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TRENDS OF TEMPERATURE AT HIGH- AND LOW-DENSELY POPULATED DIVISIONS IN BANGLADESH

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ABSTRACT

The present study is carried out to determine the trends in changes in temperature at Dhaka and Khulna divisions in Bangladesh using non parametric Mann-Kendall test for the period 1960-2015. Temperature is considered as one of the most important climatic variables in terms of climate change. Results show increasing trends in all monsoon seasons (pre-monsoon, monsoon and post monsoon season) for both divisions. Highest increasing rate is found in post monsoon season at Dhaka division with Sen's slope estimate 0.27 °C/decade which is statistically significant at 99% level. Winter season shows increasing trend at Dhaka division whereas decreasing trend at Khulna division. The highest decreasing rate at Khulna division is -0.06 °C/decade which is statistically insignificant. In the month of January, trends of both divisions are decreasing. The increasing trend in central and high populated-industrial Dhaka division and decreasing trend in southern low populated-nonindustrial Khulna division is due to characteristics of the two divisions. The warmest year is 2010 for both Khulna and Dhaka divisions. The coldest year is 1981 for Khulna division while 1971 for Dhaka. The decadal change of temperature indicates that the colder season experiences lowest temperature whereas warmer season experiences highest temperature day by day. This is a clear indication of climate change in the region. The study for the trend of another valuable climatic parameter precipitation is recommended to understand the impact of climate change across the country.

KEYWORDS: Trend, Temperature, Mann-Kendall test, Sen's slope estimate, Bangladesh.

INTRODUCTION

Bangladesh is a disaster prone country for its geological location with the Himalayas in the north and Bay of Bengal in the south. The climatic change issues have become international priorities during the last few decades. It is evident that the global average temperature has increased with a change rates 0.3ºC to 0.6ºC per decade over the last 100 years and highest warmest years being in the 1980s [17,18]. The global average surface temperature has been showed an increasing trend of 0.085 ºC [0.065 to 1.06 ºC] over the study period of 1880-2012 [8]. Jain and Kumar (2012) pointed out that the surface air temperature over a given region varies annually and seasonally depending upon latitude, altitude and location. Mann-Kendall and Sen's slope methods were applied for the existence of the trend and its magnitude respectively [6,14]. There are many scientific researches in the world on trend of climatic parameter leading to change the atmospheric conditions [11, 1,9,4]. Non-parametric methods are mainly used for trend analysis. Mann-Kendall test [12]is one of the best methods all of them, which is preferred by different studies [19,10]. This test is used for analysis and ascertains statistical significance of climatic variables [19,13]. The advantages of the Mann-Kendall test are that it does not require that datasets follow normal distribution and show homogeneity in variance; transformations are not basically required if data already follows normal distribution, in skewed distribution greater power is achieved [5]. The non-parametric Mann-Kendall test is used to trend analysis [7].
Among the eight divisions of Bangladesh, only two divisions, Dhaka and Khulna, are considered in this present

study as examples. The Dhaka division is more industrial and densely populated than Khulna division. Dhaka is the capital and largest city in Bangladesh. It has an area of 20,509 km^2 with population 36,433,505 at the 2011 Census. It has a tropical climate which experience hot, wet and humid. The Dhaka city faces nearly 80% average rainfall of 1854 mm in monsoon season. The monsoon season has average temperature of 25 ºC. Khulna region is mainly coastal area. It has an area of 22,284 km^2 and a population of 15,563,000 at the 2011 Census. The climate of Khulna is classified as tropical. It's average temperature is 26.1 ºC and average annual rainfall is 1736 mm [16]. In the current warming era of climate change, the comparison of changes in temperature between a highly populated-industrial city and a low populated-nonindustrial city is interesting to discuss.

This paper aims to describe the trends of change in temperature for the highly populated Dhaka division and relatively low populated Khulna division in Bangladesh with long-term historical data records. So, a comparative study on the trend of change of seasonal and annual temperature at Dhaka and Khulna divisions using Mann-kendall test is done.

DATA USED AND METHODOLOGY

The temperature data of Khulna and Dhaka divisions in Bangladesh for the period 1960-2015 are used in this study. These data are collected from Bangladesh Meteorological Department which comply the World Meteorological Organization terms and conditions in maintaining the data collection. Monthly data are obtained from the daily data. Again, from the monthly data, seasonal mean values are computed for the four seasons such as pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February). Data for each division are evaluated from the station value under the respective division and surrounding divisional data are used for the quality control. In quality control, data from Jessore, Khulna and Satkhira stations are considered for Khulna division. And Dhaka and Faridpur stations are considered for Dhaka division. The missing data are filled up by the time mean values of the existing years. The trend of the dataset is analyzed using Mann-Kendall test.

MANN-KENDALL ANALYSIS

The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i \qquad (1)$$

Where $f(t_i)$ is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time.

We want to test the null hypothesis of no trend, H_0, i.e. the observations x_i are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. In the computation of this statistical test MAKESENS exploits both the so called S statistics given in Gilbert (1987) and the normal approximation (Z statistics). For time series with less than 10 data points the S test is used, and for time series with 10 or more data points the normal approximation is used.

NUMBER OF DATA VALUES 10 OR MORE

If n is at least 10 the normal approximation test is used. However, if there are several tied values (i.e. equal values) in the time series, it may reduce the validity of the normal approximation when the number of data values is close to 10.

First the variance of S is computed by the following equation which takes into account that ties may be present:

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

Where x_j and x_k are the annual values in years j and k, j>k, respectively, and

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

A large positive number of S reveals the later-measured values tend to be larger than earlier values and an upward trend is indicated. When S is a large negative number, later values tend to be smaller than earlier values and a downward trend is indicated. When the absolute value of S is small, no trend is indicated. The test statistics τ can be computed as;

$$\tau = \frac{S}{n-(n-1)/2} \qquad (4)$$

It is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend. The variance of S is computed as;

$$VAR(S) = \frac{1}{18}[(n-1)(2n+5)\sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \qquad (5)$$

Here q is the number of tied groups and t_p is the number of data values in the p^{th} group. The values of S and VAR(S)are used to compute the test statistics Z as follows;

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if S > 0 \\ 0 & if S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if S < 0 \end{cases} \qquad (6)$$

Z score follows a normal distribution. At a choice of α=0.05 (95% level of significance) and two sided alternative, the critical values of z are equal to -1.96 to 1.96 ($Z_{0.025}$ = 1.96). The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance, while it is increasing if Z is positive and greater than the level of significance. If the absolute value of Z is less than the level of significance, there is no trend. When n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann-Kendall. In MAKESENS the two-tailed test is used for four significance level α: 0.1, 0.05, 0.01 and 0.001. If n is at least 10 the normal approximation test is used and a statistically significance trend is evaluated using the Z score. MAKESENS tested the Z score significance level at α: 0.001, 0.01, 0.05 and 0.1.

SEN'S SLOPE ESTIMATOR

Many hydrologic variables exhibit a marked right skewness partly due to the influence of natural phenomena, and do not follow a normal distribution. Similarly, the climatic data also fluctuate and deviated from a normal distribution. Hence, the Sen's slope estimator, which is a nonparametric method, was used to develop the linear models in this study. Sen's nonparametric method generally used to estimate the true slope of an existing linear trend. If a linear trend present in a time series, then the true slope (change per unit time) can be estimated by using a simple nonparametric procedure. This means that linear model f (t) can be describe as

$$f(t)=Qt+B \quad (7)$$

where Q is the slope, B is a constant and t is time. To derive an estimate of the slope Q, the slopes of all data pairs are calculated using the equation;

$$Q_i=\frac{x_j-x_k}{j-k}\ ,\ i=1,2,3,\ldots\ldots..N, j>k \quad (8)$$

If there are n values x_j in the time series there will be as many as N = n (n-1)/2 slope estimates Q_i. To obtain estimates of B in equation the n values of differences $x_i–Qt_I$ are calculated. The median of these values gives an estimate of B. The estimates for the constant B of lines of the 99% and 95% confidence intervals are calculated by a similar procedure. Data were processed using an Excel macro names MAKESENS created by Salmi *et al*. (2002).

Table 1: Selected station's latitude, longitude, elevation, population density and distance from the Bay of Bengal (BoB).

	Station	Latitude(°N)	Longitude(°E)	Elevation (m)	Population Density (per km^2)	Distance from BoB (km)
Dhaka division	Dhaka	23.46	90.23	8.45	8200	210
	Faridpur	23.36	89.51	8.1	920	188
Khulna division	Jessore	23.12	89.2	6.1	1060	170
	Khulna	22.47	89.34	3.6	530	123
	Satkhira	22.43	89.05	3.96	540	115

RESULTS AND DISCUSSION

Mann-kendall trend and sen's slope for temperature in khulna division

Considering the temperature data of Khulna division in Bangladesh for the period 1960-2015, average temperature for different months and four seasons are computed using Mann Kendall test. These values are tabulated in Table2. It shows increasing trends for pre-monsoon, monsoon and post monsoon seasons while decreasing trend in winter season. The pre-monsoon season has a positive trend with a Sen's slope estimate of 0.004ºC (0.04 ºC per decade).The pre-monsoon season's trend is statistically insignificant. The trends of monsoon and post monsoon seasons are only significant with Sen' slope estimates of 0.018ºC (0.18ºC per decade) and 0.010ºC (0.10 ºC per decade) respectively. Average temperature (Tavg) shows negative trend with a Sen' slope estimate of -0.006ºC (-0.06 ºC per decade) in winter season. The winter season trend is statistically insignificant. Analysis of monthly trends reveals that Tavg are rising from April to December (Table2). Statistically significant trends are found on May, June, July, August, September, October and December where the Sen' slope estimates are 0.013ºC, 0.020ºC, 0.020ºC, 0.013ºC, 0.010ºC, 0.012ºC and 0.003ºC respectively. Statistically insignificant trends are found on April and November where April may be considered as the transition month between positive and negative trend but there is no significance argument for the month of November. Tavg trends are falling on month of January, February and March with a Sen' slope estimates of -0.017ºC, -0.003ºC and -0.004ºC respectively. Among them trend on month of January is only statistically significant.

The annual average temperature shows increasing trends in Khulna, Jessore and Satkhira for the study period 1960-2015 (Figure1). In Khulna, annual Tavg is increasing by 0.05ºC/decade with its average 26.37ºC. The warmest year in Khulna is 1969 where Tavg is 27.33˚C and coldest year is 1981 where Tavg is 25.64ºC. Annual Tavg in Jessore is increasing by 0.13ºC/decade with its average 25.82ºC. The warmest year in Jessore is 2010 where Tavg is 27.04ºC and coldest year is 1974 where Tavg is 25.57ºC. Annual Tavg in Satkhira was increasing by 0.06ºC/decade with its annual average 26.24 ºC. The warmest year in Satkhira is 1979 where Tavg is 27.40ºC and coldest year is 1981 where Tavg is 25.59 ºC. In Khulna division the increasing rates of Tavg are low because of less population, less industrial based area and less distance from big source of water body like the Bay of Bengal.

The data for the period 1960-2015 are divided into 5 decades those are 1966-1975, 1976-1985, 1986-1995, 1996-2005 and 2006-2015. Decadal change of temperature for Khulna division is shown in Figure2. Positive and negative trends are obtained in different month for different decades except for the months of January, March and November where they have only negative trend. Negative trends are found for the months of December and February in all decades except 1996-2005. Specially, negative trends are found in 2006-2015 decade. Considering the negative and positive trends of different decades, decreasing trend are considered from November to March. Again, positive and negative trends are obtained from April to October for different decades .Where negative trends are found for the months of May, July, August and September especially for the decade 1966-1975. Negative trend is also found on months July and September for the decade 1976-1985. Positive trend is found in almost decades except 2006-2015 for the month of April. Warmer season is experienced increasing trend whereas winter season is experienced decreasing trend. These implies that warmer season become more warmer and colder season become more cold. These are the evidence of climate change in the region.

So, warm and cold both are increasing which will make the environment more critical in terms of climate change issues.

Table 2: Monthly and seasonal Sen's slope estimates with Z test value for Khulna and Dhaka divisions.

Khulna Division			**Dhaka Division**		
Month/Season	Z Test	Sen's slope	Month/Season	Z Test	Sen's slope
January	-2.41	-0.017**	January	-1.89	-0.011*
February	-0.35	-0.003	February	0.42	0.004
March	-0.46	-0.004	March	0.12	0.002
April	0.12	0.001	April	0.37	0.005
May	2.01	0.013**	May	2.20	0.023**
June	4.18	0.020***	June	4.78	0.035***
July	4.62	0.020***	July	5.64	0.028***
August	5.42	0.019***	August	6.06	0.030***
September	4.19	0.013***	September	5.29	0.031***
October	2.42	0.010**	October	4.68	0.032***
November	1.70	0.012	November	4.93	0.033***
December	0.57	0.003*	December	1.83	0.015*
Pre-monsoon	0.86	0.004	Pre-monsoon	2.75	0.017***
Monsoon	6.31	0.018***	Monsoon	6.23	0.021***
Post monsoon	2.52	0.010**	Post monsoon	5.60	0.027***
Winter	-1.36	-0.006	Winter	4.62	0.021***

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

Figure 1: Annual average temporal variation in Khulna division.

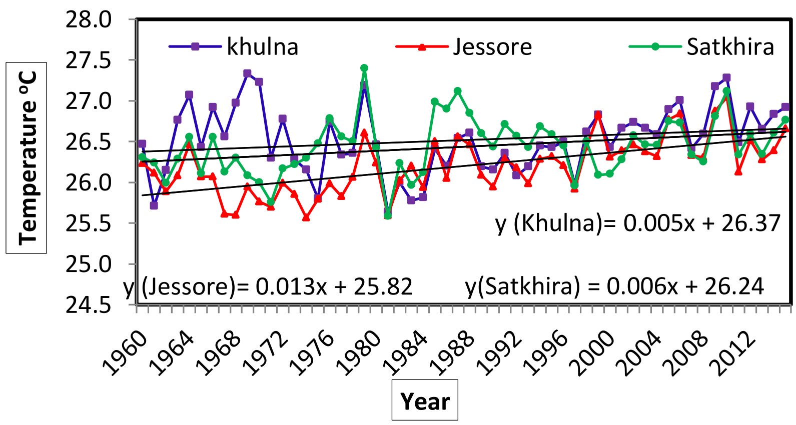
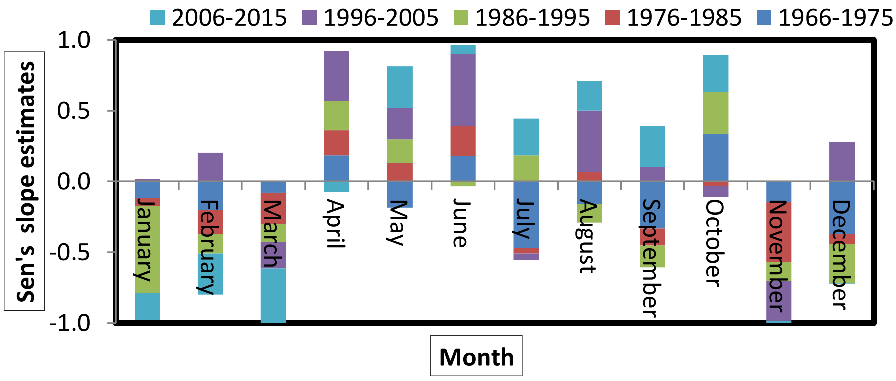


Figure 2: Decadal Sen's slope estimates for Khulna division.



Mann kendall trend and sen's slope for temperature in dhaka division

Considering the temperature data of Dhaka division in Bangladesh over the period 1960-2015, Tavg for different months and four seasons are computed using Mann Kendall test. These values are tabulated in Table2. It shows increasing trends for all seasons. The pre-monsoon season shows positive trend with a Sen's slope estimate of 0.017ºC (0.17 ºC per decade).The pre-monsoon season trend is statistically significant at 99%. The monsoon, post monsoon and winter seasons also shows positive trend. The monsoon, post monsoon and winter seasons trends are statistically significant with Sen's slope estimates of 0.021ºC, 0.027ºC and 0.021ºC respectively. Analysis of monthly trends reveals that Tavg are rising from February to December months. Statistically significant trends are found on May to December with the Sen's slope estimates are 0.023ºC, 0.035ºC, 0.028ºC, 0.030ºC, 0.031ºC, 0.032ºC, 0.033ºC and 0.015ºC respectively. Statistically significant trends are not found for from February to April. Tavg trend is falling only month of January with a Sen's slope estimates of -0.011ºC. Month of January is statistically insignificant.

The annual Tavg shows increasing trend in Dhaka and Faridpur over the study period 1960-2015 (Figure3). In Dhaka, annual Tavg is increasing by 0.21ºC/decade with its average 25.48ºC.The warmest year in Dhaka is 2010 where Tavg is 27.12ºC and coldest year is 1971 where Tavg is 24.98ºC. Annual Tavg in Faridpur is increasing by 0.20ºC/decade with its annual average 25.19ºC. The warmest year in Faridpur is 2006 where Tavg is 26.83ºC and coldest year is 1974 where Tavg is 24.67ºC. In Dhaka division the increasing rates of Tavg are high because of high population, industrial based area and distance from big source of water body like Bay of Bengal.

To test the decadal variation, the data for the period 1960-2015 are divided into 5 decades those are 1966-1975, 1976-1985, 1986-1995, 1996-2005 and 2006-2015. Decadal change of temperature for the Dhaka division is shown in Figure4. Highest increasing and decreasing rates are found for 1986-1995 decade on the months of April and February respectively. Figure3 also indicates that the change rate of temperature for 1976-1985 and 2006-2015 decades are relatively more increasing trend than that of other decades of the study period. Positive and negative trends are obtained in different month for different decades except for the months of April where they have only positive trend. For the month of December to February and May found decreasing trends whereas other months are shows increasing trend for decade 2006-2015. So, the last decade 2006-2015 indicates that the cold season is become getting colder and the warm season is become getting warmer day by day (Figure4). So, warm and cold both are increasing which are signatures of climate change and climate extremes.

Figure 3: Annual average temporal variation in Dhaka division.

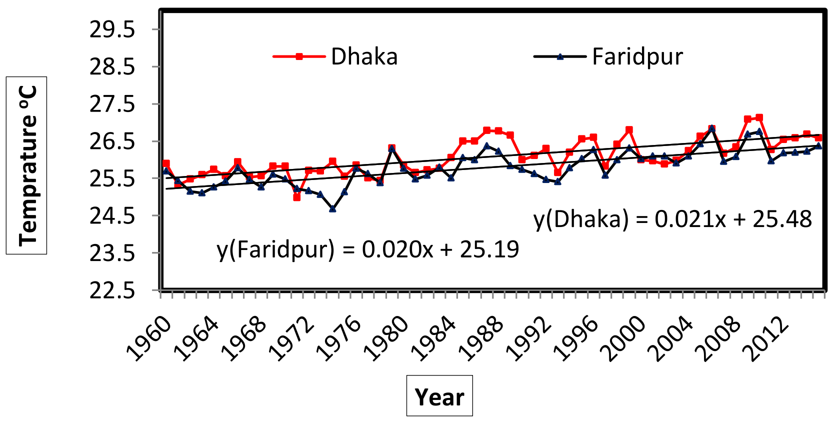
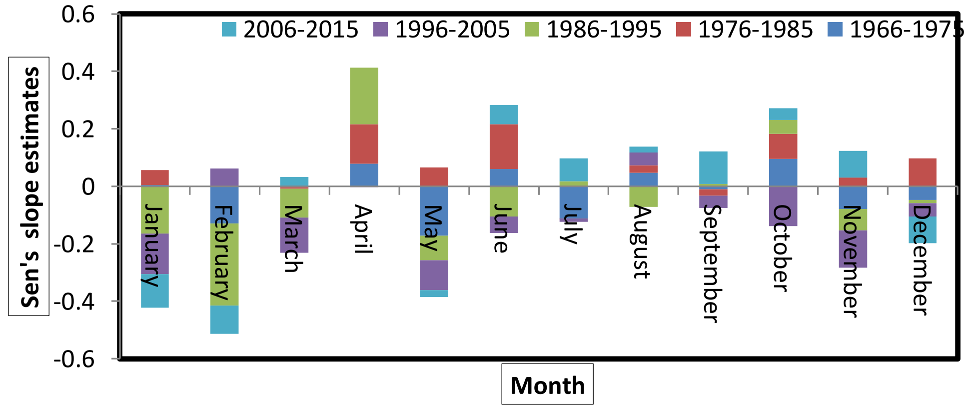


Figure 4: Decadal Sen's slope estimates for Dhaka division.



Comparison of temperature between khulna and dhaka divisions

The Tavg shows increasing trends in Khulna and Dhaka divisions for the study period 1960-2015 (Figure5). In Khulna, annual Tavg is increasing by 0.08ºC/decade with its average 26.15°C. The warmest year in Khulna is 2010 where Tavg is 27.15ºC and coldest year is1981 where Tavg is 25.61ºC. In Dhaka, annual Tavg is increasing trend by 0.21ºC/decade with its average 25.33ºC. The warmest year in Dhaka is 2010 where Tavg is 26.94ºC and coldest year is 1971 where Tavg is 25.10ºC. It may conclude that Dhaka, as a high populated and industrial city, getting warmer at a faster rate compared to low populated and less industrial city like Khulna.

This Figure 6 shows that Sen's slope value in Dhaka and Khulna divisions. Average temperature shows increasing trends for pre-monsoon, monsoon and post monsoon seasons for both divisions. Two winter months December and February show increasing trend in Dhaka division whereas decreasing trend in Khulna division for January and February. Highest increasing rate found in post monsoon season at Dhaka division with Sen's slope estimate 0.027ºC (0.27ºC per decade) which is statistically significant at 99% level. Whereas highest decreasing rate is found in winter season at Khulna division with Sen's slope estimate -0.006ºC (-0.06ºC per decade) which is statistically insignificant. In Dhaka division, the monthly trends are almost increasing. Only decreasing trend indicates in January month. Whereas in Khulna division the monthly trends are also almost increasing trend. But decreasing trends found in from January to March. In the month of January, trends of both divisions are decreasing. It is concluded that there is annual cyclic variation of temperature in both divisions. Again, maximum Sen's slope values in Dhaka division are greater than that of Khulna division without any exception.

Beside the temperature, the comparative study for the different divisions in Bangladesh for another important climatic variable precipitation is required, particularly for the climate change impacts studies including food security of the country [3]. The study of precipitation is also required for aridity risk calculation [15], therefore suggested for a separate documentation in near future.

Figure 5: Annual average temporal variation between Dhaka and Khulna divisions.

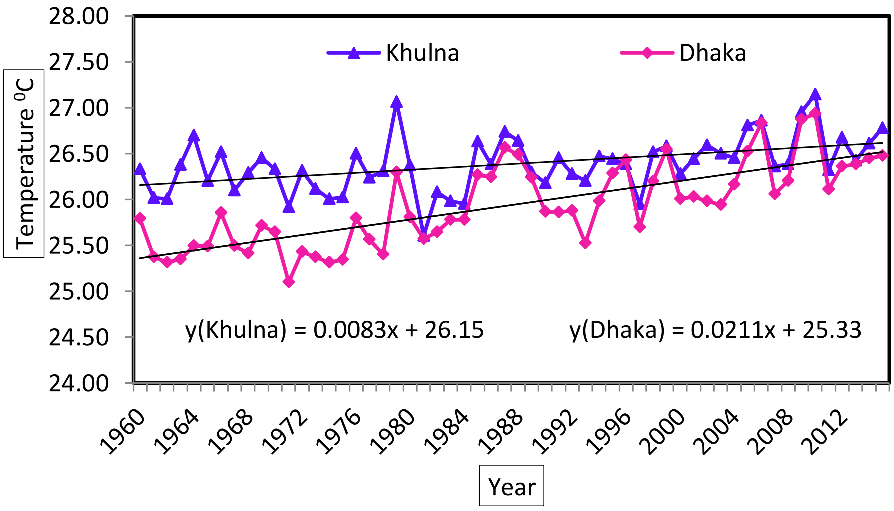
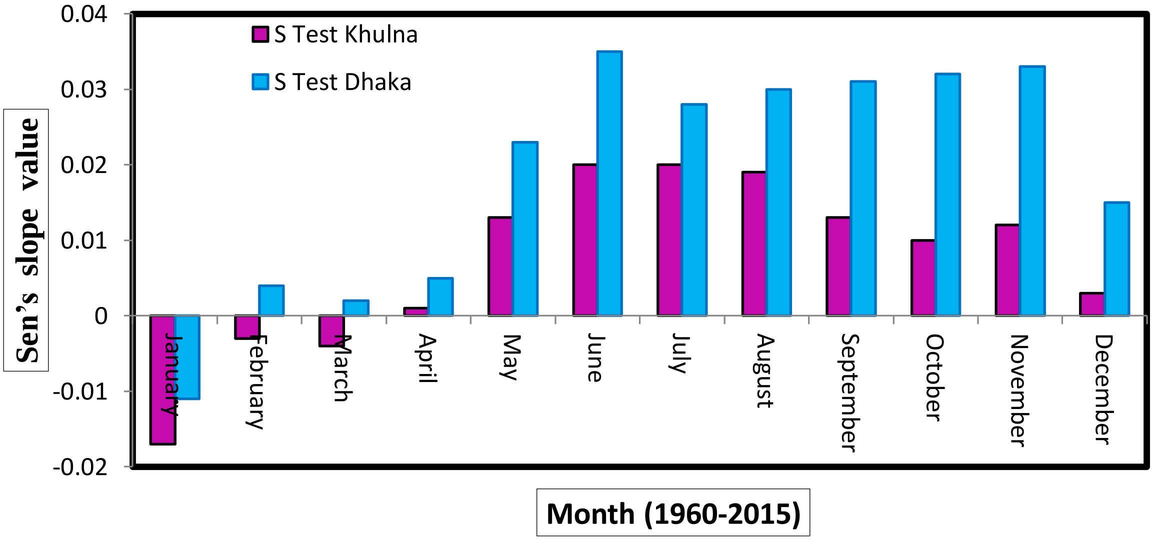


Figure 6: Comparison between Sen's slope estimates for Dhaka and Khulna divisions.



The number of positive trends of average temperature of Dhaka division is relatively more than that of Khulna division (Table3). Also increasing trend for Dhaka division is more than that of Khulna division. So, Dhaka division getting rapid warmer than the Khulna division. It indicates alarming situation for climate change of Dhaka division comparing to Khulna division. Analyzing all the stations data from eight divisions in Bangladesh, the spatial distribution can be obtained which in turn can be used to find the Intensity-Frequency-Duration (IDF) curves at non data collecting locations over the country [2]. Therefore, this study can be transformed in climate change vulnerability measures, particularly for food security in Bangladesh [3].

Table 3: Monthly and Seasonal trends of temperature for Khulna and Dhaka divisions

	Khulna Division			**Dhaka Division**		
	Increasing	Decreasing	Trend not significant	Increasing	Decreasing	Trend not significant
January		√			√	
February			√			√
March			√			√
April			√			√
May	√			√		
June	√			√		
July	√			√		
August	√			√		
September	√			√		
October	√			√		
November			√	√		
December	√			√		
	7	1	4	**8**	1	3
Pre-monsoon			√	√		
Monsoon	√			√		
Post monsoon	√			√		
Winter			√	√		
	2		2	**4**		

CONCLUSIONS

From the study of the change rates of trend of temperature and it's comparison between Dhaka and Khulna divisions in Bangladesh using non parametric Mann-Kendall test for the period 1960-2015, the following conclusions are made:

a) The number of positive trends of average temperature of central and high-populated Dhaka division is relatively more than that of southern and less-populated Khulna division.
b) The value of positive trends of average temperature of Dhaka division is relatively higher than that of Khulna division.
c) The trends are statistically significant for all seasons in Dhaka division but the trends are statistically significant only for two seasons (monsoon and post-monsoon) in Khulna division.
d) The trends are statistically significant for more months in Dhaka division than that of Khulna division but the trends are statistically not significant for months February, March and April in both divisions.
e) The warmest year is 2010 for both Khulna and Dhaka divisions. The coldest year is 1981 for Khulna division while 1971 for Dhaka.
f) The cold season is getting more colder and the warm season is getting more warmer day by day. So, warming and cooling both are increasing which will make the environment more critical that can be considered as impact of climate change.
g) High populated and industrial region getting warmer at a faster rate compared to low populated and less industrial region.

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