		
	HR	-0.37*	0.07	-0.34	-0.11	0.54*	1.00	
	WS	-0.01	0.1	-0.12	-0.24	0.19	0.03	1.00
All Regions	T_{max}	1.00						
	T_{min}	0.60*	1.00					
	MTR	0.21	-0.16	1.00				
	$T_{ave.}$	0.73*	0.84*	-0.12	1.00			
	PT	-0.17	0.21	-0.46*	0.05	1.00		
	HR	-0.21	0.14	-0.41*	-0.08	0.56*	1.00	
	WS	-0.72*	-0.31	-0.20	-0.31	0.12	0.05	1.00

* significant at ≥95% level of confidence.

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Table 5. Spearman Rho's correlation coefficient of precipitation, humidity, and wind speed with temperature variables in different regions of Bangladesh.

Climatic Region	Temperature Variables	Winter			Pre-monsoon			Monsoon			Post-Monsoon			Annual		
		P_T	H_R	WS	P_T	H_R	WS	P_T	H_R	WS	P_T	H_R	WS	P_T	H_R	WS
South-East (A)	T_{max}	-0.72*	-0.22	-0.59*	-0.39*	-0.51*	-0.37*	0.42*	0.08	-0.58*	0.01	0.28	-0.17	-0.30	-0.17	-0.21
	T_{min}	-0.13	0.29	0.12	-0.48*	-0.20	-0.11	0.03	-0.28	-0.69*	0.25	0.52*	0.23	0.17	0.21	0.15
	MTR	-0.49*	-0.35	-0.55*	0.07	-0.44*	-0.34	0.35	0.27	0.00	-0.19	-0.25	-0.37*	-0.29	-0.31	-0.40*
	$T_{ave.}$	-0.32	0.04	0.05	-0.51*	-0.32	-0.17	-0.22	-0.35	-0.50*	0.01	0.32	0.10	0.04	-0.12	-0.34
North-East (B)	T_{max}	-0.54*	-0.20	-0.01	-0.39*	-0.78*	-0.25	-0.28	-0.42*	-0.31	-0.18	-0.32	0.02	-0.36	-0.55*	-0.47*
	T_{min}	0.11	-0.15	0.35	0.42*	0.05	0.02	-0.02	-0.44*	-0.36*	0.16	0.48*	0.36	-0.11	0.18	-0.07
	MTR	-0.60*	-0.17	-0.14	-0.63*	-0.71*	-0.23	-0.20	-0.01	-0.15	-0.15	-0.57*	-0.30	-0.15	-0.35	-0.16
	$T_{ave.}$	-0.16	-0.28	0.39*	-0.37*	-0.63*	-0.14	-0.46*	-0.70*	-0.47*	-0.10	0.07	0.20	-0.22	-0.42*	-0.24
Northern of North Region (C) and North-West (D)	T_{max}	-0.52*	0.08	-0.33	-0.57*	-0.69*	0.29	-0.31	-0.50*	-0.53*	-0.18	-0.08	-0.13	-0.13	-0.52*	0.26
	T_{min}	-0.03	0.04	-0.08	0.10	0.18	-0.33	-0.42*	-0.32	-0.74*	0.34	0.53*	-0.08	0.18	-0.04	0.21
	MTR	-0.38*	0.04	-0.21	-0.58*	-0.65*	0.38*	-0.02	-0.30	0.01	-0.38*	-0.42*	0.00	-0.24	-0.36	0.09
	$T_{ave.}$	-0.27	-0.30	0.13	-0.50*	-0.44*	-0.04	-0.61*	-0.74*	-0.58*	-0.11	0.23	-0.35	-0.06	-0.04	-0.44*
West (E)	T_{max}	-0.59*	-0.05	-0.06	-0.69*	-0.85*	0.24	-0.33	-0.62*	-0.67*	-0.51*	0.02	-0.24	-0.32	-0.59*	0.22
	T_{min}	-0.10	0.03	-0.10	-0.10	0.09	-0.41*	-0.28	-0.33	-0.74*	0.29	0.47*	0.00	-0.12	-0.18	-0.05
	MTR	-0.36*	-0.01	-0.02	-0.51*	-0.76*	0.50*	-0.18	-0.51*	-0.22	-0.43*	-0.40*	-0.11	-0.34	-0.42*	0.06
	$T_{ave.}$	-0.34	-0.35	0.16	-0.73*	-0.68*	-0.01	-0.54*	-0.74*	-0.71*	-0.13	0.44*	0.00	-0.34	-0.18	-0.37*
South-West (F)	T_{max}	-0.25	0.01	-0.21	-0.55*	-0.73*	0.03	0.20	-0.75*	-0.48*	-0.28	0.02	-0.09	-0.28	-0.35	0.04
	T_{min}	-0.34	0.10	-0.10	-0.40*	-0.33	-0.38*	-0.08	-0.48*	-0.53*	0.28	0.40*	-0.08	0.13	0.18	0.01
	MTR	0.03	-0.14	-0.16	-0.27	-0.49*	0.35	0.28	-0.30	-0.06	-0.38*	-0.36*	0.05	-0.35	-0.38*	0.10
	$T_{ave.}$	-0.27	-0.18	0.07	-0.58*	-0.52*	-0.12	-0.10	-0.81*	-0.45*	-0.24	0.11	-0.08	-0.06	-0.35	-0.41*
Mid-South (G)	T_{max}	-0.67*	0.18	-0.37*	-0.66*	-0.70*	-0.11	0.00	-0.46*	-0.76*	-0.29	-0.10	-0.19	-0.29	-0.36*	0.02

(*continued on next page*)

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Table 5. (*Continued*)

Climatic Region	Temperature Variables	Winter			Pre-monsoon			Monsoon			Post-Monsoon			Annual		
		P_T	H_R	WS	P_T	H_R	WS	P_T	H_R	WS	P_T	H_R	WS	P_T	H_R	WS
	T_{min}	-0.18	0.01	-0.05	-0.24	-0.16	-0.17	-0.25	-0.40*	-0.45*	0.23	0.45*	0.12	-0.16	0.01	0.12
	MTR	-0.52*	0.43*	-0.83*	-0.12	-0.15	-0.54*	-0.25	-0.19	0.07	-0.40*	-0.30	-0.30	-0.44*	-0.27	-0.34
	$T_{ave.}$	-0.20	-0.17	0.12	-0.62*	-0.49*	-0.07	-0.40*	-0.67*	-0.57*	-0.12	0.18	-0.03	-0.10	-0.21	-0.15
All Regions	T_{max}	-0.71*	-0.03	-0.58*	-0.63*	-0.75*	-0.17	0.21	-0.38*	-0.75*	0.03	0.19	-0.22	-0.18*	-0.23*	-0.73
	T_{min}	-0.19	0.05	0.04	-0.28	-0.27	-0.19	-0.02	-0.40*	-0.73*	0.36	0.62*	0.12	0.22	0.15	-0.32
	MTR	-0.48*	-0.07	-0.52*	-0.42*	-0.59*	-0.02	0.16	-0.16	-0.26	-0.35	-0.35	-0.26	-0.47	-0.28	-0.32
	$T_{ave.}$	-0.31	-0.21	0.17	-0.57*	-0.53*	-0.09	-0.28	-0.70*	-0.67*	-0.05	0.42*	-0.03	-0.04	-0.19	-0.30

* Significant at ≥95% confidence level.

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Long-term climate change and some local anthropogenic effects (e.g., local urbanization, changes in irrigation, and more) may cause the increase in T_{max} and MTR (Price et al., 1999). However, Karl et al. (1988, 1995) reported that the DTR trends remain unchanged even after correcting for the urbanization effect and increased irrigation. Similarly, there is also no effect of the changes in urbanization and irrigation on MTR. Long-term changes in cloud cover, soil moisture, precipitation, atmospheric water vapor, WS, and other variables are often cited as the most likely causes of the changes in temperature variables (Plantico et al., 1990; Karl et al., 1993; Dai et al., 1997, 1999; Liu et al., 2004). Thus, the increase in cloud cover, soil moisture, atmospheric water vapor, and greenhouse gases and the decrease in WS may be the major causes that increase T_{max} as well as MTR over Bangladesh.

4. Conclusion

This study was carried out to assess the spatial and temporal climatic variability and trends in Bangladesh and its different regions based on appropriate statistical analysis of the related climatic dataset during 1988−2017. All the temperature extremes in most of the regions show a warming trend, while the daily average temperature has significantly increased by 0.27 °C/decade in the last 30 years. The overall increasing rate of T_{max} (0.35 °C/decade) in daytime is more than T_{min} (0.16 °C/decade) at nighttime. However, monsoonal T_{max} (0.40 °C/decade) has increased by a higher rate than T_{min} (0.30 °C/decade), and the warming rate is more significant during winter than the monsoonal months in most of the regions. Consequently, the annual MRT has increased significantly (0.20 °C/decade) over the country, including by the highest rate (0.56 °C/decade) in region A. It is observed from the trend patterns of T_{max}, T_{min}, and MTR that most of the regions (particularly regions A and B) have been colder during winter and hotter during the monsoon. Furthermore, the monsoonal T_{max} and T_{min} have increased significantly in the northwestern regions (NW; regions C, D, E, and F), resulting in a comparatively lower increase in MTR, which reveals the severity of warming that has occurred in these areas. The increasing rate of monsoonal precipitation in region A (mainly coastal areas) is relatively higher than the other regions; however, it has decreased significantly in the NW regions of the country. In addition, WS has intensely decreased in all regions during all seasonal and annual series, with the highest decreasing rate in region E (0.64 kt/decade) and the lowest in region B (0.36 kt/decade). In addition, the pre-monsoonal and monsoonal WS have decreased more progressively across the country. Significant negative correlations of precipitation, humidity, and WS with temperature variables have been found in Bangladesh and have reached extreme levels in the NW regions. The increase in temperature and decrease in wind circulation speed may cause a decrease in rainfall in these regions. Besides these factors, the significant decrease in WS in most of the regions of the country may cause

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an increase in temperature variables. The changes in humidity are not significant except in the monsoon season. In some cases, the observed changes in a climatic variable are minor or inconsequential. However, if these changes progress in the future, they will likely be the cause of significant negative impacts on the climate of Bangladesh. Therefore, further advanced studies should be carried out with related model projections to investigate climate change in Bangladesh and its impact on the global climate.

Declarations

Author contribution statement

Md Hafijur Rahaman Khan, Ananna Rahman: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Chuanxiu Luo: Conceived and designed the analysis.

Sazal Kumar: Conceived and designed the analysis; Analyzed and interpreted the data.

G. M. Ariful Islam, Mohammad Akram Hossain: Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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