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L E T T E R S

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DISCOVERING THE CHANGE OF MAJOR CLIMATIC ELEMENTS IN BANGLADESH: A STATISTICAL APPLICATION OF TRENDS, GROWTH AND VARIABILITY ANALYSIS

1. Climate change is one of the key environmental problems (Hasan *et al*., 2013) and it is a long term effect of change in average weather conditions whose main elements are temperature and precipitation (Rahman *et al*., 2015; Thornton *et al*., 2014). The world's temperature is increasing (Dash *et al*., 2007), precipitation is decreasing and both are affected through all over the world by various factors such as the burning of fossil fuels, uncontrolled industrial factories and clearing of the jungle, and forest areas using fire, rapid urbanization etc. (IPCC 2014; Rajeevan *et al*., 2008). The lower and developing countries are the worst victims of it (Tol, 2012). As a developing country, Bangladesh is one of the most vulnerable countries in the world due to climate change (Hasan *et al*., 2013) and ranked 6th in the Global Climate Risk Index (Dastagir, 2015; Kreft *et al*., 2017).

The weather of Bangladesh is a subtropical monsoon (Alam, 2013; Khatun and Rashid, 2016; Mondol *et al*., 2018) and it is categorized by wide seasonal variations in precipitation, high temperatures and humidity (Shahid, 2010). It mainly covers three distinct seasons : a tropical summer from March to June; a rainy monsoon season from June to October; and a dry winter from October to March (Chowdhury *et al*., 2012; Jega and Haque, 2018). In Bangladesh, the maximum summer temperatures generally lie between 30 °C and 40 °C (Khatun and Rashid, 2016; Limon, 2017; Noorunnahar, 2013). The warmest month is April and it is in most parts of the country. On the other hand, January is the coldest month, when the average temperature of the country is about 10°C.

The extrapolation of the future climate of Bangladesh is available based on some atmospheric models and time series models (Dastagir, 2015; Rahman *et al*., 2015). But the determination and the precision of these models are still now improving. On the other hand, the temperature of Bangladesh is getting intolerable day by day with its lower rate of precipitation. So it is necessary to study its change and take the necessary steps. Relatively a few studies have been done in this respect but most of them are based on small time series data and the growth and instability are not significantly identified. That is why, this study attempted to measure the trends, growth, and variability in temperature and precipitation of Bangladesh based on the recent large scale time series data from 1960 to 2017 years.

2. The current study used secondary time series data on the yearly average of maximum temperature and yearly total precipitation for 58 years from 1960 to 2017 years. The data were collected from the Bangladesh Meteorological Department (BMD). The available temperature and precipitation data (1960-2017) are purposively divided into two halves 1960-1988 years (Period-I) and 1989-2017 years (Period-II) to compare the variability and growth between two time periods. To examine the nature of change, instability and the growth in maximum temperature and precipitation, various descriptive statistical tools, such as mean, correlation coefficient and coefficient of variation were used. The paired sample *t*-test and a semi-log growth model were also used to analyse the data. The entire study used SPSS (version 20) program to perform the statistical analysis.

2.1. *Paired t-test*: The paired sample *t*-test was used to test the significant difference of temperature and precipitation between Period-I and Period-II (Arp and Yin, 1992; Deslauriers *et al*., 2007; Hsu and Lachenbruch, 2008; Morrison *et al*., 2002; Serbin and Kucharik, 2009). To test the significance, the probable null and alternative hypotheses for all the age groups are

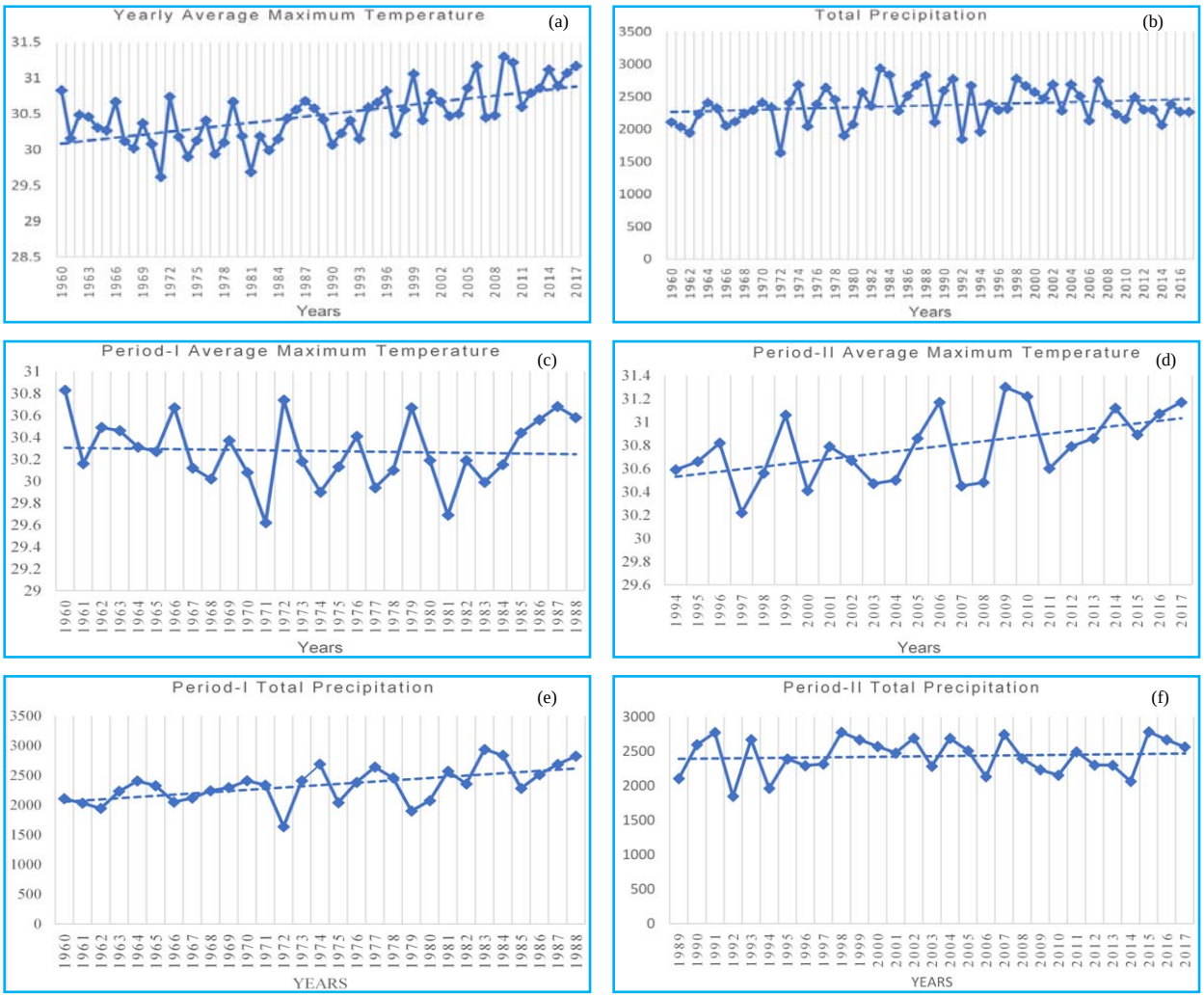
H_0 : The average temperatures of Period-I and Period-II are equal

H_1 : They are not equal

and

H_0 : The average precipitation of Period-I and Period-II are equal

H_1 : They are not equal



Figs. 1(a-f). Trends of yearly (a) Maximum temperature in whole period, (b) Total precipitation in whole period, (c) Maximum temperature in Period-I, (d) Maximum Temperature in Period-II, (e) Total precipitation in Period-I and (f) Total precipitation in Period-II

2.2. *Measurement of growth rates* : The growth rates of maximum temperature and total precipitation were studied by fitting a semi-log function (Farhana and Uddin, 2018; Uddin*et al*., 2015) of the type:

$$\text{Log}\,(y) = \alpha + \beta \qquad \text{(i)}$$

where,y is the maximum temperature (in degree Celsius) or yearly total precipitation (in millimeters) and t is the time period (in year).

2.3. *Measurement of instability* : To examine the nature and degree of instability in average maximum temperature and total precipitation, an index of instability was performed. The coefficient of variation (CV) was worked out for the yearly average of maximum temperature and yearly total precipitation to measure the variability. Since simple Coefficient of Variation (CV) does not explain properly the trend component characteristic in the time series data, the Coefficient of variation around the trend (CV_t) rather than coefficient of variation around the mean (CV) was suggested alternatively by Cuddy and Della (1978) as a better measure of variability (Bera *et al*., 2011; Bezabeh*et al*., 2017; Hasan*et al*., 2008; Rowhani *et al*., 2011; Singh and Byerlee, 1990).

3. *Change in maximum temperature and total precipitation* : This study includes 58 years of time series data for yearly average maximum temperature (in Degree Celsius) and yearly total precipitation (in Millimeter) covering all the weather Station of Bangladesh during the time period1960 to 2017 years. For our convenience, we divided the total time periods into two periods. One for1960 to 1988year (Period-I) and another was 1989 to2017 year (Period-II). Overall, the change of yearly maximum temperature found an increasing trend whereas

TABLE 1

Change in average maximum temperature and yearly total precipitation in Bangladesh

Field of Measurement	Mean Value		*t*-Value	Sig. (two-tailed)
	Period- I (1960-1988)	Period- II (1989-2017)		
Average Max. Temperature	30.2748	30.6904	-4.805	0.0001
Average Precipitation	2336.5736	2430.4158	-1.237	0.226

TABLE 2

Relationship between yearly average maximum temperature and yearly total precipitation in Bangladesh

Criteria	Value of correlation (r)		Sig. (two-tailed)
Average Max. Temperature *vs.*Total Precipitation	Whole Period (1960-2017)	-0.151	0.257
	Period-I (1960-1988)	-0.382	0.041
	Period-II (1989-2017)	-0.203	0.291

the yearly total precipitation showed an unstable but slight decreasing trend [Figs. 1(a&b)]. The average temperature and precipitation were found 30.46 °C and 2375 mm where the minimum and maximum value of temperature and precipitation were 29.62 °C *vs.* 31.30 °C and 1637.83 mm *vs.* 2937.96 mm respectively in the full period (1960-2017). When we considered Period-I and period-II, we found a dissimilar change of variation in both temperature and precipitation. In Period-I, the maximum temperature found highest (30.83°C) in the year of 1960 whereas the maximum temperature in period-II found highest (31.30°C) in 2009. For the first period (Period-I), the yearly maximum temperature showed a minor decreasing trend but in the second period (period-II) it increased gradually with satisfying a small fluctuation [Figs. 1(c&d)]. The average yearly total precipitations were 2336.57 mm and 2430.41 mm in the Period-I and period-II respectively. Although the average level of precipitation in period-II was higher, the average slope of this period was comparatively very lower than Period-I [Figs. 1(e&f)].

This study performed paired *t*-test to check the significant difference in temperature and precipitation between Period-I and Period-II. From this test, it was noted that the yearly average maximum temperature was significantly (p<0.0001) increased in period-II as compared to the Period-I and the average of total precipitation was unstable and no insignificant difference was found (Table 1).

3.1. *Correlation analysis* : From the correlation analysis, it was observed that the yearly average maximum temperature is negatively correlated (r = -0.151) with its yearly total precipitation in the whole period. This negative relationship implies that the decrease in total rainfall slightly affects to increase the average temperature. The reason is that besides the decrease in precipitation, there are also many factors that are highly correlated with the temperature. We also observed the negative correlation for both first and second study period and the correlation found statistically significant (p<0.05) for the first period (Period-I) (Table 2).

3.2. *Growth rate of yearly average temperature and yearly total precipitation* : The growth rate of yearly average temperature and yearly total precipitation provides a good measure of change in the past and acceptable indication of the change in the future. The exponential modelling is a good approach to measure the growth rate of average maximum temperature and total precipitation. Overall, the growth of both yearly averages of maximum temperature and total precipitation were significantly increased for the whole periods where the growth rates were 0.0457% and 0.2292% respectively. But there was a significant difference between Period-I and Period-II of both temperature and precipitation. In Period-I, the temperature was decreasing and precipitation was increasing. As a result, the growth of temperature was negative (-0.0071%) because of the positive (0.8301%) growth of precipitation. On the other hand, the yearly maximum temperature was increasing significantly in period-II than Period-I. At the same time, the precipitation was comparatively decreasing in period-II than Period-I. The rate of growth was 0.0905% and -0.1386% for the temperature and precipitation respectively (Table 3).

3.3. *Instability of yearly average maximum temperature and yearly total precipitation* : In this study, the yearly average maximum temperature and yearly total precipitation were found unstable results for the whole

TABLE 3

The Growth rate of yearly average maximum temperature and yearly total precipitation in Bangladesh

Field of Measurement	Measurement statistics	Growth Rate (%)	Sig. (two-tailed)
Average Max. temperature	Whole Period	0.0457%	0.0001
	Period-I (1960-1988)	-0.0071%	0.761
	Period-II (1989-2017)	0.0905%	0.0001
Average Precipitation	Whole Period (1960-2017)	0.2292%	0.017
	Period-I (1960-1988)	0.8301%	0.003
	Period-II (1989-2017)	0.1386%	0.586

TABLE 4

Instability in yearly average maximum temperature and yearly total precipitation in Bangladesh

Field of measurement	Measurement statistics	Whole period (1960-2017)	Period-I (1960-1988)	Period-II (1989-2017)
Average Max. temperature	CV	1.263%	1.019%	1.116%
	R-square	0.374	0.003	0.477
	Sig. (two-tailed)	0.0001	0.761	0.0001
	D-W	1.635	1.802	2.218
	CV_t	0.999%	1.017%	0.807%
Total Precipitation	CV	11.986%	13.005%	10.827%
	R-square	0.097	0.313	0.008
	Sig. (two-tailed)	0.017	0.002	0.642
	D-W	2.027	1.918	2.380
	CV_t	11.390%	10.779%	10.777%

period and for both Period-I & period-II. But yearly total precipitation found more unstable than the yearly maximum temperature. It was also observed that the instability of the yearly average maximum temperature was statistically significant for the whole period and period-II. On the other hand, the insignificant instability of yearly total precipitation found in the whole period and Period-I (Table 4).

4. Climate change is one of the important environmental problems whose main components are precipitation and temperature (Chowdhury *et al*., 2012; Hasan and Rahman, 2013; Rahman *et al*., 2015; Rouf *et al*., 2011). It is a long term effect of change in average weather conditions that affects our environment and natural resources and impacts our way of life in many ways (Limon, 2017; Noorunnahar, 2013). According to the Global Climate Risk Index, Bangladesh ranked 6th out of 170 most vulnerable countries (Dastagir 2015; Kreft *et al*., 2017). That's why this study was an attempt to study the trends and variability of yearly maximum temperature (in Degree Celsius) and yearly total precipitation (in Millimeter) based on 58 years' time series data representing all weather station of Bangladesh.

To analyse the study, we divided the whole time periods into equal two halves : one for Period-I (1960 to 1988 years) and another for Period-II (1989 to 2017 years). In overall trends, both temperature and precipitation showed positive trends but there exist irregular fluctuations and precipitation showed more fluctuation than temperature. The rate of increase in temperature was found higher in period-II than Period-I whereas the higher rate of increase in precipitation was found in Period-I. The findings of this study clearly suggest that the temperature of Bangladesh was increasing and precipitation was decreasing during the whole time periods and these findings were similar to many of the studies (Cong and Brady 2012; Hasan and Rahman 2013; Issahaku *et al*., 2016; Limon 2017; Nkuna and Odiyo 2016; Rahman *et al*., 2015; Scientific and Lucia 2014; Thornton *et al*., 2014; R. Tol 2012). This may because the World Bank declared Bangladesh as a developing country and the economy of this country is rising day by day. The rapid urbanization, clearing of jungle and forest areas, uncontrolled industrial factories, burning of fossil fuels which are the significant factors of increasing temperature. As a result, the level of carbon dioxide in the atmosphere is rising and lifts the temperature of the

ground underneath it causes a general rise in temperature (Badsha *et al*., 2016; Chowdhury *et al*., 2012; Dastagir, 2015; IPCC 2014; Kreft *et al*., 2017; Saiful, 2014; Tol Richard, 2013; Weather Online, 2017).

This study was found a significant difference in average maximum temperatures between Period-I and Period-II. It was also noted that the average yearly temperature was significantly ($p<0.0001$) increased in the Period-II as compared to Period-I and this results found similarities with some of the studies (Chowdhury *et al*., 2012; Shahid 2010a).

In the whole period, the growth rate of both temperature and precipitation was positive but the periodic variation was examined when we considered Period-I and period-II. In Period-I, the growth rate of temperature was negative because of the positive growth of precipitation. On the contrary, the growth of the yearly maximum temperature in period-II was increasing due to the lower rate of precipitation. There was relatively much rate of precipitation in Period-I than Period-II. That is why the weather in Bangladesh in that period was not so worm. On the other hand, the weather of Bangladesh was comparatively warm in period-II than Period-I because of less precipitation. Although there have many factors that are responsible for the increase in temperature, precipitation has an important negative effect on temperature and many other studies support this statement (Chowdhury *et al*., 2012; Yang *et al*., 2006). In addition, the temperature and precipitation were unstable for the whole period, Period-I and Period-II where precipitation found more unstable than the temperature during the study period. This study was also similar to some of the other studies (Hasan and Rahman 2013; Issahaku *et al*., 2016; Limon 2017; Thornton *et al*., 2014; Yang *et al*., 2006).

5. This study was carried out to assess the trends, growth and climatic variability of yearly average maximum temperature and yearly total precipitation of Bangladesh using a large scale dataset. The trend of maximum temperature was increasing at the same time precipitation was also decreasing day by day. Precipitation shows more instability than maximum temperature. It is also observed that the yearly average of maximum temperature has a significant positive growth in the whole period and Period-II. On the other hand, the yearly total precipitation has also significant positive growth in the whole period and Period-I where there is a decreased growth rate of total precipitation in the Period-II compared to Period-I. 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 to investigate climate change in Bangladesh and its impact on the global climate.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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