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ANALYSIS OF RAINFALL TRENDS AND VARIABILITY AT SYLHET REGION IN BANGLADESH

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ABSTRACT

Rainfall is the type natural process varies from place to place due to convective precipitation. In this study, rainfall data for the years 2001 to 2012 have been analyzed in terms of temporal and spatial characteristics in order to identify the change of rainfall trend and spatial distribution of annual rainfall over Sylhet region with a view to understand the pattern of rainfall trend (magnitude), by applying various numerical tools on the data obtained from 8 different climate stations. Surface Map of rainfall trends was created by applying different types of geo-statistical interpolation technique to visualize the detected tendencies. The findings revealed that a significant negative trend in rainfall was recorded in the entire Sylhet district within the period of 2001 to 2012. However, majority of the station revealed a negative trend, with Sulaghar, Lalakhal, Gobindogonj, Chattak, Sherupur, Sheola, Zakigonj, and Kanaighat stations showing significant trends of magnitude of -103 mm, -17.8 mm,-38.61 mm and 152.381 mm, 4.625 mm, of -103 mm,-60.1429 mm,-15.6333 mm, and 11.51667 mm per year respectively. From this analysis high variability in rainfall in Sylhet region signifies an obvious warning of climate change.

Keywords: spatial distribution rainfall, GIS, geostatistics, ordinary kriging, semivariogram, trend, seasonal analysis.

INTRODUCTION

Rainfall is important factors affecting crop production and different types of ecological changes in a region. Accurately predicting precipitation trends can play a vital role in a country's potential economic development. Rahman and Begum noted that predicting trends using precipitation time series data is more difficult than predicting temperature trends [1]. Now a days meteorologists and other scientists worldwide have paid considerable attention to analyzing precipitation time series trends. There are various types statistical test methods are used to detect trends in hydrological and hydro meteorological time series data. These are classified as parametric and nonparametric tests [2-4].Parametric tests are more powerful statistical method requires that data be self-determining and normally distributed, which is rarely true for time series data [5]. For nonparametric tests, data must self dependent, but outliers are better tolerated. The common tests for working with time series trends are the Mann-Kendall [6, 7]. The Mann-Kendall test is the most frequent one used by researchers in studying hydrologic time series trends [19-23]; less common. In Bangladesh four distinct seasons are be recognized from the climatic point of view [8]. These are

a) Dry winter season (December to February)

b) Pre-monsoon season (March to May)

c) Rainy monsoon season (June to September) and

d) Post-monsoon autumn season (October to November)

In Bangladesh more than 75% of rainfall occurs in monsoon season and the average temperature of the country varies from 17 to 20.6°C all through winter and 26.9 to 31.1°C during summer. Average relative humidity for the whole year varies from 70.5% to 78.1% in Bangladesh [8].

METHODOLOGY

Study area description and datasets

Sylhet district is situated in the north-eastern part of Bangladesh sited on the bank of the river Surma. The total area of the district is 3452.07 sq. km. (1332.00 sq. miles). The district lies between 24º36' and 25^{0}11' north latitudes and between 91º38' and 92^{0}30' east longitudes.

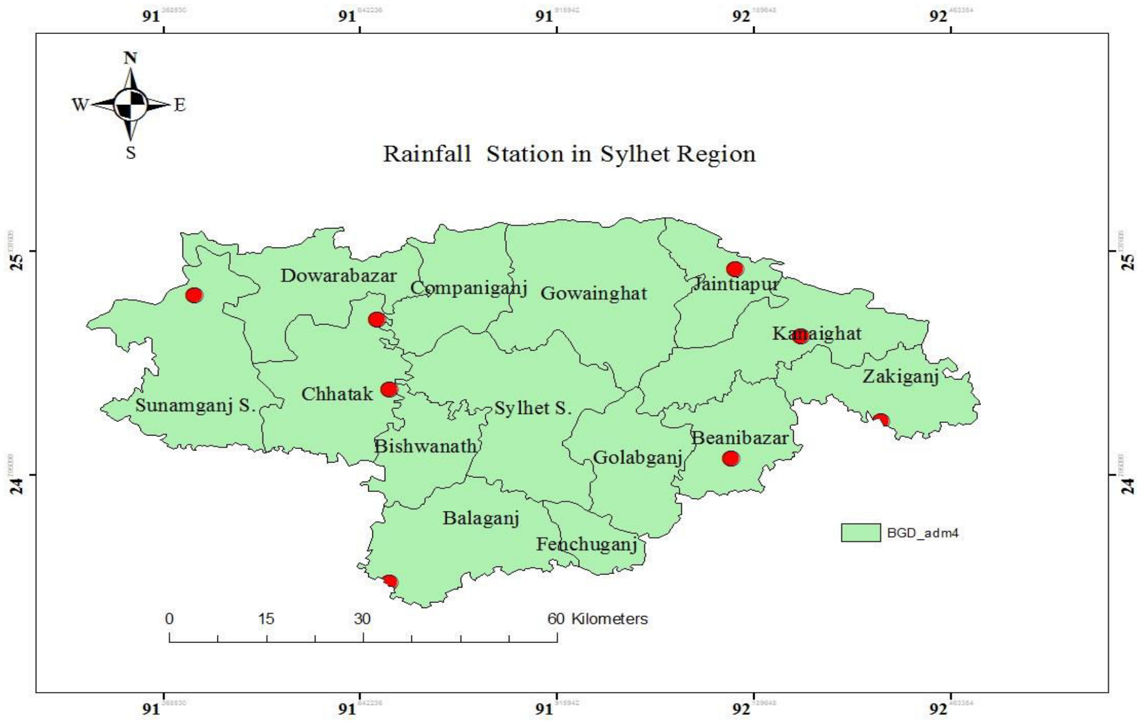

Figure-1. Location of the Meteorological Station in the study area.

Data acquisition

The time series data of monthly rainfall for the Sylhet region was collected from Bangladesh Water Development Board (BWDB). Observed monthly rainfall data of eight meteorological stations for the period 2001 to 2012 was collected to perform this study.

Mann-Kendall test (MK test)

Mann-Kendall test is used if there is a trend in the time series data. The observed data values are calculated as an ordered of time series data. Then each data value is compared to all subsequent data values. The preliminary value of the Mann-Kendall statistic (S) is assumed to be 0. The net result of all such increments and decrements yields the final value of S.

Let X_1, $X2 \ldots X_n$ correspond to n data points where Xj represent the data point at time j. Then the Mann-Kendall statistic (S) is given when S is high and positive it implies that the trend is increasing, and a very low negative value indicates a decreasing trend. The procedure to compute this probability is described in Partal and Kahya[9].

$$S = \sum_{k-1}^{n} \sum_{j-k=1}^{n} \text{sign}\,(X_j - X_k) \qquad (1)$$

Where, $sign\ (X_j - X_k) = 1$ if $(X_j - X_k) > 0$
$= 0$ if $(X_j - X_k) = 0$
$= -1$ if $(X_j - X_k) =< 0$

The positive value of S implies that the trend is increasing, and negative value indicates that there is a decreasing trend.The procedure to compute this probability is described in Kahya and Kalayci [9].

Estimation of Sen'sslope

The process Sen's slope estimator requires a time series of regularly spaced data. Sen's method is calculating the slope as a change in amount per change in time, as shown in equation

$$Q = \frac{X_j - X_k}{j - k} \qquad (2)$$

Where,

Q = Magnitude of slope between data points $X_j$and X_k
X_j = Observed data computation at time j
X_k = Observed data computation time k
j = Time after time k

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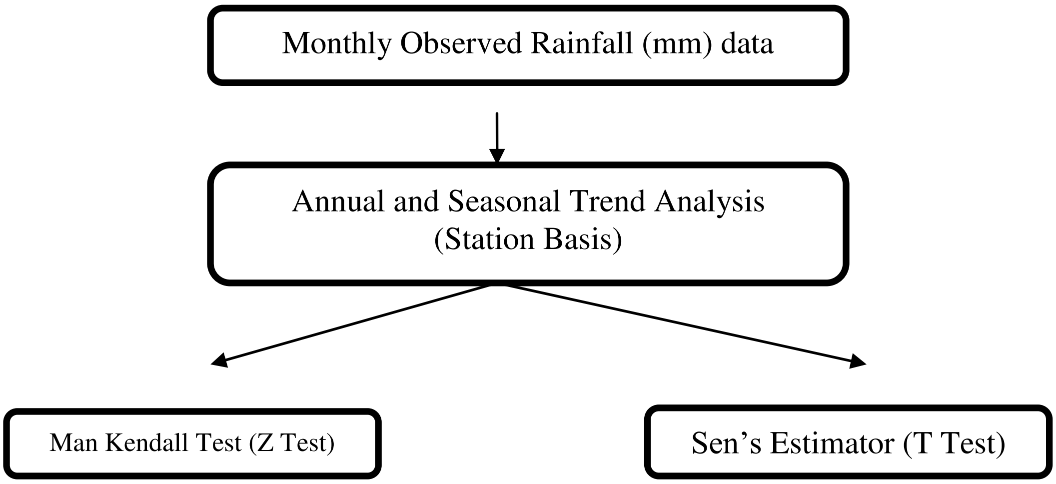

Figure-2. Organization of data used in Rainfall trend analysis.

Geostatistical analysis steps

To check the data for normal distribution with histogram tool, Q-Q plot, and trend analysis and semivariograms cloud. Geostatistical analysis is completed by the interpolation method named kriging using Arc GIS 10.3 software. The best interpolation method is chosen based on different types of prediction errors. The related surface maps are created on the basis of low prediction errors.

Geostatistics

In geostatistics, a semivariogram is used to measure the differences between observed data values as an objective of their separation distance, h. In practice, the experimental semivariogram, *(h), is calculated as follows:

$$y^{*}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \qquad (3)$$

Where, N (h) = Number of sample data pairs that are separated by a vector h and
$z_{(xi)}$ and $z_{(xi+h)}$ = values of the variable z at locations of x_i and $x_{i+h,}$ respectively.

The most widely used models in kriging method include the spherical, exponential and Gaussian models. The spherical model used in this study is defined by:

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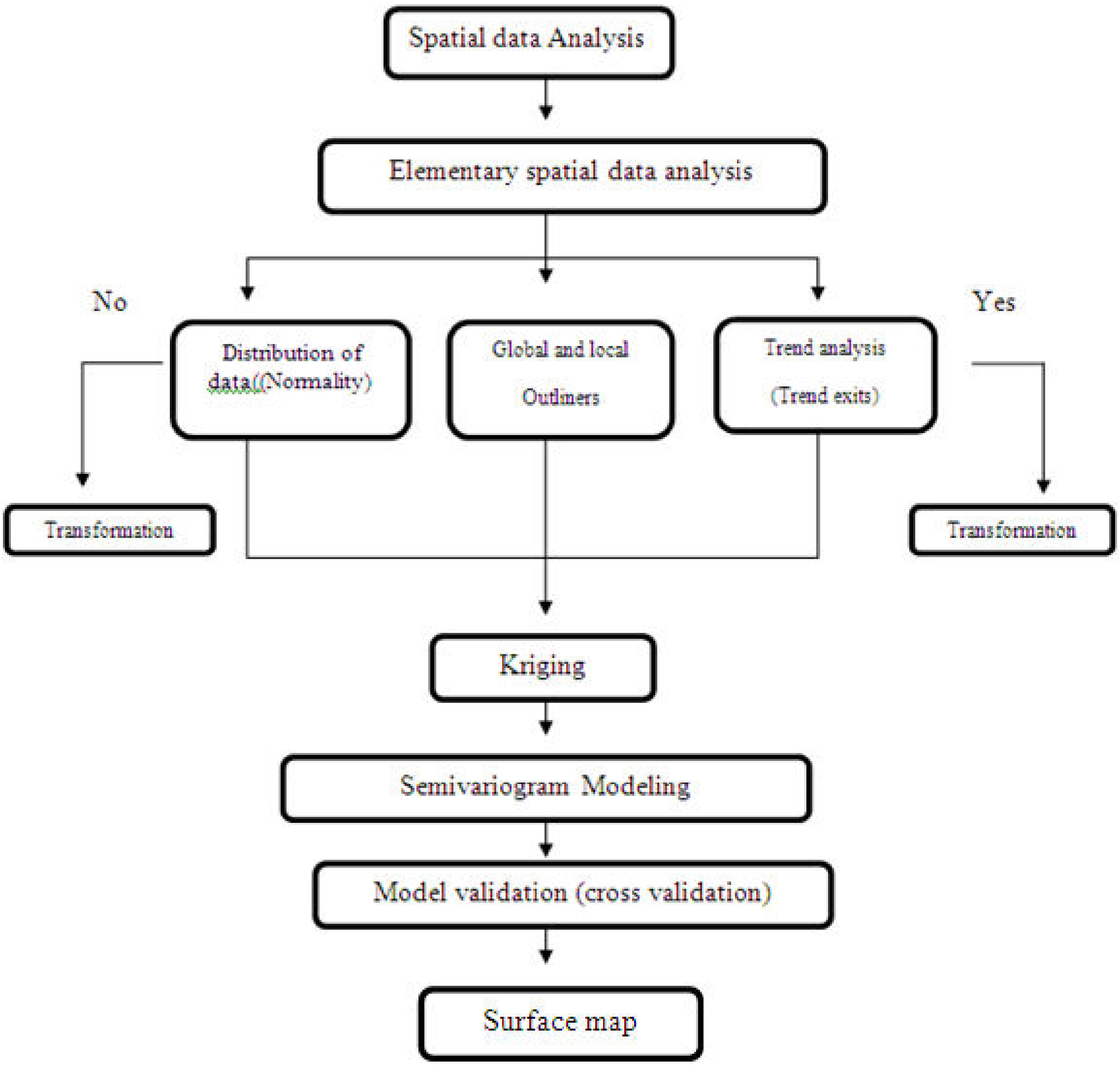

Figure-3. Flow chart of the geostatistical analysis steps used in Surface Map generation for Rainfall Trends [10].

Ordinary kriging (OK)

OK assumes that the mean is stationary but unknown [11]. Is defined as follows:

$$z^*(x_0) = \sum_{i=1}^{n(u)} \lambda_i z(x_i) \, with \sum_{i=1}^{n(u)} \lambda_i = 1 \qquad (4)$$

Where,

$z^*(x_0)$ = OK estimator at location
x_0, $z(x_i)$ = observed value of the variable at location xi,
λ_i = weight assigned to the known values near the location to be estimated and
n (u) = number of neighboring observations.

The values of λ_i are weighted to obtain a sum of unity, and the error variance is minimized as follows:

$$\begin{Bmatrix} \sum_{j=1}^{n(u)} \lambda_i \gamma(x_i, x_j) - \mu = \gamma(x_i, x_j) & j = 1, \dots, n(u) \\ \sum_{j=1}^{n(u)} \lambda_j = 1 & \end{Bmatrix} \qquad (5)$$

where μ is the Lagrange coefficient for minimizing the OK estimation variance, $\gamma(x_i, x_j)$ is the average semivariogram value between the observed values and $\gamma(x_i, x_0)$ represents the average semivariogram value between the location x_i and the location to be estimated (i.e., x_0). The OK estimation variance (or standard deviation) can be used as a measure of the estimation uncertainty as follows:

$$\sigma^{2*}(x_0) = \sum_{i=1}^{n(u)} \lambda_i \gamma(x_i, x_0) + \mu \qquad (6)$$

Simple kriging

For example, OK and SK assume a stationary but known mean. In addition, OK uses local averages and SK uses entire observation averages. The SK estimator is given as follows:

$$z^*(x_0) = m + \sum_{i=1}^{n(u)} \lambda_i [z(x_i) - m] \qquad (7)$$

Where,

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M= mean value of the variable z and
λ_i = weight assigned to the residual value of $z(x_i)$ from the mean.

This estimate is unbiased because E $[z(x_i)-m]=0$ and E $[z^*(x_0)]=m=E\ [z(x_0)]$.

Comparison of the interpolation methods

Here, the cross-validation technique was used to compare different interpolation approaches. The evaluation criteria that were used included the root mean square error (RMSE) and the mean error (ME) [12]. Which is defined by?

$$RMSE = \sqrt{\frac{1}{n}\sum_1^n[z^*(x_i) - z(x_i)]^2} \quad (8)$$

$$ME = \frac{1}{n}\sum_1^n[z^*(x_i) - z(x_i)]^2 \quad (9)$$

Where z*(xi) and z(xi) are the estimated and measured values at location xi, respectively, and n is the number of observations.

RESULTS AND DISCUSSIONS

MK test

The Mann–Kendall result in Table-1 showed the distribution of weather stations with positive and negative trends and their statistical significance. The result at regional level exhibited a negative trend in rainfall entire north-eastern Sylhet within the period of 2001 to 2012. However, majority of the station revealed a decreasing trend, with Sulaghar, Lalakhal, Kanaighat, Sherupur, Sheola stations showing significant negative trends of magnitude 103 mm/year, -17.8 mm/year -38.4167 mm/year,-60.14mm/year and -15.63 mm/year respectively.

Table-1. Annual Rainfall Trend of eight Meteorological stations in Sylhet region (2001-2012).

Location of station	Time series	First year	Last Year	n	MK Test Z	Estimated change in rainfall (mm/year)	Trend	Result
BWDB office campus, Sulaghar, Sunamganj.	Annual	2001	2012	12	-1.302	-103	Decreasing	NS
Lalakhal tea garden, Jaintia,Sylhet.	Annual	2000	2012	13	-0.427	-17.8	Decreasing	NS
Kanaighat, Sylhet.	Annual	2001	2012	12	-0.342	-38.4167	Decreasing	Sig
Gobindogonj, Syhet.	Annual	2001	2012	12	1.851	152.381	Increasing	sig
Chhatak, Sunamganj.	Annual	2001	2012	12	0	4.625	Increasing	NS
Sherupur, Syhet.	Annual	2001	2012	12	-1.577	-60.1429	Decreasing	NS
BWDB office campus, Sheola, Sylhet.	Annual	2001	2012	12	-0.205	-15.6333	Decreasing	NS
BWDB office campus, Zakigonj, Sylhet.	Annual	2001	2012	12	0.0685	11.51667	Increasing	Sig

MK: Mann-Kendall; NS: Not Significant; Sig.:Significant

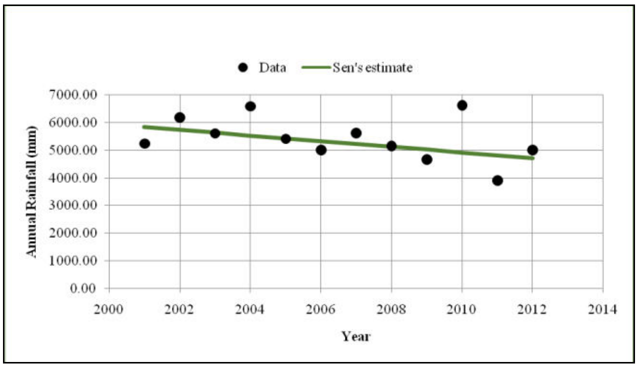

Figure-4. Annual rainfall trend of Sulaghar station.

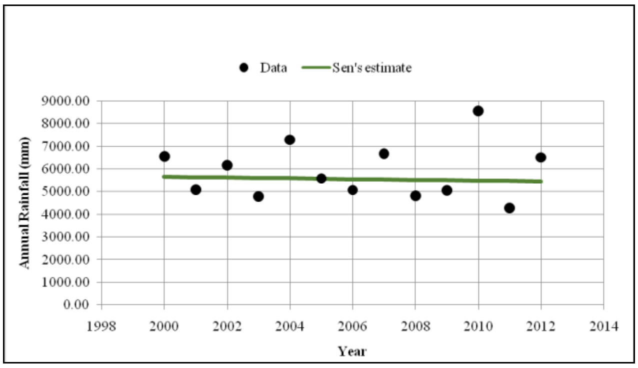

Figure-5. Annual rainfall trend of Lalakhal station.

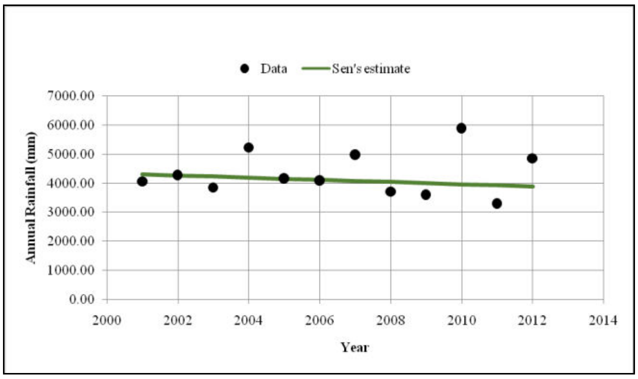

Figure-6. Annual rainfall trend of Kanaighat station.

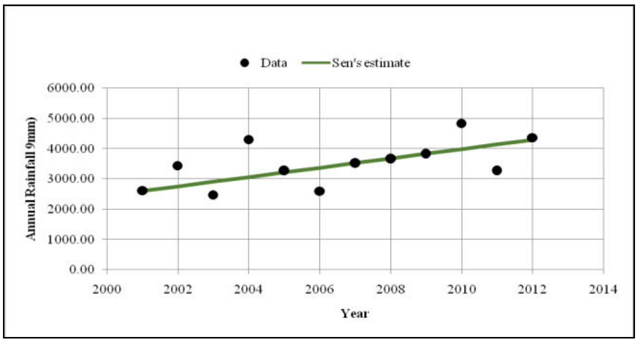

Figure-7. Annual rainfall trend of Gobindoganj station.

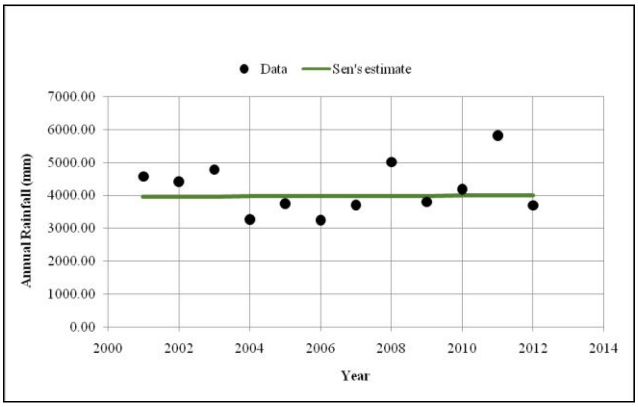

Figure-8. Annual rainfall trend of Chattak station.

Surface map generation using spatial analysis

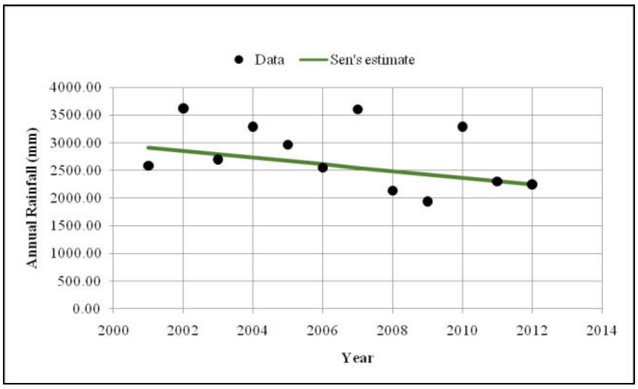

Figure-9. Annual rainfall trend of Sherpur station.

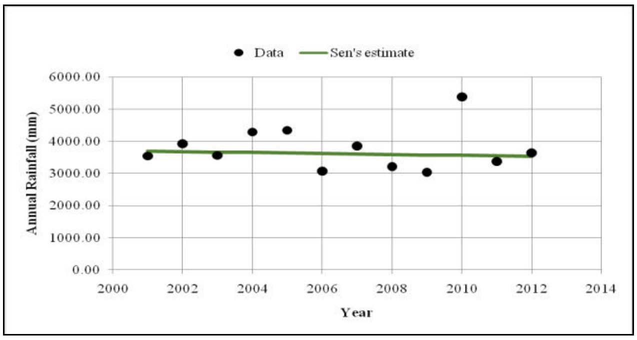

Figure-10. Annual rainfall trend of Sheola station.

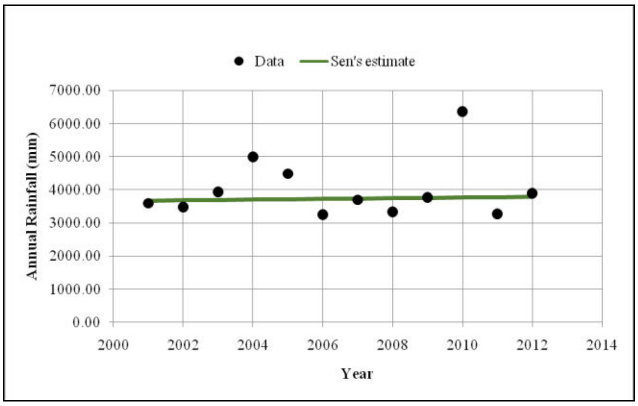

Figure-11. Annual rainfall trend of Zakigonj station.

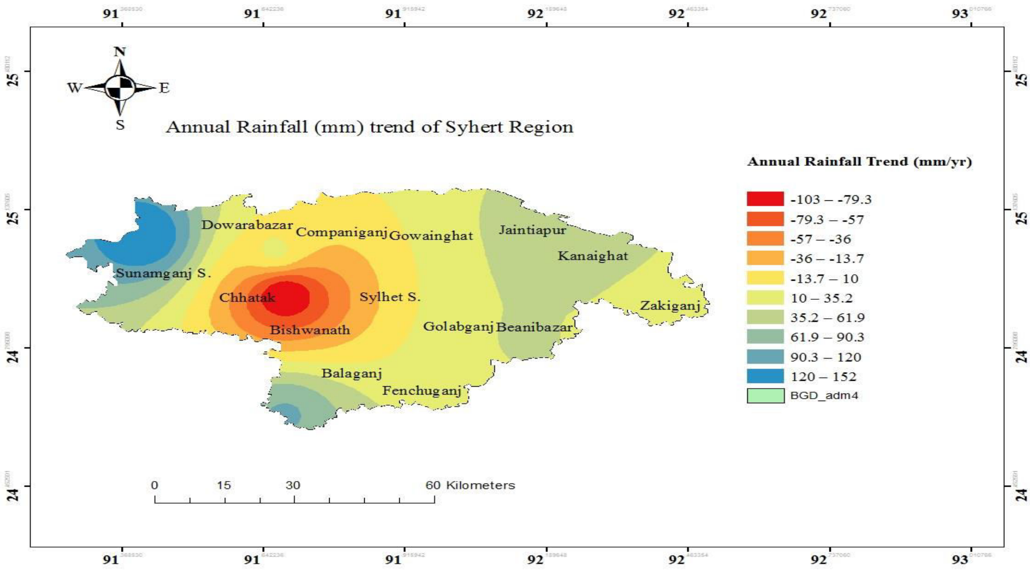

Figure-12. Annual magnitude rainfall trends in Sylhet district (2001-2012).

The annual rainfall trends are shown in Figure-12. Positive slopes indicate the increase in rainfall over the period and negative slopes represent a decrease in rainfall. The results revealed that the area with negative trends prevailed against the area with positive trends.

The positive Sen's-slope values indicated a rising rainfall trends over the period of 12 years from (2001-2012) for the entire northern East with (Gobindogonj, Chattak, Zakiganj) stations showing significant positive trends of 152.381 mm/year, 4.625 mm/year and 11.516 mm/year respectively. In contrast, a significant negative trend in rainfall was recorded in Sulaghar, Sunamganj. station with a Sen's-slope of -103 mm/year. Findings of this study clearly pointed towards a significant decrease in rainfall in northern Sylhet during the study period (2001-2012).

ARPN Journal of Engineering and Applied Sciences

Table-2. Seasonal rainfall trend of eight Meteorological stations in Sylhet region (2001-2012).

Station name	Seasons	MK Test (Z)	Estimate change in rainfall (mm/year)	Trend	Result
Sulaghor	Winter	-0.48	-0.238	Deceasing	NS
	Pre-M'Soon	-0.35	-4	Deceasing	NS
	Rainy-M'soon	-0.375	-6..34	Deceasing	Sig.
	Post- M'soon	-0.31	-5.04	Deceasing	Sig.
Lalakhal	Winter	-0.046	-0.18	Deceasing	NS
	Pre-M'Soon	0.22	-2.09	Deceasing	Sig.
	Rainy-M'soon	0.06	6.6	Increasing	NS
	Post- M'soon	-0.065	0.05	Increasing	NS
Gobindogonj	Winter	-0.08	-14.25	Deceasing	Sig.
	Pre-M'Soon	0.206	-1.09	Deceasing	NS
	Rainy- M'soon	0.1375	1.409	Increasing	NS
	Post- M'soon	-0.035	1.08	Increasing	NS
Chattak	Winter	-0.496	0	Increasing	NS
	Pre-M'soon	0.55	5.07	Increasing	Sig.
	Rainy-M'Soon	0.0027	0.25	Increasing	Sig.
	Post- M'soon	0.805	12.09	Increasing	NS
Sheola	Winter	3.33	0	Increasing	NS
	Pre-M'Soon	0.113	2.85	Increasing	Sig.
	Rainy- M'soon	-0.65	-18.746	Deceasing	NS
	Post- M'soon	-1.72	-8.58	Deceasing	NS
Zakigonj	Winter	0.14	0	Increasing	Sig.
	Pre-M'Soon	0.18	3.81	Increasing	Sig.
	Rainy- M'soon	-0.1	-0.85	Deceasing	NS
	Post- M'soon	-0.31	-1.68	Deceasing	Sig.
Kanaighat	Winter	-0.46	-1.16	Deceasing	Sig.
	Pre-M'Soon	0.23	4.27	Increasing	NS
	Rainy- M'soon	0.41	7.23	Increasing	Sig.
	Post- M'soon	-0.58	0.71	Increasing	NS

MK: Mann-Kendall; NS: Not Significant; Sig.Significant

The Mann-Kendall test results revealed downward trend in annual rainfall in five out of eight stations (Sulaghar, Lalakhal, Sherupur, Sheola and Kanaighat) and a upward trend of annual rainfall in (Gobindogonj, Chattak, Zakiganj) .Sen's slope estimate rate of increasing annual rainfall in eight meteorological stations and summarizes 12 years (2001-2012) seasonal trend of mean rainfall in Sylhet Division.

Table-2 shows that there is an increasing trend of rainfall during rainy Monsoon and post Monsoon in Lalakhal, Chattak and Sherupur. Pre-Monsoon rainfall is decreasing significantly at Gobindogonj, Chattak, Sherupur, Sheola, Zakiganj and Kanaighat and the rate of increase is 7-8 mm/year. A decreasing trend of Pre-Monsoon rainfall is significant at Sulaghar and the rate of decreasing is 4 mm/year. In Lalakhal, Gobindogonj and Chattak there are increasing trends of rainfall during rainy Monsoon. The increasing rate is statistically significant for Kanaighat and it is increasing at the rate of 7.23 mm/year. Rainfall in winter is decreasing in all the areas.

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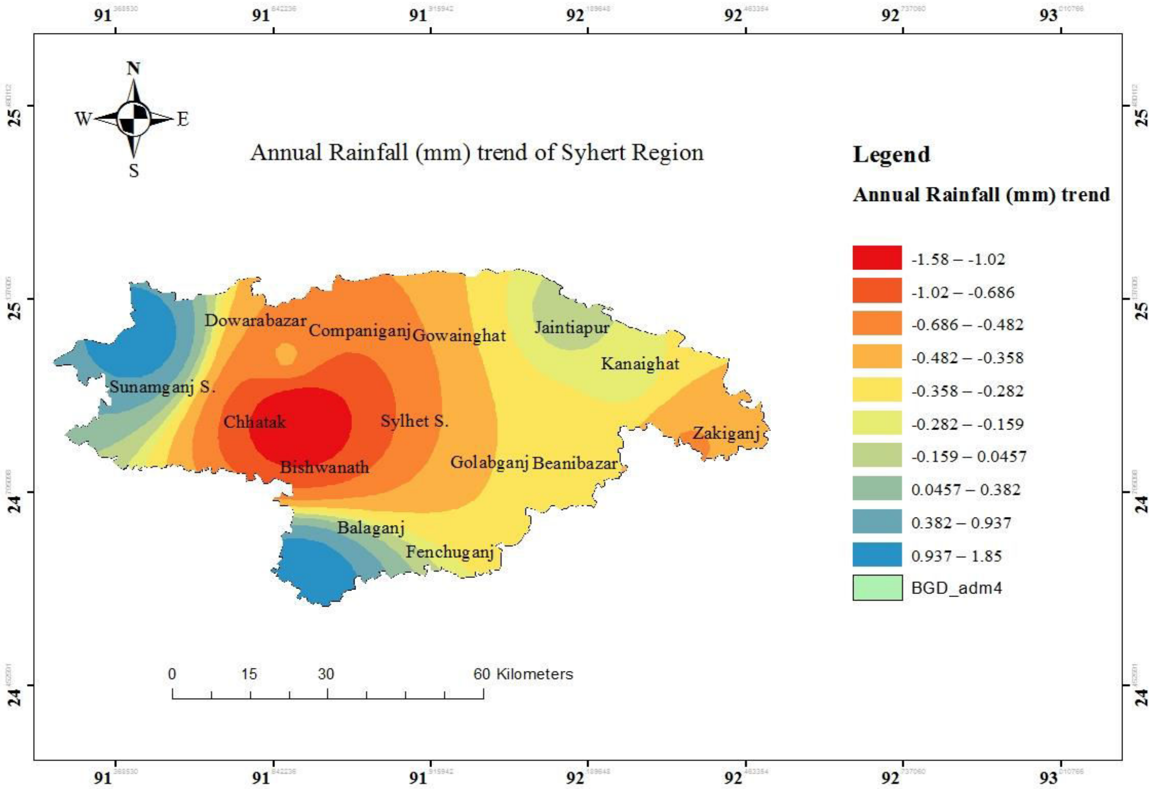

Figure-13. Spatial distributions of annual rainfall trends (MK Z test) in Sylhet district (2001-2012).

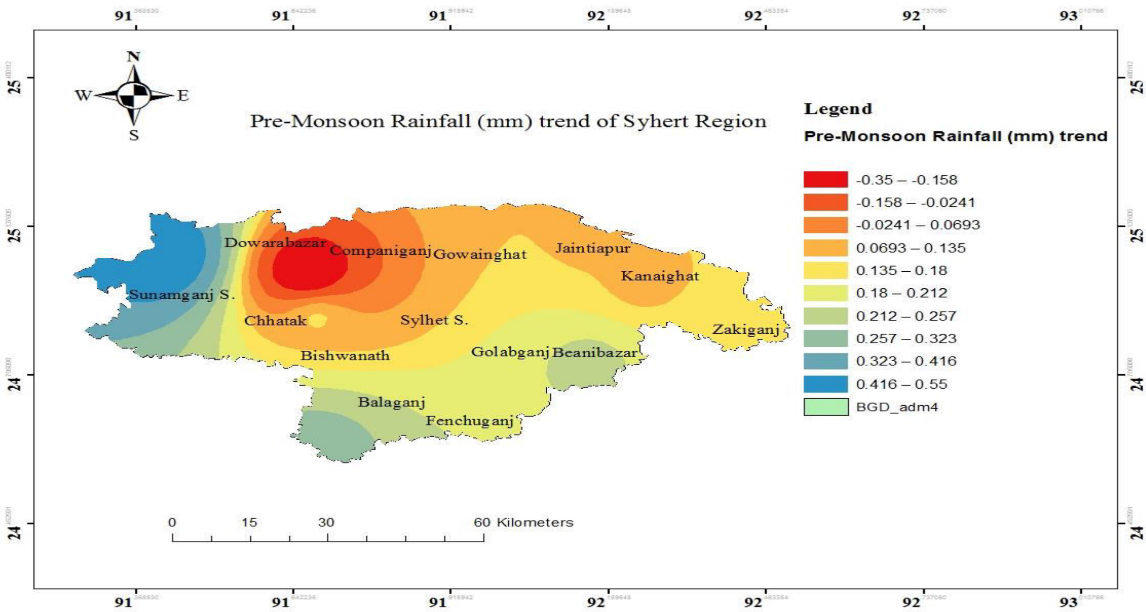

Figure-14. Spatial distributions of Pre-Monsoon rainfall trends (MK Z test) in Sylhet district (2001-2012).

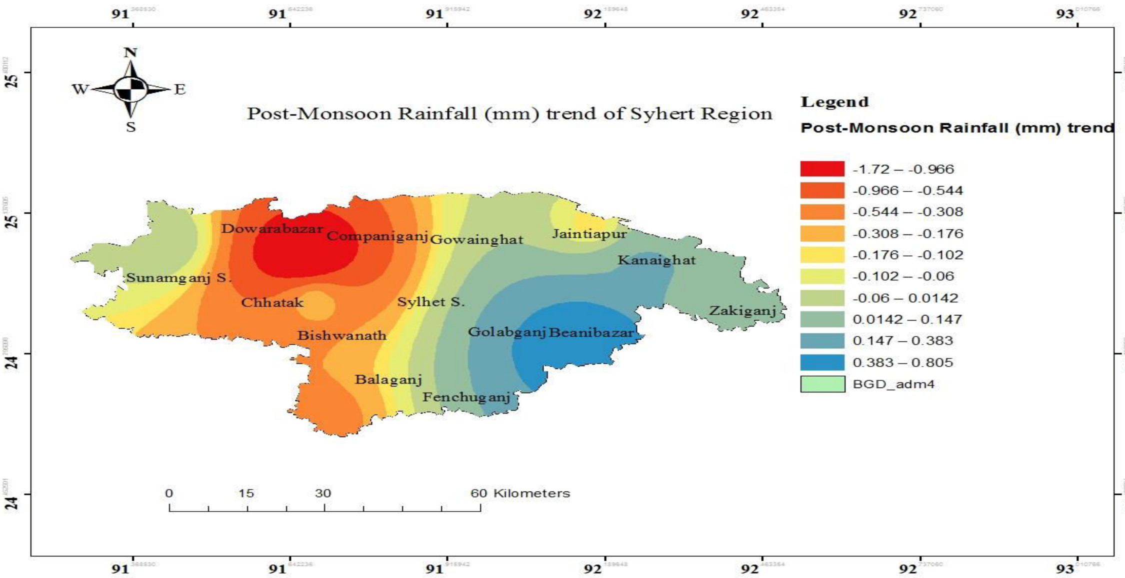

Figure-15. Spatial distributions of Post-Monsoon rainfall trends (MK Z test) in Sylhet district (2001-2012).

In Figure-13,14, 15, 16 and 17 shows Sen's slopes estimated in seasonal time scales. The median of slopes in dry winter season is lower compared with the other seasons. A predictable, rainfall trends show large variability in magnitude and direction of trend place to another. Most of the stations have negatine value of the Sen's estimator for the post monsoon seasons.

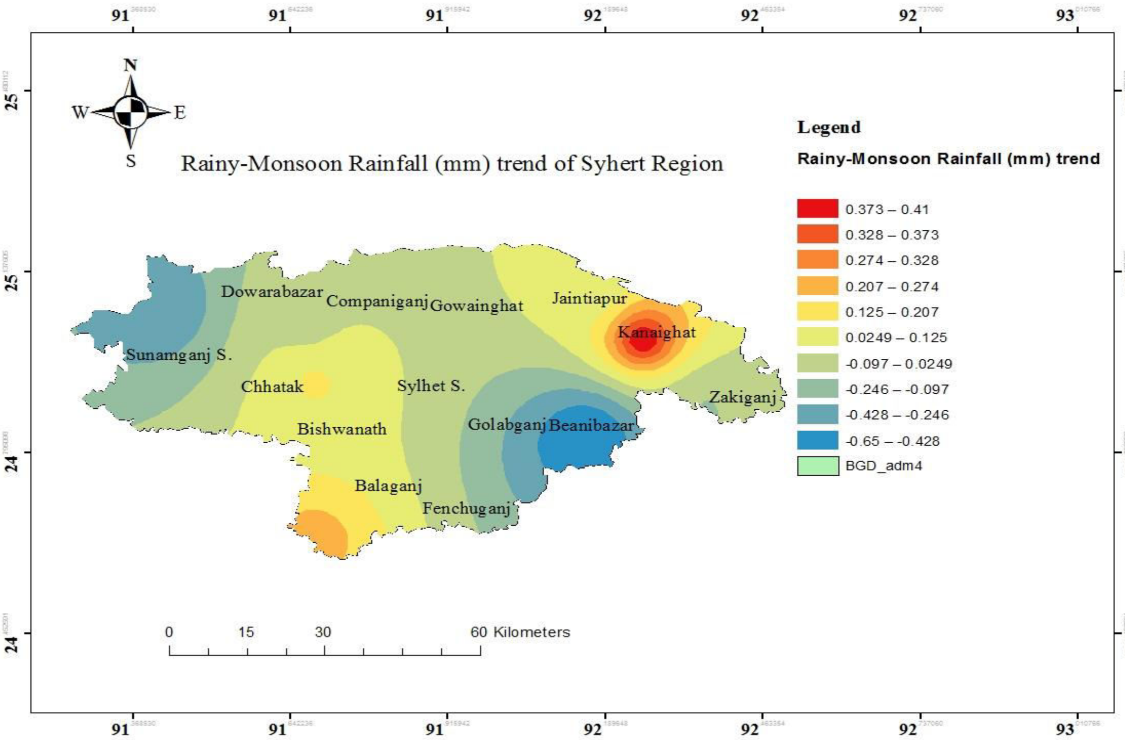

Figure-16. Spatial distributions of Rainy-Monsoon rainfall trends (MK Z test) in Sylhet district (2001-2012).

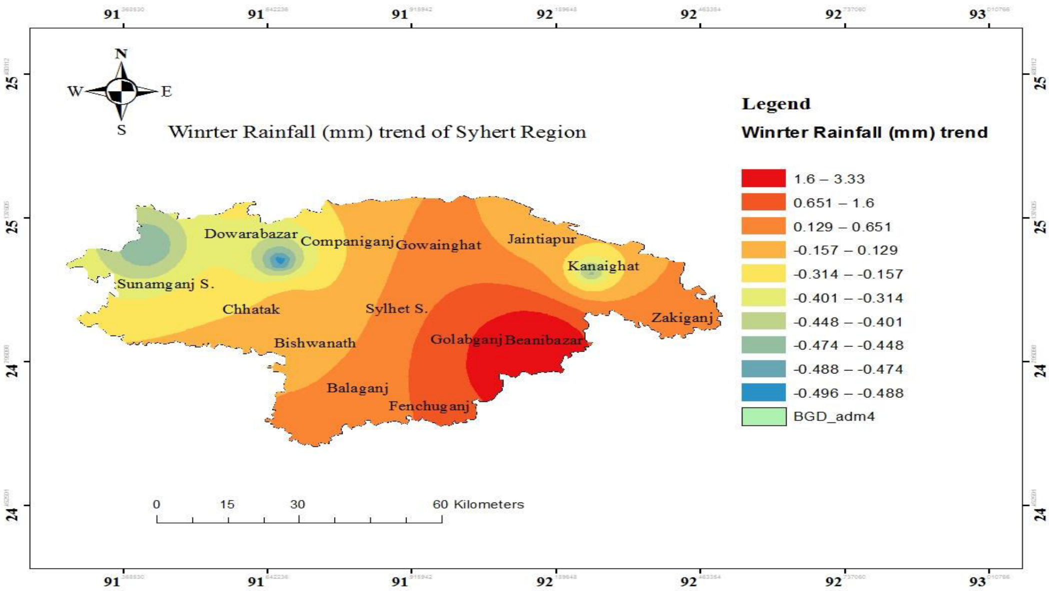

Figure-17. Spatial distributions of winter rainfall trends (MK Z test) in Sylhet district (2001-2012).

CONCLUSIONS

Monthly rainfall data from eight different meteorological stations for a period of 12 years (2001-2012) were considered in this study to analyze the most recent rainfall trends in north-eastern part (Sylhet) of Bangladesh. In addition, the result could be a strong indication of typical weather change in the region, hence calls for an intensive effort by policy makers to deal with the issue through developing mitigation and adaptation options with the plan of reducing vulnerability of weather change impact. Finally, the present analysis was limited to one element of climate; future research should include other climatic elements and attempt to cover more geographical area.

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