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Spatio-temporal Analysis of Maximum and Minimum Temperature in Bangladesh

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Abstract
The analysis of annual mean maximum and annual mean minimum temperature data are studied in GIS environment, obtained from 34 meteorological stations scattered throughout the Bangladesh from 1948 to 2013. IDW method was used for the spatial distribution of temperature over the study area, using ArcGIS 10.2 software. Possible trends in the spatially distributed temperature data were examined, using the non-parametric Mann-Kendall method with statistical significance, and the magnitudes of available trends were determined using Sen's method in ArcMap depiction. The findings of the study show positive trends in annual mean maximum temperatures with 90%, 95%, 99% and 99.9% significance levels.

Keywords: GIS, IWD, Mann-Kendall test, Temperature, Temperature interpolation

Introduction

Presently the interpolation of climate data have been the focus of much research using several methods, including precipitation-elevation analysis, isohyets mapping (Peck and Brown, 1962) and Thiessen polygons (Thiessen, 1911). Topographical methods, including topographic and synoptic parameters (Schermerhorn, 1967), and numerical methods, including optimal interpolation (Gadgil and Dhorde, 2005) kriging and its variants (Phillips et al., 1992), and smoothing splines (Hutchinson and Bischof, 1983) were developed. The Thiessen method defines area that are closest to each meteorological station relative to all other stations. This method was attempted in order to estimate the spatial distribution of precipitation and temperature in a number of studies (Fiedler, 2003; Bayraktar et al., 2005; Li et al., 2005; Chaoka et al., 2007; Cheung et al., 2008). The Thiessen method allows the estimation of the spatial distribution of climatic data over areas that have insignificant topographical differences and insufficient stations. Therefore, the present study was under taken to find out the spatio-temporal scenarios of maximum and minimum temperatures in Bangladesh.

Materials and Methods

Geographic setting of study area
Bangladesh is a developing country in South Asia located between 20°34 to 26°38 north latitude and 88°01 to 92°42 east longitude, with an area of 147,570 km². It has a population of about 128 million, with a very low per capita Gross National Product (GNP) of US$ 370 (WB, 2000). It has a border on the west, north, and east with India, on the southeast with Myanmar, and the Bay of Bengal is to the south.

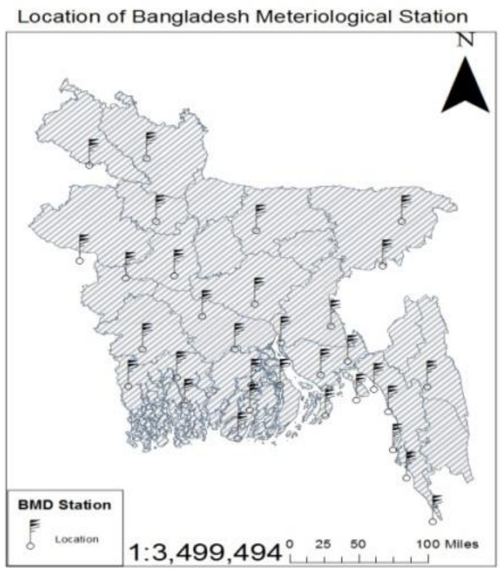

Fig.1. Location of 34 BMD stations of Bangladesh

Atmosphere and climate
The climate of Bangladesh is characterized by high temperatures, excessive humidity, and fairly marked seasonal variations of precipitation. Though more than half the area of Bangladesh is situated north of the tropics, the effect of the Himalayan mountain chain makes the climate more or less tropical throughout the year. The climate is controlled primarily by summer and winter winds, and partly by pre-monsoon and post-monsoon circulation. The Southwest Monsoon originates over the Indian Ocean, and carries warm, moist, and unstable air. The easterly trade winds are also warm but relatively drier. The Northeast Monsoon comes from the Siberian Desert, retaining most of its pristine cold, and blows over the country, usually in gusts, during dry winter months.

Data used

Owing to its computational efficiency, and without taking into consideration the topography of the study area, the IDW method was used to estimate the spatial distribution of temperature, based on data obtained from 34 meteorological stations (BMD) scattered throughout the study area (Figure-1). The time series of temperature data covers the period from January 1948 to December 2013. Secondly, the Mann-Kendall test and Sen's method were applied to monthly, seasonal and annual spatially distributed temperature data trends, for a given confidence level in order to detect trends in GIS environment.

Method selection

A number of methods are applied for trend analysis in meteorological and hydrological data those includes parametric (linear regression) as well as non- parametric (Mann, 1945; Kendall, 1975; and Sen, 1968) approaches. Classical approaches such as the Mann-Kendall (MK) Trend Test and Sen's Slope Estimator have been widely used for in hydrological time-series analysis (Hirsch *et al*., 1982; Aziz and Burn, 2006 and Park *et al*., 2011). Here, 'R' software has also been used to detect and estimate meteorological trends (Sarkar and Ali, 2009 and Ali *et al.,* 2012) that include the non-parametric MK test for trends as well as Sen's method for the magnitude of the trend (Salmi *et al*., 2002). These robust statistical trend detection methods have the advantages like, not assuming any distribution form for the data; outliers could be handled appropriately (Partal and Kahya, 2006) and could be operated with missing data. For time series analysis with fewer than 10 data points, the S test is used; and that of with more than 10 data points, the Z test is used. MK Trend Test based on the test statistics ***S*** is given as:

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

$$sign(x_j - x_k) = \begin{cases} +1 \ if \ (x_j - x_k) > 0 \\ 0 \ if \ (x_j - x_k) = 0 \\ -1 \ if \ (x_j - x_k) < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

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

$$\mathrm{Var(S)} = \frac{[\mathrm{n(n\text{-}1)(2n+5)}] - \sum_{i=1}^{m} t_i(t_i\text{-}1)(2t_i+5)}{18} \ldots\ldots\ldots (3)$$

Where, m is the number of tied groups and t_i is the size of the i^{th}tie group. Then, equations 1 and 3 are used. The test statistics Z is computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, for\ S > 0 \\ 0, for\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, for\ S < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots (4)$$

In null hypothesis, $\boldsymbol{H_o}$, that there is no trend in the records (either accepted or rejected) depending on whether the computed ***Z*** statistics is less or more than the critical value of ***Z*** statistics. In MAKESENS software the tested significance levels (α) are 0.001, 0.01, 0.05 and 0.1. (Sen, 1968) non-parametric approach is used to estimate the true slope of an existing trend (as change per unit time) where it is assumed to be linear. The estimation of slope of N pairs of data is expressed as:

$$Q_i = \frac{x_i - x_k}{j - k} \ldots\ldots\ldots\ldots\ldots (5)$$

Where, $J > k$ and x_i and x_k are data values at times j and k respectively.

The Sen's estimator of slope is given by the median slope as:

$Q_{med} = Q_{[(N+1)/2]}, \ldots\ldots.. (6)$, Where N is odd

Or

$Q_{med} = \frac{1}{2}\left(Q_{(N/2)} + Q_{[(N+2)/2]}\right) \ldots\ldots\ldots (7)$

Where N is even

Finally, Q is estimated by the nonparametric method based on the normal distribution. Details regarding the MAKESENS model can be found in Salmi et al. (2002).

Spatial interpolation methods

Interpolation techniques are classified into many categories based on various criteria. A method could be termed deterministic if weights are assigned using a mathematical formula or stochastic if weights are assigned using a statistical formula. The technique could be exact or inexact based on whether the method assigns similar values to un sampled points and measured points. It could also be local or global depending upon whether it accounts for local features. The IDW interpolation methods were used in our study. The performance of this interpolation was tested by using the cross-validation "leave one out" technique. It was not practical to include a large number of surrounding weather stations in the interpolation due to the increasing distance between weather stations. The IDW is a simple and intuitive deterministic interpolation method based on the principle that sample values closer to the prediction location have more influence on the prediction value than sample values that are farther away. The IDW computes climate variables at unknown locations (So) as follows:

$$Z(S_0) = \sum_{i=k}^{n} \lambda_i Z(Si) \ldots\ldots\ldots\ldots\ldots\ldots 1$$

The classical form of the IDW weight function is:

$$\lambda = \frac{d_i^{-p}}{\sum_{i=1}^{n} dj-p} \ldots\ldots\ldots\ldots\ldots\ldots 2$$

where S_o is the prediction location, $Z(S_o)$ is the value for the prediction location So, Z(Si) is the measured value at the ^{i}th location, i is an unknown weight for the measured value at the ith location, N is the total number of known points used in interpolation, d is the distance from the known value to the unknown value, and p is a positive real number, called the power parameter. A higher p value assigns more weight to closer points, creating a less smooth gridded surface, while a lower p value assigns a relatively lower weight to closer points, resulting in a smoother surface. Weights are not affected by spatial arrangement of samples, as weighting is an exclusive function of distance. We optimized p using ArcGIS 10.2. The major disadvantage of IDW is the "bull's eye" effect (higher gradient near observed location) and edgy surface.

Results and Discussion

To understand the distribution of temperature across Bangladesh, a plot of mean maximum and mean minimum temperature from 1948 to 2013 is shown in Figure 2. The map shows that the mean maximum temperature across Bangladesh increases from east to west. The mean minimum temperature is increased in the eastern part of Bangladesh. Station wise average annual temperature concludes that the hottest regions of Bangladesh in the period 1948-2013 were Sitakunda, Jessore, Khulna and Sathkhira where the temperature varies between 31°C to 31.495°C (Figure 2). In contrast, in the period 2000-2013 temperature increases in the range between 31°C to 32.20°C in almost all stations especially Jessore, Ishwardi, Khulna, Sathkhira, Sitakunda, Cox's bazar, Rangamati and Mongla. The hottest region was found to span from Sitakunda to Mongla. In case of average maximum temperature, most of the regions are more than 30°C or more in Dinajpur, Rangpur, Mymenshing, Maijdee court, Hatiya, Sandwip and Kutubdia except Rangpur and Mymensingh districts.

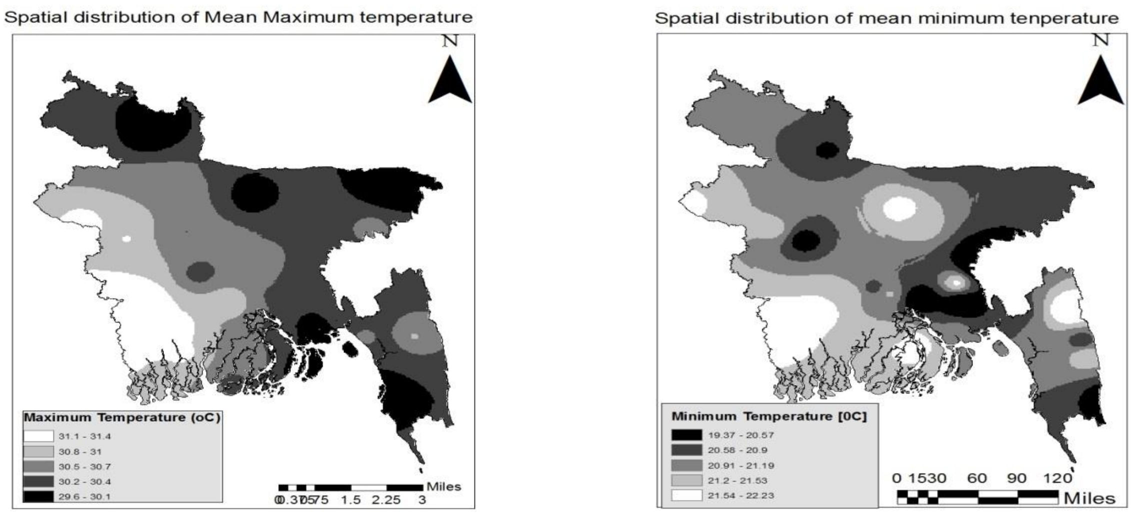

Fig. 2. Spatial distribution of maximum and minimum temperature in study area

Southern parts of the country show the higher trend of daily maximum temperature than that of other parts of the country. On the other hand, from average minimum temperature data, the Sylhet region has found to be the coolest area. In both periods the coolest area of Bangladesh is Srimongal. The northern and central parts of the country have shown the trend of gradual cooling. The Chittagong Hill Tracts region shows mixed characteristics over these time periods. From the above analysis, it could be that, the maximum temperature has been increasing over the years due to urbanization, industrialization, emission of GHGs and at the same time, the minimum temperature has also been increasing.

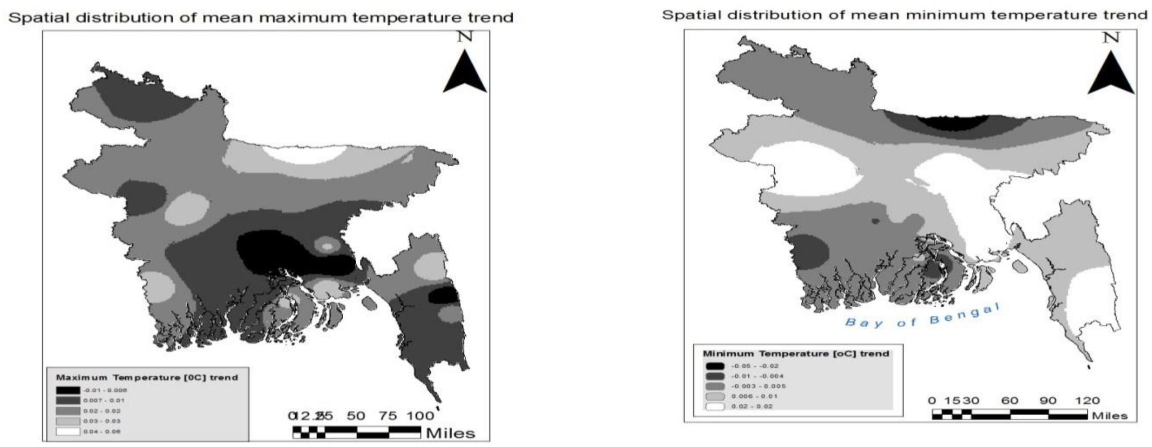

Fig.3. Spatial interpolation of maximum and minimum temperature trend in study area

The application of the Mann-Kendall test and Sen's method demonstrated a positive trend in the annual maximum and minimum temperatures over the 65-year period in Bangladesh. The trends in the annual maximum temperatures are significant at 95% and 99%, respectively, while the annual mean minimum temperature is not statistically significant. As seen from figure 3, the annual mean maximum temperature trend in Bangladesh region was -0.01 °C to .08 ^{0}C during the 65-year period. Although there is a positive trend in the annual mean maximum and minimum temperatures, the trend is more important for the maximum temperatures. The annual mean maximum temperature increased by 0.0037°C per year, while the annual mean minimum temperature experienced a 0.069°C increased between 1948 and 2013. The annual maximum and minimum temperature trend are depicted in spatial interpolation (figure 3) clearly reveals station basis changing pattern of temperature scenario in Bangladesh.

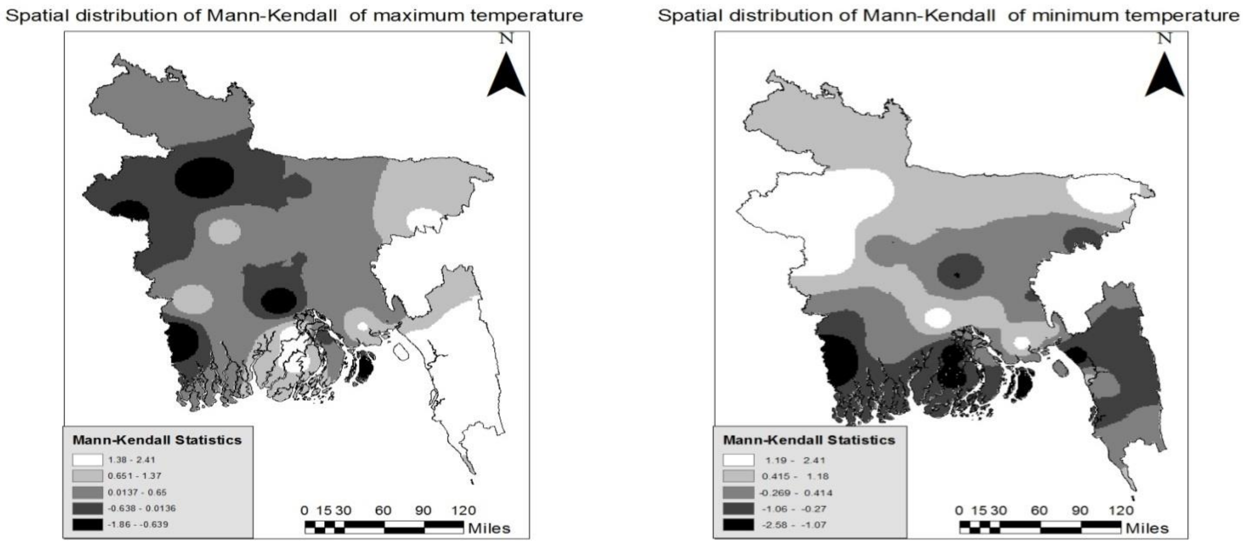

Fig.4. Spatial distribution of Mann-Kendall statistics of maximum and minimum temperature

Conclusions

This study presents a trend analysis of spatially distributed annual mean minimum and mean maximum temperatures in the Bangladesh region during the 64-year period between 1948 and 2013. Spatial distribution of temperature over the study area, and possible trends in the spatially distributed temperature were examined using the non-parametric Mann-Kendall test with statistical significance. The findings of the study show positive trends in the annual mean and mean maximum temperatures with 90% and 99% significance levels. If the current trend continues, it is inevitable that these increasing trends in temperature will affect the region's natural environment.

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