A comparative analysis of the climate patterns of Comilla District with different regions of Bangladesh: A Study of Temperature and Rainfall Trends

Abstract

According to the global climate change index, Bangladesh has been identified as one of the countries facing the most vulnerability from climate change. In this proposed research, a comparative climate change trend analysis was done on various temperature and rainfall criteria for three climatic zones of Bangladesh (i.e., Comilla, Ishwardi, and Cox's Bazar). The weather data was collected from the Bangladesh Meteorological Department (BMD), which covers the years 1950–2020 except Ishwardi station starts from the year 1961. The linear trend analysis revealed that the temperature was increased in all study stations, but Comilla station showed less increment in maximum 0.511°C and in minimum 0.546°C temperature compared to the other station. On the other hand, the Mann-Kendall trend analysis test found that the amount of rainfall that fell each year in Ishwardi, and Comilla was going down but is increasing in Cox's Bazar in Mk test 0.735. So far, the magnitude of change assessed by Sen's Slope estimates also indicated the same trend direction for rainfall analysis with -1.67, 2.28, -7.00 Ishwardi, Cox's Bazar and Comilla respectively. Overall, the study found that the climate pattern of the Comilla district is much better for people and farming activities than the other two regions of Bangladesh. It never falls into an extreme situation in temperature, neither during summer nor in winter. It is also neither wet nor dry.

Keywords: Climate change; temperature; rainfall; trend analysis.

1. INTRODUCTION

Now-a-days, climate change has become a burning issue throughout the world. Once, we must consider it to be one of the greatest hazards to the planet. Both developed and undeveloped countries are significantly impacted by the adverse effects of climate change. The main meteorological factors that affect the country's climate are temperature and rainfall. If these two variables change over an extended period of time, the surrounding weather scenario would be changed. The adverse effects of climate change are observed to have a disproportionate impact on the Least Developed Countries (LDCs), such as Bangladesh, mostly due to their substantial reliance on natural resources and farming activities (FAO, 2007). The most likely effects of climate change on the LDCs are rising temperatures, high and low levels of rainfall, deforestation, constant natural disasters and floods, degradation of agricultural land, rising sea levels, frequent and persistent droughts, and so on (Ayers & Huq, 2009). By the last decade of the 21st century, the Intergovernmental Panel on Climate Change (IPCC) projects that the global temperature will increase by 1.8 to 4 degree Celsius (IPCC, 2007). Another observation from the IPCC report is that by the end of this century, drought conditions in Asian countries may have increased by 5 to 10% as the consequence of global warming (IPCC, 2022). Bangladesh is widely recognized as the most climate-vulnerable nation in the world, according to the global climate change index. This country's economy is heavily based on the farming industry, and about 80% people directly or indirectly depends on primary economic activity. (Kamruzzaman et al., 2018). The faster rates of economic growth in Bangladesh have facilitated a more rapid reduction in poverty over the past decade compared to earlier periods (Coirolo et al., 2013). However, it is important to note that populations residing in geographically vulnerable areas have experienced a deterioration in living circumstances as a result of climate change-related hazards (World Bank, 2010). According to World Meteorological Organization (WMO), the sub-continental region experiences a high frequency of natural disasters, leading to adverse impacts on both human well-being and financial stability. Particularly, the impoverished population bears a disproportionate burden, facing significant loss of life, as well as detrimental effects on their livelihoods. Furthermore, these calamities inflict substantial harm on economic and infrastructural resources. Bangladesh experiences three distinct seasons based on its climate: the pre-monsoon hot season, which runs from March to May; the rainy monsoon season, which begins in June and lasts until October; and the cold dry season, which extends from November through February (Banglapedia, 2003).

Numerous studies have been carried out related to temperature and rainfall changes. Many researchers have independently formulated their own perspectives, focusing on various geographical regions and pursuing diverse objectives. In recent years, Bangladesh has received significant attention due to its extreme vulnerability to the adverse effects of climate change (IPCC, 2014). Mia et al. (2016) carried out studies evaluating climate factors throughout several climatic sub-regions of Bangladesh. The study conducted a comparative analysis of the rates of change of important climatic variables, including yearly maximum and minimum temperatures, annual total rainfall, and annual average humidity, across the three primary climatic sub-regions of Bangladesh, namely the Western zone, Northwestern zone, and North-Eastern zone. It was discovered that the north-eastern zone had the highest annual maximum temperature and average minimum temperature change rates, with yearly changes of 0.048°C and 0.046°C, respectively. Shahid (2010) analyzed the rainfall and temperature trend of 17 meteorological stations of Bangladesh and he discovered that the average maximum and minimum temperatures exhibited an increase of 0.91°C and 0.097°C per decade, respectively. According to Rakib (2013), it was found that Bangladesh experienced an upward trend in temperature during the period of the past 18 years. Particularly, the annual temperature climbed by a range of 0.4-0.6°C between the years 1981 and 2010. Rahman & Lateh, (2016) constructed a regression model for trend detection from 1971 to 2010 and forecasting ten-year period of rainfall by the ARIMA method from 34 meteorological stations in Bangladesh. Their findings showed that annual rainfall was forecasted to decline by 153 mm between 2011 and 2020. Basak et al. (2013) found that the yearly average maximum temperature was increasing at 0.0186°C per year, while the minimum temperature was increasing per year at 0.0152°C. Rahman et al. (2014) investigated the regional variation of climate variables, specifically temperature and rainfall, across five locations in Bangladesh: Dhaka, Cox's Bazar, Rajshahi, Bogra, and Shylet during the period of 1953 to 2012. The analysis used the non-parametric Mann-Kendall test, which revealed statistically significant increases and decreases in several areas. Bari et al. (2016) described 50 years of seasonal and annual rainfall trends and their fluctuations during the period 1964 to 2013 in northern Bangladesh. For their study different non-parametric test (Mann-Kendall test, Sen’s Slope estimator) was applied to examine rainfall trends and magnitude of change, the Sequential Mann-Kendall test was utilized to detect any changes in the trends over the years and to locate possible point of areas in rainfall dataset. They found that there was a decreasing seasonal rainfall trend after the early 90's for the majority of the stations. Sa'adi et al. (2017) identified the spatial pattern of changes of rainfall extremes in Sarawak, Malaysia during the year 1980-2014. They analyzed the trends in annual, seasonal and monthly rainfall and rainfall extremes of 31 stations using the Mann–Kendall (MK) test along with modified Mann–Kendall (m-MK) test, which can discriminate multi-scale variability of unidirectional trend. In the study area the trends indicated that changes in annual, seasonal and monthly rainfalls and rainfall extremes were not significant.

The proposed study aims to find the comparison of climate variation over three districts in Bangladesh during the period 1950-2020. Our main objective is to compare the climate variables such as temperature, rainfall of Comilla with extreme and moderate temperature area of Bangladesh. Hence to find out the actual situation such as nature of temperature increasing/decreasing, trend of changes in temperature in different time scale, annual rainfall prediction by non-parametric method of three districts. According to the World Bank report, 31.5% of the total population is in the below poverty line. As a result, a comparative research of climate change at different places is a crucial issue for the development of the agro-economic scenario.

2. STUDY AREA AND DATA COLLECTION

2.1 Geography and Study Area

One of the most difficult decisions was deciding which extreme and moderate temperature zones to analyze because they represented the entire country and that was compared to Comilla. Over the years, this district is typically surrounded with monsoons, high temperature and heavy rainfall. The average annual temperature of the area is 25.5 °C (77.9 °F) and annually 2,295 mm (90.35 in) of precipitation falls. (Banglapedia, 2003). In order to obtain an image of the extreme and moderate temperature zones, yearly and monthly long-term average maximum and minimum temperature and annual rainfall, are analyzed to obtain the objective of the study. The temperature and rainfall data are retrieved from BMD and BARC. During study, yearly average maximum temperature analysis, "Ishwardi" station was found to 36.12°C while its nearest station was recorded at Rajshahi 36.04°C. In case of average minimum temperature, "Srimangal" station was the lowest temperature with 9.16°C and Ishwardi was the 2nd lowest weather station with 10.18°C. So, for extreme temperature we have chosen Ishwardi station which is located on the northwest region and also by the side of north east region. In choice of moderate area for study, we studied both long term average maximum and long-term average minimum temperature.

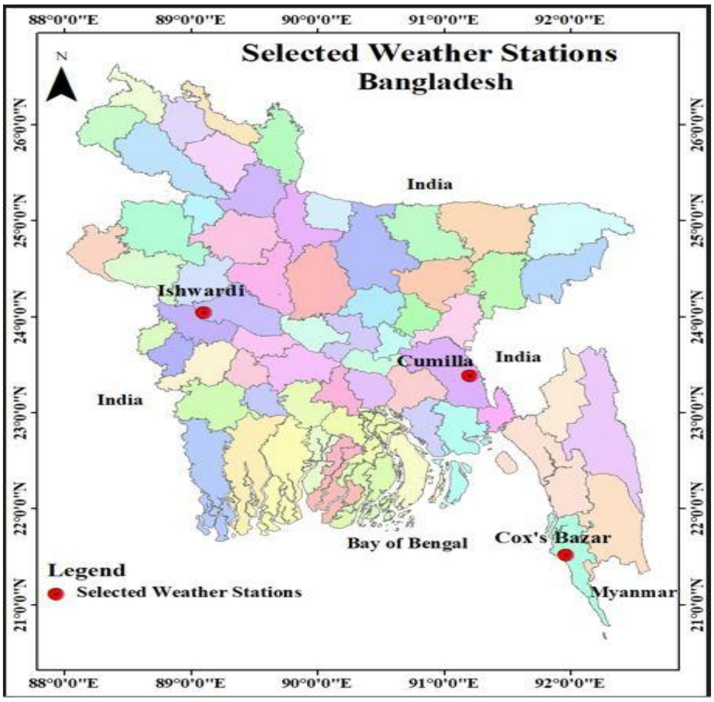


Fig.1. Study area weather Stations (Ishwardi, Comilla, Cox's bazar)

"Cox's Bazar" station has the highest value in the long-term average minimum temperature record and 3rd lowest value in the long-term average maximum with 14.98°C and 32.81°C respectively. No other station has proven that much effectiveness on the selection of moderate area. Cox's Bazar is located on the south east region. So, Ishwardi station is chosen for extreme zone and Cox's Bazar is moderate zone.

2.2 Data and Sources

The study area mainly covers three meteorological stations Comilla, Ishwardi, Cox's Bazar. and the weather data collected from Bangladesh Metrological Department (BMD), Agargaon, Dhaka and also recorded at Bangladesh Agricultural Research Council (BARC). They supervised climate data such as rainfall and temperature based on meteorological records during the period of 1950 to 2020 except Ishwardi station started from start from the year 1961 to 2020.

3. MATERIALS AND METHODS

Different statistical technique has been implemented for required analysis and this are described in the following sections. General exploratory statistical analysis such as maximum, minimum, mean/ average, median, standard deviation has been applied to present the general characteristic of temperature data.

3.1 Linear Regression

Linear regression is commonly used as a parametric method for identifying linear trend in time series data. It is used to obtain the slope of hydro-meteorological variables on time (Tabari & Talaee, 2011). Positive values of slope indicate increasing trend and vice versa. The least square method to calculate a straight line that best fits the data and returns an array that describes the line can be calculated as (Rahman & Lateh, 2016)

$$y = mx + b \quad \text{………………………………..} \quad (1)$$

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

$$b = \bar{y} - m\bar{x}$$

In equation (1) y is the dependent and a function of the independent x value, m is coefficient (the slope) corresponding to each x value, and b is a constant value (the intercept) and $\bar{x}$and $\bar{y}$ are sample means(Rahman & Lateh, 2016). For temperature data we normally use this linear regression technique to know the temperature trend detection.

3.2 Mann-Kendall (MK) Test

In this study, the rank –based non-parametric Mann-Kendall (MK) (Mann, 1945; Kendall, 1975) method is used as the base method of trend detection. This technique is widely used in hydro-meteorological time series data to determine whether the time series has a monotonic upward and downward trend (Das et al., 2021; Kamruzzaman et al., 2018, 2022; Rahman et al., 2017). Here we detect the annual and monthly rainfall trend analysis by This non-parametric method. The test statistic (S) of the series $x_1, x_2, x_3 \ldots\ldots$ and $x_n$is calculated by using the following formula

$$S = \sum_{K=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$sgn(x_j - x_k) = \begin{cases} +1, if (x_j - x_k) > 0 \\ 0, if (x_j - x_k) = 0 \\ -1, if (x_j - x_k) < 0 \end{cases} \ldots\ldots\ldots (3)$$

Here S value indicates the detection of trend. A positive value of **S** indicates increasing trend and vice versa. The MK test has documented that when data size is ≥ 10, the test **S** is approximately normally distributed and variance is as follows:

$$Var(S) = \frac{[(n(n-1)(2n+5)] - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \ldots\ldots\ldots (4)$$

Where **m** is the number of tied groups and t_i is the size of the ith group. The test statistic **Z is** computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, for S > 0 \\ 0, for S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, for S < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Generally, the positive and negative values of Z statistic depict the increasing and decreasing trends in the time series, respectively. In the null hypothesis (H_0) there is no trend in records (either accepted or rejected) depending on whether the computed Z statistic is less or more than the critical value of Z statistic.

3.3 Sen's-Slope Estimator

Sen's non-parametric method (Sen, 1968) which gives the robust estimation of time series is used to estimate the magnitude of trends in the weather time series data of Bangladesh. When change in time series is present but cannot be detected using statistical tests to a satisfactory level then Sen's slope estimation (Q) gives a better output (Radziejewski & Kundzewicz, 2004). (Shahid, 2010) used this method to detect the magnitude of trends in rainfall time series of Bangladesh. The estimation slope Q can be obtained from N pairs of data as:

$$Q_i = \frac{x_k - x_j}{k-j}, i = 1,2,3 \ldots \ldots \ldots N, k > j \text{ ....(6)}$$

Where x_k and x_j represents values of data at k and j times and Q_i is the median slope respectively.

4. RESULT AND DISCUSSION

Mainly "Ishwardi" and "Cox's Bazar" are the two extreme and moderate area of climatic region compare with Comilla climatic zone. The all three stations discuss about by descriptive and graphical analysis. After that, the next section will deliberate about time series analysis and forecasting.

4.1 Temperature Analysis

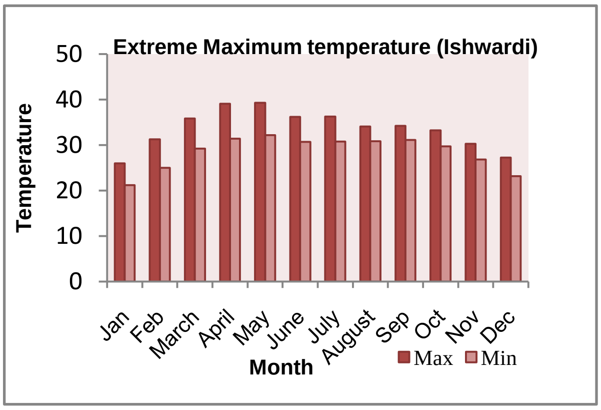
4.1.1 All-Time Extreme Temperature of Ishwardi Station

For all-time extreme maximum temperature record, maximum temperature in summer (May) was recorded 39.31°C while in winter maximum temperature was recorded 21.18°C (January). Mean extreme maximum temperature is found 36.12 °C.

Table 1. Month-wise all-time extreme temperature of Ishwardi

Statistics	Extreme Maximum Temperature	Extreme Minimum Temperature
Maximum	39.31	27.37
Minimum	21.18	8.29
Range	18.13	19.08
Mean	36.12	10.18

Meanwhile, extreme minimum temperature record it is found that the extreme minimum temperature recorded in Ishwardi was 8.29°C on winter (January) and 27.37°C was recorded as a minimum temperature on June. Mean extreme minimum temperature was found to be 10.18°C.



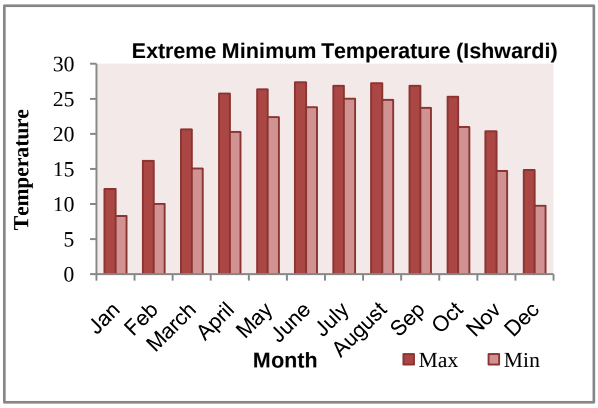


Fig. 2. Bar diagram showing month-wise extreme maximum and minimum temperature of Ishwardi

From (Fig. 2) we can see that for extreme maximum temperature of Ishwardi lies between 36.28°C to 39.31°C during the period 1961-2020. April to July are the hottest months. December and January are the coldest months.

4.1.2 All Time Extreme Temperature Cox's Bazar Station

In extreme maximum temperature record, 34.91°C was found to be the maximum summer temperature and 24.42°C was found to be the maximum temperature in winter at Cox's Bazar. Mean of the extreme maximum temperature is 32.81°C

Table 2. Month-wise all-time extreme temperature of Cox's Bazar

Statistics	Extreme Maximum Temperature	Extreme Minimum Temperature
Maximum	34.91	27.02
Minimum	24.42	12.84
Range	10.49	14.18
Mean	32.81	14.98

On the other hand, extreme minimum temperature record at Cox's Bazar, minimum temperature was 12.84°C in winter and in summer the extreme minimum temperature was 27.2°C. Mean of the extreme minimum temperature is 14.98°C.

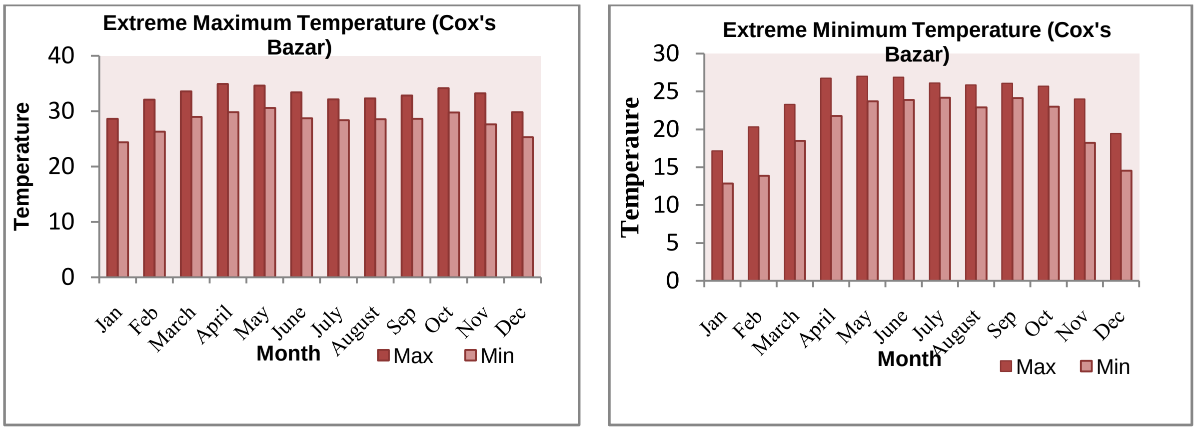


Fig. 3. Bar diagram showing extreme maximum and minimum temperature of Cox's Bazar

From the above multiple Bar diagram (Fig. 3) extreme maximum and minimum temperature of Cox's Bazar station shows different temperature. For extreme maximum temperature-April, May and October have the maximum value. But in case of extreme minimum temperature, May month has the highest value.

4.1.3 All Time Extreme Temperature of Comilla Station

From Table 4 extreme maximum and minimum temperature recorded in Comilla station was 35.04°C as maximum temperature once and lowest temperature was recorded 9.89°C. Mean of extreme maximum and minimum temperature was 33.23°C and 12.25°C respectively.

Table 4 Month-wise all-time extreme temperature of Comilla

Statistics	Extreme Maximum Temperature	Extreme Minimum Temperature
Maximum	35.04	26.54
Minimum	22.72	9.89
Range	12.32	16.65
Mean	33.23	12.25

Fig.4 indicated that April month had the highest temperature once in Comilla and January had the lowest temperature value

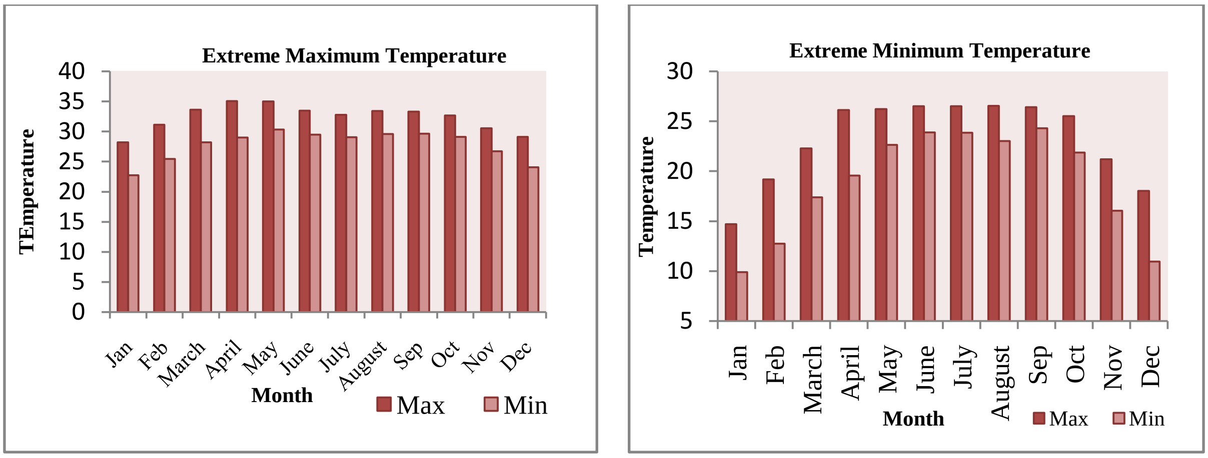


Fig. 4. Bar diagram showing extreme maximum and minimum temperature of Comilla

4.2 Comparison of Temperature of Comilla with Extreme and Moderate Area

4.2.1 Long-term Yearly Average Maximum and Minimum Temperature

From Table 5 a comparison analysis on year-wise long-term average maximum and minimum temperature among three meteorological stations representing three area of Bangladesh. Primarily we are focusing on the temperature Comilla which would be compared with other two meteorological stations representing extreme (Ishwardi) and moderate (Cox's Bazar) temperature area. On long term average maximum temperature analysis; maximum, minimum and mean temperature of Ishwardi station is 31.92°C, 29.81°C and 31.03°C, temperature of Cox's Bazar is 31.66°C, 28.9°C and 30.22°C and followed by Comilla station are 31.20°C, 28.64°C, and 30.25°C respectively. Among all three stations, Comilla always has possessed temperature between the values of Ishwardi and Cox's Bazar station

Table 5. Long term average maximum and minimum temperature for comparison

Long Term Average Maximum Temperature				Long Term Average Minimum Temperature			
Statistics	Ishwardi Max Temp	Cox's Bazar Max Temp	Comilla Max Temp	Statistics	Ishwardi Min Temp	Cox's Bazar Min Temp	Comilla Min Temp
Maximum	31.92	31.66	31.20	Maximum	21.48	23.31	22.5
Minimum	29.81	28.90	28.64	Minimum	19.47	20.88	20.03
Range	2.11	2.76	2.56	Range	2.01	2.43	2.47
Mean	31.03	30.22	30.25	Mean	20.08	22.02	21.02
Median	31.02	31.66	30.30	Median	20.38	23.31	20.95

On the other hand, during the period 1950 -2020 long term average minimum temperature analysis; maximum, minimum and mean temperature of Ishwardi station recorded are 21.48°C, 19.47°C and 20.08°C, temperature of Cox's Bazar station is 23.31°C, 20.88°C and 22.02°C and finally temperature of Comilla station are 22.50°C, 20.03°C and 21.02°C respectively. Just like long term average maximum temperature, here we also get that Comilla is on the middle position. It's also been showed graphically that Comilla is always on the middle position on long term average temperature among these three stations. No matter maximum or minimum temperature, Comilla has got the middle ground.

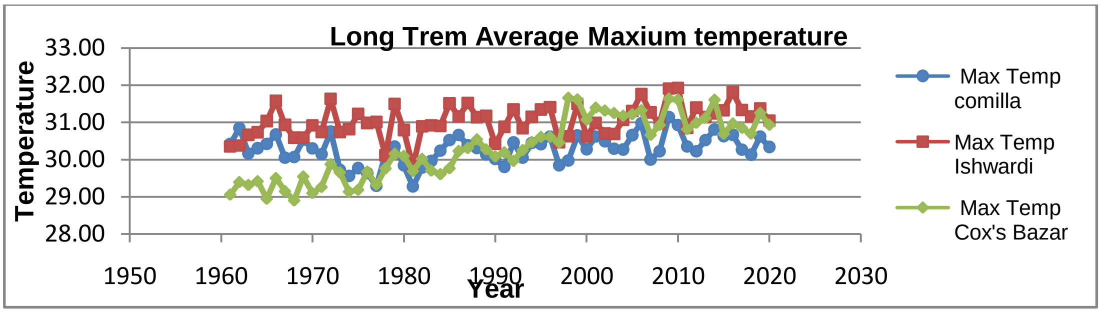


Fig.5 Long term yearly average maximum temperature

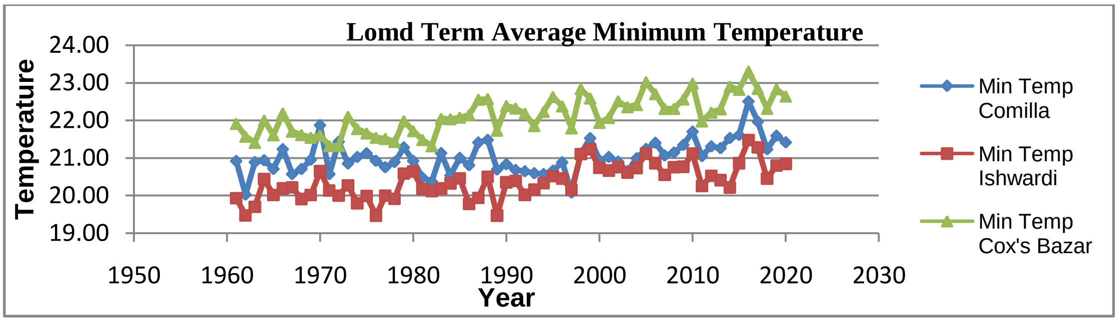


Fig. 6. Long term yearly average minimum temperature

4.2.2 Monthly Maximum and Minimum Temperature

Monthly maximum and minimum temperature during the study period clearly depicts the scenario of month temperature of three weather stations. Among the three stations Ishwar station shows highest temperature during the month March to August compare to the other two stations. It also receives lowest temperature during winter season. It is mostly observed that Comilla station predicts favorable condition in monthly temperature in the period 1950-2020 compare to Ishwardi and Cox's Bazar. The temperature is mostly suit for economic and agricultural production.

Table 6. Maximum and minimum monthly temperature during the study period

Month	1961-2020 Ishwardi		1950-2020 Comilla		1950-2020 Cox's Bazar	
	Max	Min	Max	Min	Max	Min
Jan	23.57	10.22	25.46	12.29	26.52	14.99
Feb	28.13	13.12	28.29	15.97	29.19	17.08
March	32.54	17.84	30.91	19.84	31.28	20.86
April	35.24	23.02	32.01	22.86	32.36	24.27
May	35.75	24.35	32.67	24.43	32.62	25.37
June	33.47	25.59	31.46	25.21	31.07	25.37
July	33.52	25.95	30.93	25.20	30.25	25.15
August	32.48	26.03	31.50	24.79	30.42	24.37
Sep	32.69	25.27	31.47	25.36	30.73	25.10
Oct	31.50	23.14	30.89	23.71	31.97	24.35
Nov	28.57	17.53	28.64	18.63	30.44	21.13
Dec	25.21	12.32	26.60	14.49	27.56	16.98

4.2.3 Long Term Average Monthly Rainfall

Climate parameters are often related to each other. Changing on weather does not depend on only one particular parameter but the relationship and fluctuations of temperature are very noticeable. To know about various temperature changes at different month in the study area we may need to observe the behavior of rainfall and its trend analysis. From Table 7 and Figure 4.2 (c) we can see that mean of the long-term average rainfall of Ishwardi station is 131.83 millimeter. June-July is the rainiest season of the year and maximum rainfall recorded for a month is 310.63 mm. Mean of the average rainfall of Cox's Bazar is 303.16 millimeter and highest rainfall recorded here is 956.83 mm in July. But during the winter season (December-January) rainfall is same on the two areas. Although Cox's Bazar has the record of average maximum rainfall in a month, but in the month of January it has less average rainfall record than Ishwardi.

Table 7. Comparison of long-term average monthly rainfall

Statistics	Ishwardi	Cox's Bazar	Comilla
Maximum	324.56	977.87	435.83
Minimum	7.77	6.57	6.56
Range	316.79	971.30	181.45
Mean	131.83	303.16	429.27
Median	102.55	170.12	155.45
Total	1581.99	3637.90	2177.40

Now in case of Comilla station, the recorded long-term average rainfall is 175.37 mm. Highest rainfall during July with 435.83 mm on average band January seems to be driest month with average of 6.56 mm of rainfall.

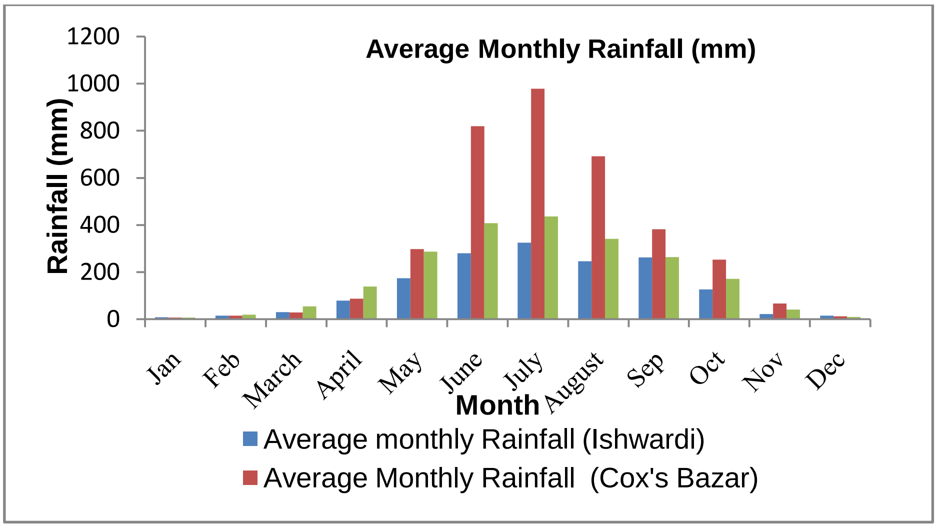


Fig. 8 Multiple bar diagram for average monthly rainfall (mm)

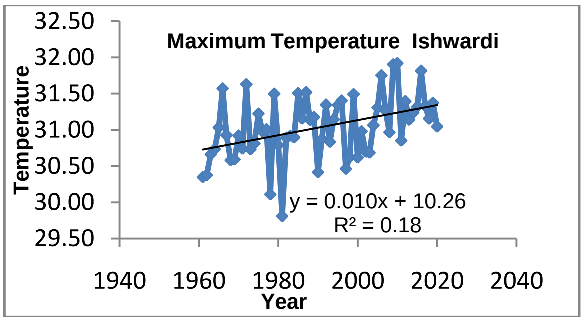
So, it is clear that average rainfall during summer (and rainy season) of Cox's Bazar is greater than Ishwardi and Comilla. But in winter all the areas are almost dry. Hence comparing with Ishwardi and Cox's Bazar, Comilla has less rainfall than Cox's Bazar and more than Ishwardi during summer and rainy season. On total, Comilla has 2177-millimeter rainfall per year which is on the middle position of Ishwardi and Cox's Bazar with 1582 millimeter and 3638-millimeter rainfall per year respectively.

5. TREND ANALYSIS

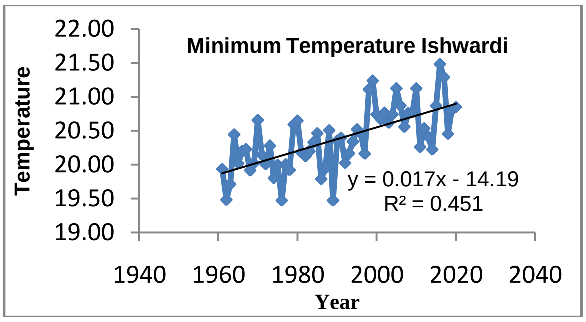
Trend analysis is a technique used in technical analysis that attempts to predict future maximum and minimum temperature and annual rainfall movements based on recently observed trend data from 1950 to 2020 except Ishwardi station starts from 1960.

5.1 Comparison of Maximum and Minimum Temperature by Linear Trend

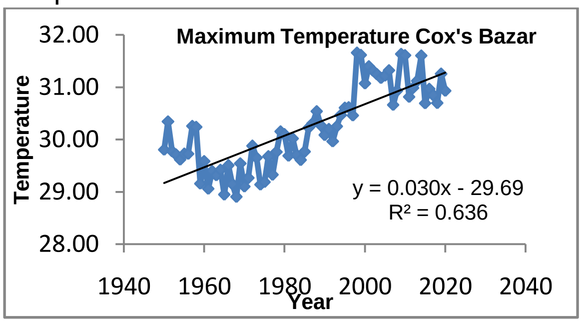
The linear regression model (a) of Ishwardi station shown an upward trend in the data series of yearly average maximum temperature with a model which is defined by. According to this model, each year temperature increasing rate o is 0.010°C and the yearly average maximum temperature raised by total 0.59°C during the study period 1961-2020. On the other hand, yearly average minimum temperature trend (b) shown also an upward trend in the data series with the model$y_t = -14.119 + 0.0174x_t$. Hence the average minimum temperature increases by 0.0174°C per year with total increase 1.003°C. If we see the (c) average maximum temperature of Cox's Bazar has raised 0.0302 °C per year with fitted model $y_t = -29.69 + 0.0302x_t$with negative intercept total of 2.114°C temperature has risen per year since 1950-2020.



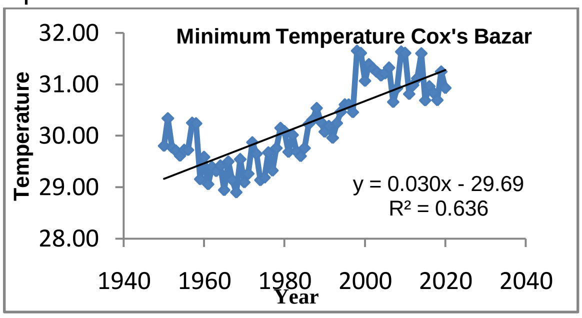
(a) Time series plot with trend of maximum temperature of Ishwardi



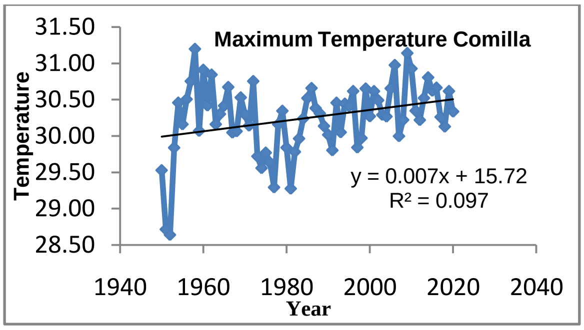
(b) Time series plot with trend of minimum temperature of Ishwardi



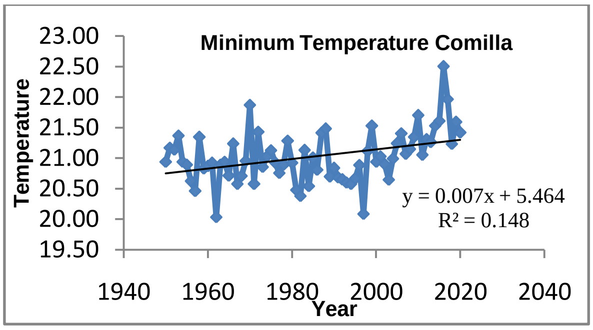
(c) Time series plot with trend of Maximum Temperature of Cox's Bazar



(d) Time series plot with trend of minimum temperature of Cox's Bazar



(e)Time series plot with trend of maximum temperature of Comilla



(f) Time series plot with trend of minimum temperature of Comilla

Fig. 9. Linear trend detection of (maximum and minimum) temperature

Upward trend of average minimum temperature shown in (d) with increment of 0.0213°C per year and in that case a total temperature change for last 70 years at Cox's Bazar 1.49°C. The trend model can be defined as – $y_t = -20.333 + 0.0213x_t$.Finally, during the study period temperature movement of Comilla station also (e) shown an upward trend in the data series of yearly average maximum temperature with a rising rate of every year 0.0073°C followed by the total temperature increment within this period is 0.511°C. The fitted trend model can be defined as $y_t = 15.725 + 0.0073x_t$. Further, time series plot (f) for average minimum temperature also predict increasing trend with total increment of 0.546 °C since 1950. It is clearly observed that trend analysis of all three meteorological stations forecasts increasing temperature with a decent rate.

Table 8. Comparison of temperature criteria of three stations

	Ishwardi		Cox's Bazar		Comilla	
	Maximum Temperature	Minimum Temperature	Maximum Temperature	Minimum Temperature	Maximum Temperature	Minimum Temperature
Intercept	10.27	-14.18	-29.69	-20.233	15.75	5.465
Increment	0.010	0.0017	.0302	0.0213	0.0073	0.0078
Total Increment	**0.591°C**	**1.003°C**	**2.114°C**	**1.49°C**	**0.511°C**	**0.546°C**
R^2	0.18	0.45	.64	0.65	0.09	.16

From above comparison table analysis, we see that average maximum and minimum temperature for all stations has risen from 0.511°C to 2.114°C. Examining R^2 values, we can see all of our models are not statistically significant. But it won't matter in this study because R^2 is calculated considering all the values including the extreme ones of summers and winters. As Ishwardi station has been chosen as extreme area and Cox's bazar as moderate area, temperature of moderate area (Cox's Bazar) has risen more than extreme area (Ishwardi) and R^2 values are much less than Ishwardi stations model and relatively greater than Cox's Bazar station. Comparing with Ishwardi and Cox's Bazar station, the temperature of Comilla has not raised that much in both summer and winter. Although no decrement of temperatures is found on any of the stations. From this analysis it is clear that temperature rising is certain. But it increases gently in extreme areas, rapidly in moderate areas and less increment in Comilla during the study period. That means overall temperature of Bangladesh will be rising on a great scale within next century. Sooner or later, moderate temperature area will be lost and all the country will be transformed into extreme temperature area gradually.

5.2 Comparison of Rainfall station by Linear Trend

It is clearly observed that annual rainfall of three weather stations described the rainfall pattern of the study area. In Comilla and Ishwardi stations annual rainfall are decreasing after the year 1995 with 1800 mm to 2000 mm, meanwhile after the year 2005 annual rainfall around 3000 mm in Cox's Bazar station (Fig.10). So, Cox's station is received more increase amount of rainfall in future compare to other two stations.

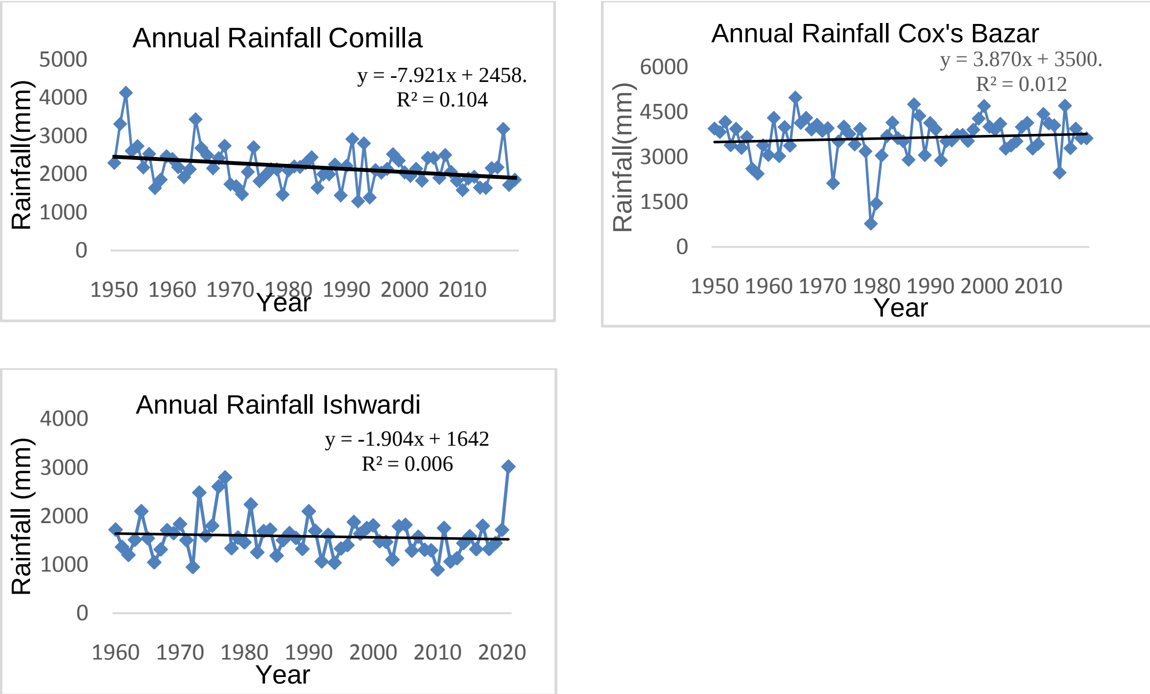


Fig.10 Linear trend detection of annual rainfall

5.3 Comparison of Rainfall Trend Analysis by MK test and Sen's Slope Estimator

The three stations have shown both positive and negative trend in the study area. Positive slope indicates increasing amount of rainfall and negative slope indicates decreasing amount of rainfall. In extreme area rainfall is decreasing at a rate of 1.61 mm/year followed by Comilla also at a rate of 7.00 mm/year, which is statistically significant. The Mann-Kendall Z statistics of annual rainfall time series also shown negative trend with 0.808 and 2.66.

Table 9. Comparison of Annual Rainfall Trend analysis

Station	MK test	Sen's Slope	Kendall tau	P value
Ishwardi	-0.808	-1.67	-0.071	0.42
Cox's Bazar	0.735	2.28	0.061	0.46
Comilla	-2.66	-7.00	-0.217	0.01

On the other hand, Cox's Station have positive trend with 0.735 and a rate of change 2.28 mm/year but the trend is not statistically significant. So, in a nutshell moderate area annual rainfall increases rapidly in future comparison to Ishwardi and Comilla.

6. CONCLUSION

In connection with existing problems, there is a need to conduct comparative research on climate change at different parts of Bangladesh in order to improve the country's agro-economic status quo. It is clear that comparison with extreme and moderate area, we can say about Comilla that has a favorable climate condition with adequate rainfall and temperature. It is neither ever dry like extreme temperature area and neither ever wet like rainy regions. It's temperature much more favorable for human growth, farming and cultivation. This is why Comilla is one of the most beautiful cities of Bangladesh. GDP of Bangladesh is also benefited with agricultural production from Comilla. Our study revealed that other climate factors are having an impact on temperature behavior, and that the global average temperature will raise by about 1-2 degrees Celsius over the course of the next century. It will become harder for humans to survive on earth. Increment of surface temperature will make imbalance on biodiversity and nature. By analyzing data, we also discovered that decreasing rate of rainfall in the above two rainfall stations out of three, which will have a significant effect on ground water resources and agricultural planning in this area. In Bangladesh, agriculture is heavily dependent on precipitation. Lack of rainfall during the irrigation time could affect on ground water extraction. In the end, global warming is a problem. Bangladesh is a key region that is suffering from climate change. According to the World Meteorological Organization (WMO), country on the baseline of the ocean will go under water soon if we do not prevent or control global warming.

References

1. Adams RM, Hurd BH, Lenhart S, Leary N. Effects of global climate change on agriculture: an interpretative review. Climate research. 1998;11(1):19-30.
2. Agrawala S, Ota T, Ahmed AU, Smith J, Van Aalst M. Development and climate change in Bangladesh: focus on coastal flooding and the Sundarbans. Paris: OECD; 2003.
3. Alam M, Rabbani MG. Vulnerabilities and responses to climate change for Dhaka. In Adapting Cities to Climate Change. 2012; 112-129.
4. Ali A. Climate change impacts and adaptation assessment in Bangladesh. Climate research. 1999;12(2-3):109-16.
5. Amin MR, Tareq SM, Rahman SH, Uddin MR. Effects of temperature, rainfall and relative humidity on visceral leishmaniasis prevalence at two highly affected upazilas in Bangladesh. Life Sci J. 2013;10(4):1440-6.
6. Ara M, Hossain MA, Alam MM. Surface dry bulb temperature and its trend over Bangladesh. Journal-Bangladesh Academy of Sciences. 2005;29(1):29.
7. Ayers JM, Huq S. The value of linking mitigation and adaptation: a case study of Bangladesh. Environmental Management. 2009; 43:753-64.
8. Bangladesh Meteorological Department. Temperature issued under the authority of the Director General. BMD Bangladesh. 2010.
9. Bank A.D. Country Environmental Analysis Bangladesh. 2004. pp 17.
10. Bari SH, Rahman MT, Hoque MA, Hussain MM. Analysis of seasonal and annual rainfall trends in the northern region of Bangladesh. Atmospheric Research. 2016; 176:148-58.
11. Basak JK, Titumir RA, Dey NC. Climate change in Bangladesh: a historical analysis of temperature and rainfall data. Journal of Environment. 2013;2(2):41-6.
12. Chan KL. Climate Issues in Hong Kong: Mitigation and Adaptation. Bachelor of Engineering degree in Civil and Environmental Engineering at Hong Kong University of Science and Technology, 4p. 2006.
13. Chowdhury MH, Debsharma SK. Climate change in Bangladesh–A statistical review. InReport on IOC-UNEP Workshop on Impacts of Sea Level Rise due to Global Warming, NOAMI 1992.

14. Chowdhury JA, Islam MT, Kamruzzaman M, Khalek MA, Rahman MS. Climate Change between Extreme and Moderate Temperature Area in Bangladesh: A Comparative Study. International Journal of Statistical Sciences.2017;17:1-17.
15. Comilla Climate "Climate Data. Org". Retrieved from https://en.climate-data.org/asia/bangladesh/chittagong-division/Comilla-3331/. (Accessed in 2022)
16. Easterling DR, Horton B, Jones PD, Peterson TC, Karl TR, Parker DE, Salinger MJ, Razuvayev V, Plummer N, Jamason P, Folland CK. Maximum and minimum temperature trends for the globe. Science. 1997;277(5324):364-7.
17. Food and Agriculture Organization of the United Nations (FAO). Adaptation to Climate Change in Agriculture, Forestry and Fisheries: Perspective, Framework and Priorities; FAO Inter-Departmental Working Group on Climate Change: Rome, Italy, 2007.
18. Hasan AB, Rahman MZ. Change in temperature over Bangladesh associated with degrees of global warming. Asian Journal of Applied Science and Engineering. 2013;2(2):62-75.
19. Islam AS. Analyzing changes of temperature over Bangladesh due to global warming using historic data. Young Scientists of Asia Conclave, Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR). 2009; 15:15-7.
20. Karmakar, S. Recent climatic changes in Bangladesh. SAARC Meteorological Research Centre. 2000; No-4.
21. Mehrotra D, Mehrotra R. Climate change and hydrology with emphasis on the Indian subcontinent. Hydrological sciences journal. 1995 ;40(2):231-42.
22. Mia MY, Ali MR, Roy S. Comparison of climatic variables among different climatic sub-regions of Bangladesh. Bangladesh Journal of Scientific Research. 2016;29(1):63-71.
23. Hossain MZ, Mondal MN, Sarkar SK, Haque MA. Seasonal Variation of Temperature in Dhaka Metropolitan City, Bangladesh. Jordan Journal of Earth and Environmental Sciences. 2014;6(2):93-7.
24. Nury AH, Koch M, Alam MJ. Time series analysis and forecasting of temperatures in the sylhet division of Bangladesh. In4th International Conference on Environmental Aspects of Bangladesh (ICEAB), August 2013; 24-26.
25. Parthasarathy B, Sontakke NA, Monot AA, Kothawale. DR. Droughts/floods in the summer monsoon season over different meteorological subdivisions of India for the period 1871–1984. Journal of Climatology. 1987 ;7(1):57-70.
26. Peterson TC, Connolley WM, Fleck J. The myth of the 1970s global cooling scientific consensus. Bulletin of the American Meteorological Society. 2008 ;89(9):1325-38.
27. Planton, S. Annex III. Glossary: IPCC–Intergovernmental Panel on Climate Change. PDF. IPCC Fifth Assessment Report, 2013, 1450-1451.

28. Rahman MD, Mustafi MA, Islam AF, Mohammad N. The effect of rainfall, temperature and humidity on saline in the southern area of Bangladesh. Journal of Biology, Agriculture and Healthcare. 2014;4(22):58-61.
29. Rajib MA, Rahman MM. A comprehensive modeling study on regional climate model (RCM) application—regional warming projections in monthly resolutions under IPCC A1B scenario. Atmosphere. 2012;3(4):557-72.
30. Rajib MA, Mortuza MR, Selmi S, Ankur AK, Rahman MM. Increase of heat index over Bangladesh: Impact of climate change. International Journal of Civil and Environmental Engineering. 2011;5(10):434-7.
31. Rakib ZB. Extreme temperature climatology and evaluation of heat index in Bangladesh during 1981-2010. J. Pres. Univ. B. 2013; 2:84-95.
32. Sa'adi Z, Shahid S, Ismail T, Chung ES, Wang XJ. Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann–Kendall test. Meteorology and Atmospheric Physics. 2019; 131:263-77.
33. Shahid S. Recent trends in the climate of Bangladesh. Climate Research. 2010;42(3):185-93.
34. Shaw R, Mallick F, Islam A. Climate change: Global perspectives. Climate change adaptation actions in Bangladesh. 2013; 3-14.
35. Shepherd JM, Shindell D. O'Carroll, CM. What's the difference between weather and climate. Retrieved from NASA 2016; 6.
36. The Editors of Encyclopedia Britannica (2013). Comilla. Retrieved February 15, 2019; from Encyclopædia Britannica.
37. IPCC (2007). Climate change 2007: Working group 1, The physical science basis, summary for policy makers p. 13, 2007.
38. Das J, Mandal T, Rahman AS, Saha P. Spatio-temporal characterization of rainfall in Bangladesh: an innovative trend and discrete wavelet transformation approaches. Theoretical and Applied Climatology. 2021;143(3-4):1557-79.
39. Kamruzzaman M, Rahman AS, Ahmed MS, Kabir ME, Mazumder QH, Rahman MS, Jahan CS. Spatio-temporal analysis of climatic variables in the western part of Bangladesh. Environment, Development and Sustainability. 2018; 20:89-108.
40. Kamruzzaman M, Rahman AS, Basak A, Alam J, Das J. Assessment and adaptation strategies of climate change through the prism of farmers' perception: A case study. International Journal of Environmental Science and Technology. 2023;20(5):5609-28.
41. Radziejewski M, Kundzewicz ZW. Detectability of changes in hydrological records/Possibilité de détecter les changements dans les chroniques hydrologiques. Hydrological Sciences Journal. 2004;49(1):39-51.

42. Rahman MA, Yunsheng L, Sultana N. Analysis and prediction of rainfall trends over Bangladesh using Mann–Kendall, Spearman’s rho tests and ARIMA model. Meteorology and Atmospheric Physics. 2017;129(4):409-24.
43. Rahman MR, Lateh H. Spatio-temporal analysis of warming in Bangladesh using recent observed temperature data and GIS. Climate Dynamics. 2016; 46:2943-60.
44. Sen PK. Estimates of the regression coefficient based on Kendall's tau. Journal of the American statistical association. 1968;63(324):1379-89.
45. Shahid S. Rainfall variability and the trends of wet and dry periods in Bangladesh. International Journal of climatology. 2010 Dec;30(15):2299-313.
46. Shahid S. Rainfall variability and the trends of wet and dry periods in Bangladesh. International Journal of climatology. 2010 ;30(15):2299-313.
47. Coirolo C, Commins S, Haque I, Pierce G. Climate change and social protection in Bangladesh: are existing programmers able to address the impacts of climate change? Development Policy Review. 2013; 31:74-90.
48. World Bank. The Social Dimensions of Adaptation to Climate Change in Bangladesh. Discussion Paper 12. Washington, DC: World Bank. 2010.
49. Banglapedia. Climate https://en.banglapedia.org/index.php/Climate 2003. (Accessed 13 August, 2022).
50. Rahman MR, Lateh H. Spatio-temporal analysis of warming in Bangladesh using recent observed temperature data and GIS. Climate Dynamics.2016;46:2943-60.