Jahangirnagar University Journal of Statistical Studies
ISSN 1022-4734

http://www.juniv.edu/department/stat

JUJSS, Vol. 36, 2022, pp. 139-155

Analysis of Rainfall Frequency Trend in Pre-Monsoon and Monsoon Season over Bangladesh

Md. Bazlur Rashid*
Meteorologist, Bangladesh Meteorological Department, Dhaka

Khadija Khatun
Department of Applied Mathematics, University of Dhaka

Afruza Sultana
Assistant Meteorologist, Bangladesh Meteorological Department, Dhaka

A.K.M. Nazmul Hoque
Meteorologist, Bangladesh Meteorological Department, Dhaka

Abstract

This study has been conducted on the basis of climate data such as rainfall of 30 selected stations for the period of 37 years from 1981 to 2017. Data are collected from Bangladesh Meteorological Department in daily basis. In this paper, the changing pattern of rainfall frequency in Bangladesh has been investigated. For this study, the Mann-Kendall test have been used to run 5% significance level on time series data for each station over the study period to detect the trend in rainfall frequency. We have observed that, rainfall frequency in pre-monsoon season are decreasing over all but not significantly. Here, it can easily understand that very heavy rainfall in March and moderately heavy to very heavy rainfall in April are decreasing significantly and the maximum frequency is 0.271/ year of very heavy rainfall in April. Their decreasing rates vary from 0.164 to 0.271. The light rainfall frequency in May of pre-monsoon and the whole monsoon season are increasing significantly. The increasing rates vary from 0.168 to 0.292 and the peak of increasing rate is 0.292/year, which occurs in July and the rest of the categories are insignificant. Spatial distribution of light and moderate to very rainfall frequency has been shafted in Bangladesh at decadal based, especially moderate to very rainfall frequency is changing rapidly in the country. From our study, it is projected that rainfall frequency in pre-monsoon season will slightly increase but in monsoon season it will decrease in the future.

***Keywords**:* Rainfall Frequency, Mann-Kendall Test, Trend Analysis, Spatial Distribution.

1. Introduction

Bangladesh is situated in the tropical monsoon county and its weather or climate is influenced by high temperature, heavy rainfall, often excessive humidity and is also depended on seasonal variations. The most prominent element of its climate is the reversal of the wind rotation between summer and winter, which is a fundamental part of the rotation system of the South Asian subcontinent. Bangladesh is a subtropical monsoon climate region. The climate of this country can be described under four seasons: Winter or Northeast Monsoon (December – February), which is characterized by very light northerly

* Corresponding author: bazlur.rashid76@gmail.com

winds, mild temperature and dry weather and clear to occasionally cloudy skies with fog over the country and the mean temperature is in the range of 18-20°C; Summer or Pre-Monsoon (March-May), the average temperature during the summer season holds within 23-30°C, April and May are the hottest months in this country and the highest maximum temperature ranging from 36-40°C is attained in the north-western and south-western districts. Southwest Monsoon (June-September), in this season, the surface wind changes to south-westerly/southerly direction over the southern and the central districts and to south-easterly over the northern districts of the country, generally rain with widespread cloud cover and high humidity are the characteristics of this season, more than 71% of the total annual rainfall occurs in this season (Khatun et. al. 2016). The transition of season from the summer monsoon to the winter take places through Autumn or Post-Monsoon (October-November), when rainfall decreases noticeably. The dry period starts over the country and only 8% of the total annual rainfall occurs in this season.

Rainwater is very vital for the economic growth, disaster managing and hydrological planning for the country. An increasing in intensity of heavy rainfall events in Bangladesh through the simulation of variability and extremes of daily rainfall was predicted by May (2004). In the study of Rani et. al. (2014), where the rainfall data of Coimbatore for a period of 106 years (1907-2012) was analyzed, it is predicted that the rainy days are increasing but the changes were not statistically significant. An analysis of rainfall data for the generation of intensity duration frequency relationships showed that it has no significant change in rainfall intensities by Rimi et. al. (2016).

In this study, the changing pattern of rainfall frequency in Bangladesh has been investigated. The Mann-Kendall (MK) test is used to run 5% significance level on time series data for each station for the period of 1981 to 2017 and for future projection, Holt-Winters statistical model has been used here.

2. Data Sources

All categories of weather data like daily or monthly scale are existing at Bangladesh Meteorological Department (BMD), Agargaon (Dhaka), Bangladesh**.** In the present study, we have collected thirty-seven years' (1981-2017) daily rainfall data in millimeter(*mm*) of 30 rainfall stations throughout Bangladesh from BMD. To perform statistical analysis, monthly data have been prepared by taking mean of the daily data. Rainfall data from March to September have been classified as: Light rain (1-10 *mm*), Moderate rain (11-22 *mm*), Moderately heavy rain (23-44 *mm*), Heavy rain (45-88 *mm*), and very heavy rain (>88 *mm*).

3. Methodology

The approximation, extrapolation and calculation of trends and related statistical and numerical implication are important aspects of climate study. The rate at which rainfall changes over a time period is known as trend of the rainfall (Ahasan et. al. 2010). In the trend investigation, parametric and nonparametric equally are used broadly. Regression analysis methods are used for parametric purposes. Nonparametric approaches deal a smart alternative in this concern. Nonparametric prototypes for simulating rainfall fluctuate from the traditional procedures. The extremity performance of the data does not improperly impact the probability distribution in the core group of the data, and successive dependency is well-maintained in a more overall logic. As a consequence, the demonstration of separate outlier events may not be any better than that realized through the general parametric methods. But, the properties of classifications, including the statistics of a run of outlier events, may be better denoted. Removing the extremes data, nonparametric methods may provide an effective tool. The MK test can be used to measure monotonic trend (linear or non-linear) implication. So, in this study, we have used the MK test to detect the trend of rainfall frequency in Pre-monsoon as well as monsoon seasons in Bangladesh.

3.1 Mann- Kendall (MK) Test

The MK experiment developed by Mann, H. B. (1945) and Kendall, M. G. (1975) is generally used for tendencies classifying in climatologic and weather data in time series analysis. There are two benefits of using the MK test - (i) data need not to be normally distributed, and (ii) sensitivity reduces to be in a minimum level due to non-homogeneity of time series data (Tabari *et al*, 2011). The hypothesis for the test are as follows:

H_0: No monotonic trend.
H_1: Monotonic trend is present.

The MK test statistic (S) is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(T_j - T_i).$$

$$Sign(T_j - T_i) = \begin{cases} 1 \; if \; T_j - T_i > 0 \\ 0 \; if \; T_j - T_i = 0 \\ -1 \; if \; T_j - T_i < 0 \end{cases}.$$

Where, T_j and T_i are the monthly values in months j and i, $j > i$ respectively.

If $n < 10$, the value of $|S|$ is shares straight to the theoretical distribution of S derived by MK. The two tailed experiment is used. At definite likelihood level H_0 is rejected in favor of H_1 if the original value of S equals or exceeds a certain value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the lowest S which has the possibility less than $\frac{\alpha}{2}$ to execute in case of no trend. A positive (negative) value of S designates an upward (downward) trend. For $n \geq 10$, the statistic S is almost normally distributed with the mean and variance as follows:

$$E(S) = 0.$$

The σ^2 for the S statistic is expressed by:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18}.$$

Where, t_i's represent the number of ties to extent i. The synopsis term in the numerator is used only if the data series contains tied values. The standard test statistic Z_s is considered as bellows:

$$Z_s = \begin{cases} \frac{S-1}{\sigma} \; for\; S > 0 \\ 0 \; for\; S = 0 \\ \frac{S+1}{\sigma} \; for\; S < 0 \end{cases}.$$

The test statistic Z_s is used a quantity of significance of trend. In detail, this experiment statistic is used to experiment the null hypothesis, H_0. If $|Z_s|$ is greater than $Z_{\alpha/2}$, where α denotes the special implication level (eg: 5% with $Z_{0.025} = 1.96$) then the null hypothesis is inacceptable suggesting that the trend is important.

3.2 Nearest Neighbor (NN) Method

Spatial patterns or spatial distribution of data are generated by NN method. NN procedures are among the most popular methods used in statistical pattern recognition (Holmes et. al. 2002). The models are conceptually simple and empirical, studies have shown that their performance is highly competitive against other techniques such as Kriging, Inverse distance a power, triangulation with linear interpolation etc. It turns out that whether or not the data are regular or irregular is unimportant once anybody define what is known as NN.

Let $\mathcal{R} = \{s_i : i = 1, 2, \dots n\}$ where, $\mathcal{R} \subset \mathcal{R}^d$, for d a positive integer, be the set of all sites making up a finite lattice. Two sites are said to be neighbors, if the response variables at these sites depend on each other directly. Let $N_i = \{S_k\,;\, S_k \text{ is a neighbor of } s_i\}$, $i = 1, 2, \dots, n$. Then the set $G_{\mathcal{R}} = \{S_i, N_i : 1, 2, \dots, n\}$ is defined as a NN for $\mathcal{R}$, with the following two properties:

1. $s_i \notin N_i, i = 1, 2, \dots, n$ (a site is not a neighbor of itself).
2. $s_j \in N_j \Rightarrow s_j \in N_i, \forall_i, j = 1, 2, \dots, n.$

Example of NN: Suppose a realization $y = \{y\,(s_i) : i = 1,2, \dots, n\}$ is taken from a regular $n_1 \times n_2$ grid of sites in $\mathcal{Z}^2$ (the two dimensional integer space) where, $n = n_1 \times n_2$ is the number of sites in the lattice. For this setup, a two dimensional coordinate (j, k) corresponds naturally to each site S_i. Hence, this two dimensional lattice $\mathcal{R}$ and corresponding realization can be defined by:

$\mathcal{R} = \{(j,k); j = 1,2,\dots,n_1 \ and \ k = 1,2,\dots n_2\}.$

$y = \{y_{jk}; j = 1,2,\dots,n_1 \ and \ k = 1,2,\dots n_2\}.$

The first-order neighborhood system consists with the horizontal and vertical adjacent units. Precisely, this neighborhood system is defined with the sites for which the following criteria is satisfied.

$$N(j,k) = \left\{(j',k'): (j-j')^2 + (k-k')^2 = 1\right\}.$$

The second-order neighborhood system for a given site (i,j) is defined the sites for which the following criteria is satisfied

$$N(j,k) = \left\{(j',k'): (j-j')^2 + (k-k')^2 \leq 2\right\}.$$

The same idea can be extended for defining a neighborhood system of higher order. Lattice or areal data units are neighbors if they are within a distance d. Distance based neighboring suggests that, one can create distance bins such as $(0,d_1], (d_1,d_2], (d_2,d_3]$, and so on, to extend the concept of neighborhood system in terms of first-order neighborhood, second-order neighborhood, third-order neighborhood and so on, respectively. In this type of neighborhood, those units who are within $(0,d_1]$ distance from unit i are said to be first order neighbor of unit i, those units who are within $(d_1, \ d_2]$ distance from unit i are said to be second order neighbor of unit i and so on.

3.3 Holt-Winters Exponential Smoothing Additive Model

Holt (1957) and Winters (1960) methods contain the forecast equation and three smoothing equations for- level, trend and seasonality with smoothing parameters. In this study, we have used Holt-Winters trend method to detect the trend in monthly rainfall frequency data of pre-monsoon and monsoon season. The component form for the additive model is

Forecast equation: $\hat{y}_{t+h|t} = l_t + hb_t$.
Level equation: $l_t = \alpha y_t + (1-\alpha)(l_{t-1} + b_{t-1})$.
Trend equation: $b_t = \beta * (l_t - l_{t-1}) + (1 - \beta *)b_{t-1}$.

Where, l_t denotes an estimate of the level of the series at time t, b_t denotes an estimate of the trend (slope) of the series at time t, α is the smoothing parameter for the level, $0 \leq \alpha \leq 1$, and $\beta *$ is the smoothing parameter for the trend, $0 \leq \beta * \leq 1$.

The level equation shows l_t is a weighted average of the observation y_t and the one step ahead training forecast for time t is given by l_{t-1}+b_{t-1}. The trend equation shows that, b_t is a weighted average of the estimated trend at time t based on $l_t - l_{t-1}$ and b_{t-1}, and h is the linear function of the forecast.

4. Results and Discussions

4.1 Trend of Rainfall Frequency in Pre-Monsoon Season

From Table 4.1, we observed that rainfall frequency in the pre-monsoon season are decreasing over all but not significantly. Here, it is clear that very heavy rainfall in March is decreasing at the rate 0.164/ year (Fig. 4.1.1), whereas light rain in May is increasing at the rate 0.257/year with 5% level of significance. In April, on the other hand, moderately heavy, heavy and very heavy rainfall is significantly decreasing, shown in Figs. (4.1.2 – 4.1.4)**,** where the highest decrement rate is 0.271 per year for very heavy rainfall.

Table 4.1. Trend of Rainfall Frequency in Pre-monsoon Season

Categories	March		April		May	
	τ	p	τ	p	τ	p
Light rain (1-10 *mm*)	-0.036	0.382	0.000	0.5	**0.257**	**0.013***
Moderate rain (11-22 *mm*)	0.017	0.448	-0.103	0.19	0.079	0.252
Moderately heavy rain (23-44 *mm*)e	-0.125	0.144	-0.225	**0.026***	0.101	0.194
Heavy rain (45-88 *mm*)**5-88)**	-0.053	0. 333	-0.224	**0.029***	-0.045	0. 352
Very heavy rain (>88 *mm*) **e**	**-0.164**	**0.099**$^{+}$	-0.271	**0.013***	-0.031	0.402

‘+’ indicates the presence of monotonic trend at 10% level and ‘*’ indicates the presence of monotonic trend at 5% level of significance

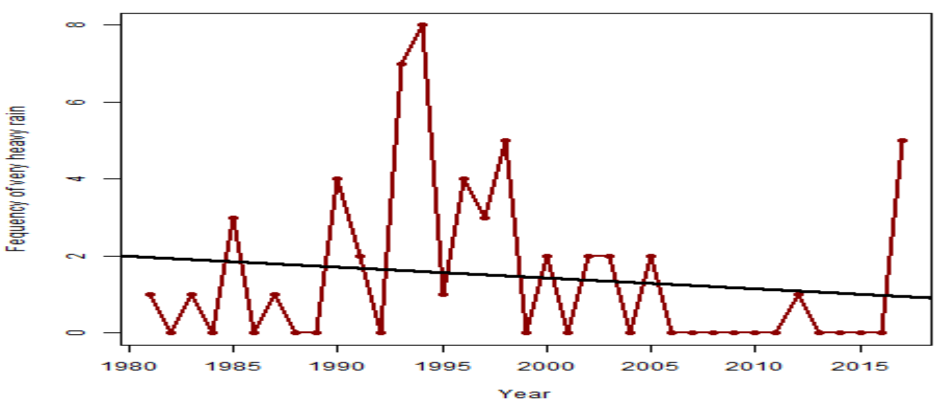

Figure 4.1.1. Trend Analysis of Frequency of Very Heavy Rain in March

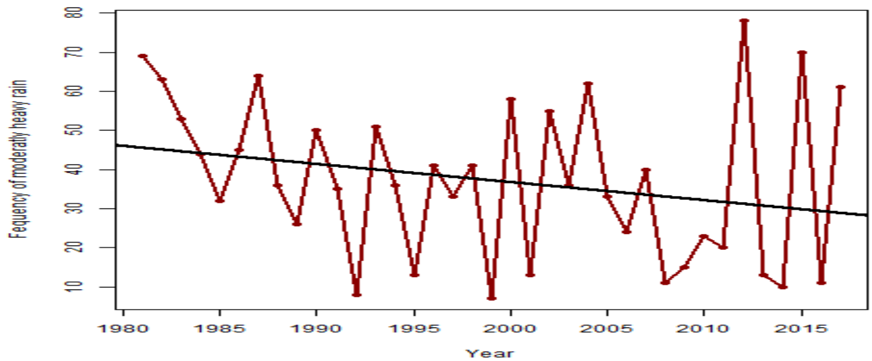

Figure 4.1.2. Trend Analysis of Frequency of Moderately Heavy Rain in April

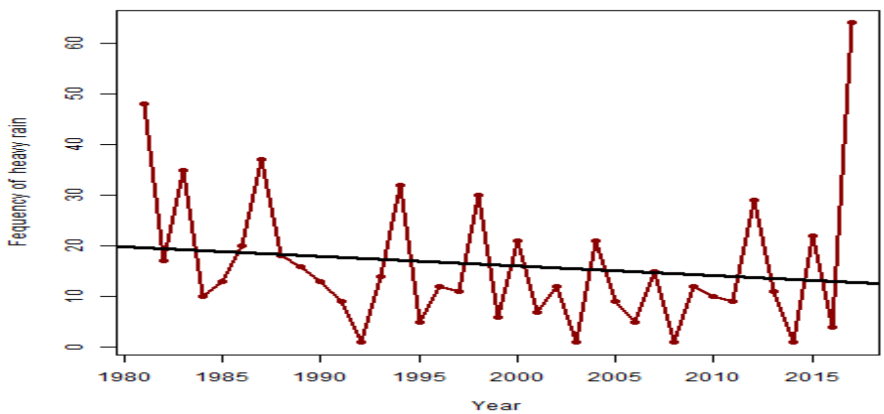

Figure 4.1.3. Trend Analysis of Frequency of Heavy Rain in April

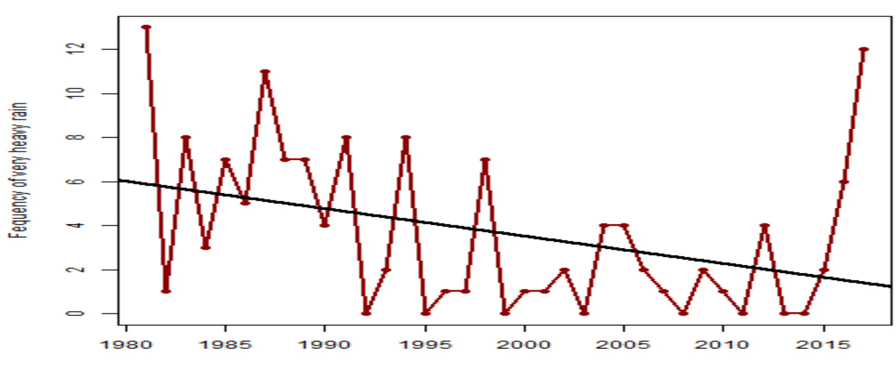

Figure 4.1.4. Trend analysis of frequency of very heavy rain in April

4.2 Trend of Rainfall Frequency in Monsoon Season

From this study, it is obvious that light rainfall frequency in the whole monsoon season are increasing significantly. In Table 4.2, we see light rainfall frequency are increasing with rates 0.168/year, 0.292/year, 0.246/year and 0.206/year in June, July, August and September respectively. The trend of these months are shown in Fig.4.2. We also observe that the highest increment rate is in July and it varies from 0.168 to 0.292. But, the trend of the rest of the categories are insignificant.

Table 4.2. Trend of Rainfall Frequency in Monsoon Season

Categories	June		July		August		September	
	τ	p	τ	p	τ	p	τ	p
Light rain (1-10 *mm*)	0.168	0.07^{+}	**0.292**	**0.006***	0.246	**0.017***	0.206	**0.038***
Moderate rain (11-22 *mm*)	-0.064	0.295	-0.002	0.5	0.094	0.212	-0.018	0.443
Moderately heavy rain (23-44 *mm*)e	0.059	0.309	0.076	0.269	**0.265**	**0.011***	0.019	0.219
Heavy rain (45-88 *mm*) **5-88)**	0.103	0.190	-0.006	0.484	0.116	0.159	0.052	0. 333
Very heavy rain (>88 *mm*) **e**	0.0272	0.412	0.138	0.119	0.22	0.427	-0.051	0. 338

'+' indicates the presence of monotonic trend at 10% level and '*' indicates the presence of monotonic trend at 5% level of significance

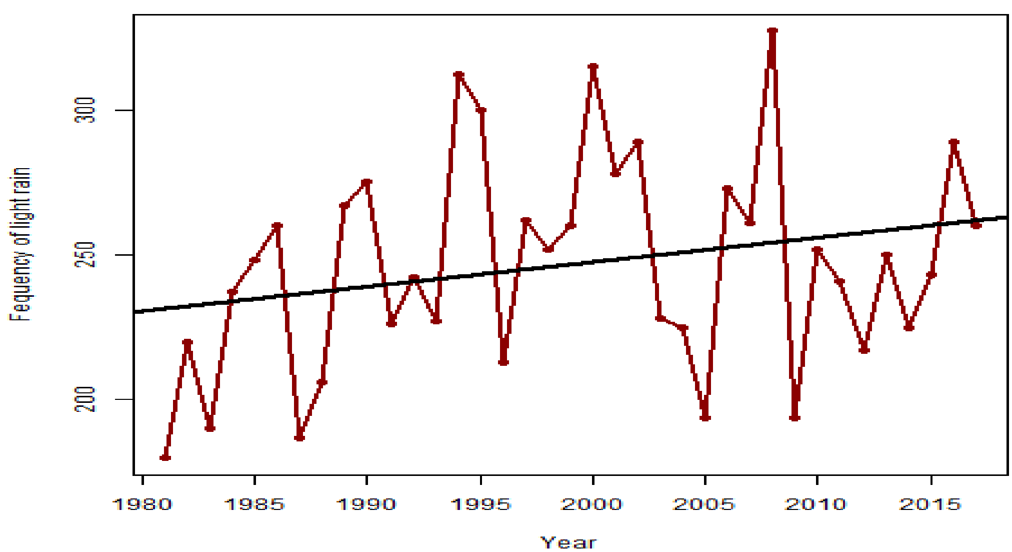

Figure 4.2.1. Trend Analysis of Frequency of Light Rain in June

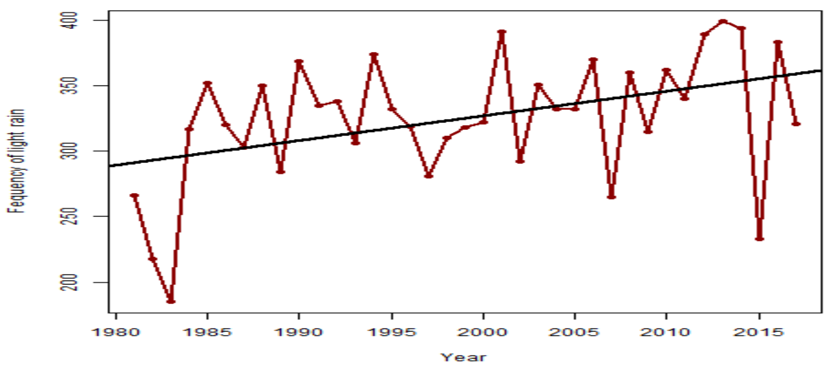

Figure 4.2.2. Trend Analysis of Frequency of Light Rain in July

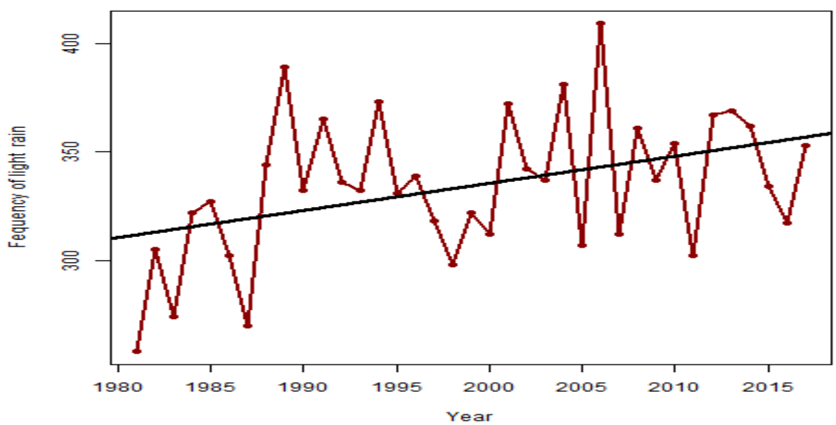

Figure 4.2.3. Trend Analysis of Frequency of Light Rain in August

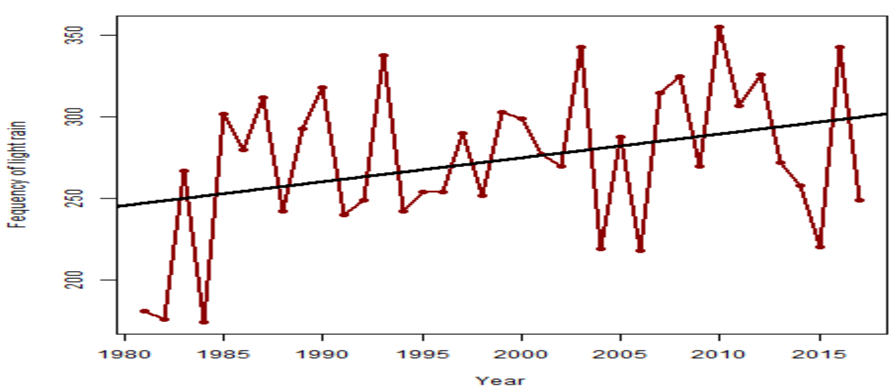

Figure 4.2.4. Trend Analysis of Frequency of Light Rain in September

4.3 Spatial distribution of decadal rainfall frequency in pre-monsoon season during (1981-2020)

Light rainfall frequency in the pre-monsoon season lies among 110-140 in the most part except the northeast and the south-southeastern part of Bangladesh during the period 1981-1990 (Fig. 4.3.1). But in 1991-2000, these areas become declined and it lies at the major central part and hilly regions of Bangladesh. After that 2001-2010 period, light rainfall frequency (140-170) has been increased in the north and the northeastern part of the country and it is continued in the next decade and in the last two decades, frequency (80-140) is also shifted and spread in some areas (Fig. 4.3.2 -4.3.4).

Moderate to very heavy rainfall frequency (80-140) in pre-monsoon season has captured in the major part of the country during 1981-1990 and it has increased at 100-200 in some areas in 1991-2000. But in the next decade 2001-2010, it has decreased in the southwestern part of the country. At the last decade 2011-2020, this frequency has again increased in the major part of the country (Fig. 4.3.5-4.3.8).

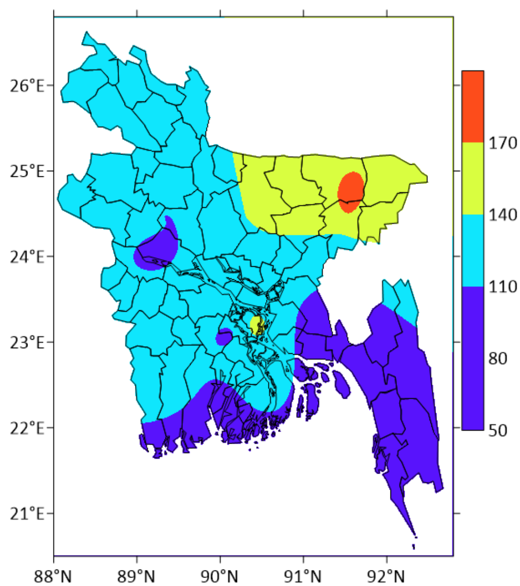

Figure 4.3.1. Light Rainfall in Pre-Monsoon Season During (1981-1990)

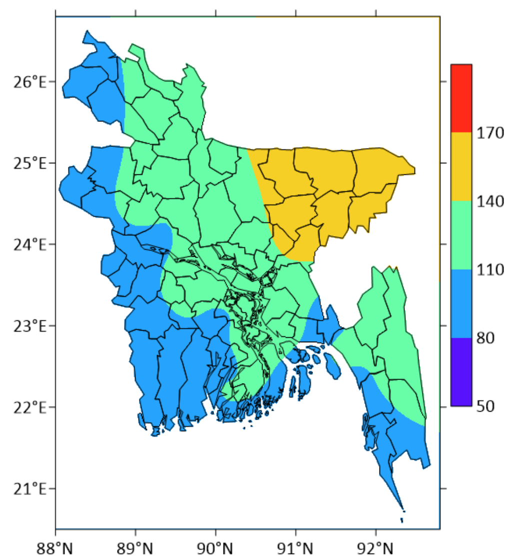

Figure 4.3.2. Light Rainfall in Pre-Monsoon Season During (1991-2000)

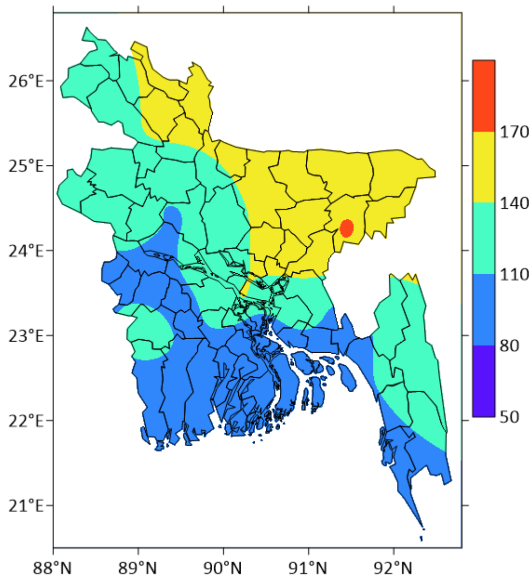

Figure 4.3.3. Light Rainfall in Pre-Monsoon Season During (2001-2010)

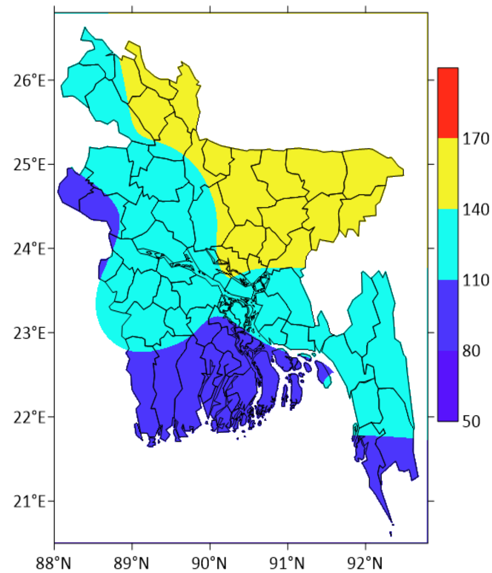

Figure 4.3.4. Light Rainfall Pre-Monsoon Season During (2011-2020)

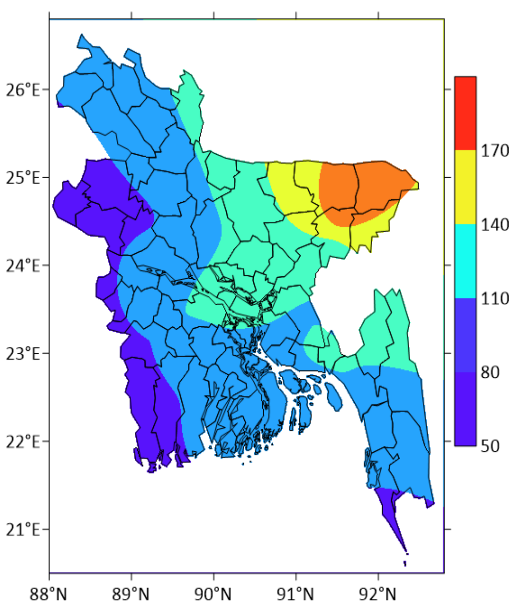

Figure 4.3.5. Moderate-Very Heavy Rainfall in Pre-Monsoon Season During (1981-1990)

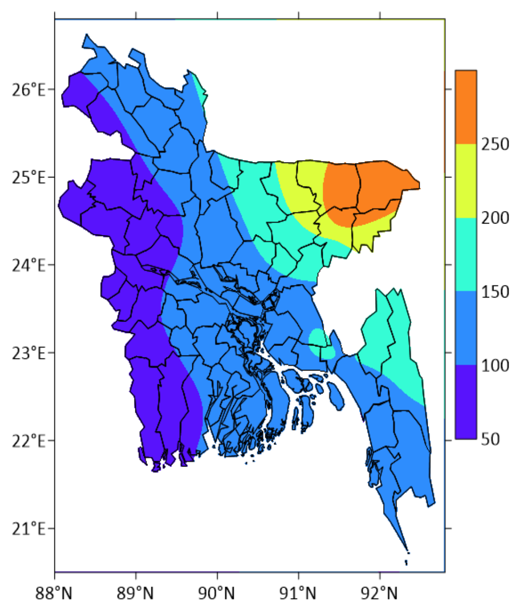

Figure 4.3.6. Moderate -Very Havy Rainfall in Pre-Monsoon Season During (1991-2000)

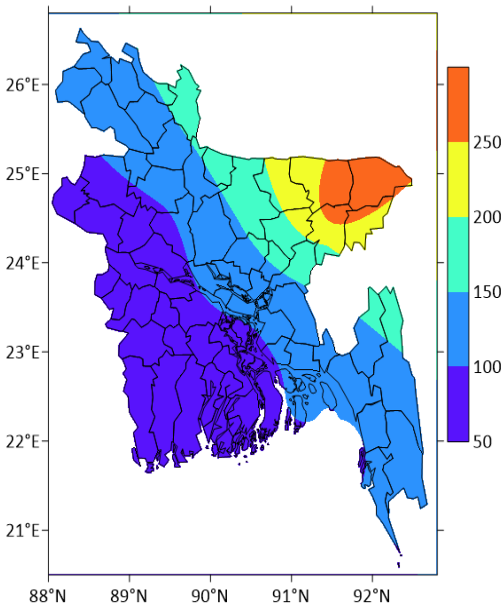

Figure 4.3.7. Moderate-Very Heavy Rainfall in Pre-Monsoon Season During (2001-2010)

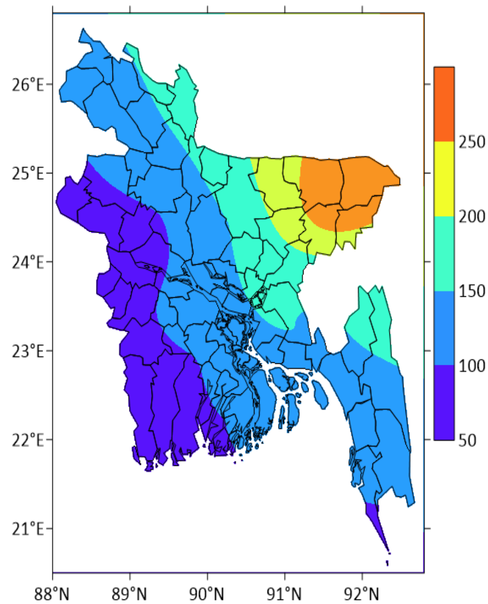

Figure 4.3.8. Moderate-Very Heavy Rainfall in Pre-Monsoon Season During (2011-2020)

4.4 Spatial distribution of decadal rainfall frequency in monsoon season during (1981-2020)

The highest light rainfall frequency in monsoon season 400 or more lies among the central part to the southwest part of Bangladesh in the decade 1981-1990. But, in the next decade (1991-2000) it has increased in the major part of the country except for the northwest and some part of Sylhet and Noakhali and it is remaining unchanged in the following decade (2001-2010). However, in the last decade (2011-2020) it is again going to the downward trend (Fig 4.4.1 - 4.4.4).

The number of moderate to very heavy rainfall frequency in monsoon season lies among 200 to 400 in the major part except for the northeast and the southeastern part of the country in the period 1981-1990. Almost the same conditions stay in the following decade (1991-2000). On the other hands, in some areas like Rajshahi, Pabna and Kushtia, the number of this frequency are decreasing in 2001-2010 and it is also rapidly decreased over the western part of Bangladesh in the last decade 2011-2020 (Fig 4.4.5 - 4.4.8).

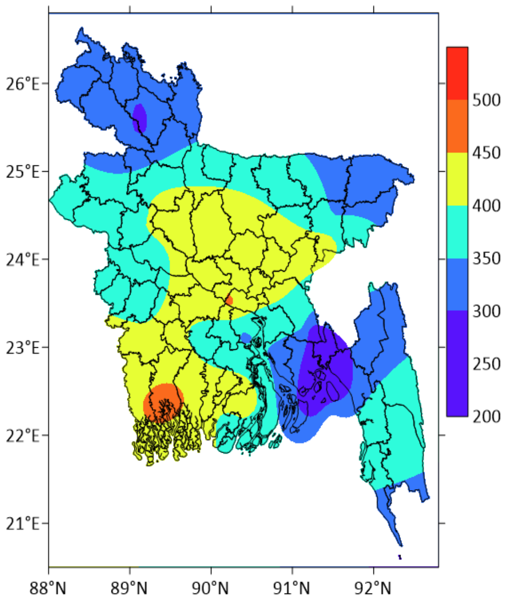

Figure 4.4.1. Light Rainfall in Monsoon Season During (1981-1990)

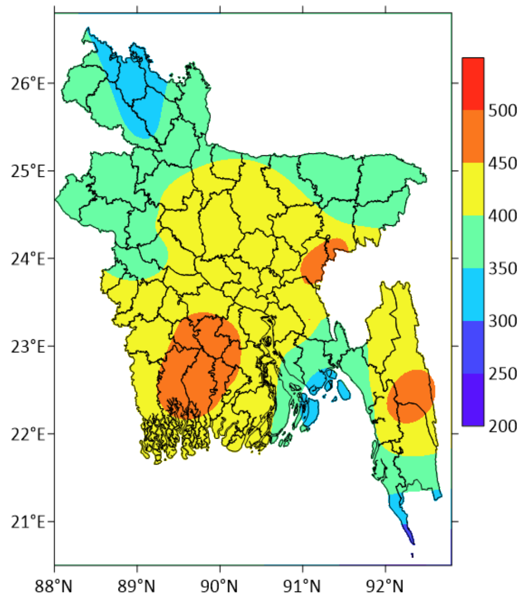

Figure 4.4.2. Light Rainfall in Monsoon Season During (1991-2000)

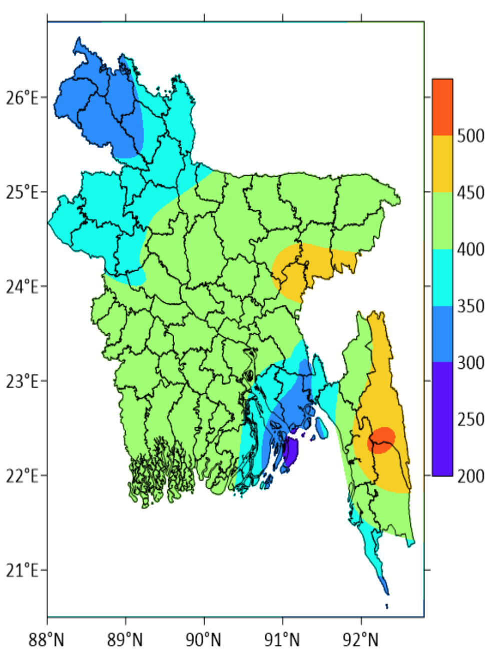

Figure 4.4.3. Light Rainfall in Monsoon Season During (2001-2010)

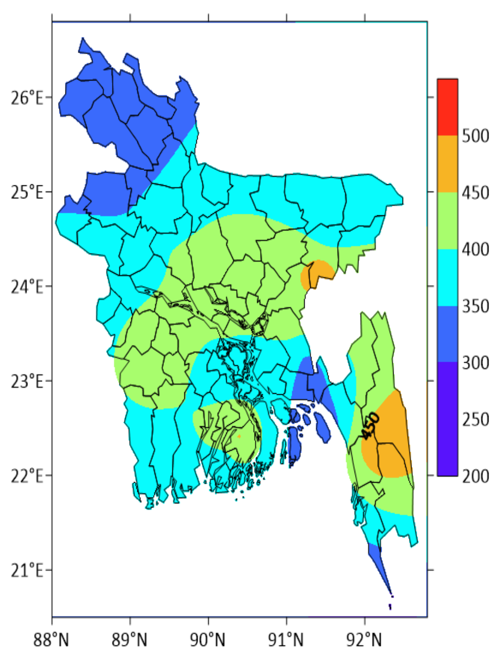

Figure 4.4.4. Light Rainfall in Monsoon Season During (2011-2020)

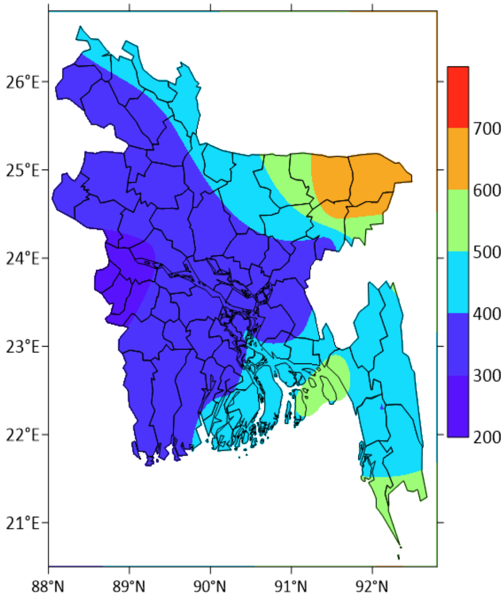

Figure 4.4.5. Moderate-Very Heavy Rainfall in Monsoon Season During (1981-1990)

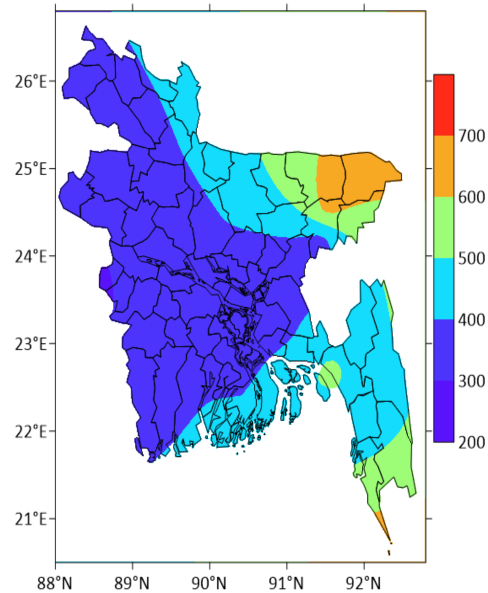

Figure 4.4.6. Moderate-Very Heavy Rainfall in Monsoon Season During (1991-2000)

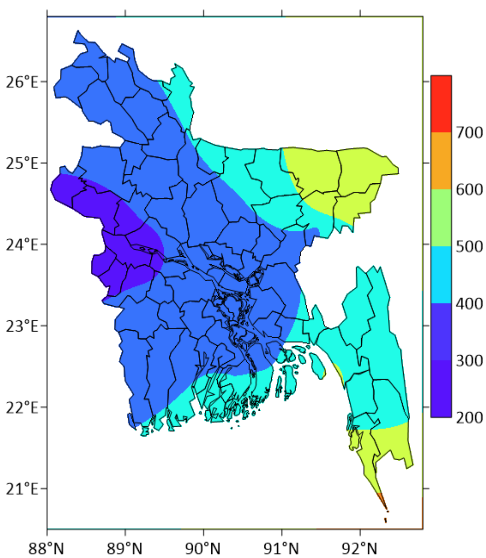

Figure 4.4.7. Moderate-Very Heavy Rainfall in Monsoon Season During (2001-2010)

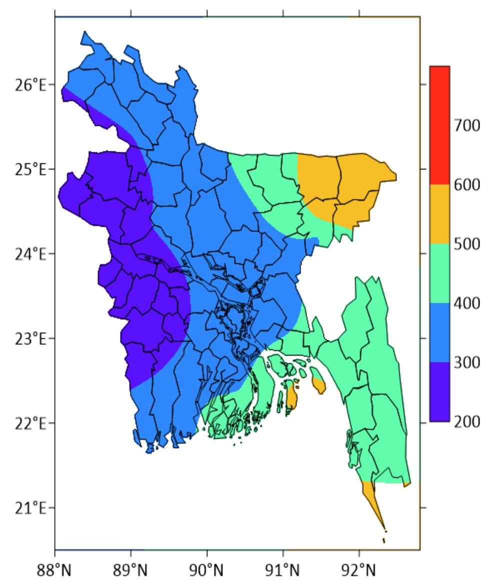

Figure 4.4.8. Moderate-Very Heavy Rainfall in Monsoon Season During (2011-2020)

4.5 Rainfall frequency forecast using Holt-Winters exponential smoothing method for pre-monsoon season during (2021-2030)

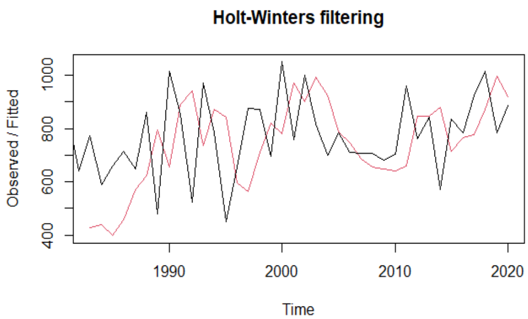

Figure 4.5.1. Holt-Winters Exponential Smoothing Applied to Pre-Monsoon Rainfall Frequency of Bangladesh During 1981-2020.

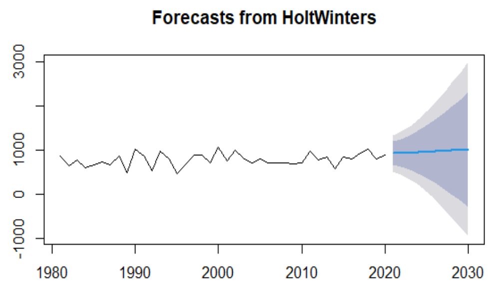

Figure 4.5.2. Forecast of Rainfall Frequency of Pre-Monsoon Season During (2021-2030) using Holt-Winters Exponential Smoothing Additive Model in Bangladesh.

In Fig. 4.5.1, the black line is the observed line and the red line is the model fitted line. For pre-monsoon season, the observed line of rainfall frequency and the model fitted line of rainfall frequency are closed, despite some years. So, the Holt-Winters Exponential Smoothing additive models' forecasts are good fitted with the observations. In Fig. 4.5.2, the blue line shows the forecasts with the 80% prediction interval as a deep shaded area and the 95% prediction interval as a light shaded area.

Table 4.3. Forecast for Rainfall Frequency in Pre-Monsoon Season During 2021-2030

Year	Forecast	Lowest (80%)	Highest (80%)	Lowest (95%)	Highest (95%)
2021	914.4249	648.24078	1180.609	507.3314	1312.518
2022	924.4676	606.5189	1242.416	438.2069	1410.728
2023	934.5102	542.2531	1326.767	334.6047	1534.416
2024	944.5529	459.3598	1429.746	202.5140	1686.592
2025	954.5955	361.3273	1547.864	47.2701	1861.921
2026	964.6382	250.6595	1678.617	-127.2979	2056.574
2027	974.6809	129.0786	1820.283	-318.5562	2267.918
2028	984.7235	-2.20901	1971.656	-524.6595	2494.107
2029	994.7662	-142.3261	2131.859	-744.6646	2733.799
2030	1004.8088	-290.6093	2300.227	-976.3623	2985.980

The estimated value of alpha is 0.4434968 and beta is 0.4729901 which indicate that, the level and the slope of the time series both change quite a lot over time. The sum of squared errors is 1626243. The forecasted rainfall frequency for the pre-monsoon season from 2021-2030 with 80% and 95% prediction intervals (lowest, highest) are shown in Table 4.3.

4.6 Rainfall frequency forecast using Holt-Winters exponential smoothing method for monsoon season during (2021--2030)

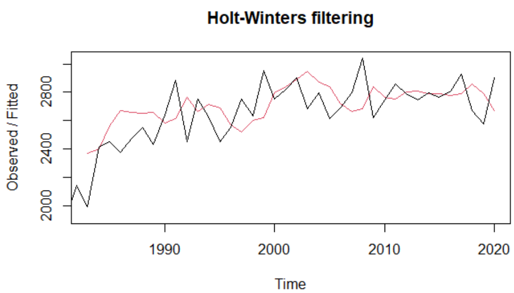

Figure 4.6.1. Holt-Winters Exponential Smoothing Applied to Monsoon Rainfall Frequency of Bangladesh During 1981-2020

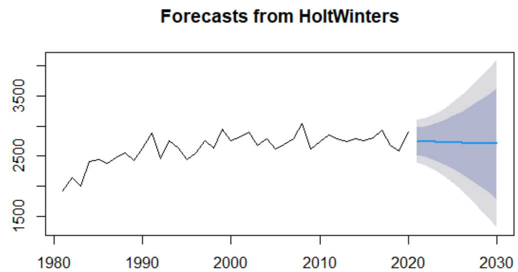

Figure 4.6.2. Forecast of Rainfall Frequency for Monsoon Season During (2021-2030) from Holt-Winters Exponential Smoothing Method in Bangladesh

In Fig. 4.6.1, the black line is the observed line and the red line is the model fitted line. For pre-monsoon season, the observed line of rainfall frequency and the model fitted line of rainfall frequency are mostly closed except some years. So, the Holt-Winters Exponential Smoothing additive models' forecasts are pretty good fitted with the observations. In Fig. 4.6.2, the blue line shows forecasts with the 80% prediction interval as a deep shaded area and the 95% prediction intervals as a light shaded area.

Table 4.4. Forecast for Rainfall Frequency in Monsoon Season During 2021-2030

Year	Forecast	Lowest (80%)	Highest (80%)	Lowest (95%)	Highest (95%)
2021	2746.263	2516.055	2976.471	2394.190	3098.336
2022	2741.568	2482.702	3000.434	2345.667	3137.469
2023	2736.873	2433.363	3040.384	2272.694	3201.053
2024	2732.178	2369.511	3094.846	2177.526	3286.830
2025	2727.484	2293.377	3161.591	2063.574	3391.393
2026	2722.789	2206.947	3238.631	1933.877	3511.701
2027	2718.094	2111.736	3324.452	1790.750	3645.439
2028	2713.399	2008.849	3417.949	1635.883	3790.915
2029	2708.705	1899.097	3518.312	1470.516	3946.893
2030	2704.010	1783.085	3624.935	1295.576	4112.443

The estimated value of the alpha and beta is 0.340226 and 0.511534, which indicate that the level and the slope of the time series both change quite a lot over time. The sum of squared errors is 1239350. The forecasted rainfall frequency for monsoon season from 2021-2030 with 80% and 95% prediction intervals (lowest, highest) are shown in Table 4.4.

5. Conclusion

In this analysis, all over the rainfall frequency in the pre-monsoon season are decreasing but not significantly. Here, it can easily understand that very heavy rainfall in March and moderately heavy to very heavy rainfall in April are decreasing significantly and the maximum frequency is 0.271/year in case of very heavy rainfall in April. Their decreasing rates vary from 0.164 to 0.271 per year. On the other hand, light rainfall frequency in May and the whole monsoon season are increasing significantly and the maximum increasing is in July and its increasing rates differ from 0.168 to 0.293 and the trend of the rest of the categories are insignificant. Spatial distribution of decadal rainfall frequency in pre-monsoon and monsoon season has changed in some particular areas of Bangladesh both light and moderate to very rainfall categories. Our study predicts that, rainfall frequency in pre-monsoon will slightly increase in future, however, in monsoon it will decrease in future gradually.

References

Ahasan, M. N, Chowdhury, A. M. and Quadir, D. A. (2010.: "*Variability and trends of summer monsoon rainfall over Bangladesh*", J Hydr & Meteo 7(1).

Holmes, C.C. and Adams, N.M. (2002). "*A probabilistic nearest neighbor method for statistical pattern recognition".* J.R. Statist. Soc. B 64, Part2, pp. 295-306.

Holt, C.C. (1957). *"Forecasting Seasonal and Trends by Exponentially Weighted Moving Averages".* ONR Memorandum, Vol. 52, Carnegie Institute of Technology, Pittsburgh.

Kendall, M. G. (1975). "*Rank Correlation measure*", Charles Griffin, London 1, 25-55.

Khatun, M. A., Rashid, M. B. and Hygen, H. O. (2016): "*Climate of Bangladesh"*, MET Report, BMD, Climate no. 08/2016, ISSN 2387-4201.

Mann, H. B. (1945). "*Non-parametric tests against trend*", Econometrica, New York 13, 245-259.

May, W. (2004). "*Simulation of variability and extreme of daily rainfall during the Indian summer monsoon for present and future times in a global time-scale experiment*", Clim Dyn 22(2-3), 183-204.

Rani, B. A., N. Manikandan and N. Maragatham (2014). "*Trend analysis of rainfall and frequency of rainy days over Coimbatore*", Mausam, 65(3), 379-384.

Rimi, S.S. and Matin M. A. (2016). "*Analysis of rainfall data for generation of intensity duration frequency relationships for Selected Urban cities of Bangladesh*" 3rd International on Advance in Civil Engineering 21-23.

Tabari, H., Marofi, S., Aeini, A., Talaee, P. H., Mohammadi, K. (2011). "*Trend Analysis of Reference Evapotranspiration in the Western half of Iran"*. Agricultural and Forest Meteorology 151,128-136.

Winters Peter R. (1960). "*Forecasting Sales by Exponentially Weighted Moving Averages",* Graduate School of Industrial Administration, Carnegie Institute of Technology, Management Science, Vol. 6.