Journal of Climate Change, Vol. 6, No. 1 (2020), pp. 7-14.
DOI 10.3233/JCC200002

Analysis of Spatio-Temporal Rainfall Variability over Bangladesh

Md. Nurul Hoque Upal
Center for Environmental and Geographic Information Services (CEGIS)
Rd No 23/C, Dhaka 1212, Bangladesh
✉ upalhoque@yahoo.com

Received September 6, 2019; revised and accepted December 15, 2019

Abstract: Rainfall is one of the most important climatic components for Bangladesh. This study is an attempt to evaluate the spatial and temporal changing pattern of rainfall in all over the country. The analysis is based on the rainfall variations over 27 meteorological stations of Bangladesh Meteorological Department (BMD). Time series statistical tests were applied to examine the annual and seasonal trends for rainfall during the period of 1975–2013 respectively. The nonparametric Mann Kendall test was used to determine whether there was a positive or negative trend in rainfall data with their statistical significance and the Theil-Sen estimator was used to determine the trend magnitude. Overall the rainfall pattern showed a declining trend both annually and seasonally. Apart from the post-monsoon, rainfall had been decreased in all other seasons in most parts of the country. Comparatively the declining trend is higher in the north and northeastern regions. Increase of rainfall had only been observed in southeastern part of the country.

Keywords: Bangladesh; Climate; Rainfall; Trend.

Introduction

Bangladesh is located at the downstream of the Ganges-Brahmaputra-Meghna (GBM) delta which is one of the largest delta systems in the world. The country comprises low and flat land, shaped mainly by the sediments carried by the Ganges and the Brahmaputra River systems except for the hilly regions in the north-eastern and south-eastern parts. The physiography of Bangladesh is characterized by two distinct features: an extensive deltaic plain subject to regular flooding, and a small hilly region traversed by swiftly flowing rivers (IBP, 2012). The country possesses a humid, warm, tropical climate which is influenced primarily by monsoon and partly by pre-monsoon and post-monsoon circulations (Ahmed, 2006). There are extensive differences in the intensity of the seasons at various places in the country.

Bangladesh is climatologically classified into four seasons: winter (December-February), pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October-November). The winter season is very arid, which contributes less than 4% of the total annual rainfall. On average less than 2 cm annual rainfall in the west and south and more than 4 cm rainfall in the northeast part of the country occur during this season. Rainfall in winter season is resulted by the wind coming from the Mediterranean region that enters the country from the northwestern part of India along the Ganges basin. High temperatures and the occurrence of thunderstorms are the highlighting characteristics of pre-monsoon. It is the hottest season of the year and during this period there is some rainfall accompanied by norwester and hailstorm and often with a recurrence of tornadoes.

The monsoon is the season of heavy rainfall. About 80 percent of the country's total rainfall occurs during this season. Weak tropical depressions that are carried from the Bay of Bengal by wet monsoon winds result in heavy rainfall in the season (Ahmed and Kim, 2003). The post-monsoon is the transition period from summer to winter and it is quite hot in October. During this season, a centre of high pressure remains over the northwestern part of India (Himalayan zone) which results in a stream from north or northwest direction inside Bangladesh (Banglapedia, 2017).

Bangladesh is highly vulnerable to climate change due to its geological and geographical settings. The Germanwatch long-term Climate Risk Index (CRI) has identified Bangladesh as the sixth most affected country by extreme climate events during 1996–2015 (Kreft et al., 2016). The climate change concern is evident not only for the global scenario but also perceived at the regional level of Bangladesh. Several studies have been conducted to observe the rainfall changing pattern in Bangladesh. Syed and Amin (2016) investigated changing trend of rainfall from 1978 to 2007 over Bangladesh. The study found that average rainfall trend is negative in pre-monsoon and winter. The geospatial modelling of the study revealed that the northeastern Sylhet region has shown incoherence in the monsoon progression (southeast to northwest) and the northeast region compared to the typical monsoon progression from the southeast to the northwest showed an uncharacteristic early onset.

Basak et al. (2013) analyzed precipitation data of 34 meteorological stations of BMD for the period of 1976-2008. Increasing trend of rainfall data during monsoon and post-monsoon seasons was observed for the same study period for most of the stations while falling trend of total rainfall during winter was found for a significant number of weather stations. However, any significant change in total rainfall observed was during pre-monsoon.

Data and Methods

Data

Monthly total rainfall observation data from 27 meteorological stations of Bangladesh Meteorological Department (BMD) were collected from the National Water Resources Database (NWRD) (Figure 1). The data were collected for a period of 39 years (1975-2013). Spreadsheet packages of MS Excel were used for data analysis, whereas ArcGIS 10.2 was used for geo-spatial analysis. A Spatial Analysis Tool in the ArcGIS 10.2 package was applied for exploring spatial patterns in data.

Methods

The collected rainfall data were processed and arranged accordingly for trend analysis. There are many statistical techniques for calculating trends. This study adopted Mann-Kendall test at 95% confidence level for detecting a trend. The slope of the trend was analyzed using Theil and Sen's slope method which is a nonparametric substitute to the parametric ordinary least squares regression method. Finally, the magnitude of the trend was identified and exhibited as a change of percentage over the period. Spatial distribution maps have been developed by using Kriging interpolation techniques.

Checking of Consistency and Missing Data

The study duration has been selected based on the availability of the least number of missing data. There was no missing data found of maximum or minimum temperature record of BMD within the 41 years study period. There were, however, few missing rainfall records for Chittagong and Sylhet stations which have been filled by normal ratio method. In the normal ratio method, the rainfall of observed stations is estimated as a function of the normal monthly or annual rainfall of the station under question and those of the neighbouring stations for the period of missing data at the station under question (NPETL, 2017). According to normal ratio method, the precipitation of the missing stations can be calculated as

$$P_x = \frac{1}{n}\sum_{i=1}^{i=n} \frac{N_x}{N_i} P_i \qquad (1)$$

where P_x is the missing precipitation for any storm at the interpolation station X, P_i is the precipitation for the same period for the same storm at the *i*th station of a group of index stations, N_x the normal annual precipitation value for the X station and N_i the normal annual precipitation value for the *i*th station.

The double mass analysis method was applied for consistency checking of rainfall data. This method compares the cumulative annual values of the examined station with those of a reference station (Ponce, 1989). The reference station is generally the mean of several neighbouring stations. The cumulative pairs (double-mass values) are plotted in a two-dimensional coordinate system and the plot is observed for trend changes. If the plot is effectively linear, the record at the examined station is consistent. If the plot shows a discontinuity in slope, the record at the examined station is inconsistent and needs to be corrected. The correction is performed

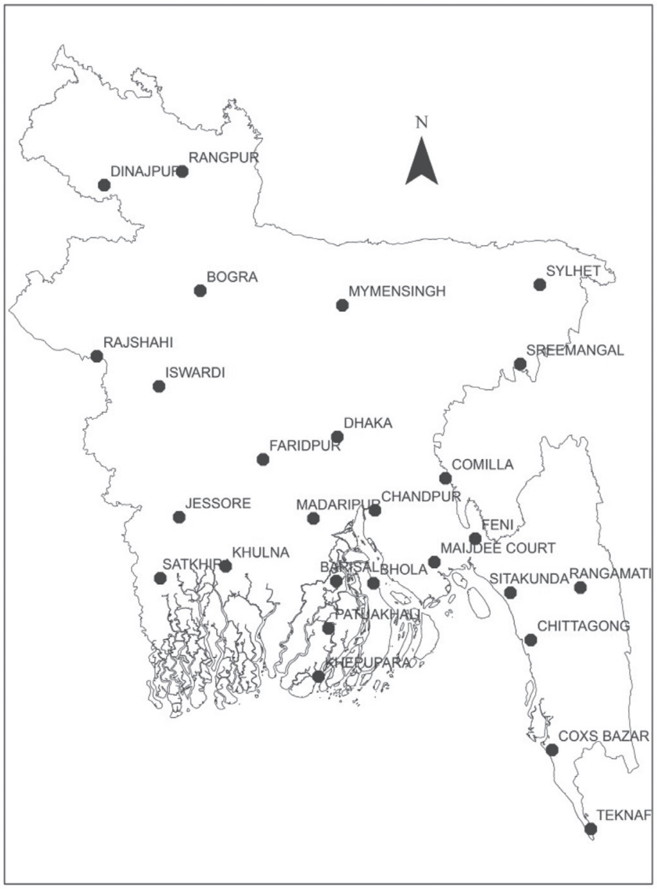


Figure 1: Location of selected meteorological stations of BMD.

by adjusting the records prior to the break to reflect the new state. To accomplish this, the annual rainfall data prior to the break are multiplied by the ratio of slopes after and before the break (Ponce, 1989).

Mann Kendall Test

Mann Kendall test is a statistical trial widely exercised for the analysis of the trend in climatologic and in hydrologic time series (Yue and Wang, 2004). There are two benefits of using this test. Firstly, it is a non-parametric test and does not necessitate the data to be normally distributed. Secondly, the test has a low sensitivity to sharp breakdowns because of inhomogeneous time series (Basistha et al., 2009; Tabari et al., 2011).

According to this test, it is assumed that the null hypothesis H_0 has no trend (the data is independent and randomly ordered) and this is verified against the alternative hypothesis H_1, which assumes that there is a trend (Onoz and Bayazit, 2012). The rank correlation test (Kendall, 1975) for two sets of observations $X = x_1, x_2 \ldots x_n$ and $Y = y_1, y_2 \ldots y_n$ is expressed as follows. The statistic S is calculated from the following equation:

$$S = \sum_{i<j} a_{ij} b_{ij} \tag{2}$$

a_{ij} and b_{ij} is correspondingly defined for the observations in Y. Under the null hypothesis where X and Y are independent and randomly ordered, the statistic S tends to normality for large n, with mean and variance are given by:

$$E(S) = 0 \tag{3}$$

$$V(S) = n\,(n-1)\,(2n+5)/18 \tag{4}$$

If the values in Y are substituted with the order of the time series X, i.e. 1, 2, ... n, the test can be used as a trend test. In this circumstance, the statistic S decreases as

$$S = \sum_{i<j} a_{ij} = \sum_{i<j} \operatorname{sgn}(x_j - x_i) \tag{5}$$

$$\operatorname{Sign}(x_j - x_i) = \begin{cases} 1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i > 0 \end{cases} \tag{6}$$

with the same mean and variance as in equations, and x_j and x_i are the annual values in years j and i, $j > i$, respectively. The standard test statistic Z_s is calculated as follows:

$$Z_s = \begin{cases} \dfrac{s-1}{\sigma} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \dfrac{s-1}{\sigma} & \text{for } S < 0 \end{cases} \tag{7}$$

where $V(S)$ is from Equation (4). The rest is as in the MK test.

Theil and Sen's Slope Estimator

When a monotonic trend is determined using the Mann Kendall test and the trend seems to be linear, we can use a Theil-Sen line to estimate the slope of the trend. The slope line is a nonparametric substitute to the parametric ordinary least squares regression line. The slope of N pairs of data is estimated by Theil and Sen's estimators (Theil, 1950; Sen, 1968) using the following formula

$$Q_i = (x_j - x_k)/(j - k) \text{ for } i = 1, \ldots N \tag{8}$$

where x_j and x_k represent values at times j and k ($j > k$), respectively. The median of these N values of Q_i is considered as the Sen's estimator of the slope. If there is a single data in each time period, then

$$N = \frac{n(n-1)}{2} \tag{9}$$

where n is the number of time periods. The median of the N assessed slopes is obtained in the normal way, i.e., N values of Q_i are ranked by $Q_1 \le Q_2 \le ... \le Q_{n-1} \le Q_n$ and

$$\text{Sen's estimator} = \begin{cases} Q_{(N+1)/2} & \text{if } N \text{ is odd} \\ \left(\frac{1}{2}\right)\left(Q_{N/2} + Q_{(N+2)/2}\right) & \text{if } N \text{ is even} \end{cases} \quad (10)$$

That is, the change of percentage equals median slope (β) multiplied by the length of the study period divided by the corresponding mean, expressed as a percentage.

Kriging

Kriging is a geo-statistics method that is named after the South African mining-engineer Krige (1919–2013), who unraveled the problem of interpolating results that were found at few locations for gold mining (Kleijnen, 2017). It is considered as a statistical model of a phenomenon that predicts the value in a geographic area given a set of measurements instead of an interpolating function (Sunila and Kollo, 2007; Hengl, 2007). The method assumes that the distance or direction between sample points indicates a spatial correlation between sample points that can be utilized to rationalize variation in the surface (Dubin, 2008). It uses a model for a spatial continuity in the interpolation of unknown values based on values at neighbouring points (Sunila et al., 2004). Kriging is defined as an optimal method because the interpolation weights are chosen to deliver for the value at a given point the best Linear Unbiased Estimate (Jesus, 2003).

The general formula for kriging interpolation is formed as a weighted sum of the data:

$$\overline{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) \quad (11)$$

where $Z(s_i)$ is the measured value at the ith location, λ_i is an unknown weight for the measured value at the ith location, s_0 is the prediction location and N is the number of measured values.

Results and Discussion

Changing Trends of Rainfall

Annual Rainfall

Spatial distribution of rainfall in Bangladesh is not uniform, as mean annual rainfall ranges from 1429 mm (Rajshahi) to 4255 mm (Teknaf). However, most parts of the country usually receive at least 2000 mm of rainfall per year. Northeast and southeast regions of the country receive significant amount of rainfall whereas north and west-central part is known as low rainfall region.

Likewise changing pattern of rainfall is not uniform throughout the country. However, the annual rainfall had fallen down apart from southeast and a few portion of south-central region (Figure 2). A large portion area of the country covering northeast, northwest, central and south-central parts were mostly trended to rainfall reduction. The reduction rate is higher in northern side in comparison to southern part. Out of the 27 stations, the yearly rainfall decreased significantly in eight stations namely Bhola, Faridpur, Madaripur, Maijdee Court, Mymensingh, Rajshahi, Rangpur, and Sylhet (Table 1). The reduction trend was highest in Sylhet with a rate of 25.6 mm/yr. On the other hand, rainfall

Table 1: Result of the MK test (95% confidence level) and Sen's Slope analysis of annual rainfall

Station	*Mean*	*Z*	*Sen's Slope*
Barisal	2075	-1.60	-10.5
Bhola	2214	-2.37*	-17.2
Bogra	1754	-1.91	-15.2
Chandpur	2171	-1.94	-15.2
Chittagong	2920	0.08	1.4
Comilla	2066	-1.22	-10.1
Cox's Bazar	3729	0.51	4.0
Dhaka	2061	-1.69	-13.8
Dinajpur	1983	-1.63	-13.1
Faridpur	1803	-2.76*	-23.8
Feni	2987	-1.50	-17.9
Ishwardi	1483	-1.70	-12.4
Jessore	1703	-0.60	-5.2
Khepupara	2760	1.63	14.5
Khulna	1812	-0.11	-0.5
Madaripur	1990	-2.84*	-21.0
Maijdee Court	3122	-2.60*	-22.0
Mymensingh	2264	-1.97*	-18.8
Patuakhali	2558	-1.50	-13.6
Rajshahi	1429	-2.03*	-10.7
Rangamati	2538	0.17	1.9
Rangpur	2298	-2.31*	-17.2
Satkhira	1748	-0.65	-2.9
Sitakunda	3221	-0.23	-3.1
Sreemangal	2353	-0.37	-3.2
Sylhet	4084	-2.22*	-25.6
Teknaf	4255	1.75	18.1

Z values with (*) mark indicate a significant trend

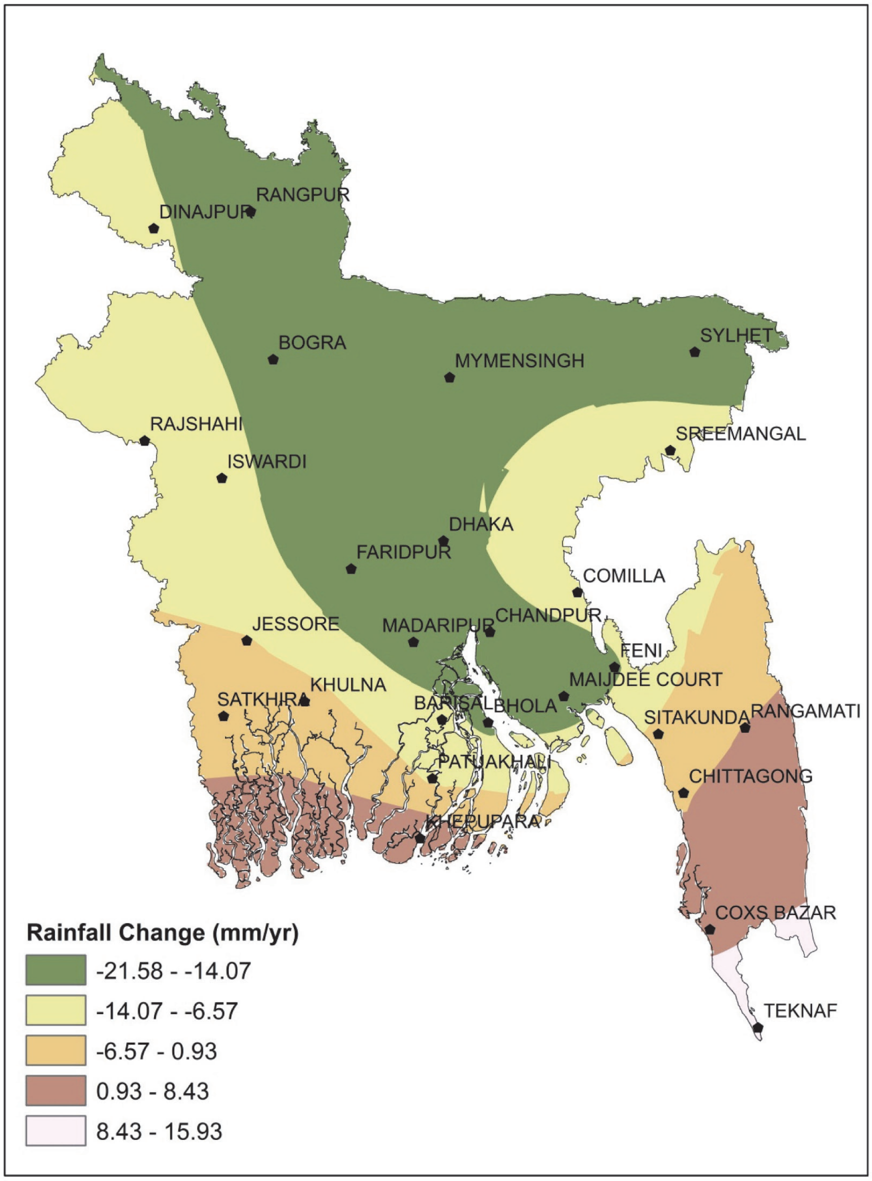


Figure 2: Trend of annual rainfall change over Bangladesh from 1975 to 2013.

had been increased to the southeast region. The highest rate of rising was observed as 18.1 mm/yr in Teknaf, the southern-most region of the country.

Seasonal Rainfall

Pre-Monsoon: Decreasing trend of rainfall has been observed during pre-monsoon season all over Bangladesh. Substantial diminution occurred in the central part of the country especially Dhaka and its surroundings (Figure 3). Most significant decline was in Faridpur at a rate of 10.85 mm/yr (Table 2). Rainfall in the season had been increased only in four locations namely Cox's Bazar, Khepupara, Rangpur and Teknaf; among them only the Teknaf station had a significant increasing trend of 8.03 mm/yr.

Monsoon: Monsoon is the peak rainfall season of the country. Apart from southeast and few parts of southwest region the monsoon rainfall had been declined throughout the country. Moving from south to north, the declining rate was progressively higher. Most significant decrease was in Bhola with a rate of 13.1 mm/yr. In contrast, only five stations namely Jessore, Khepupara, Khulna, Rangamati, and Sitakunda had been shown with a rising trend in the season.

Post-Monsoon: Rainfall in post-monsoon had been increased in almost all parts of the country. The analysis result indicates that the monsoon rainfall is periodically shifting to post-monsoon. The spatial rainfall changing pattern shows a reverse trend to that of the monsoon season

Table 2: Result of the MK test (95% confidence level) and Sen's Slope analysis of seasonal rainfall

Meteorological stations	*Pre-monsoon*		*Monsoon*		*Post-monsoon*		*Winter*	
	Z-value	*Sen's slope*	*Z-value*	*Sen's slope*	*Z-value*	*Sen's slope*	*Z-value*	*Sen's slope*
Barisal	-1.41	-2.97	-0.95	-5.39	0.31	1.36	-1.38	-0.67
Bhola	-2.03*	-6.26	-2.15*	-13.10	0.91	3.11	-2.13*	-1.08
Bogra	-1.92	-5.02	-1.49	-8.80	0.48	1.00	-1.43	-0.64
Chandpur	-1.92	-9.69	-1.10	-8.81	0.64	1.44	-1.26	-0.56
Chittagong	-0.48	-1.33	-0.45	-3.15	0.82	3.00	-1.52	-0.66
Comilla	-1.81	-5.31	-0.50	-2.95	0.15	0.45	-1.43	-0.54
Cox's Bazar	1.60	6.29	0.43	6.35	0.37	1.12	-2.34*	-0.33
Dhaka	-2.42*	-8.71	-0.37	-2.67	-0.36	-0.85	-1.27	-0.74
Dinajpur	-0.48	-1.12	-1.46	-9.45	0.20	0.36	-1.88	-0.79
Faridpur	-3.78*	-10.85	-1.22	-5.41	0.00	0.11	-1.13	-0.61
Feni	-2.00*	-5.79	-1.52	-12.18	0.95	2.98	-1.75	-0.96
Ishwardi	-2.00*	-4.82	-1.35	-8.13	0.39	0.42	-1.58	-0.85
Jessore	-2.19*	-3.86	0.26	1.73	0.56	1.25	-1.95	-1.34
Khepupara	0.11	0.20	0.57	3.48	1.66	6.92	-1.44	-0.66
Khulna	-1.89	-4.09	0.45	3.71	1.19	2.90	-1.74	-0.90
Madaripur	-2.11*	-6.46	-1.91	-11.69	1.13	2.63	-1.19	-0.80
Maijdee Court	-1.32	-5.71	-1.69	-10.78	2.03*	7.16	-1.75	-1.17
Mymensingh	-1.69	-5.50	-1.61	-11.58	-0.64	-1.71	-1.97*	-0.84
Patuakhali	-2.17*	-5.95	-1.60	-12.35	1.26	4.00	-1.83	-1.05
Rajshai	-0.74	-1.34	-2.09*	-9.68	0.17	0.33	-1.66	-0.75
Rangamati	-0.39	-2.05	0.68	3.48	1.10	2.83	-2.42*	-1.14
Rangpur	0.25	0.65	-3.08	-19.68	0.96	2.42	-2.56*	-1.00
Satkhira	-0.28	-0.56	-0.48	-2.80	1.07	2.25	-1.64	-1.16
Sitakunda	-0.70	-3.23	0.42	5.18	-0.40	-2.19	-1.15	-0.34
Sreemangal	-0.42	-2.85	-0.25	-0.61	0.06	0.17	-0.88	-0.47
Sylhet	-1.07	-6.72	-1.84	-18.05	0.57	1.21	-1.95	-1.16
Teknaf	2.39*	8.03	0.51	4.15	0.81	3.05	-1.63	-0.44

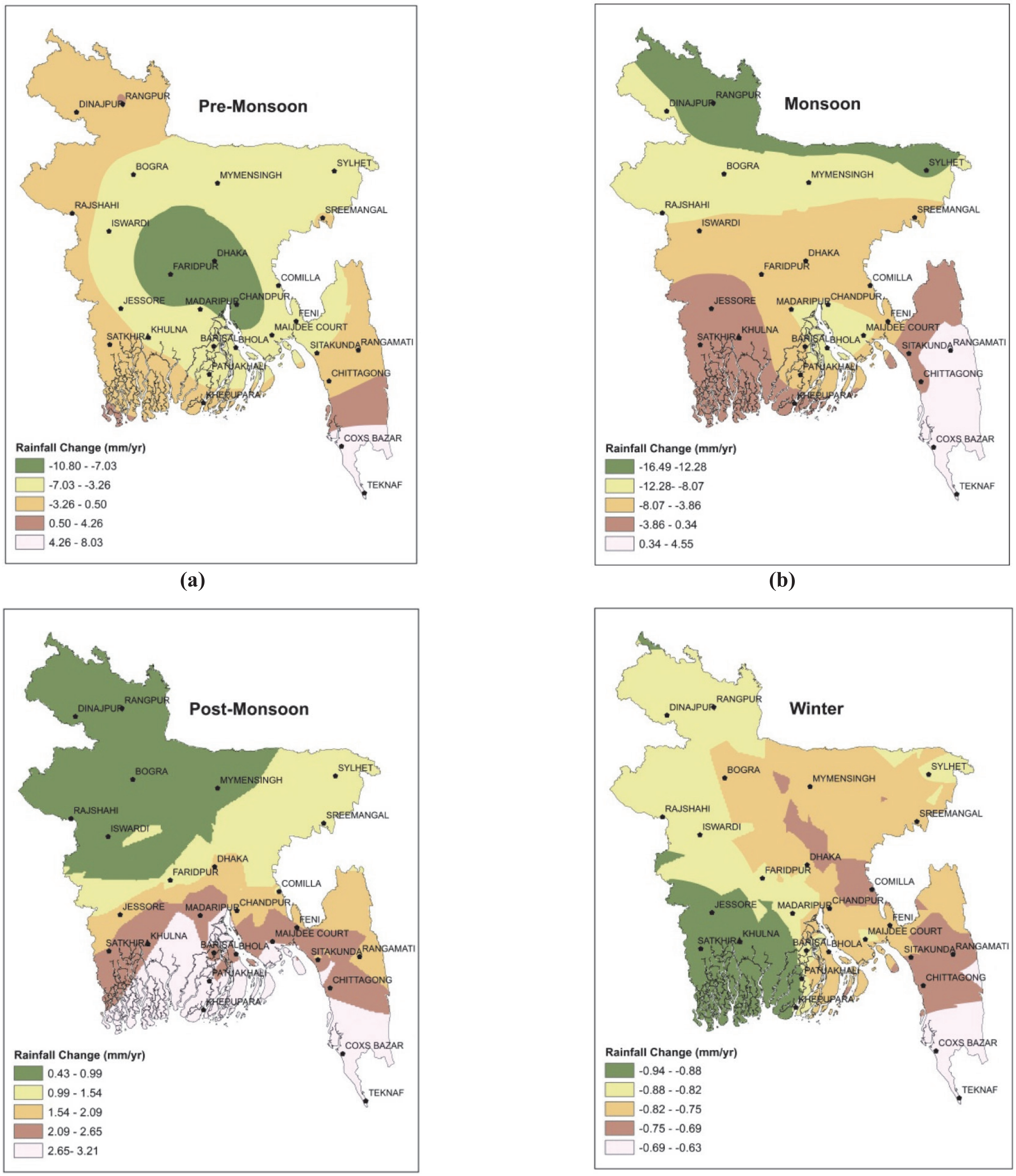
Z values with (*) mark indicate a significant trend

i.e. the rising trend had gradually been decreased as it moves from north to south. Dhaka and Mymensingh are the only two stations, which exhibited negative trend.

Winter: Winter is the driest season of the country. It is the only season when rainfall has not been increased at any of the studied BMD stations. Significant decrease had been observed in Bhola, Cox's Bazar, Mymensingh, Rangamati and Rangpur. Interestingly, the southeast part of the country had also shown decreasing trend.

Conclusions

Rainfall variability in respect to space and time is an important finding of the study. Annual, monsoon, pre-monsoon, and winter rainfall had been decreased in most parts of the country. Rising trend has only been found in post-monsoon season. The most substantial decrease was observed in northwestern part, as it is known as low rainfall region of the country. On the other hand, only the southeast region exhibited rising



(c) (d)

Figure 3: Trend of seasonal rainfall change over Bangladesh from 1975 to 2013.

trend. The increase of rainfall in the post-monsoon season and decrease in the other three seasons gives an indication of shifting of the rainy season.

Rainfall variability in Bangladesh can be triggered by several natural and human-induced factors including deforestation, diminution of water bodies, air pollution, El Nino and La Nina effects and so on. Impact of climate change in terms of rainfall variability in Bangladesh can be very critical, as it is one of the most vulnerable nations to Global Climate Change impact. The change can affect many sectors including agriculture and food security, water resources, ecosystems and biodiversity, human health, socioeconomic condition and so on. And detail study is essential to understand the scenarios of individual sectors so that proper adaptation and mitigation plan can be developed to face the challenges.

References

Ahmed, A.S.M.S. and Kim I.K., 2003. Patterns of daily rainfall in Bangladesh during the summer monsoon season: Case studies at three stations. *Physical Geography*, **24:** 295-318.

Ahmed, A.U., 2006. Bangladesh: Climate Change Impacts and Vulnerability—A Synthesis Climate Change Cell. Department of Environment, Bangladesh.

Banglapedia, 2017. Climate: National Encyclopedia of Bangladesh. http://en.banglapedia.org/index.php?title=Climate (accessed 26 June 2017).

Bangladesh Country Study Guide, 2012. Volume 1. International Business Publications, USA.

Basak, J.K., Titumir, R.A.M. and Dey, N.C., 2013. Climate Change in Bangladesh: A Historical Analysis of Temperature and Rainfall Data. *Journal of Environment*, **2(2):** 41-46.

Basistha, A., Arya, D.S. and Goel, N.K., 2009. Analysis of historical changes in rainfall in the Indian Himalayas. *International Journal of Climatology*, **99:** 555-572.

Dubin, R., 2008. Kriging. *In:* Encyclopedia of GIS. Shekhar, S. and Xiong, H. (eds). Springer US.

Hengl, T., 2007. A Practical Guide to Geostatistical Mapping of Environmental Variables. JRC Publications, European Communities, Luxembourg.

Jesus, R., 2003. Kriging: An Accompanied Example in IDRISI. GIS Centrum University for Oresund Summer University, Sweden.

Kendall, M.G., 1975. Rank Correlation Methods. 4thEdition. Charles Graffin, London.

Kleijnen, J., 2017. Kriging: Methods and Applications. *SSRN Electronic Journal*. 10.2139/ssrn.3075151.

Kreft, S., Eckstein D. and Melchior I., 2016. Global Climate Risk Index 2017: Who Suffers Most from Extreme Weather Events? Weather-related Loss Events in 2015 and 1996 to 2015. Germanwatche.V.

NPTEL, 2017. National Programme on Technology Enhanced Learning. http://nptel.ac.in/courses/105107129/module3/lecture4/lecture4.pdf (accessed 07 February 2018)

Onoz, B. and Bayazit, M., 2012. The Power of Statistical Tests for Trend Detection. *Turkish Journal of Engineering & Environmental Sciences*. **27(2003):** 247-251.

Ponce, V.M., 1989. Engineering Hydrology Principles and Practice. Prentice Hall.

Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, **63(324):** 1379-1389.

Sunila, R., Laine E. and Kremenova O., 2004. Fuzzy Modelling and kriging for imprecise soil polygon boundaries. Proceedings 12th International Conference on Geoinformatics − Geospatial Information Research: Bridging the Pacific and Atlantic. Gävle, Sweden.

Sunila, R. and Kollo, K., 2007. A comparison of geostatistics and fuzzy application for digital elevation model. The International Archives of the Photogrammetry. Remote Sensing and Spatial Information Sciences, 34. Part XXX.

Syed, A. and Amin, A.M., 2016. Geospatial modeling for investigating spatial pattern and change trend of temperature and rainfall. *Climate*, **4(21)**. doi:10.3390/cli4020021

Tabari, H., Marofi, S., Aeini, A., Talaee, P.H. and Mohammadi, K., 2011. Trend analysis of reference evapotranspiration in the western half of Iran. *Agricultural and Forest Meteorology*, **151(2):** 128-136. https://doi.org/10.1016/j.agrformet.2010.09.009

Theil, H., 1950. A rank invariant method of linear and polynomial regression analysis. Part 3. *Nederl. Akad. Wetensch Proc.*, **53:** 1397-1412.