Proceedings of the 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), 7~9 February 2020, KUET, Khulna, Bangladesh (ISBN-978-984-34-8764-3)

ANALYZING LONG-TERM TRENDS IN MONTHLY AND ANNUAL RAINFALL OVER WESTERN PART OF BANGLADESH

Zarin Tasnim*[1] and Sajal Kumar Adhikary[2]

[1]*Undergraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, e-mail: zarintasnim.zt3@gmail.com*
[2]*Professor, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, e-mail: sajal@ce.kuet.ac.bd*

***Corresponding Author**

ABSTRACT

Rainfall is the key climatic variable that governs the regional hydrologic cycle and availability of water resources. The climatic variability is referred to the long-term changes in rainfall, temperature, humidity, evaporation, wind speed and other meteorological parameters. In order to identify the change, quantification of environmental change is necessary that will be supportive to make forecast for future. This will result into a better planning and awareness for natural disasters. The objective of the study is to examine the rainfall variability over the western part of Bangladesh. This will give an understanding about trends or changes in rainfall over the studied region. In the current study, trend analysis has been carried out on monthly and annual rainfalls for the selected eleven rainfall stations located within the western part of Bangladesh. The well-known statistical trend analysis techniques including Mann-Kendall test and Sen's slope estimator are used to detect trends at the 5% significance level on time series data of the study area for the time period from 1948 to 2014. These tests are adopted to identify the change in magnitude and direction of existing trend over time. The analysis for trend detection using the Mann-Kendall test and Sen's slope estimator is undertaken in the XLSTAT 2016 platform. Trend detection of rainfall using the adopted techniques over 65 years shows increasing trend in monthly rainfall for four rainfall stations, namely Satkhira, Khulna, Jessore and Ishurdi stations. Three of them are located in the southwest coastal part of the study area. Furthermore, the analysis indicates similar trend in annual rainfall and the increasing trend is evidenced for three rainfall stations, namely Satkhira, Khulna and Ishurdi stations in which two are located in the coastal part. The findings of this analysis would be of interest to water resources managers and policy makers for the effective planning and management of water resources in Bangladesh.

Keywords: *Ranfall trend, Rainfall variability, Mann-Kendall test, Sen's slope, XLSTAT.*

1. INTRODUCTION

Water resource has become a major concern for any change and development including food manufacture, effective management and controlling of floods. Potential changes in climate might impact rainfall trend, which ultimately affects the overall water availability along with the drought risk as well as floods increases. Intergovernmental Panel on Climate Change (IPCC) demonstrates that the temperature has increased by 0.74°C ± 0.18°C throughout the most recent 100 years. In additiona, rainfall is expected to increase by 0.2 to 0.3% every period over zones of land in 21^{st} century (IPCC, 2007). To address environmental changes and its effects on the various parts, the impact of climate change on agriculture, increased water shortages, rapid melting of glaciers and decrease in streamflows should be properly assessed.

Rainfall is the key climatic variable that governs the regional hydrologic cycle and availability of water resources. This is also an important parameter that can indicate the evidence of climate change. The climatic variability is referred to the long-term changes in rainfall, temperature, humidity, evaporation, wind speed and other meteorological parameters. In order to identify the change, quantification of environmental change is necessary that will be supportive to make forecast for future. This will result into a better planning and awareness for natural disasters.

Rainfall and its intensity are vital factors on the climate of Bangladesh for agricultural production (Shahid, 2010a). The total economy of this country highly depends on rainfall. A slight change in rainfall patterns can cause a blessing or misfortune for this country. The variability and trends in rainfall and temperature patterns have been documented by many researchers in Bangladesh (Bhuyan et al., 2018; Shahid, 2010a; Shahid, 2010b). However, none of the studies have been found specific to the western part of Bangladesh, which is an important region of the country from the socio-economic point of view.

The objective of the study is to examine the rainfall variability and trends over the western part of Bangladesh. Detection of trends in rainfall in various scales will give an improved understanding to the issues related with flood inundations and scarcities of water for utilizing in different climatic conditions. Assessment of rainfall and analysis of annual maximum daily rainfall would upgrade the management of water resources as well as the viable utilization of water resources (Mondal et. al., 2013). In the current study, trend analysis has been carried out on monthly and annual rainfalls for the selected eleven (11) rainfall stations located within the western part of Bangladesh. Since the impact of climate change on rainfall is also a serious concern to water resources managers and policy makers, a trend analysis of the extreme rainfall events is also undertaken in the current study.

2. STUDY AREA AND DATA USED

The rainfall is highly variable in the western part of Bangladesh. Particularly, this part of the country experiences the shortages of rainfall compared to other parts of the country and thus frequent droughts occur in this region (Shahid & Behrawan, 2008). Furthermore, the coastal belt in this part of the country faces severe problems of water salinity and freshwater shortages. The potential impact of climate change may aggravate the problems in this part of the country (Hossain, 2014). Therefore, the western part of Bangladesh is selected as a case study area in this study for long-term rainfall trend analysis. It could be helpful for setting up future water management plans and strategies.

In the trend analysis, one of the limitations is the use of short dataset to assess the variability of rainfall in time. If the dataset is not long enough it is difficult to determine whether the observed trends in rainfall data series are due to natural fluctuations in the weather and climate or whether the atmospheric forcing has experienced (anthropogenic/deterministic) a change (Hajani et al., 2017). Therefore, daily rainfall data for a period of 65 years from 1948 to 2014 for eleven (11) rainfall stations located in the study area is obtained from the Bangladesh Meteorological Department (BMD). Details of those stations are presented in Table 1. Table 1 also presents the duration of records used for trend analysis for each rainfall station. This daily rainfall data is used to calculate the monthly and annual rainfall data series, which is finally used for estimating long-term trend in the monthly and annual rainfall series. The locations of the selected eleven rainfall stations in the study area are shown in Figure 1.

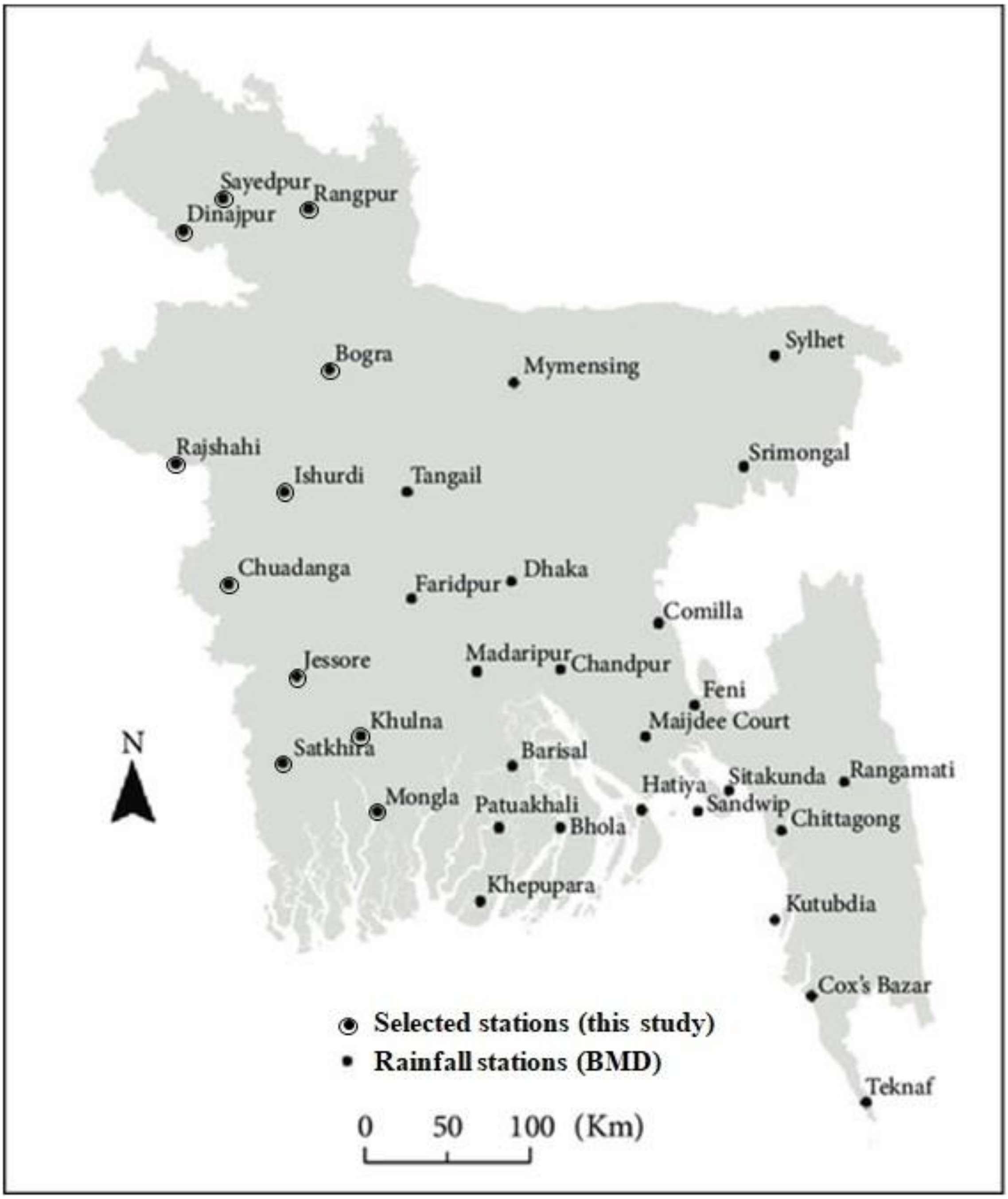

Figure 1: The study area (western part of Bangladesh) with location of rainfall stations

Table 1: Details of rainfall stations used for trend analysis in this study

SN	Station Name	Latitude (N)	Longitude (E)	Elevation (m)	Data Period
1	Bogra	24˚51′	89˚22′	17.9	1948-2014
2	Chuadanga	23˚39′	88˚49′	11.58	1989-2014
3	Dinajpur	25˚39′	88˚41′	37.58	1948-2014
4	Ishurdi	24˚09′	89˚02′	12.9	1961-2014
5	Jessore	23˚12′	89˚20′	6.1	1948-2014
6	Khulna	22˚47′	89˚32′	2.1	1948-2014
7	Mongla	22˚28′	89˚36′	1.8	1991-2014
8	Rajshahi	24˚22′	88˚42′	19.5	1964-2014
9	Rangpur	25˚44′	89˚16′	32.61	1954-2014
10	Satkhira	22˚43′	89˚05′	3.96	1948-2014
11	Sayedpur	25˚45′	88˚55′	39.6	1991-2014

3. METHODOLOGY

In the current study, the long-term trend analysis is performed for the monthly and annual rainfall data series for the selected eleven (11) rainfall stations located in the western part of Bangladesh. The generic framework of methodology adopted in this study for the rainfall trend analysis is shown in Figure 2. A non-parametric trend estimation technique, widely known as the Mann-Kendall's test (Panda & Sahu, 2018) is adopted in this study to obtain the trends in monthly and annual rainfall data series in the study area. Generally, the parametric (distribution-dependent) or non-parametric (distribution-free) statistical tests can be used to decide whether there is a statistically significant trend in the data series. This non-parametric test is taken into consideration over the parametric one because it can avoid the problem roused by the skewed data. The trend analysis rainfall in the current study is carried out in the XLSTAT 2016 software platform. The main advantage of this software is that it allows taking into account and removing the effect of autocorrelation in the data series.

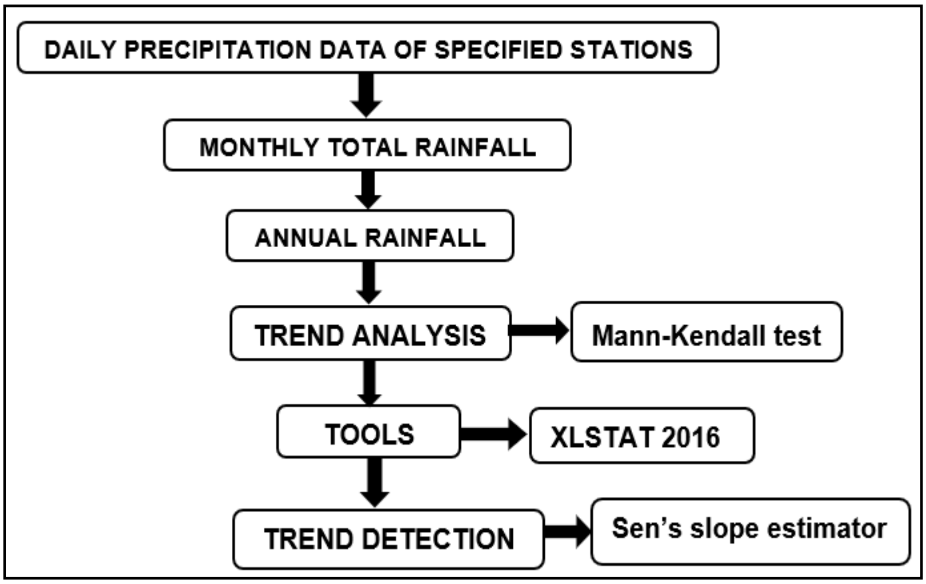

Figure 2: Framework of methodology adopted in this study for trend analysis

3.1 Mann Kendall Test

The initial value of Mann-Kendall's statistic, S, is assumed to be 0 (e.g., indicating no trend). A very high positive value of S is an indicator of an increasing trend and a very low negative value indicates a decreasing trend (Khambhammettu, 2005). The three alternative hypotheses are that there is a negative, non-null, or positive trend. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend. Kendall's tau (Hollander et al., 2014) is used to identify strength of the trend and alpha (α) indicates the level of significance. The null hypothesis is tested at 95% confidence level for the monthly and annual rainfall data series for all selected station in this study. In order to calculate the p-value of this test, a normal approximation is used. If the p-value is less than the significance level α (alpha = 0.05), H_0 is rejected. The rejection of H_0 indicates that there is a trend in the time series, while accepting H_0 indicates that there is no trend present in the data series. On rejecting the null hypothesis, the result is said to be statistically significant.

3.2 Sen's Slope Estimator

The Sen's Slope method (Sen, 1968) involves the calculation of slopes for all the pairs of ordinal time points and then using the median of these slopes as an estimation of the overall slope. The Sen's method assumes that the trend is linear (Shahid, 2010b). In the current study, the magnitude of the trend is estimated by the Sen's slope method, which have been widely used for estimating the magnitude of the trend (e.g., Kamal & Pachauri, 2019).

4. RESULTS AND DISCUSSION

4.1 Trends in Monthly and Annual Rainfall Data

Initially, the statistical analysis is carried out for the monthly and annual rainfall data series for all the selected eleven (11) rainfall stations in the western part of Bangladesh, which is presented in Table 2.

Table 2: Summary of statistics of monthly and annual rainfall data in the study area

SN	Station Name	Mean (mm)	Max (mm)	Min (mm)	Std. Dev (mm)
Monthly Rainfall					
1	Bogra	139.4	835.0	0.0	164.616
2	Chuadanga	122.3	818.0	0.0	143.682
3	Dinajpur	153.4	1196.0	0.0	193.102
4	Ishurdi	120.2	1167.0	0.0	149.024
5	Jessore	131.0	917.0	0.0	147.383
6	Khulna	139.5	846.0	0.0	159.114
7	Mongla	159.1	983.0	0.0	169.142
8	Rajshahi	122.2	763.0	0.0	140.247
9	Rangpur	174.2	1314.0	0.0	208.372
10	Satkhira	133.8	728.0	0.0	151.695
11	Sayedpur	177.1	951.0	0.0	214.904
Annual Rainfall					
1	Bogra	1607.8	2516.0	751.0	408.243
2	Chuadanga	1380.0	1951.0	381.0	345.869
3	Dinajpur	1742.3	3179.0	479.0	510.346
4	Ishurdi	1448.5	2742.0	525.0	436.474
5	Jessore	1505.0	2444.0	494.0	376.341
6	Khulna	1571.0	2762.0	271.0	464.171
7	Mongla	1506.5	2786.0	569.0	415.449
8	Rajshahi	1248.0	2241.0	429.0	332.658
9	Rangpur	1958.8	3748.0	427.0	596.806
10	Satkhira	1413.6	2251.0	297.0	460.246
11	Sayedpur	1978.0	3145.0	562.0	586.905

As can be seen from Table 2, mean monthly rainfall in the study area varies from 120.2 mm at Ishurdi station to 177.1 mm at Sayedpur station whereas mean annual rainfall in the study area varies from 1248.0 mm at Rajshahi station to 1978.0 mm at Sayedpur station. It is worth mentioning that Ishurdi and Rajshahi stations are close to each other and thus the lowest rainfall occurs in those areas. However, the highest monthly and annual rainfall occurs at Sayedpur station located in the furthest north-western part of the study area. The higher elevation combined with the effect of the Himalayan located north of the country boundary line may cause this increase rainfall in the furthest north-western part of the study area. Another interesting finding is that the rainfall is relatively lower in the coastal belt (including the area covered by Jessore, Khulna, Mongla and Satkhira stations), particularly in the south-west part of the study area. Overall, it can be concluded based on the statistical analysis of monthly and annual rainfall that there is a great variation of rainfall patterns in the western part of Bangladesh from north to south.

In order to estimate the trend in rainfall data series, the Mann-Kendall test is performed using the XLSTAT 2016 software. After performing the Mann-Kendall test on the monthly rainfall data series for the selected eleven (11) rainfall stations in the study area, the trend analysis results for monthly rainfall data is obtained, which is presented in Table 3. The results given in Table 3 indicate that the null hypothesis is accepted for seven (7) rainfall stations (e.g., Bogra, Chuadanga, Dinajpur, Mongla, Rajshahi, Rangpur and Sayedpur). On the other hand, the null hypothesis is rejected for remaining four (4) rainfall stations (e.g., Ishurdi, Jessore, Khulna and Satkhira). The rejection of null hypothesis indicates that the p-value of this test is less than the significance level of alpha. The initial value of Mann-Kendall statistic S is positive for the aforementioned four stations. Since the positive value of S remains for the increasing trend, these four stations show the signs of having the increasing trend. Ishurdi station, which is located in the north-western region of Bangladesh, shows the increasing trend. It is also found that the other three stations, Jessore, Khulna and Satkhira, which are located in the south-western coastal belt of Bangladesh, exhibit the increasing trend. The results of Sen's slope estimator also indicate that the magnitude of trend for these four stations is positive. It is interesting to see from the results that Mongla station does not show any trend although it is located near to Khulna and Satkhira stations. This may be due to the fact that the duration of available data is much lower than the aforementioned two stations. It is important to note that it is difficult to determine the non-parametric trends or may give fake results if the dataset is not long enough (Hajani et al., 2017).

Table 3: Trend analysis results for monthly rainfall data in the study area

SN	Station Name	Kendall's tau	S	p-value	alpha	Decision	Sen's slope	Trend Interpretation
1	Bogra	0.020	6385	0.395	0.05	Accept	0	Not Significant
2	Chuadanga	-0.004	-164	0.927	0.05	Accept	0	Not Significant
3	Dinajpur	0.049	11707	0.057	0.05	Accept	0	Not Significant
4	**Ishurdi**	0.077	15487	0.004	0.05	Reject	0.007	**Increasing**
5	**Jessore**	0.048	14662	0.046	0.05	Reject	0.006	**Increasing**
6	**Khulna**	0.054	15371	0.028	0.05	Reject	0.004	**Increasing**
7	Mongla	-0.024	-923	0.559	0.05	Accept	0.006	Not Significant
8	Rajshahi	-0.015	-2471	0.597	0.05	Accept	0	Not Significant
9	Rangpur	0.045	10898	0.078	0.05	Accept	0.004	Not Significant
10	**Satkhira**	0.059	17337	0.015	0.05	Reject	0.004	**Increasing**
11	Sayedpur	-0.007	-277	0.861	0.05	Accept	0	Not Significant

Table 4 presents the results of the Mann-Kendall test on the annual rainfall data series for the selected eleven (11) rainfall stations in the western part of Bangladesh. As can be seen from the table, three stations including Ishurdi, Khulna and Satkhira exhibit the sign of increasing trends whereas the remaining eight (8) rainfall stations show the non-significant trend. Furthermore, the magnitude of trend for these three stations is found positive based on the results of Sen's slope estimator on the annual rainfall data. It is also seen from the results that the trend results of the annual rainfall data are consistent with the trend results of the monthly rainfall data.

Table 4: Trend analysis results for annual rainfall data in the study area

SN	Station Name	Kendall's tau	S	p-value	alpha	Decision	Sen's slope	Trend Interpretation
1	Bogra	0.021	7672	0.365	0.05	Accept	0	Not Significant
2	Chuadanga	0.004	237	0.906	0.05	Accept	0	Not Significant
3	Dinajpur	0.046	12851	0.065	0.05	Accept	0	Not Significant
4	**Ishurdi**	0.08	18917	0.002	0.05	Reject	0.009	**Increasing**
5	Jessore	0.045	16171	0.051	0.05	Accept	0.007	Not Significant
6	**Khulna**	0.051	16964	0.032	0.05	Reject	0.005	**Increasing**
7	Mongla	-0.012	-539	0.763	0.05	Accept	0	Not Significant
8	Rajshahi	-0.01	-1905	0.718	0.05	Accept	0	Not Significant
9	Rangpur	0.043	12228	0.080	0.05	Accept	0.005	Not Significant
10	**Satkhira**	0.057	19481	0.016	0.05	Reject	0.006	**Increasing**
11	Sayedpur	0.001	67	0.970	0.05	Accept	0	Not Significant

4.2 Trends in Extreme Rainfall Events

In the recent past, it has been suggested that the extreme rainfall events are becoming more intense due to the impact of climate change. An attempt is made to identify if there are any differences in the intensities of extreme rainfall events for the stations showing increasing trend of rainfall (e.g., Ishurdi, Jessore, Khulna and Satkhira) as identified in the non-parametric trend analysis. The index adopted to measure the intensity of rainfall events is the 'maximum 1-day rainfall' in a year for those stations. Figure 3 shows the bar plots for the maximum 1-day rainfall at Ishurdi, Jessore, Khulna and Satkhira stations.

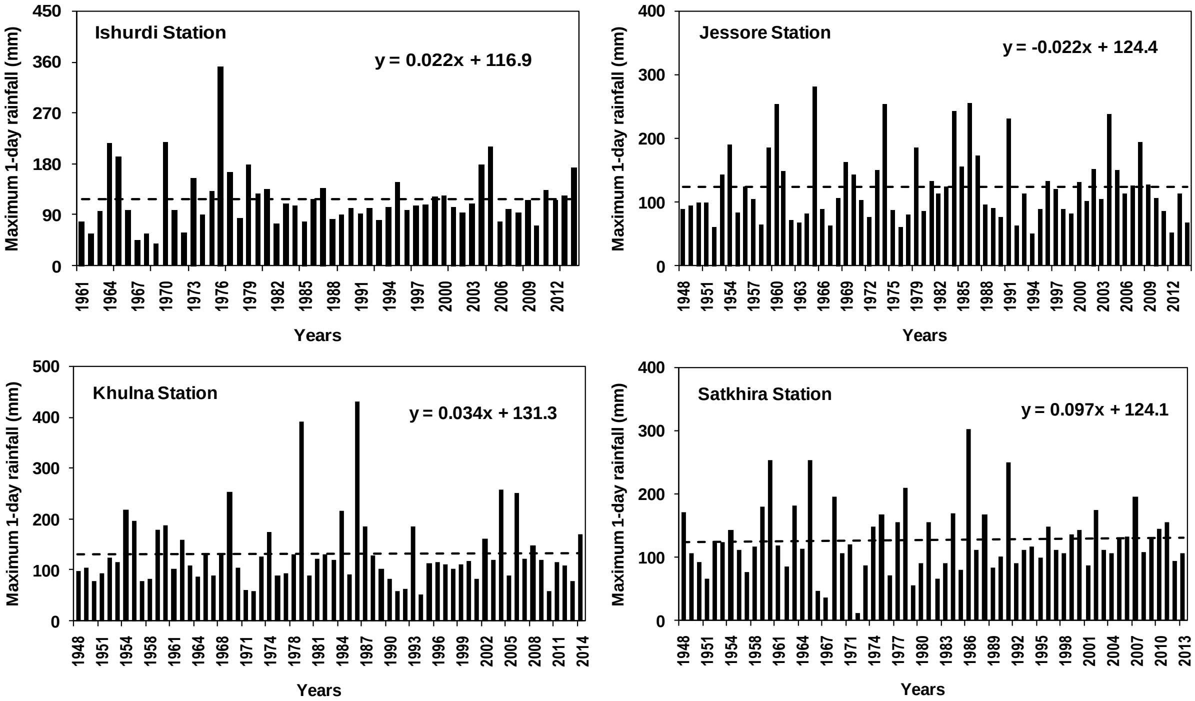

Figure 3: Maximum 1-day rainfall at stations showing increasing trend of rainfall

It can be seen from Figure 3 that the trends of maximum 1-day rainfall is increasing for Ishurdi, Khulna and Satkhira stations whereas for Jessore station, the trend of maximum 1-day rainfall is decreasing. It is worth mentioning that this result is consistent with the results obtained by the non-parametric trend analysis using the Mann-Kendall test based on the annual rainfall data series. Thus, it is clearly observed that the storm events are becoming more intense along with the long-term increasing trend of rainfall. This has serious implications on the water management in those areas where these stations are located. Specifically, the low-lying coastal belt could be severely affected due to the increasing trend of extreme rainfall events combined with the potential impact of climate change.

5. CONCLUSIONS

This study focuses on the analysis and detection of trends of long-term trend monthly and annual rainfall data series for selected eleven (11) rainfall stations located within the western part of Bangladesh. For this purpose, the widely used Mann-Kendall's test and Sen's slope estimator is adopted at 5% significance level on monthly and annual rainfall time series data for each of the eleven stations for the time period, 1948 to 2014. The results of Mann-Kendall's test statistic (S) indicate how strong the trend in rainfall data is and whether it is increasing, stable or decreasing. Trend detection of rainfall using the adopted techniques over 65 years shows increasing trend in monthly rainfall for four rainfall stations, namely Satkhira, Khulna, Jessore and Ishurdi stations. Three of them are located in the southwest coastal part of the study area. The trend analysis results for annual rainfall data also demonstrate similar patterns and the increasing trend is evidenced for three rainfall stations, namely Satkhira, Khulna and Ishurdi stations in which two are located in the coastal part. On the other hand, linear trend line plotting of the maximum 1-day rainfall for Satkhira, Khulna, Jessore and Ishurdi stations indicates an increasing trend of rainfall in Ishurdi, Khulna and Satkhira stations and a decreasing trend of rainfall in Jessore station. This finding is consistent with the trend analysis results for the annual rainfall data series obtained by the non-parametric Mann-Kendall test. The findings of this analysis would be of interest to water resources managers and policy makers for the effective planning and management of water resources in Bangladesh.

REFERENCES

Bhuyan, M.D. I., Islam, M.M., & Bhuiyan, M.E.K. (2018). A trend analysis of temperature and rainfall to predict climate change for northwestern region of Bangladesh. *American Journal of Climate Change*, 7, 115-134.

Hajani, E., Rahman, A., & Ishak, E. (2017). Trends in extreme rainfall in the State of New South Wales, Australia, *Hydrological Sciences Journal*, 62(13), 2160-2174.

Hossain, M. F. (2014). Impact of climate change in Bangladesh: Rainfall. *International Journal of Agriculture Innovations and Research,* 2(5), 2319-1473.

Intergovernmental Panel on Climate Change (IPCC) (2007). *Climate Change 2007: The Scientific Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon et al., Cambridge University Press, New York.

Kamal, N., & Pachauri, S. (2019). Mann-Kendall, and Sen's Slope estimators for precipitation trend analysis in north-eastern states of India. *International Journal of Computer Applications*, 177(11), 7-16.

Khambhammettu, P. (2005). *Mann-Kendall Analysis for the Fort Ord site*. HydroGeoLogic, Inc., California, USA.

Mondal, M.S., Jalal, M.R., Khan, M.S.A., Kumar, U., Rahman, R., & Huq, H. (2013). Hydro-meteorological trends in southwest coastal Bangladesh: Perspectives of climate change and human interventions. *American Journal of Climate Change*, 2(1), 62-70.

Panda, A. & Sahu, N. (2018). Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmospheric Science Letters*, 20(2), e932, DOI: 10.1002/asl.932.

Sen, P. K. (1968). Estimates of the Regression Coefficient Based on kendall's Tao. *Journal of the American Statistical Association*, 63(324), 1379-1389.

Shahid, S. (2010a). Recent trends in the climate of Bangladesh. *Climate Research, 42(3)*, 185-193.

Shahid, S. (2010b). Rainfall variability and the tends of wet and dry periods of Bangladesh. *International Journal of Climatology,* 30(15), 2299–2313.

Shahid, S. & Behrawan, H. (2008). Drought risk assessment in the western part of Bangladesh. *Natural Hazards*, 46(3), 391-413.