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Maximum and Minimum Temperature Trends Variation over Northern and Southern Part of Bangladesh

N. M. Refat Nasher[1] and M. N. Uddin[2]

[1] Department of Geography and Environment, Jagannath University
[2] Institute of Water and Flood Management (IWFM),Bangladesh University of Engineering and Technology (BUET)

Abstract: Temperature is one of the pivotal climatic variables in our world climate literature. In the present study monthly, seasonal and yearly highest maximum and lowest minimum temperatures of two cities were analyzed. Mann-Kendall test and Sen's Slope Estimator were used to determine the trend and slope magnitude. Chittagong, as the coastal city and Rajshahi, as Barind track were selected as a study area due to its respective geographical location. Such types of data of 52 years for Chittagong as well as 48 years for Rajshahi were collected from Bangladesh Meteorological Department (BMD). Monthly highest maximum and lowest minimum temperature data from 1950-2002 for Chittagong and 1964-2012 for Rajshahi were used for analysis. In Rajshahi, significant rising trends were found in highest maximum post-monsoon temperature, lowest minimum monsoon temperature and highest maximum temperature from July to October, June and August for lowest minimum temperature. Falling trends were found in annual highest maximum and lowest minimum temperatures, pre-monsoon highest maximum temperature, lowest minimum winter temperature and January lowest minimum temperature. For Chittagong, significant increasing trends found in post-monsoon highest maximum temperature, June to December highest maximum temperature except July and December lowest minimum temperature. No significant decreasing trend was found in Chittagong.

Key Words: Maximum temperature, Minimum temperature and Temperature

Introduction

Temperature extreme has become a prime concern under the present climatic variations. The impact of climate extreme in future is quite serious. In Bangladesh Northern parts have extreme temperatures events where as Sothern part is moderate. The surface temperature over a given region varies annually and seasonally depending upon latitude, altitude and location with respect to geographical features such as a water body (river, lake or sea) (*Jain and Kumar, 2012*). Global mean surface temperature has increased by 0.4-0.8˚C over the last century. Over the period of 1990-2100, the global average surface temperature has projected to increase by 1.4-5.8˚C (*IPCC WGI, 2001*). A more pronounced warming of mean annual temperature was found in Ganges-Brahmaputra-Meghna (GBM) basin (*Kothyari and Singh, 1996*).Providing Regional Climates for Impacts Studies (PRECIS) generated maximum and minimum temperature trends during 2010-2020 for Bangladesh. The trends showed an increase of maximum temperature in a rate of about 0.004˚C per year while the increase rate of minimum temperature was almost half (0.002 ˚C) compared to that of maximum temperature (*Islam, 2009*). Later on *Islam et al.* (2008) used PRECIS with the surface observational rainfall and temperature data from the Bangladesh Meteorological Department (BMD) for the period of 1961-1990.In the annual scale, the model underestimated temperature of about 0.61˚C that varies within a range of +1.45 to -3.89˚C in different months.

Chittagong is a major port city and second largest metropolitan area in Bangladesh. It is located in the southern region of the country, straddling the hills at the estuary of the Karnafuli River. Rajshahi is a northwestern city in Bangladesh. This region is consists of Barind Track, Diara and Char lands. The main rivers are Padma, Pahananda, Baral and Barnai. Rajshahi town stands on the bank of river Padma (*Banglapedia, 2006*).

Four distinct seasons can be recognized in Bangladesh from climatic point of view; (i) the dry winter season from December to February, (ii) the pre-monsoon summer from March to may, (iii) the rainy monsoon season from June to September and (iv)the post-monsoon season from October to November.

The highest annual maximum temperature of Chittagong was 39.5˚C in May, 2001. The lowest minimum temperature was found 7.7˚C in January, 1979. The city experienced highest maximum temperature in post-monsoon was37˚C, 39.5˚C in pre-monsoon, 35.2˚C in winter and 39.3˚C in monsoon. The lowest minimum temperature in post-monsoon was 12.2˚C, 10˚C in pre-monsoon, 7.7˚C in winter and 14.5˚C in monsoon over the study period (1950-2002).

On the other hand, Rajshahi experienced the annual highest maximum temperature in May, 1972 which was 45.1˚C and lowest minimum temperature was 3.4˚C in January, 2003. The seasonal highest temperature was 36˚C in post-monsoon, 45.1˚C in pre-monsoon, 43.5˚C in monsoon and 36.8˚C in winter. The lowest minimum temperature in post-monsoon was 8.9˚C, 9.5˚C in pre-monsoon, 14.5˚C in monsoon and 3.4˚C in winter respectively over the study period (1964-2012).

Variability over Rajshahi and Chittagong were found in maximum and minimum temperature. The highest maximum temperature was higher in Rajshahi and minimum lowest temperature was lower in Rajshahi. The trends were calculated to know the variation of spatial climate change impact in Northern and Southern part of Bangladesh.

Data and Methodology

Monthly highest maximum and minimum temperatures records of 53 years from 1950 to 2002 for Chittagong and 49 years from 1964 to 2012 for Rajshahi have been collected from Bangladesh Meteorological Department (BMD).

Non-Parametric test is being used for studying the spatial variation and temporal trends of hydro-climatic series. A non parametric test is taken into consideration as it can evade the problem roused by data skew (*Smith, 2000*). Mann-Kendall test is preferred when more than one station were tested in a single study (*Hirch et al., 1991*). Non-parametric test for trend detection and the test statistics distribution for testing non-linear trend and turning point had been formulated by Mann (1945) and Kendall (1975).

Trend Analysis

Mann-Kendall test for trend and Sen's slope estimates used for detecting and estimates trends in the time series of the annual values of maximum and minimum temperature and rainfall. A number of Excel templates developed for Mann-Kendall test for trend and Sen's slope estimation. Of them Mann-Kendall test for trend and Sen's slope estimates (MAKESENS) used for detecting and estimating trend. There are two phases in trend analysis; first the presence of a monotonic increasing or decreasing trend and secondly the slope of a linear trend is estimated. Both of the cases nonparametric tests were applied. For monotonic trend analysis the nonparametric Mann-Kendall test and for slope of linear trend estimation the nonparametric Sen's slope estimator used. Correlation coefficient of the meteorological variables and time were also computed to determine the better strength and understanding of the linear relationship between variables.

Mann-Kendall Analysis

The Mann-Kendall test generally applied where the data do not uniform to a normal distribution. This test evaluates a nonparametric form of monotonic trend regression analysis of y values tend to increase or decrease over time. The non-parametric Mann-Kendall test is commonly used for hydrologic data analysis, can be used to detect that are monotonic but not necessarily linear (*Olofintoye,O.O and Sule, B.F, 2010*). The Man-Kendall test assumed that a value can always be declared less than, greater than, or equal to another value; that are independent; and that the distribution of data remain constant in either the original units or transformed units (*Helsel and Hirsch, 1992*). The null hypothesis in the Mann-Kendall is that the data are independent and randomly ordered. The Mann-Kendall test does not require the assumption of normality, and not only indicates the direction but not the magnitude of significant trends (McBean and Motiee, 2008). The Mann-Kendall test compute the difference between the later measured value and all early measured values, $(x_j - x_k)$, where *j*>*k*, and test statistics S is calculated using the formula;

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

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

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 & if\, x_j - x_k > 0 \\ 0 & if\, x_j - x_k = 0 \\ -1 & if\, x_j - x_k < 0 \end{cases} \quad (2)$$

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;

$$\tau = \frac{S}{n - \frac{n-1}{2}} \quad (3)$$

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;

$$VAR(S) = 1/18\,[n(n-1)(2n+5) - \sum_{p=1}^{q} [t_p(t_p - 1)(2t_p + 5)]]$$
(4)

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;

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad (5)$$

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 (*Khambhammettu, 2005*).

When n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann-Kendall (Gilbert, 1987). 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 slope estimator is a nonparametric method for slope estimation. Sen's nonparametric method generally used to estimate the true slope of an existing linear trend (as change over time). 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 developed by Sen (1986). This means that linear model *f*(t) can be describe as

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

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;

$$Q_i = \frac{x_j - x_k}{j - k}, \quad i = 1,2,3,\ldots N, \quad j > k \quad (7)$$

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 (*Sirois, 1998*). 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).*

Result and Discussion

In Rajshahi, both annual highest maximum and lowest minimum temperatures trends were decreasing. The trends were also statistically significant. The decreasing slopes showed the rate at 0.040˚C/year for highest maximum temperature and 0.038˚C/year for lowest minimum temperature showed in Table 1.

Table 1. Mann-Kendall trend and Sen's Slope for annual temperature in Rajshahi.

Time	Z		S	
	Maximum	Minimum	Maximum	Minimum
Annual	-2.02	-2.87	-0.040*	-0.038**

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

As Table 2, highest maximum temperatures trends in pre-monsoon and winter seasons were negative with a Sen's Slope estimates of -0.044 and -0.004 respectively. Pre-monsoon trend was statistically significant. Both in monsoon and post-monsoon highest maximum temperatures trends were increasing. The monsoon trend was only significant with a Sen's Slope estimate of 0.021. For lowest minimum temperature significant upward trend was found only in monsoon period, where the slope was 0.026. Pre-monsoon, post-monsoon and winter lowest minimum temperature trends were negative but only significant in winter with a slope of -0.036.

Table 2. Mann-Kendall trend and Sen's Slope for seasonal temperature in Rajshahi.

Seasons	Z		S	
	Maximum	Minimum	Maximum	Minimum
Pre-monsoon	-2.19	-0.01	-0.044*	0.000
Monsoon	0.85	2.93	0.021	0.026**
Post-monsoon	3.13	-1.57	0.035**	-0.27
winter	-0.28	-2.64	-0.004	-0.036**

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

From Table 3, it is found that in monthly trends, highest maximum temperature trends were rising from June to November. The Sen's Slope Estimates were 0.001 in June, 0.030 in July, 0.029 in August, 0.023 in September, 0.035 in October and 0.005 in November. The statistically significant trend only found from July to October. Highest maximum temperature trends were falling from December to May. But none of that were statistically significant. In case of lowest minimum temperature negative trends were found from October to March, where January trend was only statistically significant with a slope of -0.038. From April to September the trends of lowest minimum temperature were positive and statistically significant trends were found in June and August with a Sen's Slope Estimates of 0.028 and0.019.

Table 3. Mann-Kendall trend and Sen's Slope for monthly temperature in Rajshahi.

Month	Z		S	
	Max	Min	Max	Min
Jan	-1.94	-2.58	-0.027	-0.038**
Feb	-0.60	-0.42	-0.011	-0.004
Mar	-0.15	-0.01	0.000	0.000
Apr	-1.72	0.82	-0.032	0.011
May	-1.42	1.39	-0.036	0.017
Jun	0.16	3.17	0.001	0.028**
Jul	2.45	1.63	0.030*	0.010
Aug	2.66	2.66	0.029**	0.019**
Sep	2.63	1.92	0.023**	0.022
Oct	3.18	-1.81	0.035**	-0.035
Nov	0.58	-1.57	0.005	-0.027
Dec	-0.16	-1.51	0.000	-0.025

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

According to Table 4, highest maximum and minimum annual temperature trend were rising but not statistically significant in Chittagong.

Table 4. Mann-Kendall trend and Sen's Slope for annual temperature in Chittagong.

Time	Z		S	
	Maximum	Minimum	Maximum	Minimum
Annual	0.63	1.62	0.006	0.018

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

In Table 5, the trends of highest maximum temperature trends in pre-monsoon, monsoon and post-monsoon period were increasing but only post-monsoon trend was significant with a Sen's Slope Estimates of 0.033. The winter trend of highest maximum temperature was insignificant decreasing trend. The lowest minimum temperature trends for all seasons were insignificant but increasing.

Table 5. Mann-Kendall trend and Sen's Slope for seasonal temperature in Chittagong.

Seasons	Z		S	
	Maximum	Minimum	Maximum	Minimum
Pre-monsoon	0.45	0.15	0.003	0.000
Monsoon	1.78	1.51	0.018	0.017
Post-monsoon	3.75	1.33	0.033***	0.018
winter	-0.61	1.48	-0.007	0.015

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

Monthly highest maximum temperature showed in Table 6, increasing trends all the months except April. Among the months June and from August to December trends were statistically significant with a Sen's Slope Estimates of 0.026 in June, 0.032 in August, 0.025 in September, 0.033 in October, 0.040 in November and 0.026 in December. In cases of lowest minimum temperature trends, April to June showed insignificant falling trends, where as July to March revealed rising trends. In rising trends, December trend was only significant with a Sen's Slope Estimate of 0.031.

Table 6. Mann-Kendall trend and Sen's Slope for monthly temperature in Chittagong.

Month	Z		S	
	Max	Min	Max	Min
Jan	1.01	1.07	0.010	0.011
Feb	0.49	1.58	0.006	0.019
Mar	0.43	0.25	0.004	0.002
Apr	-0.02	-0.61	0.000	-0.010
May	1.42	-0.47	0.015	-0.004
Jun	2.61	-0.34	0.026**	0.000
Jul	1.64	0.72	0.015	0.002
Aug	4.44	1.75	0.032***	0.014
Sep	3.13	1.01	0.025**	0.009
Oct	3.94	0.22	0.033***	0.000
Nov	3.83	1.33	0.040***	0.018
Dec	2.00	2.45	0.26*	0.031*

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

Conclusion

From the result of the analysis, it is concluded that the Sen's Slope Estimates of temperature trend in sixteen cases were rising and fifteen cases were falling and zero trends in three cases in Rajshahi. Among these,eight significant rising trends and three significant falling trends were found. In Chittagong, Sen's Slope Estimates of temperature trends were found increasing in twenty seven cases and decreasing trends in three cases and zero trends in four cases, whether eight significant increasing trends found in Chittagong also but no significant decreasing trends found. Finally, it is concluded that climate variability is more pronounced in Rajshahi than Chittagong. The climate of Rajshahi is more prone to extreme nature. On the contrary, Chittagong climate is more prone to warming.

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