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Time Series Analysis of Temperature and Rainfall Data of Dhaka Division

Khadija Khatun[1], M A Samad[2*] and Md. Bazlur Rashid[3]

[1,2]*Department of Applied Mathematics, Dhaka University, Dhaka-1000, Bangladesh*

[3]*Bangladesh Meteorological Department, Agargaon, Dhaka-1207, Bangladesh*

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Abstract

In this paper, thirty five years' (1981-2015) temperature and rainfall data have been studied to detect the recent trends in temperature and rainfall over Dhaka division of Bangladesh. Data of climatic factors such as annual average maximum temperature (MAXT), minimum temperature (MINT), mean temperature (MEANT), monsoon total rainfall (MTR) and annual total rainfall (ATR) have been analyzed. Sen's non-parametric estimator of slope has been frequently used to estimate the magnitude of trend, whose statistical significance is assessed by the Mann–Kendall test. For this purpose, data from four meteorological stations (Dhaka, Mymensingh, Tangail and Faridpur) have been used. It is observed that annual average maximum, minimum and mean temperature of the study area are increasing at the rates $0.017℃/\text{year}$, $0.009℃/\text{year}$ and $0.013℃/\text{year}$ respectively and the upward trend is statistically stable with 10% level of significance. On the other hand, monsoon total rainfall and annual total rainfall are decreasing at the rates of $4.94mm/\text{year}$ and $16.11mm/\text{year}$ respectively where the downward trend of MTR is insignificant but the trend of ATR is significant with 10% level of significance.

Key Words: Climate, Level of significance, Slope, Trend analysis

I. Introduction

Climate change in Bangladesh is an extremely crucial issue and according to German Watch's Global Climate Risk Index (CRI)[1] of 2011, Bangladesh ranks first as the most vulnerable to the impacts of Climate Change in the coming decades. Climate is changing at both the global (Lambert et al.[2], Dore[3]) and the regional scales (Gemmeret al.[4], Kayano & Sansigolo[5]) due to global warming. The implications of climate change are particularly significant for the regions already under stress, Such as in Bangladesh where hydrological disasters are common phenomena (Shahid & Behrawan[6]).The Intergovernmental Panel on Climate Change (IPCC) has termed Bangladesh as one of the most vulnerable countries in the world due to climate change (IPCC[7]). It has been predicted that due to climate change, there will be a steady increase of temperature and change in rainfall pattern which might have a number of implications in agriculture (Karim et al.[8]), water resources (Fung et al.[9]) and public health (Shahid S[10]) in Bangladesh.

Shahid S[11] analyzed the trend of the fifty (1958-2007) year's climate phenomena of whole Bangladesh using time series analysis with the detection of the trend. Studies and assessments of impacts, vulnerabilities and adaption to climate change and sea level rise for Bangladesh, clearly demonstrates that Bangladesh is one of the most climate vulnerable countries in the world (BCAS[12]).

Since climate is changing global scale as well as regional scale hence there are many studies in different region of Bangladesh. M. G. Ferdous & M. A. Baten[13] studied climatic variables and their trends over Rajshahi and Rangpur Division with 50 (1961-2010) years of climatic data. M. A. Sattar & M. N. H. Khan[14] studied the climate phenomena of Dhaka division they took 60 (1948 - 2010) years data. In their studies only trend of climate variables were analyzed but the true detection of trend and the magnitude of change in climate time series were not determined.

Though those analyses were carried out mostly on data before 2010 recent changes in the climate might not be traced in those analyses. In this current study, trends in the annual temperature and annual and monsoonal (June-September) rainfall of Dhaka Division in last Thirty five years (1981-2015) are studied. Mann-Kendall test (Mann[15], Kendall[16]) is used to detect the trend and the Sen.'s slope method (Sen.[17]) is used to determine the magnitude of change in climate time series.

II. Data Sources and Methodology

All types of climatic factors data in daily scale or monthly scale are available at Bangladesh Meteorological Department (BMD), Agargaon, and Dhaka, Bangladesh. In the present study we have investigated two climatic parameters, temperature and rainfall. For this purpose, thirty five years accumulation data on daily rainfall in mm and daily maximum and minimum temperature in ^{0}C was obtained for four stations, including Dhaka, Mymensingh, Tangail and Faridpur from Bangladesh Meteorological Department (BMD). The data used in this study for Dhaka, Mymensingh and Faridpur stations are for the time period: 1981-2015 and for Tangail the time period is 1987-2015 because this station was established at 1987. Annual time series of mean temperature, mean maximum and minimum temperature are prepared from monthly average of their daily data. In addition, annual total rainfall data and monsoonal are prepared from their monthly total data from daily total rainfall data.

Mann Kendall Trend Test

Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic and in hydrologic time series. There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series. Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a

* Author for correspondence. e-mail: samad@du.ac.bd

trend.

The computational procedure for the Mann Kendall test considers the time series of n data points and T_i and T_j as two subsets of data where $i = 1,2,3,\ldots,n-1$ and $j = i+1, i+2, i+3,\ldots,n$.

The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

The Mann-Kendall S Statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(T_j - T_i), \quad (1)$$

$$\operatorname{Sign}(T_j - T_i) = \begin{cases} 1 \text{ if } T_j - T_i > 0 \\ 0 \text{ if } T_j - T_i = 0 \\ -1 \text{ if } T_j - T_i < 0 \end{cases}, \quad (2)$$

Where T_j and T_i are the annual values in years j and i, $j > i$, respectively. If $n < 10$, the value of $|S|$ is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two tailed test is used. At certain probability level H_0 is rejected in favor of H_1 if the absolute value of S equals or exceeds a specified value $S\alpha/2$, where $S\alpha/2$ is the smallest S which has the probability less than $\alpha/2$ to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend.

For $n \geq 10$, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0, \quad (3)$$

The variance$(\sigma^2)$for the S-statistic is defined by

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18}, \quad (4)$$

In which t_i denotes the number of ties to extent i. The summation term in the numerator is used only if the data series contains tied values. The standard test statistic Zs is calculated as follows:

$$Z_S = \begin{cases} \frac{S-1}{\sigma} \text{ for } S > 0 \\ 0 \text{ for } S = 0 \\ \frac{S+1}{\sigma} \text{ for } S < 0 \end{cases}, \quad (5)$$

The test statistic Z_S is used a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H_0. If $|Z_S|$ is greater than $Z_{\alpha/2}$ where α represents the chosen significance level (eg. 5% with $Z_{0.025} = 1.96$) then the null hypothesis is invalid implying that the trend is significant.

Sen's Slop Method

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method is used. The Sen's method can be used in cases where the trend can be assumed to be linear. This means that the continuous monotonic increasing or decreasing function of time, $f(t)$, is given by

$$f(t) = Qt + B, \quad (6)$$

where Q is the slope and B is a constant.

To get the slope estimate Q in equation (6) we first calculate the slopes of all data value pairs

$$Q_i = \frac{x_j - x_k}{j-k}, \quad (7)$$

where Q_i is the slope between data values x_k and x_j

x_k=data value at time k and
x_j =data value at time j

If there are n values x_j in the time series we get as many as $N = n(n-1)/2$ slope estimates Q_i.

The Sen's estimator of slope is the median of these Nvalues of Q_i. The Nvalues of $Q_i$are ranked from the smallest to the largest and the Sen's estimator given as

$$Q = \begin{cases} Q_{\frac{N+1}{2}} \text{ if } N \text{ is odd} \\ \frac{1}{2}\left(Q_{\left(\frac{N}{2}\right)} + Q_{\frac{N+2}{2}}\right) \text{ if } N \text{ is even} \end{cases}, \quad (8)$$

where N is the number of calculated slopes.

A 100(1-α) % two-sided confidence interval about the slope estimate is obtained by the non-parametric technique based on the normal distribution. The method is valid for n as small as 10 unless there are many ties.

Mann-Kendall test is applied to detect the trend in rainfall time series and the Sen's slope method is used to determine the magnitude of change. Confidence levels of 90%, 95% and 99% are taken as thresholds to classify the significance of positive and negative temperature and rainfall trends.

III. Sources of Error

No information is available about the number of rainfall gauges and temperature sensors used in each state to record rainfall and temperature data. In addition, the exact location of these gauges and sensors is unknown. The lack of uniformity in rainfall gauges and temperature sensors can influence the quality of recorded data. However, quality control is performed, but a 100% correction rate is not possible.

IV. Results and Discussion

The analysis of temperature and rainfall trends reveals changes in both temperature and rainfall of Dhaka division over the time period 1981–2015.Three variables related to temperature, viz. annual average, annual average maximum and annual average minimum and two variables related to rainfall, viz. monsoon total rainfall and annual total rainfall are considered to analyze. The results of trend analysis of these variables at 4 stations of Dhaka division are given in the Table as well as in the Figures bellow. The values in the table are obtained by Sen's slope method represent the change of temperature in °C/year and change of rainfall in mm/year. The significance of the change is assessed by

Mann-Kendall trend test. The single star number in the table indicate that the change is significant at 90% level of confidence, the numbers in double star indicate the change is significant at 95% level of confidence and the number in triple star indicate the change is significant at 99% level of confidence.

Table. Trends of Temperature and Rainfall over the study area during 1981-2015

Station	MAXT (^{0}C/year)	MINT (^{0}C/year)	MEANT (^{0}C/year)	MTR (mm/year)	ATR (mm/year)
Dhaka	0.013	0.024**	0.018**	0.5	-12.56
Mymensingh	0.003	0.019**	0.012*	-8.31	-16.25*
Tangail	0.033**	-0.002	0.015*	-0.33	-8.87
Faridpur	0.026**	0.015*	0.022***	-3.04	-19.23*
Average	0.017*	0.009*	0.013*	-4.94	-16.11*

* if trend at 10% level of significance, **if trend at 5% level of significance and *** if trend at 1% level of significance

Trends of Temperature

From table we see that annual average maximum temperature gives increasing trend in all over the region of Dhaka division and significantly increasing in the Tangail and Faridpur regions at rate 0.033^{0}C/year and 0.026^{0}C/year with 95% level of confidence (Fig.1). In case of annual average minimum temperature it also gives increasing trend in all regions while minimum temperature of the Dhaka and Mymensingh regions increasing at the rates 0.024^{0}C/year and 0.019^{0}C/year with 95% level of confidence but the exception occurs at the Tangail region where the trend is decreasing (Fig.2). Finally, the trend of annual average mean temperature is also increasing all over region of Dhaka division but this trend is unexpectedly increasing in Faridpur region at the rate 0.022^{0}C/year with 99% level of confidence; maybe there is an instrumental error or unwanted human activities (Fig.3).

Over all it is clear that the temperature of Dhaka division is increasing with 90% level of confidence as the average maximum, minimum and mean temperatures are increasing at the rates 0.017^{0}C/year, 0.009^{0}C/year and 0.013^{0}C/year respectively.

Trends of Rainfall

From the above table we see that the trend of monsoon total rainfall is decreasing all the regions but it is increasing in the Dhaka region (Fig. 4). In case of annual total rainfall the trend is decreasing all over the region of Dhaka division where this trend is significantly decreasing in the region Mymensingh and Faridpur at the rates 16.25mm/year and 19.23mm/year with 90% level of confidence (Fig. 5). In case of rainfall, we find that monsoon total rainfall and annual total rainfall of Dhaka division are decreasing at the rates 4.94mm/year and 16.11mm/year respectively where this decreasing trend is significant for annual total rainfall with 90% level of confidence.

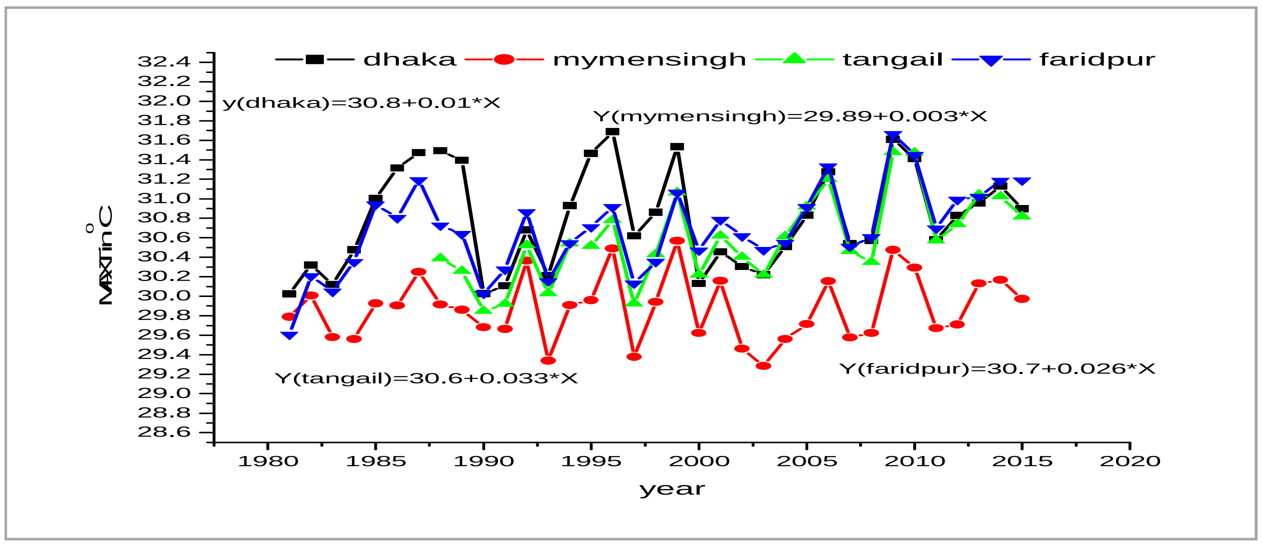

Fig. 1. Annual average maximum temperature in ^{0}C of the Study Area during 1981-2015

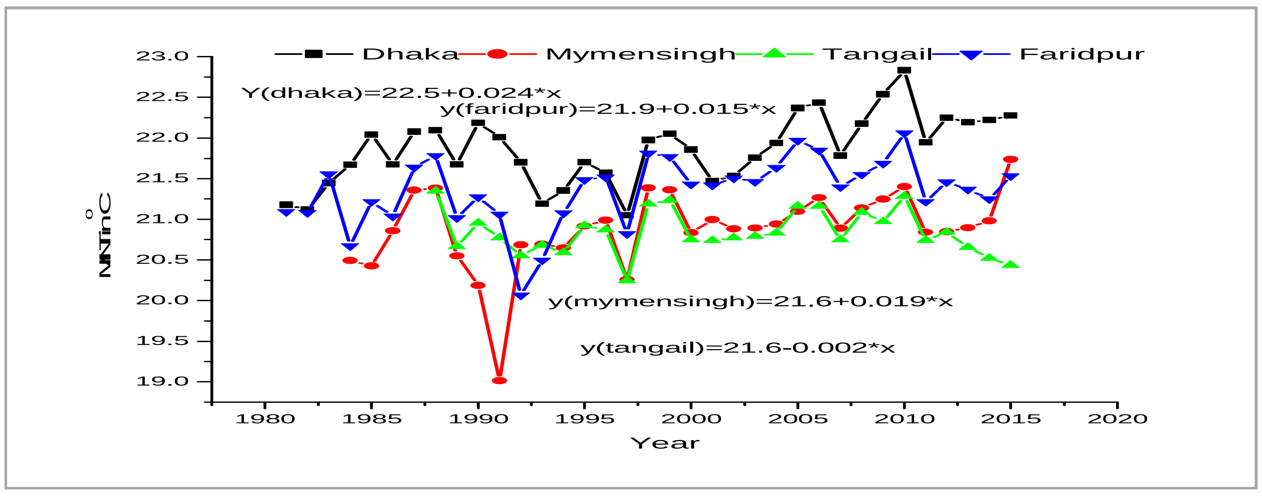

Fig. 2. Annual average minimum temperature in ^{0}C of the study area during 1981-2015

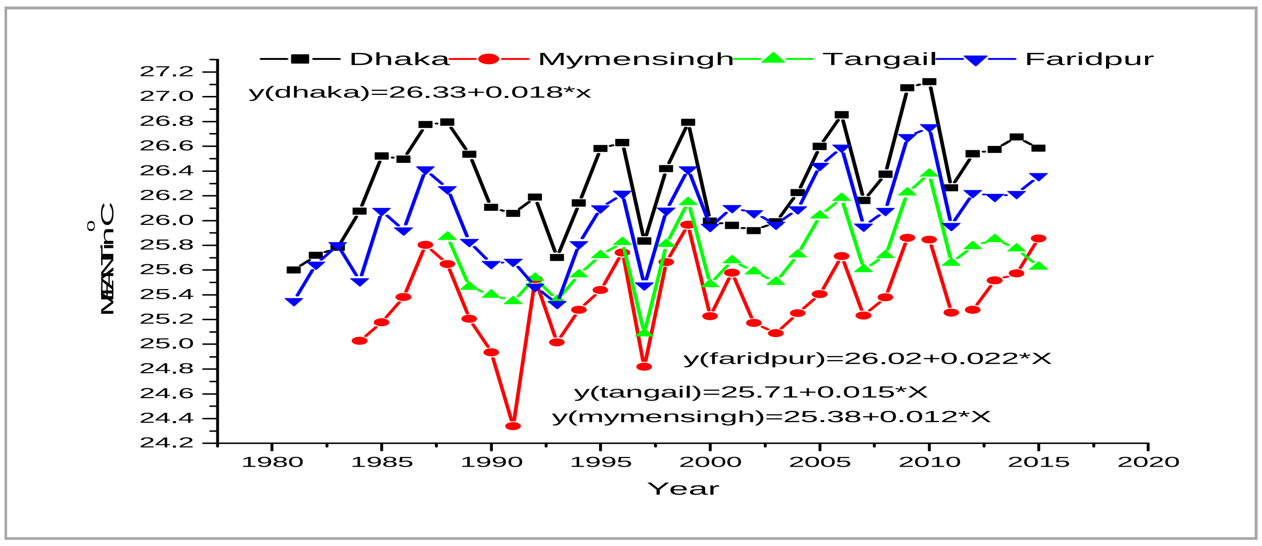

Fig. 3. Annual averages mean temperature in ^{0}C of the study area during 1981-2015

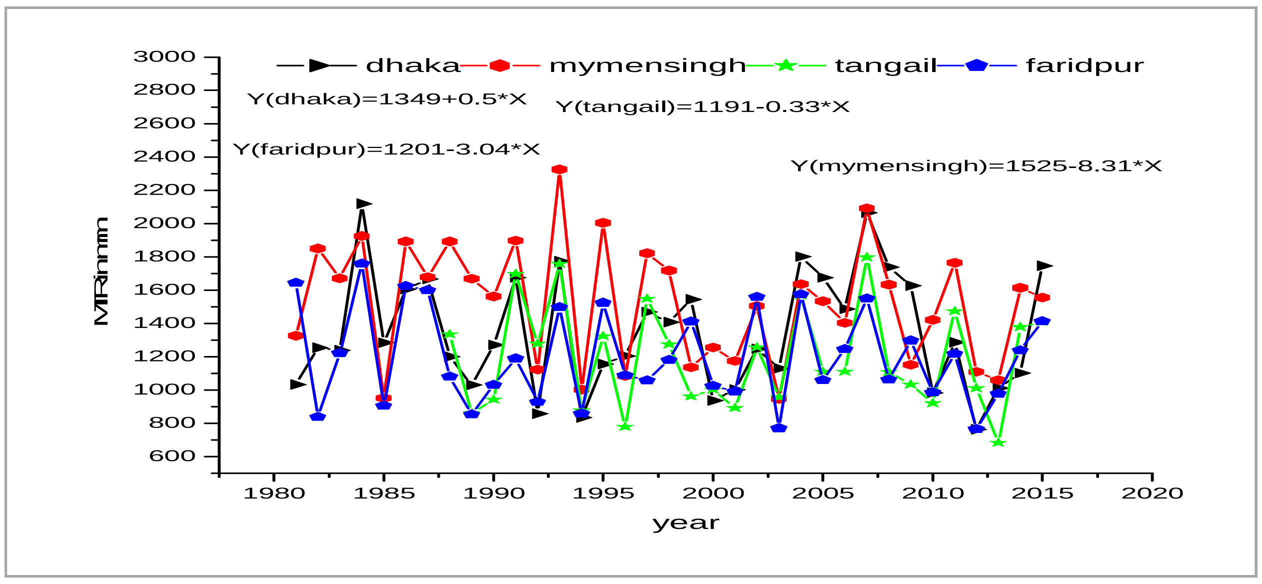

Fig. 4. Monsoon total rainfall (MTR) in mm of the study area during 1981-2015

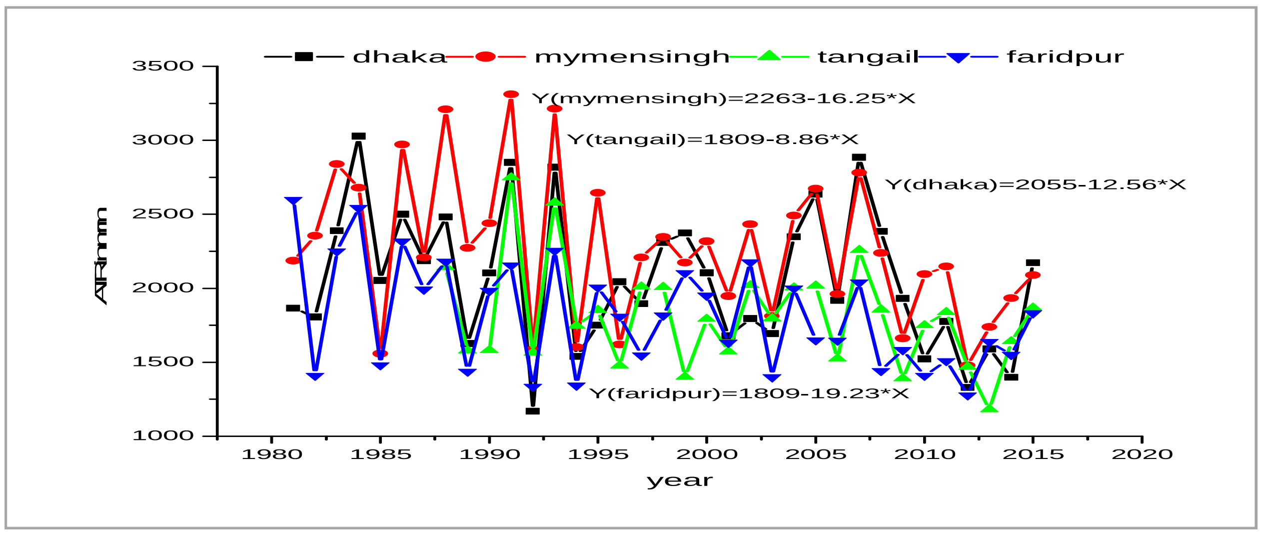

Fig. 5. Annual total rainfall (ATR) in mm of the study area during 1981-2015

V. Conclusion

From the overall study of Dhaka division, it is clear that the annual average maximum, minimum and mean temperature are increasing and monsoon total rainfall as well as the annual total rainfall are decreasing significantly. Additionally, temperature is the highest in Dhaka and the lowest in Mymensingh whereas the total monsoon as well as annual total rainfall is the highest in Mymensingh and the lowest in Dhaka.

The study, therefore, offers remarkable insights and new perspective for policy makers and planners in helping them take proactive measures in the context of climate change. Timely measures and institutional changes can certainly help in reducing the irreparable damages that can be caused by climate change, since the trends in 35-year temperature and rainfall data do not deny climate change is occurring.

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* Author for correspondence. e-mail: samad@du.ac.bd