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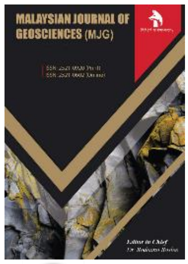

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RESEARCH ARTICLE

CLIMATOLOGY IN BARISHAL, BANGLADESH: A HISTORICAL ANALYSIS OF TEMPERATURE, RAINFALL, WIND SPEED AND RELATIVE HUMIDITY DATA

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ABSTRACT

The Climatological data (temperature, rainfall, wind speed & relative humidity) recorded at Barishal divisional meteorological station and Bangladesh Meteorological Departments over the period of 1961-2019 is used for an assessment of climatological aspects, climate change and the variability of Barishal in Bangladesh. The trend of variant of yearly average maximum and minimum temperature has been found to be increasing at a rate of 0.0055 ºC & 0.0087 ºC/year. Analysis of rainfall data observed that for majority of stations, the total rainfall showed decreasing trend for pre-monsoon, monsoon and winter seasons, while little increasing trend was observed for the post-monsoon. Calculated annual total rainfall in Barishal was showed declining at the rate of -0.18488 mm/year and annual average wind speed was increasing by 0.001783 m/s per year. Likewise, yearly average relative humidity observed to be abrupt rising at a rate of 0.342975 per year with average of 70.855 at 2 meters.

KEYWORDS

Climate Change, Meteorological Stations, Rainfall variability, Sen's slope estimator, Trend Analysis.

1. INTRODUCTION

Climate change is no longer incredible to take place in future but rather an ongoing happening. It is now clearly well-known that climate change is realism, and the adversities of climate alterations pose of the greatest challenges facing humanity at the moment (IUCN, 2011). Climate is altering at both the regional scales (Gemmer et al. 2004; Kayano & Sansigolo, 2008) and the global scales (Lambert et al. 2003; Dore, 2005) due to global warming. The InterGovernmental Panel on Climate Change (IPCC) states that climate change as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer". From the 1950s, numerous types of research have been conducted to recognize climate change, revealing that huge amounts of ice have melted and the sea level has escalated because of the warming of the atmosphere and ocean (Hartmann and Tank, 2013;IPCC, 2013).The intensity of greenhouse gases has augmented, which causes an increase inland and sea surface temperature and changes the patterns of rainfall, sea level rise and strengthening of El Nino (Basak et al., 2013;Raihan et al., 2015; Jaiswal et al., 2015;Yu et al., 2016;Islam and Nursey-Bray, 2017).The implications of climate change are principally noteworthy for the regions already under pressure, such as in Bangladesh where hydrological disasters are common phenomena (Shahid & Behrawan, 2008). The Intergovernmental Panel on Climate Change (IPCC) has termed Bangladesh as one of the most vulnerable countries in the world due to climate change (Ali, 1999; IPCC, 2007; Hashizume M. et al., 2007; Shahid, 2011; Islam and Nursey-Bray, 2017; Vij et al., 2018). IPCC, 2013 has studied that the combine global land and sea surface temperature has increased by 0.89 ºC (0.69- 1.08 ºC) during 1901 to 2012 and by about 0.72 ºC (0.49-0.89 ºC) during 1951 to 2012, and the atmospheric burden of well mixed greenhouse gases has improved from 2005 to 2011 ((IPCC, 2001; Hartmannand Tank, 2013; Yu et al., 2016). It has been predicted that due to climate change, there will be a steady go up of temperature and change in rainfall model which might have an amount of implications in agriculture (Karmakar S., 2000, 2003 and Khan T.M.A., et al. 2000), water resources (Fung et al. 2006) and public health (Shahid, 2008) in Bangladesh.

Topographically, Bangladesh is primarily a low-lying plain of about 147,570 square kilometres (56,980 sq mi), situated on deltas of the largest Ganges-Brahmaputra-Meghna Rivers flowing from the Himalayas. Bangladesh is a disaster prone country for its geological condition with the Himalayas in the north and Bay of Bengal in the south. The international community has recognized that Bangladesh ranks as high in the list of most vulnerable countries on the earth. Bangladesh's high vulnerability to climate change is due to a number of hydro-geological and socio-economic influences that include: (a) its geographical location in South Asia; (b) its extreme climate variability that is governed by monsoon and which results in acute water distribution over space and time; (c) its flat deltaic topography with very low elevation; (d) its majority of population being dependent on crop agriculture which is highly influenced by climate variability and change and (e) its high population density and poverty incidence. IPCC, 2013 has famed Bangladesh as a risky country due to climate change, where many natural disasters such as increase

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temperature, flood, cyclone, drought, saline water intrusion, sea-level rise, and heavy monsoon downpours are very common occurrences (Titumir and Basak, 2012;Basak et al., 2013). Due to the ancient climate change, Bangladesh's seasonal cycle has altered 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). Bangladesh has a sub-tropical humid climate characterized by wide seasonal variations in moderately hot temperatures, rainfall and high humidity (Rashid, 1991 and OECD, 2003). The climatic change incidents have become global priorities during the last few decades. It is marked that the global mean surface air temperature has amplified by 0.3 °C to 0.6 ºC cover last hundred years, with the five global average warmest years being in the 1980s-90s (WMO, 1991, World Bank, 2000 & IPCC, 2007). Over the same period global sea level has improved by 10-20 cm (IPCC, 2007). The economic activities of the country, especially the agriculture are dependent on the rainfall and temperature. The weather activities of Bangladesh are dominated by the southwest monsoon. The production of agriculture is also relying on temperature variability. In addition, Bangladesh is considered to become the worst victim of the impacts of global warming and related climate change. The climate change persuaded enhancement of natural disasters will cause its people to suffer innumerable loss to resources and livelihood. Variability of rainfall causes flood and droughts. The effect of these can be minimized by proper management practices which include preparedness, rescue operation and rehabilitation. Again, agriculture plan can be made suitable using the knowledge of climatic change. The trends of climatic parameters help the policy maker to develop the country especially in the agriculture sector. Since the population of Barishal city is growing, crop yield should be acceptable to balance agro-ecosystem. Barishal city is most vulnerable to climate change since the climatic parameters like temperature, rainfall variability, wind velocity and humidity are unpredictable. A strong and robust hydrometeorology monitoring network is therefore fundamental to further work on detection and attribution of present-day hydrological variations; in particular, changes in water resources and in the occurrences of extreme events like cyclones , floods, droughts, storms , irregular rainfall, cold spells etc. (IUCN Bangladesh, 2011).

The dissimilarity in temperature, rainfall, wind speed and relative humidity due to climate change during the past decades has exaggerated various problems around the world as well as Bangladesh. Presently, many studies have focused on climate change all over the world, 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 and Khan et al. 2019). 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.

Currently, Khan et al. (2019) reported 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. 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/decade) than other regions, while the monsoonal and annual precipitation have decreased by 87.35 mm/decade and 107 mm/decade, respectively. Similarly, Rahman, M.R., & Latch, H. (2015) observed that recent climate change in Bangladesh with a 0.20 °C per decade upward trend of mean temperature over a 40-year period (1971 to 2010). They also observed that an upward trend of annual rainfall (+7.13 mm per year) and downward pre-monsoon (−0.75 mm per year) and post-monsoon rainfall (−0.55 mm per year) trends during the same time frame. Their evidence's would lead to approximately 1.0 °C warmer temperatures in Bangladesh by 2020, compared to that of 1971.

However, numbers of studies have been carried out on trends of change in climate parameters in the context of Bangladesh like Haque et al (1992) stated that the average increase in temperature would be 1.3 °C and 2.6 °C for the projected years of 2030 and 2075, respectively. Similar to IPCC predictions, the increase in winter temperature in Bangladesh was predicted to be higher probably due to momentous rise in monsoon precipitation, which could also cause rigorous flooding in the future. Chowdhury & Debsarma, (1992) studied that the projected changes will be 1.4 °C in the winter and 0.7 °C in the monsoon months in 2030. For 2075, the variation would be 2.1 °C and 1.7 °C for winter and monsoon correspondingly. It is also observed that the growing tendency of lowest minimum temperature over Bangladesh.

Addisu et al. (2015), Warrick et al (1994), Karmakar & Shrestha (2000), Debsarma (2003) and Salahuddin A., (2006) studied the variation of temperature and rainfall over Bangladesh. In this study (Warrick et al, 1994), mean-annual temperatures have been expressed as departures from the reference period 1951-1980. It is evident that, on this time scale, Bangladesh region has been getting warmer. Since the later part of the last century, there has been, on average, an overall increase in temperature by 0.5 oC which was comparable in magnitude to the observed global warming. Karmaker & Nessa, (1997) and Karmakar (2003) studied on climate change and its impacts on natural disasters and southwest-monsoon in Bangladesh and the Bay of Bengal. They found that the decadal mean annual temperature over Bangladesh have shown increasing tendency especially after 1961-1970. Chowdhury & Debsarma (1992) and Mia (2003) reported variations in temperature based on analysis of chronological data of some selected weather stations in Bangladesh.

Basak et al (2013 & 2011), Titumir, R.A.M. and Basak (2012) studied the trend of variation of yearly average maximum temperature has been found to be increasing at a rate of 0.0186 °C per year, whereas the rate was 0.0152 °C per year for yearly average minimum temperature in Bangladesh for the period of 1976-2008. Shahid, S. (2010) studied an increasing mean, mean maximum and mean minimum temperatures of Bangladesh at a rate of 0.103°C, 0.091°C and 0.097°C per decade and an increasing of annual and pre monsoon rainfall of Bangladesh are also observed at a rate of 5.53 mm/year and 2.47 mm/year respectively over the time period of 1958-2007.

To address climatological challenges, KfW, Swiss Re and Barishal City Corporation (2016) teamed up to build up an adaptation strategy for Barishal in Bangladesh. Applying the Economics of Climate Adaptation methodology, the team was able to recognize the key risk drivers in Barisal: the city's annual monsoon, cyclones and sea level rise as well as urbanization. Frequent flooding, urban sewage problems and damaging effects for low-income households are just some of the negative impacts the city has to tackle every year. Communities in Barisal face yearly damages of USD 10 million due to monsoon floods and cyclones. This number is probable to add to significantly by 2050. The total climate risk by 2050 as a result of economic growth and climate change under a moderate state is projected to add up to approximately USD 130 million in damage per year.

Kfw and Barishal City Corporation (2016) observed rapid urban growth claims several challenges for the city of Barishal in Bangladesh. Natural disasters are a key unfavorable factor to sustainable development for the coastal region, including Barisal's economy. The key reasons are an arrangement of natural processes and growing anthropogenic activities, such as a swiftly rising waterfront development. Likewise, land use planning and regulation are fragile and combined with population growth and urbanization pressures this has led to an untenable urban growth.

In this study, we have tried to build upon a steadily increasing number of theoretical and experimental studies of the climatological factors such as temperature, rainfall, wind speed and relative humidity to assess their change during 1961 to 2019 in Barishal, Bangladesh according to the data. Thus, wide statistical analysis was performed using meteorological data, and an ancient 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 58 years. The dramatic climate change over the city is also a part of the focus of this study.

The present study has provided an assessment of climatological aspects, climate change and variability in Barishal based on analysis of historical data of temperature, rainfall, wind velocity and relative humidity recorded at available meteorological stations in Bangladesh. Assessments have been made, in particular, of changes in maximum temperature, changes in minimum temperature, changes in rainfall pattern, changes in wind velocity and change in relative humidity.

2. CLIMATOLOGY OF BANGLADESH

Climatology, or occasionally known as climate science, is the study of the

Earth's weather models and the systems that cause them. From the ocean oscillations to trade winds, a pressure that drives temperature, airborne particles that influence local conditions and even the phases of the moon and Earth's wobble all affect the climate. Bangladesh has a sub-tropical monsoon and humid climate characterized by wide seasonal variations in moderately warm temperatures, rainfall, wind velocity and high humidity (Rashid, 1991). Four dissimilar seasons can be renowned in Bangladesh from climatological point of view: (i) the dry winter season from December to February (January is the coldest month, when the average temperature for most of the country is about 10°C) (BMD, 2019), (ii) the pre-monsoon hot summer season from March to May (April is the warmest month in most parts of the country and temperatures range between 30°C and 40°C) (BMD, 2019), (iii) the rainy monsoon season from June to September, and (iv) the post-monsoon autumn season which lasts from October to November.

Heavy rainfall pattern is characteristic of Bangladesh. Rainfall variability in space and time is one of the most relevant uniqueness of the climatology of Bangladesh. Rainfall in Bangladesh varies from 1400-1600 mm in the west to more than 2400-4400 mm in the east (Hussain AM, & Sultana N., 1996). Higher rainfall in the northeast is caused by the additional uplifting effect of the Meghalaya plateau. About 75-80% of rainfall in Bangladesh occurs during the monsoon time, caused by weak tropical depressions that are brought from the Bay of Bengal into Bangladesh by the wet monsoon winds.

As we know that temperature gradient between places results in differences in air pressure and ultimately, wind. Wind speeds increase with a greater temperature difference. Bangladesh has high variation of warm temperature and high humidity. A study published in the journal '*Nature Climate Change'* found that winds across much of North America, Europe and Asia have been growing faster since about 2010. In Bangladesh, annual average wind speed at 30 m height along the coastal belt is above 5 m/s (Khan et al. 2000). Wind speed in northeastern parts is above 4.5 m/s while inland wind speed is around 3.5 m/s for most part of Bangladesh (Khan et al. 2000). '*Nature Climate Change' also observed that* if the speeding-up trend could continue for another decade or longer, until the next major shift occurs. That could be a boon for the wind power industry in the near future. If the current pattern continues, they suggest that average global power generation could increase by as much as 35-37% by 2024.

Higher Humidity is also characteristic of Bangladesh. As we know that if the water vapor content stays the same and the temperature falls, the relative humidity increases. If the water vapor content stays the same and the temperature rises, the relative humidity decreases. This is because colder air doesn't require as much moisture to become saturated as warmer air.

The vapor plays a key role in determining the dynamic properties of the climate system. Humidity is the amount of water vapor in the air, and relative humidity considers the ratio of the actual vapor pressure of the air to the saturated vapor pressure which is usually expressed in percentage. Humidity affects crops through evaporation, transpiration and condensation (Lenka, 1998). Crop agriculture is highly prejudiced by climatic change and majority of population is relying on agricultural crop in Bangladesh. The prediction of atmospheric factors is essential for climate monitoring, harsh weather prediction, drought revealing, agriculture and production, development in energy and industry, pollution dispersal and communication etc.

3. METHODOLOGY

3.1 Study Area

Barishal is a major city that lies on the bank of Kirtankhola River in south-central Bangladesh (Figure 1). It is the largest city and the administrative headquarter of both Barishal district and Barishal Division. The area of the city is 58 km^2 and located at 22°48′0″N 90°30′0″E (Figure 1). The climate of Barishal city is a tropical wet and dry climate. The Barishal lies on 10m above sea level. In winter, there is much less rainfall in Barishal than in summer. In Barishal, the average annual temperature is 25.9 °C | 78.7 °F. The annual rainfall is 2184 mm | 86.0 inch (BMD, 2019).

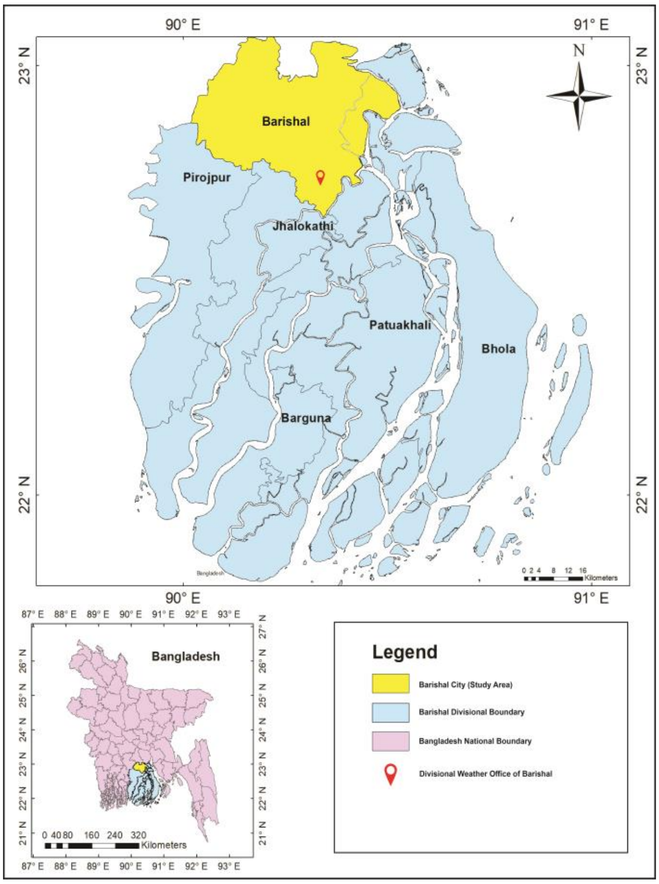

Figure 1: Study area map with showing Divisional Weather Station of Barishal.

3.2 Data Collection and Data Range

Different tools were applied to calculate and assess the trends of changes of climatic variables in Barishal. The main focus is on the assessment of the trend on changes of temperature. Different instruments, formula, tools and techniques were applied to accomplish the study.

In this study, data on temperature, rainfall, wind velocity and humidity of divisional weather stations in Barishal were collected from the Bangladesh Meteorological Department (BMD). Temperatures data included monthly average and annual mean maximum and minimum temperatures for the period January 1961 through December 2019, rainfall data, wind speed for the same period and relative humidity data for the period of January 1981 through December 2019. Fifty Eight years (1961-2019) temperature, rainfall, wind velocity and humidity (1981-2019) records of those stations are used in the present study to assess the recent change and climatology in the Barishal City. It should also be noted that there are some missing data for some months at some stations, which have been included in the trend analysis from the sources of NASA (National Aeronautics and Space Administration) and NOAA (National Oceanic and Atmospheric Administration).

3.3 Trend Analysis

Mann-Kendall test (Mann 1945; Kendall 1975) for trend and Sen's slope (Sen, 1968) estimates used for detecting and estimates trends in the time series of the annual values of yearly temperature, rainfall and wind velocity. A number of Excel template developed for Mann-Kendall test for trend and Sen's slope estimation. Of them Mann-Kendall test for trend and Sen's slope estimates (MAKESENS) used for detecting and estimating trend (Salmi et al., 2002). There are two phases in trend analysis; first the presence of a monotonic increasing or decreasing trend and secondly the slope of a linear trend is estimated. Both of the cases nonparametric tests were applied. For monotonic trend analysis the nonparametric Mann-Kendall test and for slope of linear trend estimation the non-parametric Sen's slope estimator used. Correlation coefficient of the meteorological variables and time were also computed to determine the better strength and understanding of the linear relationship between variables (Olofintoye, 2010).

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3.3.1 Mann-Kendall test

In Mann-Kendall trend test (Mann 1945; Kendall 1975) the data are estimated as an ordered time series. Each data is compared to all consequent data. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (no trend). If a data from a later time period is greater than a data from an earlier time period, S is incremented by 1. Then again, if the data from a later time period is lesser than a data sampled earlier, S is decremented by 1. The net result of all such increments and decrements produces the final value of S. If x_1, x_2, x_3 .... x_n represent n data points where x_j represents the data point at time j, then S is given by,

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

Where:

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

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

$$Z = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if } S > 0$$
$$= 0 \quad \text{if } S = 0$$
$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if } S < 0$$

At the 99% significance level, the null hypothesis of no trend is rejected if $|Z|>2.575$; at 95% significance level, the null hypothesis of no trend is rejected if $|Z|>1.96$; and at 90% significance level, the null hypothesis of no trend is rejected if $|Z|>1.645$. More specifics of Mann-Kendall test can be found in Sneyers (1990).

3.3.2 Sen's Slope Method

Sen's Slope method (Sen, 1968) contains computing slopes for all the sets of ordinal time points and then using the median of these slopes as an evaluation of the total slope. The Sen's method expected that the trend is linear. This means that the continuous monotonic aggregating or reducing function of time, f(t), is equal to

$f(t) = Qt + B$

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

$$Q^{/} = \frac{x_{t^{/}} - x_t}{t^{/} - t}$$

Where, $Q^{/}$ = slope between data points $x_{t/}$ and x_t ; $x_{t/}$ = data measurement at time $t^{/}$

x_t = data measurement at time t

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

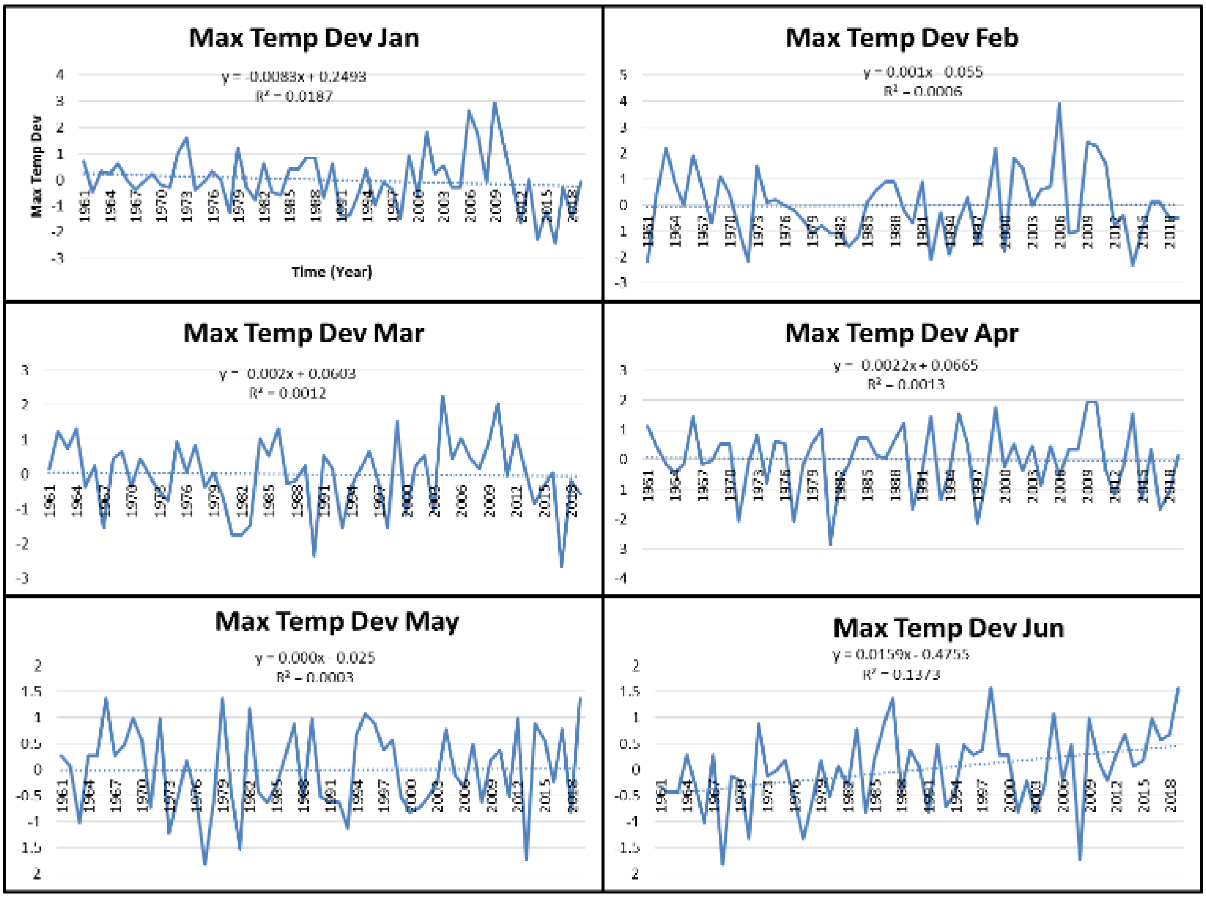
$$Q = Q'_{[(N+1)/2]} \quad \text{if } N \text{ is odd}$$
$$= (Q'_{[N/2]} + Q'_{[(N+2)/2]})/2 \quad \text{if } N \text{ is even}$$

Where, N is the number of calculated slopes. Details of Sen's slope estimation can be found in Sen (1968).

4. Result and Discussion

The analysis of temperature, rainfall, wind speed and relative humidity trends reveals abrupt changes found in Bangladesh over the time period 1961–2019. The obtained outcomes are described in the following sections.

4.1 Changes in Monthly Maximum Temperature



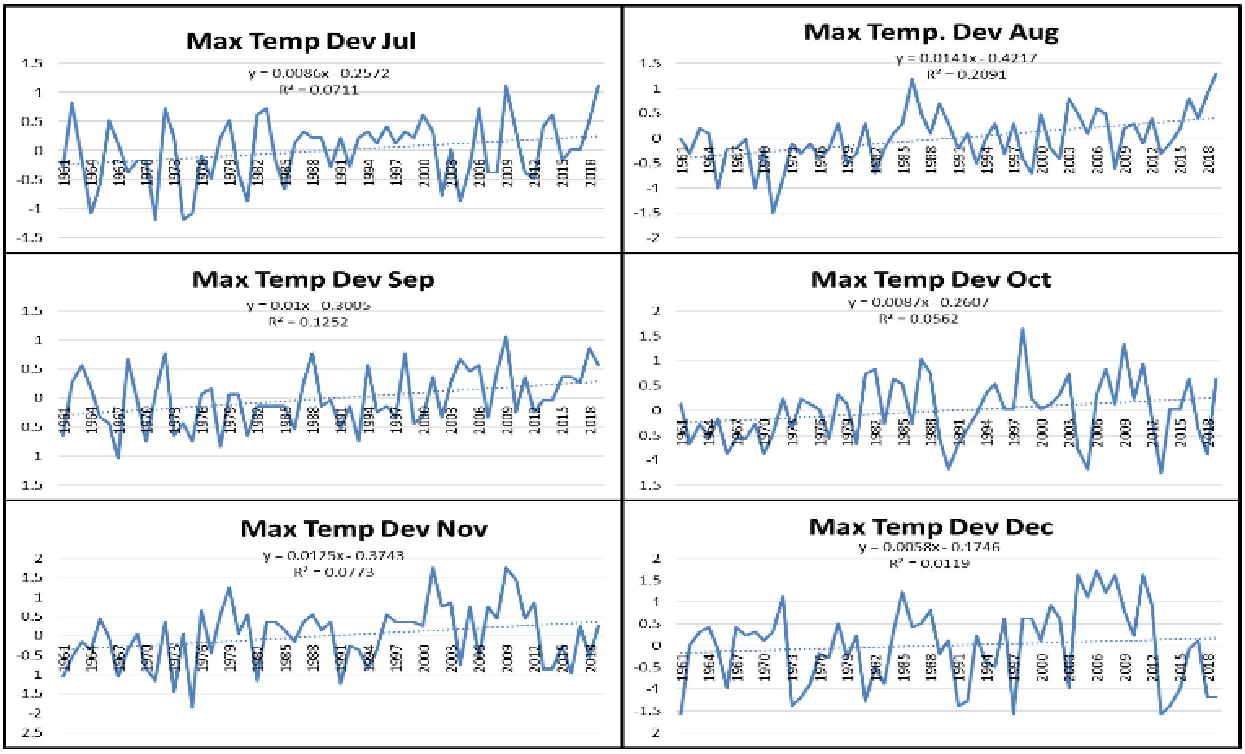


Figure 2: Temporal variation of annual average maximum temperature (ºC) in Barishal from 1961 to 2019.

(Jan: January; Feb: February; Mar: March; Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; Nov: November; Dec: December; Dev: Standard Deviation)

The trend of variation of monthly average maximum temperature was analyzed for all available stations. The monthly maximum temperature increased at most of the months expect January, March and April in Barishal during the period of 1961–2019 and the rates of changed of temperature were 0.0019 ºC, 0.0009 ºC, 0.0159 ºC, 0.0086 ºC, 0.0141 ºC, 0.01 ºC, 0.0087 ºC, 0.0125 ºC and 0.0058 ºC per year for February, May, June, July, August, September, October, November and December months respectively (Table 1 & Figure 2). In Barishal City, the increasing trend of maximum temperature has the highest coefficient of determination equal to 0.457275 in August month which was significant at 99% level of significance (Table 1). On an average yearly average maximum temperature of Barishal City has been found to be increasing at a rate of 0.0055 ºC per year with average maximum temperature of 30.38 ºC and average coefficient of determination equal to 0.193478 (Table 1). Significant increase of temperature during this 58-years period was observed at June month (0.0159 ºC) with correlation of coefficient equal to 0.37054 and minimum at January, March and April respectively (-0.0089 ºC, - 0.002 ºC and - 0.0022 ºC) (Table 1 & Figure 2).

Table 1: Total changes, Average changes and Regression equation of trend lines for Average Maximum Temperature from 1961 to 2019.

Month	Total Changes	R^2.	Correlation of coefficient r	Average	Equation
January	- 0.0083	0.0187	0.136748	25.38	y = -0.0083x + 0.2493
February	0.0019	0.0006	0.024495	28.39	y = 0.0019x - 0.0556
March	- 0.002	0.0012	0.034641	32.15	y = -0.002x + 0.0603
April	- 0.0022	0.0013	0.036056	33.36	y = -0.0022x + 0.0665
May	0.0009	0.0003	0.017321	34.12	y = 0.0009x - 0.0258
June	0.0159	0.1373	0.37054	31.62	y = 0.0159x - 0.4755
July	0.0086	0.0711	0.266646	30.68	y = 0.0086x - 0.2572
August	0.0141	0.2091	0.457275	30.81	y = 0.0141x - 0.4217
September	0.01	0.1252	0.353836	31.34	y = 0.01x - 0.3005
October	0.0087	0.0562	0.237065	31.07	y = 0.0087x - 0.2607
November	0.0125	0.0773	0.278029	29.35	y = 0.0125x - 0.3743
December	0.0058	0.0119	0.109087	26.28	y = 0.0058x - 0.1746
Average Changes	0.0055	NA	0.193478	30.38	NA

4.2 Changes in Monthly Minimum Temperature

Table 2: Total changes, Average and Regression equation of trend lines for Average Minimum Temperature from 1961 to 2019.

Month	**Total Changes**	**R^2**	**Correlation of coefficient r**	**Average**	**Equation**
January	- 0.0021	0.0019	0.04359	12.38	y = -0.0021x + 0.0621
February	0.0138	0.0693	0.26324	15.7	y = 0.0138x - 0.4152
March	0.0094	0.0297	0.17233	20.16	y = 0.0094x - 0.2805
April	0.0085	0.0374	0.19339	23.59	y = 0.0085x - 0.2558
May	0.0116	0.085	0.29154	24.22	y = 0.0116x - 0.3487
June	0.0125	0.183	0.42778	25.62	y = 0.0125x - 0.3756
July	0.0095	0.1542	0.39268	25.75	y = 0.0095x - 0.2858
August	0.012	0.2108	0.45913	25.71	y = 0.012x - 0.361
September	0.0078	0.0908	0.30133	25.57	y = 0.0078x - 0.2341
October	0.0082	0.044	0.20976	23.75	y = 0.0082x - 0.2456
November	0.0051	0.0067	0.08185	19.03	y = 0.0051x - 0.1525
December	0.0086	0.0279	0.16703	13.94	y = 0.0086x - 0.2576
Average Changes	0.008742	NA	0.250304	21.285	NA

The monthly minimum temperature showed increasing trend in the Barishal City over the study period, 1961 to 2019. On an standard yearly average minimum temperature of Barishal City has been found to be rising at a rate of 0.0087 ºC per year with average minimum temperature of 21.29 ºC and average coefficient of determination equal to 0.250304 (significant at 99% level of significance) (Table 2). An increase trend of minimum temperature showed at most of the months expects January (-0.0021 ºC) in Barishal over the period of 1961-2019 (Table 2 & Figure 3). An increase rates of changed of temperature were 0.0138 ºC, 0.0094 ºC, 0.0085 ºC, 0.0116 ºC, 0.0125 ºC, 0.0095 ºC, 0.012 ºC, 0.0078 ºC, 0.0082 ºC, 0.0051 ºC and 0.0086 ºC per year for February, March, April, May, June, July, August, September, October, November and December months respectively (Table 2 & Figure 3). In Barishal City, the increasing trend of minimum temperature has the highest coefficient of determination equal to 0.45913 in August and the lowest equal to 0.04359 in January which was significant at 99% level of significance (Table 2). Momentous increase of temperature during this 58-years period was observed at February month (0.0138 ºC) and minimum at January respectively (- 0.0021 ºC) (Table 2 & Figure 3).

Figure 3: Temporal variation of annual average minimum temperature (ºC) in Barishal from 1961 to 2019.

(Jan: January; Feb: February; Mar: March; Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; Nov: November; Dec: December; Dev: Standard Deviation)

4.3 Changes in Monthly Average Rainfall

The changes in rainfall model are significant climate change phenomena, which are likely to be observed all over the land. In the study, the annual monthly total rainfall has been showed decreasing trend in Barishal over the study period, 1961 to 2019. Annual monthly total rainfall in Barishal has been decreasing at the rate of -0.18488 mm/year and average rainfall 185.1252 mm/year with average correlation of coefficient equal to 0.079871 (significant at 99% level of significance) (Table 3).

In this study, changes in rainfall model have been assessed by analyzing changes in total rainfall during four seasons i.e., winter (December-February), pre-Monsoon (March-May), Monsoon (June-September) and post-Monsoon (October-November) for the period 1961 to 2019; analysis was made separately for available weather stations. In winter, overall rainfall was found to be decreasing at an average rate of -0.01293 mm/year (Table 3). Similarly, pre-Monsoon and Monsoon periods were found to be decreasing at an average rate of -0.01997 mm/year and -0.58508 mm/year (Table 3). However, an increasing trend was observed at an average rate of 0.11025 mm/year in the post-Monsoon time (Table 3). In Barishal City, Momentous decrease of rainfall during this 58-years period was observed highest at June month (-2.7705 mm/year) and minimum at February (-0.0031 mm/year) respectively (Table 3 & Figure 4).

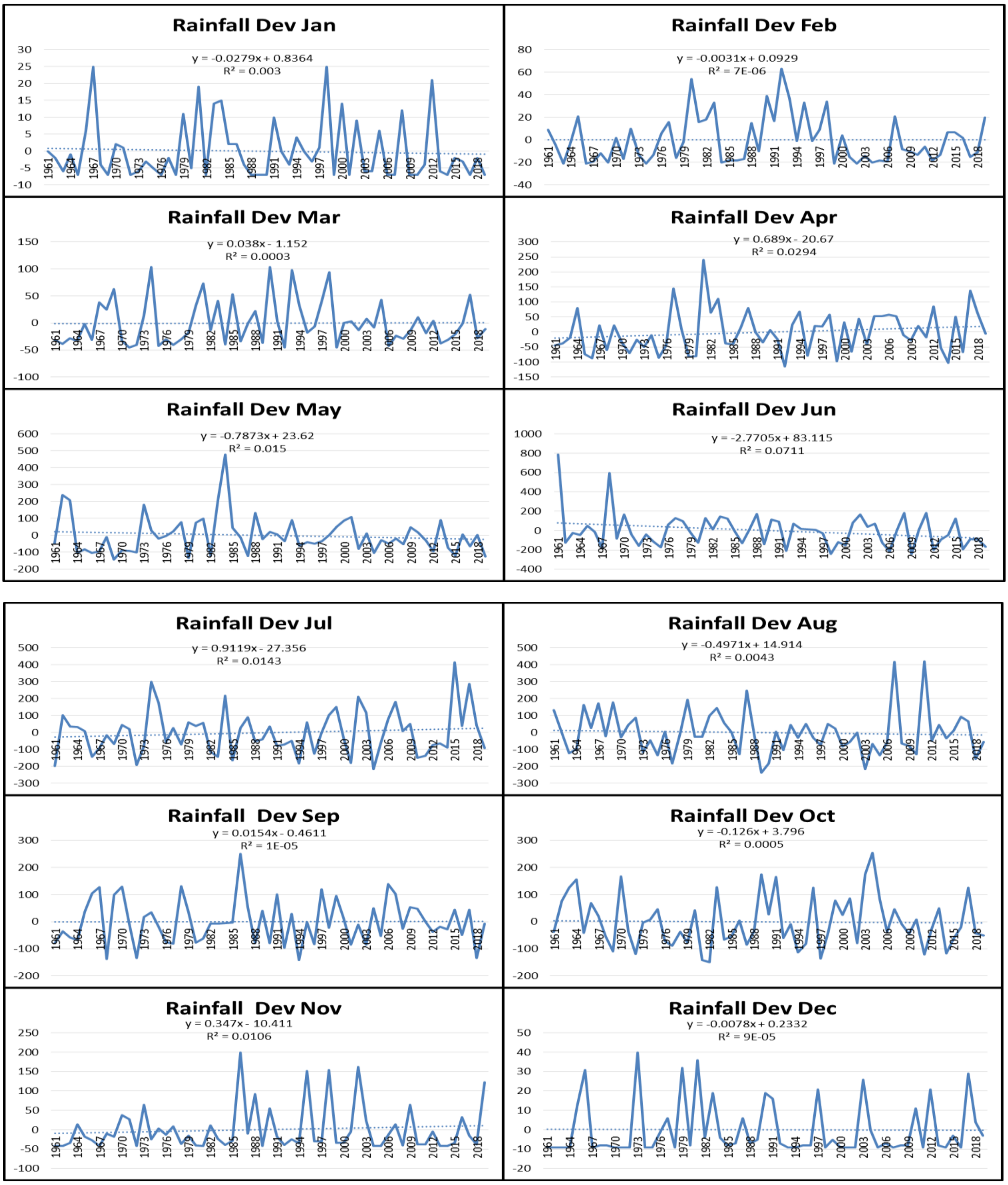


Figure 4: Temporal variation of annual average rainfall (mm) in Barishal from 1961 to 2019.

(Jan: January; Feb: February; Mar: March; Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; Nov: November; Dec: December; Dev: Standard Deviation)

Table 3: Total changes, Average changes and Regression equation of trend lines for Average Rainfall from 1961 to 2019.

Seasons	Month	Total Changes	Seasonal Average Changes	R^2	Correlation of coefficient r	Average	Equation
Winter	December	-0.0078	-0.0129333	9.00E-05	0.009487	9.102	y = -0.0078x + 0.2332
	January	-0.0279		0.003	0.054772	6.98	y = -0.0279x + 0.8364
	February	-0.0031		7.00E-06	0.002646	21.08	y = -0.0031x + 0.0929
pre-Monsoon	March	0.0384	-0.0199667	0.0003	0.017321	44.8	y = 0.0384x - 1.152
	April	0.689		0.0294	0.171464	120.8	y = 0.689x - 20.67
	May	-0.7873		0.015	0.122474	219.7	y = -0.7873x + 23.62
Monsoon	June	-2.7705	-0.585075	0.0711	0.266646	442.8	y = -2.7705x + 83.115
	July	0.9119		0.0143	0.119583	450.2	y = 0.9119x - 27.356
	August	-0.4971		0.0043	0.065574	395.3	y = -0.4971x + 14.914
	September	0.0154		1.00E-05	0.003162	289.9	y = 0.0154x - 0.4611
post-Monsoon	October	-0.1265	0.11025	0.0005	0.022361	178.4	y = -0.1265x + 3.796
	November	0.347		0.0106	0.102956	42.44	y = 0.347x - 10.411
	Average Changes	-0.18488	NA	NA	0.079871	185.1252	NA

4.4 Changes in Annual Monthly Wind Speed

Table 4: Total changes, Average changes and Regression equation of trend lines for Average Wind Speed (m/s) from 1961 to 2019.

Month	Total Changes	R^2	Correlation of coefficient r	Average (m/s)	Equation
January	0.0122	0.4446	0.666783	1.363	y = 0.0122x - 0.365
February	- 0.002	0.0203	0.142478	1.595	y = -0.002x + 0.0593
March	- 0.0057	0.0589	0.242693	2.081	y = -0.0057x + 0.1704
April	- 0.0134	0.1671	0.408779	3.066	y = -0.0134x + 0.402
May	- 0.0022	0.0046	0.067823	2.903	y = -0.0022x + 0.0654
June	0.0076	0.0821	0.286531	2.892	y = 0.0076x - 0.229
July	0.0073	0.1322	0.363593	3.051	y = 0.0073x - 0.2204
August	0.0032	0.0262	0.161864	2.754	y = 0.0032x - 0.0963
September	- 0.0004	0.0005	0.022361	2.137	y = -0.0004x + 0.0133
October	- 0.0005	0.001	0.031623	1.578	y = -0.0005x + 0.0149
November	0.0064	0.1266	0.355809	1.180	y = 0.0064x - 0.1927
December	0.0089	0.2202	0.469255	1.188	y = 0.0089x - 0.2676
Average Changes	0.001783	NA	0.268299	2.149	NA

The annual monthly average wind speed showed negligible increasing trend in Barishal City over the study period 1961-2019. In Barishal, annual average wind speed was increasing by 0.001783 m/s per year with its average 2.149 m/s (Table 4). In Barishal, the increasing trend of wind speed coefficient of determination equal to r = 0.268299. The highest change has been found in January month at a rate of 0.0122 m/s per year and the lowest has been found at a rate of -0.0004 m/s per year in September respectively (Table 4 & Figure 5).

In Barishal, the increasing rates of changed of wind speed were 0.0122 m/s, 0.0076 m/s, 0.0073 m/s, 0.00032 m/s, 0.0064 m/s and 0.0089 m/s per year for January, June, July, August, November and December months respectively for the period of 1961–2019 (Table 4 & Figure 5). Consequently, a decreasing rates of variations of wind speed were – 0.002 m/s, -0.0057 m/s, -0.0134 m/s, -0.0022 m/s, -0.0004 m/s and -0.0005 m/s per year for February, March, April, May, September and October months respectively (Table 4 & Figure 5).

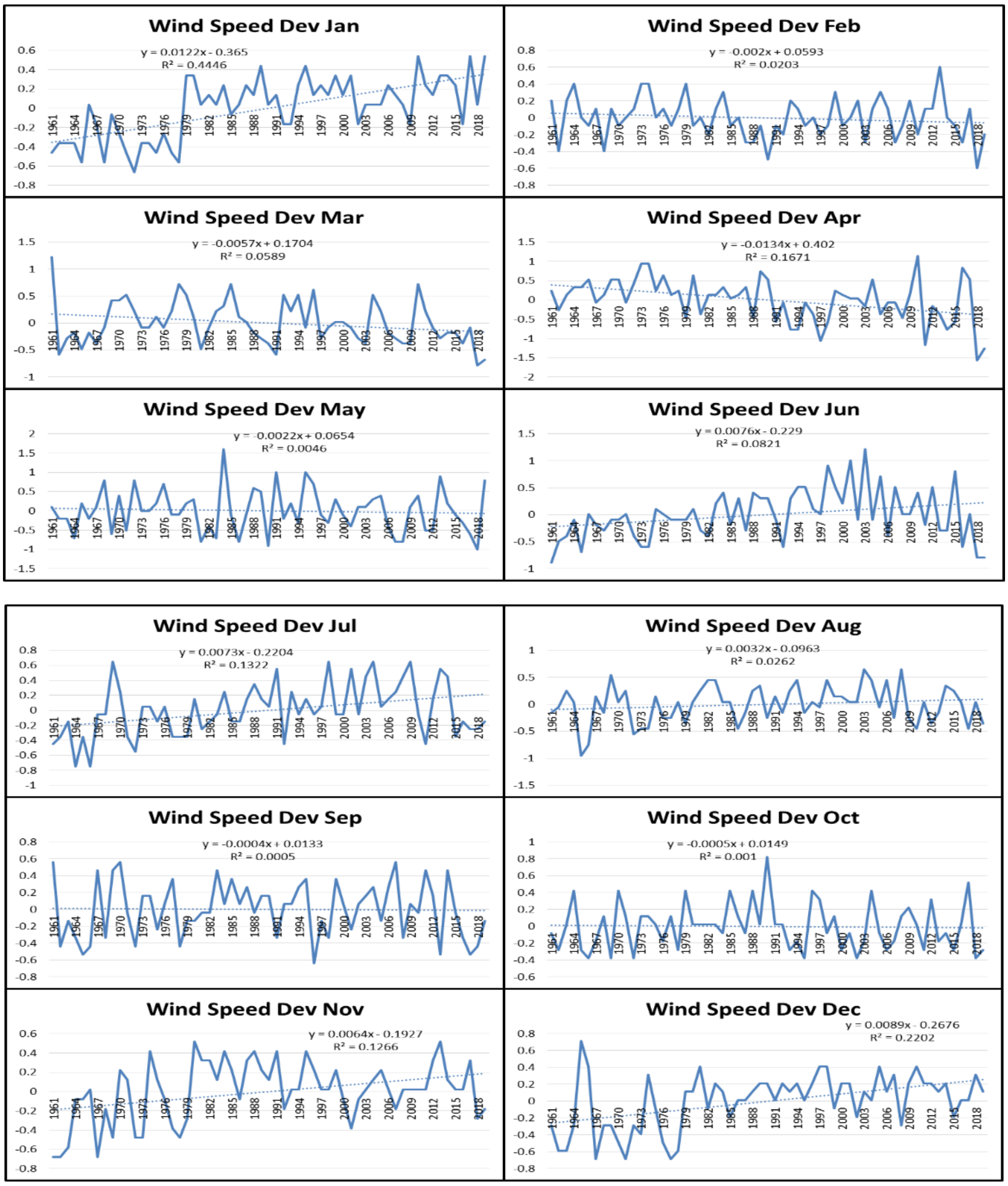


Figure 5: Temporal variation of annual average wind speed (m/s) in Barishal from 1961 to 2019.

(Jan: January; Feb: February; Mar: March; Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; Nov: November; Dec: December; Dev: Standard Deviation)

4.5 Changes in Annual Monthly Relative Humidity

Table 5: Total changes, Average changes and Regression equation of trend lines for Average Relative Humidity from 1981 to 2019.

Month	Total Changes	R^2	Correlation of coefficient r	Average (%)	Equation
January	0.6335	0.4554	0.674833	55.22	y = 0.6335x - 12.67
February	0.4095	4	2	48.55	y = 0.4095x - 8.1905
March	0.1882	0.1024	0.32	49.86	y = 0.1882x - 3.763
April	0.2156	0.1213	0.348281	60.55	y = 0.2156x - 4.3118
May	0.2771	0.2496	0.4996	71.23	y = 0.2771x - 5.5428
June	0.2735	0.3112	0.557853	83.15	y = 0.2735x - 5.4702
July	0.1831	0.3772	0.614166	87.84	y = 0.1831x - 3.6625
August	0.1252	0.3194	0.565155	88.51	y = 0.1252x - 2.5038
September	0.1186	0.2364	0.48621	87.68	y = 0.1186x - 2.3723
October	0.2736	0.353	0.594138	81.09	y = 0.2736x - 5.472
November	0.5922	0.4811	0.693614	71.73	y = 0.5922x - 11.844
December	0.8256	0.5023	0.708731	64.85	y = 0.8256x - 16.512
Average Changes	0.342975	NA	0.671882	70.855	NA

The annual monthly relative humidity showed severe increasing trend in the Barishal City over the study period, 1961 to 2019. On an standard yearly average relative humidity of Barishal City has been found to be escalating at a rate of 0.342975 per year with average relative humidity of 70.855 at 2 meters (%) per year and average correlation coefficient of r equal to 0.671882 (significant at 99% level of significance) (Table 5). An increase trend of relative humidity showed at all most of the months in Barishal over the period of 1961-2019 (Table 5 & Figure 6). In Barishal City, Momentous increase of relative humidity during this 58-years period was observed highest at December month (0.8256) and minimum at September (0.1186) respectively per year (Table 5 & Figure 6).

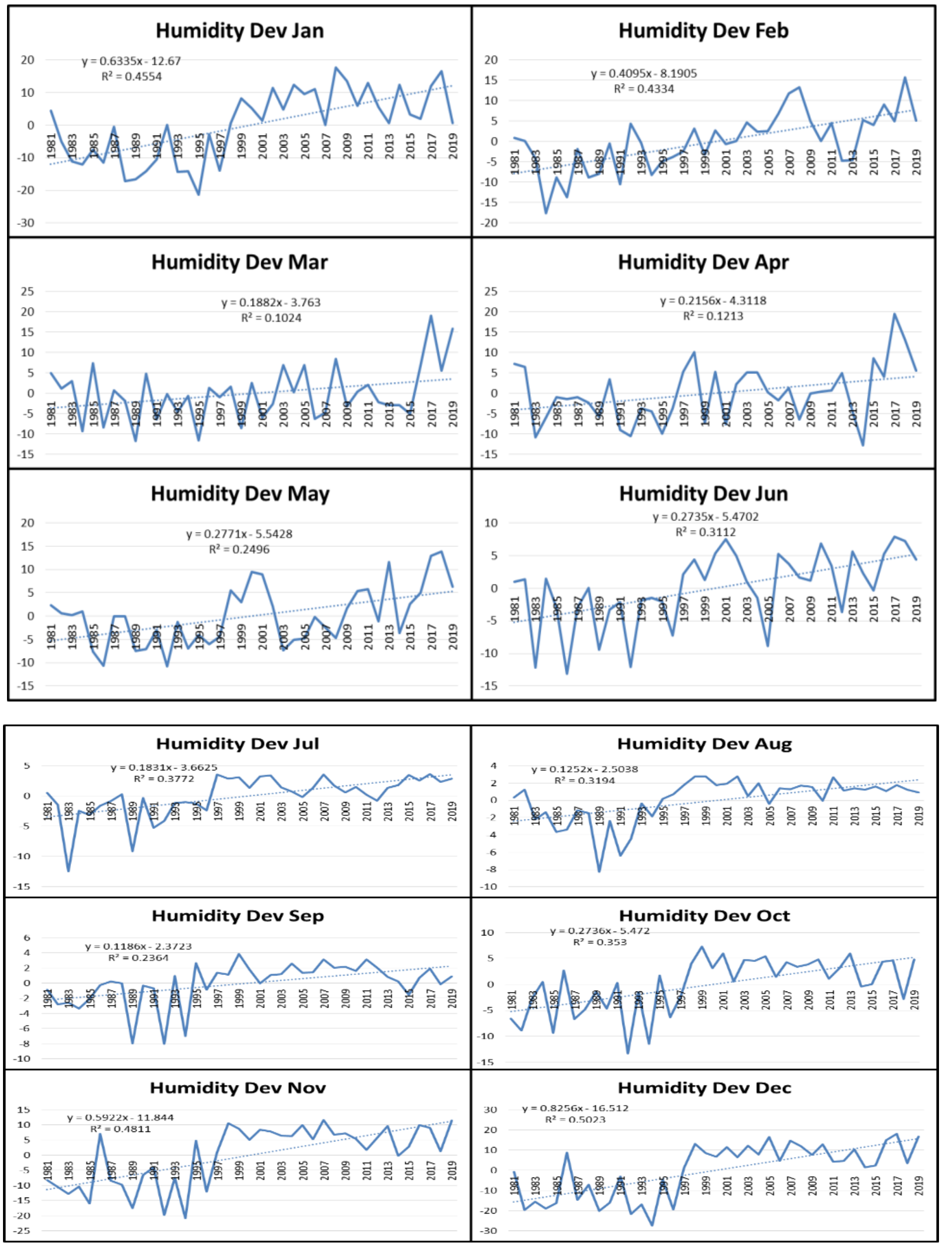


Figure 6: Temporal variation of annual average relative humidity at 2 meters (%) in Barishal from 1981 to 2019.

(Jan: January; Feb: February; Mar: March; Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; Nov: November; Dec: December; Dev: Standard Deviation)

5. Conclusions and Discussions

This study was carried out to assess the climatologically data (Temperature, Rainfall and Wind Speed) collected from Bangladesh Meteorological Department which was used for the climate change aspects (crossed match with National Aeronautics and Space Administration and National Oceanic and Atmospheric Administration data sources) over the period of 1961-2019.Only Relative Humidity data collected for the study over the period of 1981-2019. The regression equation, the coefficient of determination and standard deviation were calculated for the trend analysis. Mann-Kendall test for trend and Sen's slope estimator were also calculated for this study. All the temperature extremes in most of the regions show a warming trend, while an annual average maximum & minimum temperature showed increasing trend about 0.0055 ºC & 0.0087 ºC per year with average coefficient of determination equal to 0.193478 & 0.250304 (significant at 99% level of significance) in Barishal over the 58 years period from 1961 to 2019. Calculated highest increase rate of maximum temperature was observed at June month (0.0159 ºC) and the lowest at January, March and April respectively (- 0.0089 ºC, - 0.002 ºC and - 0.0022 ºC). Significant increase of minimum temperature during this 58-years period was observed pick point at February month (0.0138 ºC/year). The magnitude of increase in monthly average maximum and minimum temperatures during the 58 years period from 1961 to 2019 is unfairly significant.

In the study, an annual recorded total rainfall was observed to be declining at the rate of -0.18488 mm/year and average rainfall 185.1252 mm/year with average correlation of coefficient equal to 0.079871 (significant at 99% level of significance) trend in Barishal over the study period, 1961 to 2019. In winter, recorded overall rainfall was showed to be declining at an average rate of -0.01293 mm/year. In the same way, pre-Monsoon and Monsoon periods were observed to be declining at an average rate of -0.01997 mm/year and -0.58508 mm/year. On the other hand, a rising trend was found at an average rate of 0.11025 mm/year in the post-Monsoon time.

Likewise, calculated annually average wind speed was observed minor rising by 0.001783 m/s per year with its average speed 2.149 m/s per year trend in Barishal City over the study period 1961-2019. The highest change observed in January month at a rate of 0.0122 m/s per year and the lowest at a rate of -0.0004 m/s per year in September respectively. On the other side, Analysis of annually relative humidity was observed severe escalating at a rate of 0.342975 per year with average relative humidity of 70.855 at 2 meters (%) per year trend in the Barishal City over the study period. A historic increase of relative humidity during this 58-years period was observed maximum at December month (0.8256) and minimum at September (0.1186) respectively per year.

Significant negative correlations of rainfall, relative humidity, wind speed and temperature variables have been found in Barishal and have reached extreme levels in the studied regions. The increase in temperature, relative humidity and decrease in wind circulation speed may cause a decrease in rainfall in these regions. Besides the combination of frequent natural disasters, high population density, rapid urbanization and low resilience to economic shocks factors, make Barishal very vulnerable to climatic risks. However, if these changes headway in the future, they will likely be the cause of significant negative impacts on the climate of Barishal. 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.

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