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ANALYSIS OF THE STATISTICAL BEHAVIOUR OF DAILY MAXIMUM AND MONTHLY AVERAGE RAINFALL ALONG WITH RAINY DAYS VARIATION IN SYLHET, BANGLADESH

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Abstract

Climate, one of the major controlling factors for well-being of the inhabitants in the world, has been changing in accordance with the natural forcing and manmade activities. Bangladesh, the most densely populated countries in the world is under threat due to climate change caused by excessive use or abuse of ecology and natural resources. This study checks the rainfall patterns and their associated changes in the north-eastern part of Bangladesh mainly Sylhet city through statistical analysis of daily rainfall data during the period of 1957 - 2006. It has been observed that a good correlation exists between the monthly mean and daily maximum rainfall. A linear regression analysis of the data is found to be significant for all the months. Some key statistical parameters like the mean values of Coefficient of Variability (CV), Relative Variability (RV) and Percentage Inter-annual Variability (PIV) have been studied and found to be at variance. Monthly, yearly and seasonal variation of rainy days also analysed to check for any significant changes.

Keywords: Daily rainfall, Monthly distribution, Seasonal variation, Statistical analysis, Rainy days, Climate change.

1. Introduction

Bangladesh is an agriculture-based country where about 80% of its 145 million people are directly or indirectly engaged in a wide range of agricultural activities [1]. Rainfall is one of the important natural factors for the agricultural production. The variability of rainfall with respect to time and space are important for the agriculture as well as the economy of the country. The rainfall is changing on

Nomenclatures

N	Number of years
P	Daily maximum rainfall, mm
$\overline{P}$	Mean rainfall, mm
R_D	Average daily maximum rainfall in mm
R_M	Mean monthly rainfall in mm

Abbreviations

AMD	Absolute Mean Deviation
CV	Coefficient of Variability
MAIV	Mean Absolute Inter-annual Variability
MDI	Mean Daily Intensity
PIV	Percentage Inter-annual Variability
RV	Relative Variability
SD	Standard Deviation

both the global [2] and the regional scale [3] due to global warming, which is well established. The implications of these changes are particularly significant for Bangladesh where different kind of hydrological disasters is a common phenomenon [4].

Bangladesh receives some of the heaviest rainfall in the world [5]. Heavy rainfall often causes flooding in Bangladesh, and the country is one of the most flood-prone countries in the world due to its geographic position [1]. The Intergovernmental Panel on Climate Change (IPCC) termed Bangladesh as one of the most vulnerable countries in the world due to climate change. It has been predicted that due to climate change, there will be a steady increase in temperature and rainfall of Bangladesh, but its frequency and spatial distribution will change. Studies in different parts of the world indicate that global warming has altered the rainfall patterns and resulted in frequent extreme weather events, such as floods, droughts and rainstorms [6-8], etc. Study on rainfall variability and their statistical analysis are therefore important for long-term water resources planning, agricultural development and disaster management mainly for Bangladesh in the context of global climatic change.

Rainfall variability is a much discussed and researched field, yet there is a considerable scope for further work and better understanding. Although a number of studies have been carried out on rainfall patterns [9-12], only very few works have been found on rainfall trends and their variability particularly for Sylhet region. Rahman et al. [13] used trend analysis to study the changes in monsoon rainfall of Bangladesh and observed no significant changes. Ahmed [14] estimated the probabilistic rainfall extremes in Bangladesh during the pre-monsoon season. Karmakar and Khatun [15] repeated a similar study on rainfall extremes during the southwest monsoon season. However, both the studies were focused only on the maximum rainfall events for a limited period. May [16] reported that the frequency of wet days has noticeably increased over the tropical Indian Ocean who predicted that intensity of heavy rainfall events in Bangladesh will be increased in future. Immerzeel [17] predicted accelerated seasonal increases in rainfall in the 21st century with strongest increase in monsoon in the Brahmaputra basin.

The discrete nature of rainfall in time and space has always posed unique problems for the climatologist compared to more continuous climatic elements such as temperature and pressure. Rainfall totals have often been used in studies that examine large-scale fluctuations in rainfall [18]. Other pertinent studies were based on either monthly anomaly of maximum rainfall variance over a particular region [19], or on an analysis of intensity and frequency of rainfall [20,21]. Wylby [22] discussed the relationship between weather type and daily rainfall occurrence. Recently, Unkasevic and Radinovic [23] have presented a statistical analysis of daily maximum and monthly rainfall for the climate of Belgrade, Yugoslavia and found a high correlation between them. Singh [24] has studied the relationship between rainy days, Mean Daily Intensity (MDI) and seasonal rainfall in the normal, flood and drought years over India and concluded that linear relationship fits better. The present work analysed daily rainfall data using 50 years (1957-2006) record by estimating different statistical parameters. Daily rainfall and its monthly, seasonal and yearly variation as well as rainy day pattern was estimated and discussed focusing climate change.

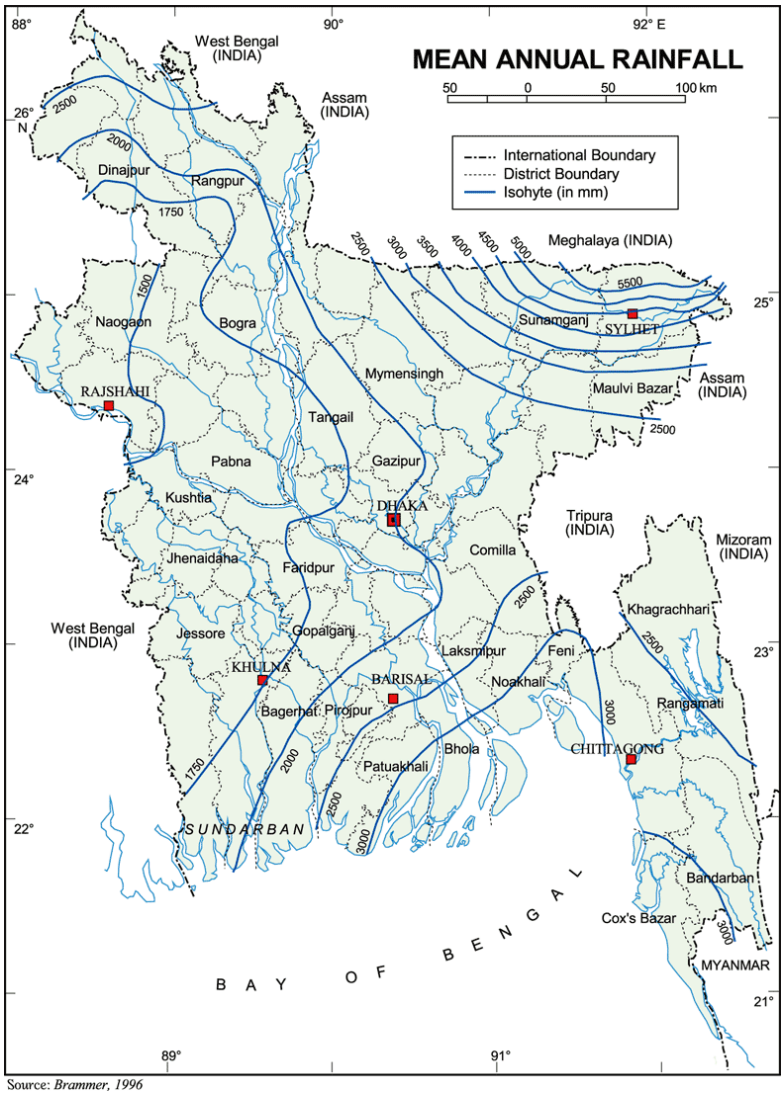
2. Hydro-climatic Condition of Sylhet

Bangladesh, is primarily a low-lying plain of about 144,000 km^2, situated on deltas of large rivers flowing from the Himalayas, has a sub-tropical humid climate characterized by wide seasonal variations. Four distinct seasons can be recognized in Bangladesh from the climatic point of view: (1) dry winter season from December to February, (2) pre-monsoon hot summer season from March to May, (3) rainy monsoon season from June to September and (4) post-monsoon autumn season which lasts from October to November [16]. Rainfall variability in space and time is one of the most relevant characteristics of the climate of Bangladesh. Spatial distribution of rainfall in Bangladesh is shown in Fig 1. Rainfall in Bangladesh varies from 1500 mm in the western part to more than 5000 mm in the north-eastern part of the country being the highest of 5500 mm in the north-east border of Meghalaya of India as shown in Fig. 1.

Sylhet, the north-eastern administrative division of Bangladesh, located at 24˚53′ latitude and 91˚52′ longitude, has a number of topographical features like rivers, hills and hillocks (tilas), haors (wetland) and high flood plain; which made it quite different from the rest of the parts of Bangladesh. Sylhet is located close to Cherrapunji, Meghalaya India which receives the highest amount of rainfall in the world. Hilly Sylhet region not only plays an important role in the socio-economic development of Bangladesh but also important for ecological balance of the country. The region is famous for its vast reserve of forest, intense tea gardens and growing rubber gardens in the hillocks, lakes and wetlands etc. Among the topographical features of the region, hills are the most dominating one, which is determining its climatic and morphological features. Heavy rainfall, tea garden, dense bamboo and cane bushes, high flood plain and the flashy rivers; all the features are very related and contributed by the hills of this region [25].

Rainfall in Bangladesh mostly occurs in monsoon period, caused by weak tropical depressions that are brought from the Bay of Bengal into Bangladesh by the wet monsoon winds. More than 75% rainfall occurs in monsoon period. Huge amount of rainfall in the north-east region is caused by the additional uplifting effect of the Meghalaya plateau. Topography of the country is mostly flat with

some upland in the north-eastern and the south-eastern part. The plain land lies almost at sea level along the southern part of the country and rises gradually towards north. Land elevation in the plain varies from 1 to 60 m above the sea level from south to north. Hilly areas are located in Chittagong and Chittagong Hill Tracts, the south-eastern part of the country, and in Sylhet, north-eastern regions. It can be observed from Fig. 1 that Sylhet (north-eastern region) and Chittagong (south-eastern region) are two distinctly wet zone separated by a wide dry zone. Hence, a comprehensive understanding of the rainfall pattern and its associated changes in this region is greatly needed to understand the hydro-climatic condition of Bangladesh particularly Sylhet region.



Source: *Brammer, 1996*

Fig. 1. Distribution of Mean Annual Rainfall over Bangladesh.

3. Data Used

Bangladesh Water Development Board (BWDB) is the principal organization responsible for collecting and preserving all hydro-meteorological data of Bangladesh with a wide network of rainfall stations distributed throughout the country, and daily rainfall records are the only available format available for Sylhet city. For this study, rainfall data of 50 years started from 1957 for Sylhet station was collected from their data record. The daily record seems very helpful, though the continuity of the data was hampered by some missing records (approximately 2%). The missing daily rainfall records were estimated as described by [26] and used for the study. Time series of accumulated monthly rainfall variation during the study period is shown in Fig. 2, which looks smooth and acceptable and no severe mischief are observed due to the interpolation of missing records.

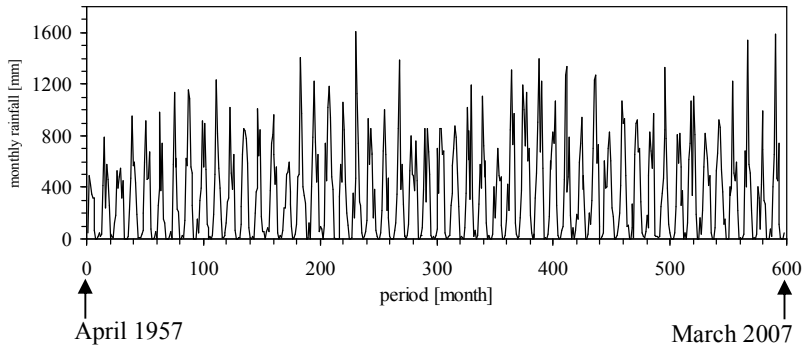


Fig. 2. Time History of Monthly Rainfall.

Figure 3 shows average rainfall in mm of the Sylhet area in different months. The average monthly variation was estimated from the rainfall record of 50 years. Month of June, which is the starting of monsoon, is getting highest amount of rainfall as can be seen from the figure. December and January are the driest month; the rainfall is then increases gradually until the peak and then decreases again steadily.

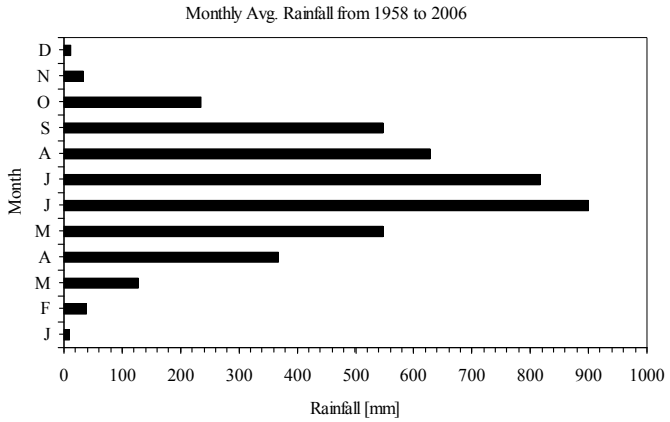


Fig. 3. Average Monthly Rainfall Distribution of Sylhet Region.

4. Rainfall Data Analysis

The daily, monthly and annual rainfall variability in this region were analysed from the collected records and discussed in the following sections:

4.1. Statistical analysis

Average of daily maximum R_D and mean monthly R_M rainfall during the study period were examined for every month and shown in Table 1 with their ratio. The highest value of mean daily maximum rainfall occurs in June, while the minimum occurs in January with a secondary minimum in December. The maximum mean monthly rainfall also occurs in June and the minimum in January during the period. Both the mean monthly and daily maximum rainfall is distributed smoothly throughout the year except for the month of September when the daily maximum is higher than the surrounding months.

Although the mean daily maximum and mean monthly rainfall varies throughout the year, their ratio (R_D / R_M) in Sylhet is almost uniform (Table 1), with an average variability of about 10%. The highest values of the ratio occur in the winter months from October to March when rainfall is reduced and the smallest values of the ratio occur in the months from April to September mostly during wet monsoon period. The mean ratio between the mean daily maximum and mean monthly rainfall is 0.37 indicating that the mean daily maximum of rainfall makes a large contribution to the mean monthly rainfall. Statistical analysis, described in next section, indicates the similar conclusions.

Table 1. Daily Maximum (R_D) and Mean Monthly (R_M) Rainfall with Their Ratio for Sylhet City during the Period of 1957 to 2006.

Months	Jan	Feb	Mar	Apr	May	Jun
R_D	7.0	20.0	43.1	94.9	112.9	173.0
R_M	10.9	39.0	123.9	377.0	564.6	912.3
R_D/R_M	0.64	0.51	0.35	0.25	0.20	0.19

Months	Jul	Aug	Sept	Oct	Nov	Dec	Yearly avg.
R_D	144.0	111.5	115.4	86.2	20.2	10.0	78.2
R_M	840.4	627.8	551.6	237.1	34.5	12.4	361.0
R_D/R_M	0.17	0.18	0.21	0.36	0.58	0.80	0.37

For statistical analysis of the rainfall data, six measurements of variability of daily maximum rainfall, monthly rainfall and their ratio for all the months were calculated. In climatologically studies, rainfall variability is expressed both in absolute as well as in relative terms. From among various absolute measures of variability, the standard deviation (SD), absolute mean deviation (AMD) and mean absolute inter-annual variability (MAIV) are used in this study. These are defined as:

$$SD = [(N-1)^{-1} \sum_{i=1}^{N} (P_i - \overline{P})^2]^{1/2} \quad (1)$$

$$AMD = (N-1)^{-1} \sum_{i=1}^{N} \left| P_i - \overline{P} \right| \quad (2)$$

$$MAIV = (N-1)^{-1} \sum_{i=2}^{N} \left| P_i - P_{i-1} \right| \quad (3)$$

where, P is the daily maximum rainfall or monthly rainfall or their ratio, and $\overline{P}$ is the temporal mean for N years.

When these three absolute measures of variability are divided by the mean and multiplied by 100 they give rise to three relative measures of variability. These are the coefficient of variability (CV), relative variability (RV) and percentage inter-annual variability (PIV), i.e.,

$$CV = \frac{100 \times SD}{\overline{P}} \quad (4)$$

$$RV = \frac{100 \times AMD}{\overline{P}} \quad (5)$$

$$PIV = \frac{100 \times MAIV}{\overline{P}} \quad (6)$$

These are useful measures of variability and widely used in the climatologically studies. The six measures of variability of daily maximum rainfall, monthly rainfall and their ratio at Sylhet for all months from 1957 to 2006 are presented in Tables 2-4. Tables 2 and 3 show absolute measures of variability assigned as SD, AMD and MAIV which have the higher values in the monsoon months compare to other months. For the ratio between the daily maximum and mean monthly rainfall, the previously mentioned measures of variability shows opposite scenario which is considerable (Table 4).

For normally distributed rainfall series, Lansberg [27] found that the ratio of mean absolute inter-annual variability and standard deviation is 1.129. Hence, our results are comparable with the results of Landsberg. For the maximum rainfall, mean monthly rainfall and their ratio (Tables 2-4), in general, CV, RV and PIV will be in increasing order of magnitude, with RV lowest and PIV highest. The maximum CVs occur in November-January and those of PIV in November-February (Table 2) because the greater values of $(P_i - \overline{P})$ and $\left| P_i - P_{i-1} \right|$ occur during these months. For low monthly rainfall during November, December and January (Table 3), the CV is higher compared to PIV, but for higher monthly rainfall it is low. The mean values of CV, RV and PIV for the daily maximum and monthly rainfall are approximately the same. But for the ratio between the daily maximum and mean monthly rainfall, the previously mentioned measures of variability are lower by approximately between one-third and one-half.

Table 2. Standard Deviation (SD), Absolute Mean Deviation (AMD), Mean Absolute Inter-Annual Variability (MAIV), Coefficient of Variability (CV), Relative Variability (RV) and Percentage Inter-annual Variability (PIV) of the Daily Maximum Rainfall (R_D) for Sylhet City during 1957-2006.

Season	Winter			Pre Monsoon		
Month	Dec	Jan	Feb	Mar	Apr	May
SD (mm)	18.05	7.6	19.8	33.8	63.6	49.6
MAIV (mm)	16.52	7.8	24.0	37.1	72.0	60.7

AMD (mm)	12.84	6.7	15.2	24.5	45.5	42.5
CV (%)	181.41	109.8	98.6	78.3	67.0	44.0
RV (%)	129.04	96.36	75.9	56.9	47.9	37.7
PIV (%)	166.03	112.0	119.6	86.1	75.9	53.8

Season	Monsoon			Post Monsoon			
Month	Jun	Jul	Aug	Sep	Oct	Nov	Mean
SD (mm)	61.8	63.3	49.9	77.3	67.6	22.9	44.6
MAIV (mm)	71.0	76.8	61.0	71.4	65.5	22.4	48.9
AMD (mm)	47.5	48.6	42.5	53.4	50.1	20.3	34.1
CV (%)	35.7	43.9	44.8	67.0	78.4	113.7	80.2
RV (%)	27.4	33.8	38.1	46.2	58.1	100.5	62.3
PIV (%)	41.0	53.3	54.7	61.8	76.0	111.0	84.3

Table 3. Same as Table 2, but for Monthly Rainfall (R_M).

Season	Winter			Pre Monsoon		
Month	Dec	Jan	Feb	Mar	Apr	May
SD (mm)	22.5	13.6	45.6	116.9	191.5	252.1
MAIV (mm)	21.0	12.6	45.4	128.6	224.5	298.0
AMD (mm)	16.1	11.2	31.5	78.6	144.8	190.5
CV (%)	181.4	124.4	116.9	94.4	50.8	44.7
RV (%)	129.8	102.6	80.8	63.5	38.4	33.7
PIV (%)	169.1	115.5	116.3	103.8	59.5	52.8

Season	Monsoon				Post Monsoon		
Month	Jun	Jul	Aug	Sep	Oct	Nov	Mean
SD (mm)	296.5	272.9	205.2	267.0	163.3	44.7	157.6
MAIV (mm)	361.3	344.2	198.6	248.2	172.4	46.2	175.1
AMD (mm)	238.1	216.8	168.2	203.9	128.8	37.1	122.1
CV (%)	32.5	32.5	32.7	48.4	68.9	129.3	79.7
RV (%)	26.1	25.8	26.8	37.0	54.3	107.4	60.5
PIV (%)	39.6	41.0	31.6	45.0	72.7	133.8	81.7

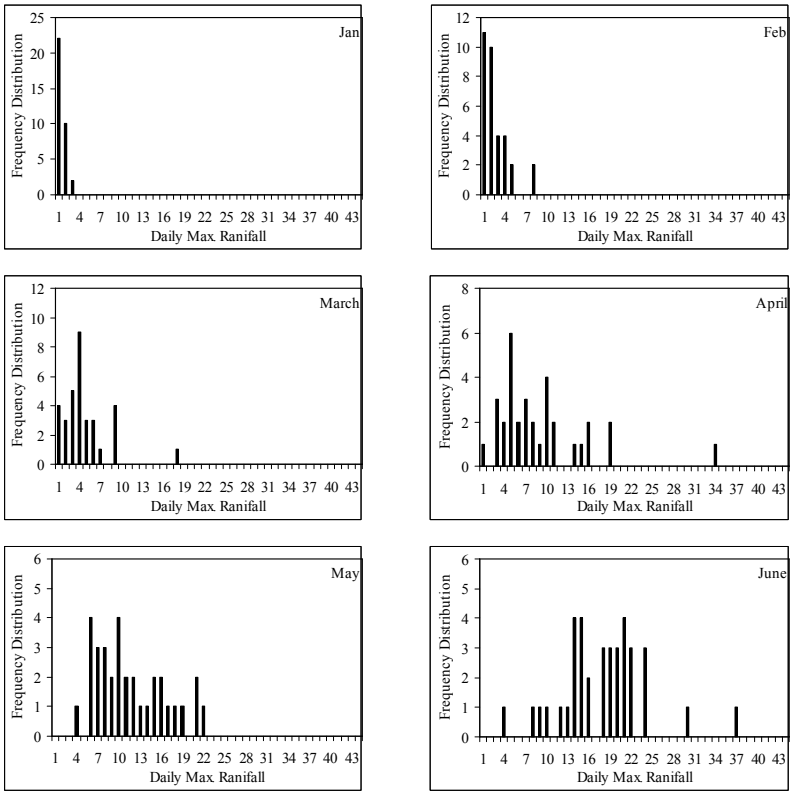
Table 4. Same as Table 2 and 3, but for the Ratio between R_D and R_M.

Season	Winter			Pre Monsoon		
Month	Dec	Jan	Feb	Mar	Apr	May
SD (mm)	0.21	0.16	0.09	0.05	0.01	0.004
MAIV (mm)	0.37	0.46	0.27	0.25	0.12	0.08
AMD (mm)	0.43	0.37	0.26	0.19	0.08	0.05
CV (%)	26.7	24.8	17.5	15.6	3.7	2.1
RV (%)	53.3	58.6	50.1	54.3	30.8	27.1
PIV (%)	45.7	71.9	53.1	72.1	45.6	38.6

Season	Monsoon			Post Monsoon			
Month	Jun	Jul	Aug	Sep	Oct	Nov	Mean
SD (mm)	0.002	0.002	0.003	0.005	0.02	0.0001	0.05
MAIV (mm)	0.05	0.05	0.07	0.08	0.14	0.37	0.19
AMD (mm)	0.04	0.04	0.04	0.05	0.11	0.28	0.16
CV (%)	1.1	1.3	1.5	2.6	4.5	0.02	8.4
RV (%)	19.7	23.0	24.4	28.7	29.4	48.6	37.3
PIV (%)	27.4	32.1	40.6	44.7	37.6	62.9	47.7

4.2. Frequency distribution

Monthly variation in the frequency distribution of the maximum daily rainfall is presented in Fig. 4 covering the study period 1957-2006. It can be observed from the figure that during the dry winter months, i.e., Dec to Feb, the frequency maxima occurs mostly in the interval between 10 to 20 mm and increases up to 80 mm. The frequency maxima increase gradually after that until the wet monsoon period appears. During monsoon, the daily maximum rainfall occurs in between 40 to 300 mm. The rainfall pattern in Sylhet region during wet period has a wide range of variation which is in contrast with the dry period.



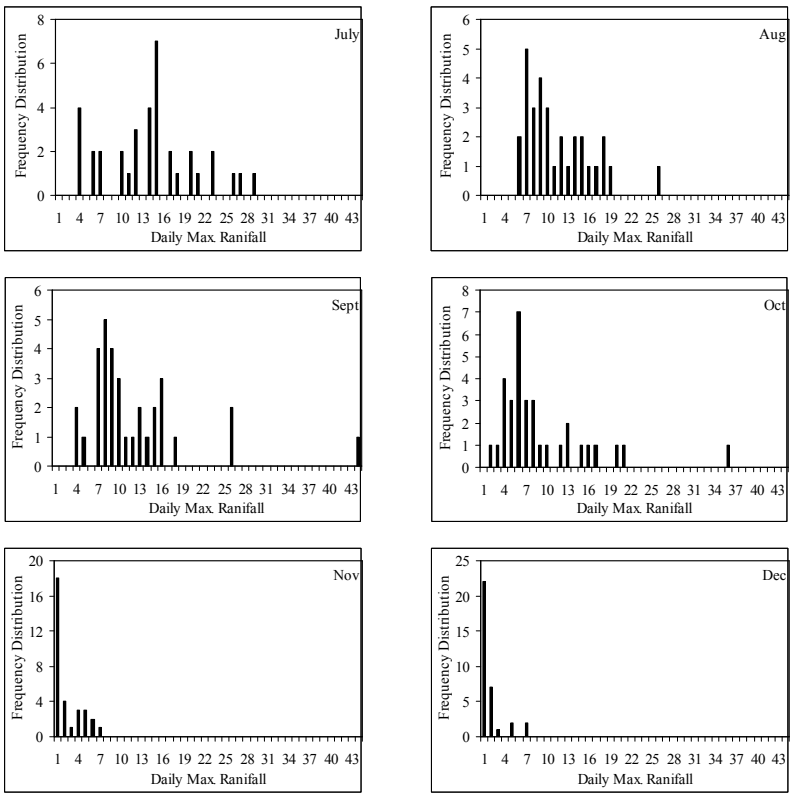


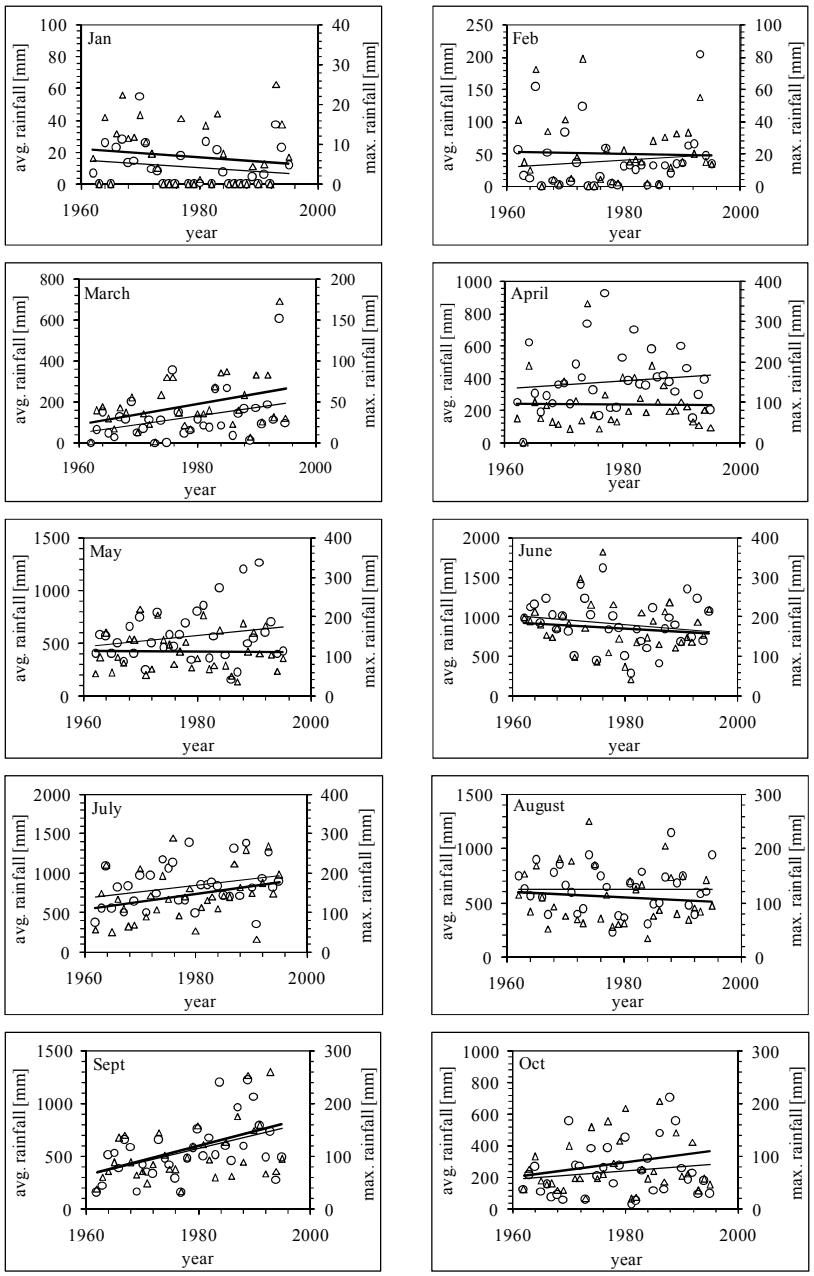
Fig. 4. Frequency Distribution of the Maximum Daily Rainfall for Sylhet City during the Period of 1957-2006. Scale *X*-Axis: (1=0–10, 2=10–20, 3=20–30….43=420–430 mm).

4.3. Linear regression

Scatter plot with linear regression line of the monthly average rainfall and daily maximum rainfall also plotted for the year 1962 to 1996 in shown in Fig. 5. Continuous rainfall data with no missing records was considered for the plots. Due to wide range of variation in the rainfall pattern mainly during wet months as shown in the frequency distribution; the mean monthly and maximum daily rainfall also have scattered variation. Similar trends for both the parameters are observed from Fig. 5 which predicts strong correlation exists between them. The trends are almost linear except for the month March, July, Sept and Dec when increasing trend is observed. Hence, the rainfall pattern is not changing significantly instead a gradual variation of changing is found.

Further the data was analysed to examine the correlation between the daily maximum (R_D) and mean monthly (R_M) rainfall. The linear regression between these parameters was done using least square curve fitting method. The linear regression of type $R_M = a + b\ R_D$ is calculated for all the months. Scatter diagrams of mean monthly and daily maximum rainfall for are shown in Fig. 6. High

correlation coefficients (varies between 0.40 and 0.92) are observed from the plots which is significant. Higher coefficients were found during the dry months compared to wet months which support the previous analysis. Similar trends also observed by Unkasevic and Radinovic [23] during their study at Belgrade, and also by Singh et al. [28] a study done at New Delhi during monsoon period.



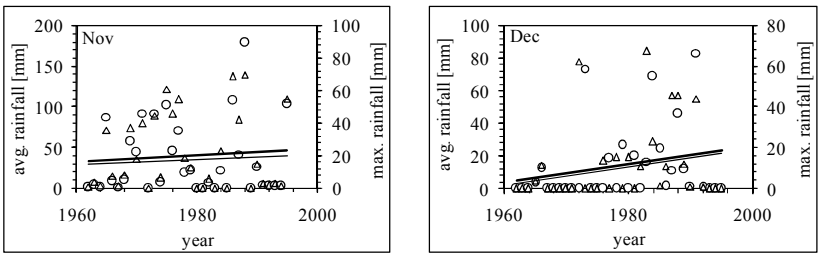
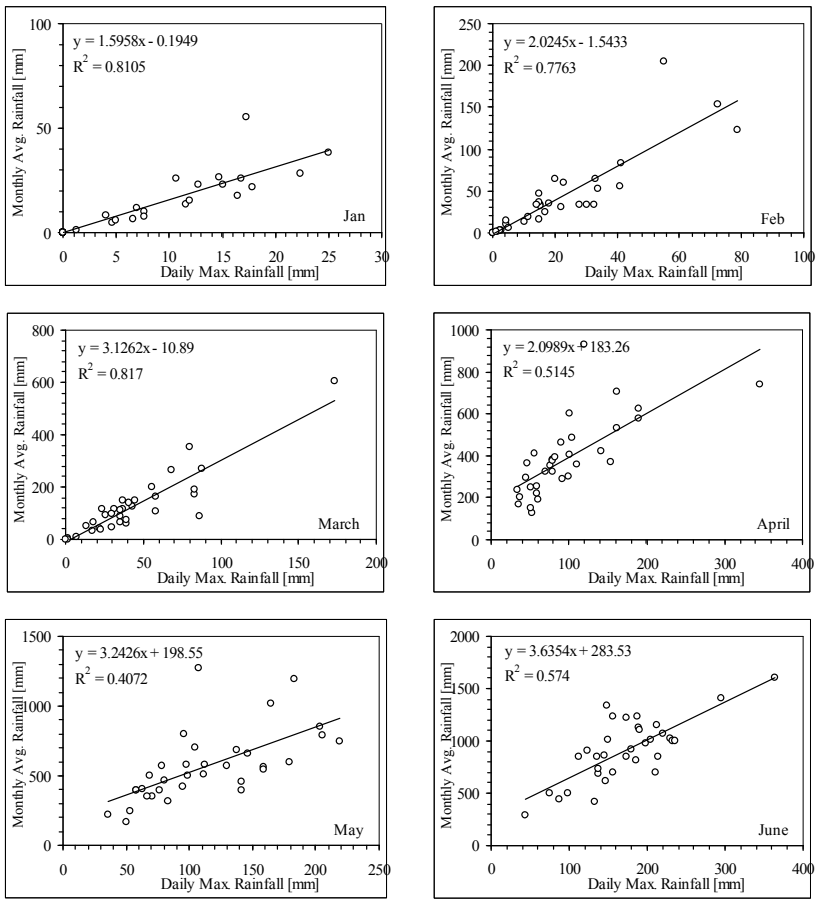


Fig. 5. Variation of Monthly Average Rainfall (Empty Circles) and Monthly Maximum Rainfall (Empty Triangles) with Their Linear Trends (Thin Line for Average One and Thick Line for Maximum One) during the Period of 1962-1996.



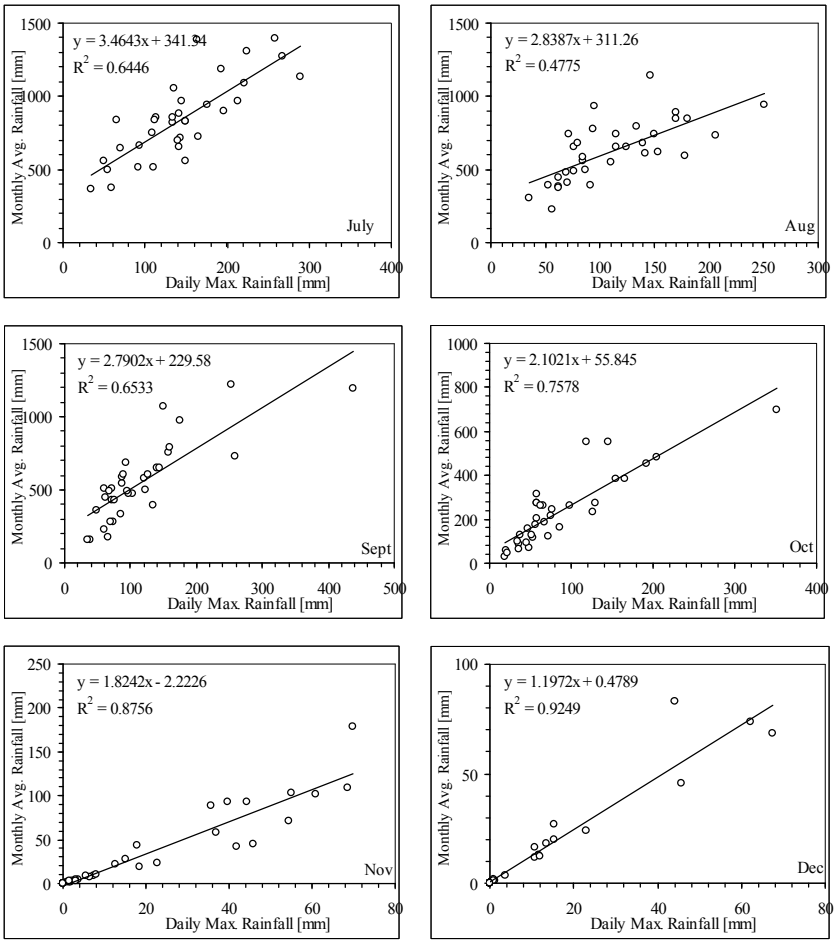
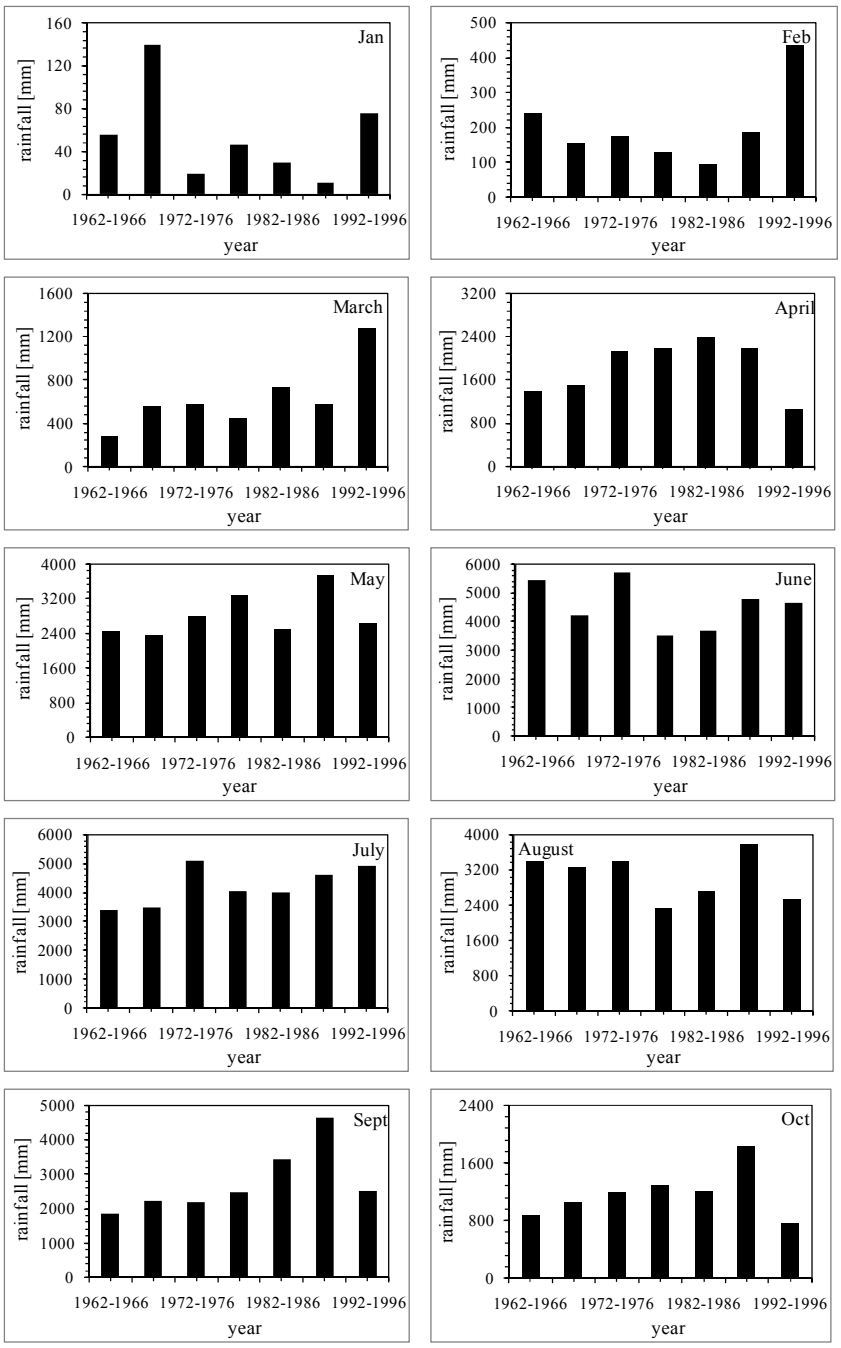


Fig. 6. Scatter Diagrams, Linear Regressions and Correlation Coefficients between the Monthly Mean (R_M) and Daily Maximum (R_D) Rainfall for Sylhet City.

Five yearly rainfall variations were plotted in Fig. 7 for every month during the period of 1962 to 1996, which could be a useful way to check the changing nature of rainfall. The average value for a particular month is shown by solid horizontal line which is five times higher than the monthly average value and found synchronized with Fig. 3. It is observed from the figure that the months of Feb, March, Sept, Oct and Dec, the rainfall has an increasing tendency whereas the remaining months are constant or decreasing tendency. Minor or steady changing pattern of rainfall can be observed from the analysis.


Jan
rainfall [mm]
160
120
80
40
0
1962-1966 1972-1976 1982-1986 1992-1996
year
Feb
rainfall [mm]
500
400
300
200
100
0
1962-1966 1972-1976 1982-1986 1992-1996
year
March
rainfall [mm]
1600
1200
800
400
0
1962-1966 1972-1976 1982-1986 1992-1996
year
April
rainfall [mm]
3200
2400
1600
800
0
1962-1966 1972-1976 1982-1986 1992-1996
year
May
rainfall [mm]
4000
3200
2400
1600
800
0
1962-1966 1972-1976 1982-1986 1992-1996
year
June
rainfall [mm]
6000
5000
4000
3000
2000
1000
0
1962-1966 1972-1976 1982-1986 1992-1996
year
July
rainfall [mm]
6000
5000
4000
3000
2000
1000
0
1962-1966 1972-1976 1982-1986 1992-1996
year
August
rainfall [mm]
4000
3200
2400
1600
800
0
1962-1966 1972-1976 1982-1986 1992-1996
year
Sept
rainfall [mm]
5000
4000
3000
2000
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0
1962-1966 1972-1976 1982-1986 1992-1996
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Oct
rainfall [mm]
2400
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year

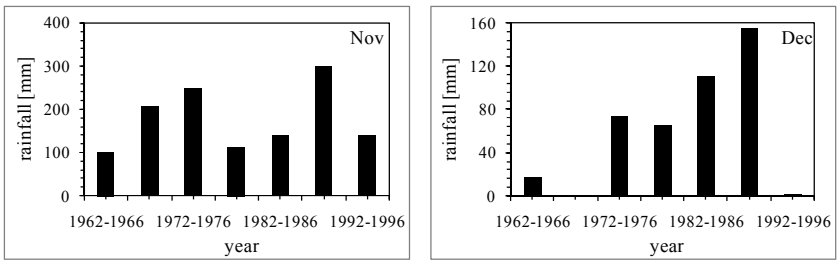


Fig. 7. Five Yearly Rainfall Variations for Every Month during the Period of 1962-1996 for Sylhet (Horizontal Line Indicates the Average Value of the Variation).

4.4. Seasonal variation

Seasonal variations of the accumulated daily rainfall with their linear regression are estimated and displayed in Fig. 8. The trend during pre-monsoon and post-monsoon period is found to be increasing whereas during dry winter and wet monsoon it is almost constant. Hence, the amount of rainfall and its distribution is not changing significantly rather slowly or steadily which also can be observed from the scatter diagrams with their linear regression.

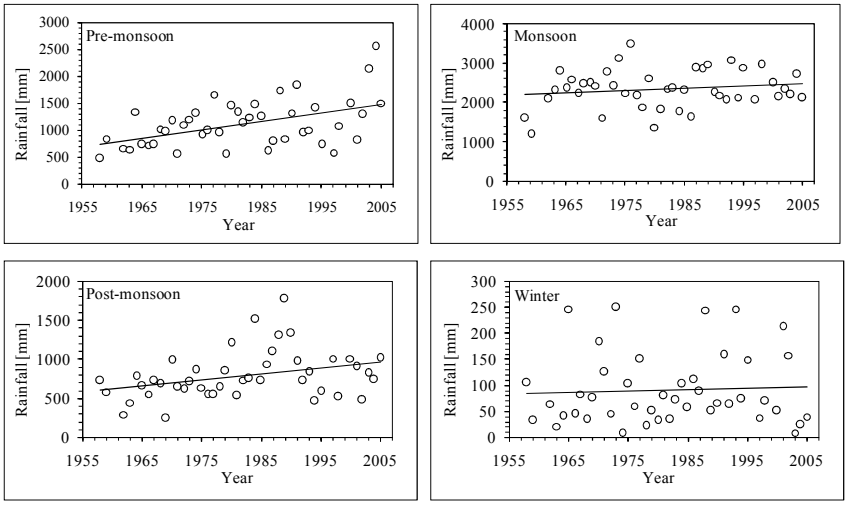


Fig. 8. Seasonal Variation of Rainfall with their Linear Regression.

4.5. Rainy days

The study also checked the frequency and trend of rainy days during the study period for Sylhet region. Any rainfall greater than 0.25 mm within a day is considered as a rainy day for this study which also considered by Soman and Kumar

[29] and few other hydrological studies for India. Number of rainy days were counted and plotted against the year (Fig. 9) to assess their variation in order to understand any climatic change. Yearly variation trend are found almost constant during the study period (1957-2006) with a narrow range between 130 and 170 days. Since the yearly distribution of rainy days did not show any significant variations, seasonal or monthly distribution also checked to get a clear picture.

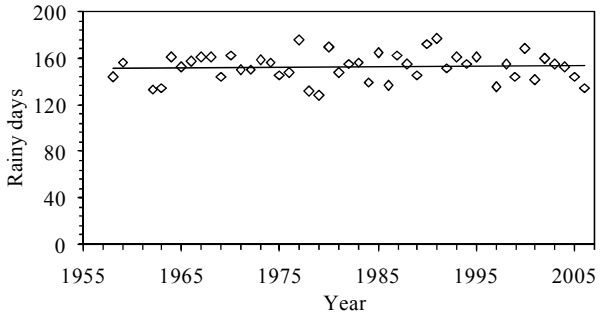
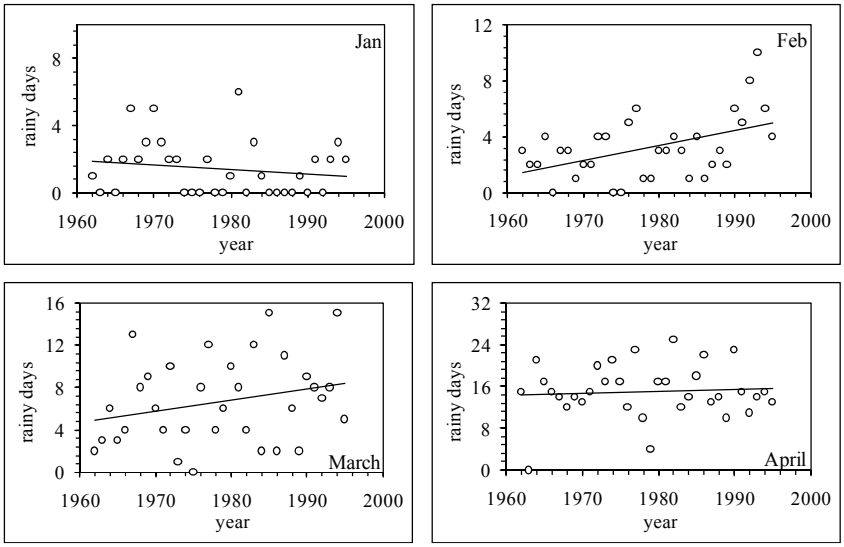


Fig. 9. Yearly Variation of Rainy Days with Their Linear Regression for Sylhet City.

The rainy days were plotted for every month during the study period as shown in Fig. 10. Rainy days are found scattered during the winter period with both increasing and decreasing tendency. However, the variation is almost constant during wet monsoon period. Seasonal variation of the rainy days were also plotted and depicted in Fig. 11 which shows observed almost constant trend. Hence, it can be concluded that the rainy days are not varying significantly in terms of climate change.



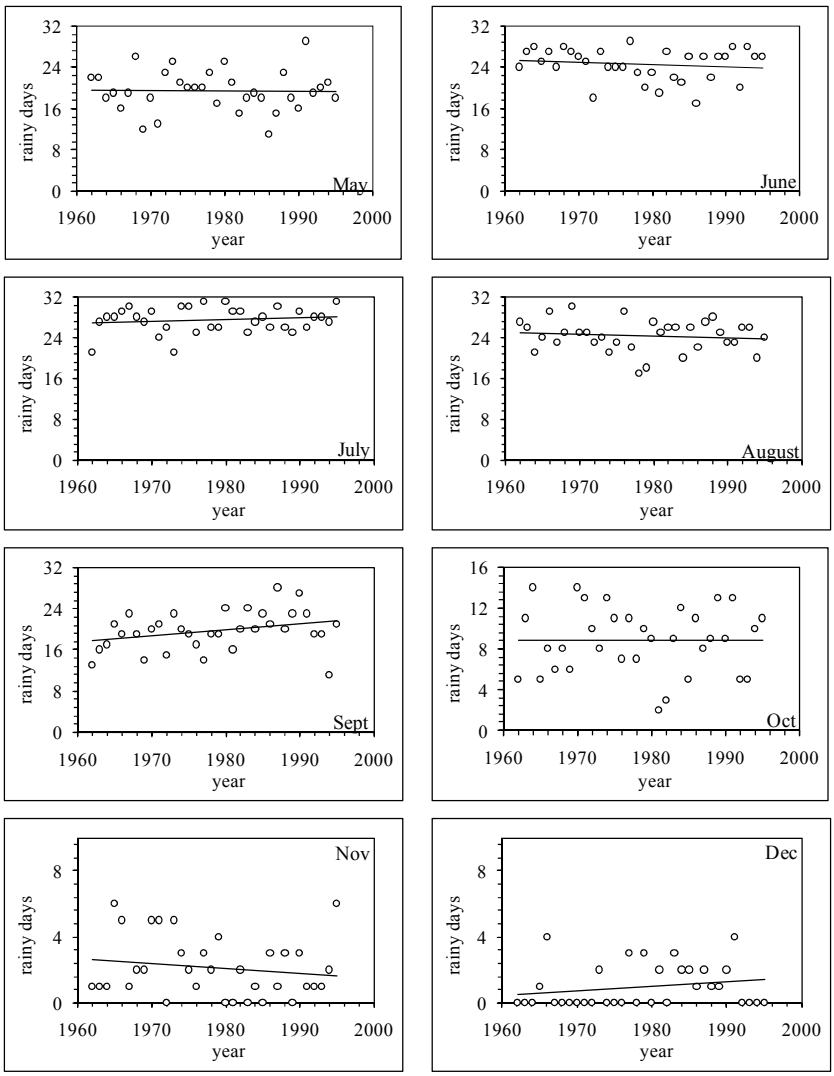
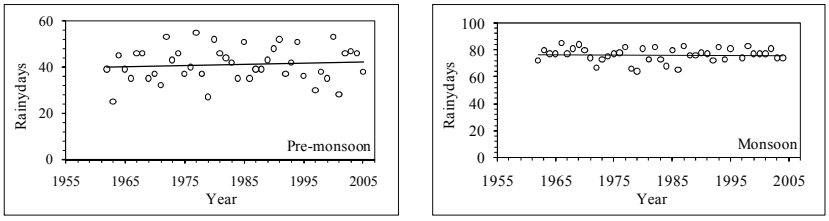


Fig. 10. Monthly Variation of Rainy Days with Their Linear Regression for Sylhet during the Period of 1962 – 1995.



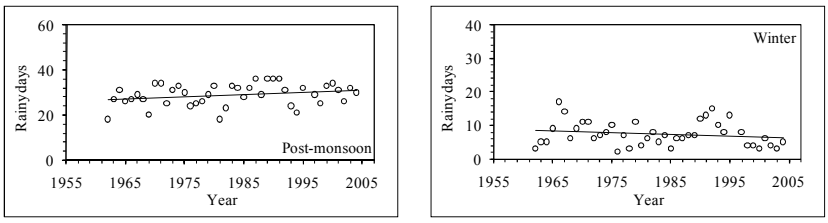


Fig. 11. Seasonal Variation of Rainy Days with Their Linear Regression.

5. Conclusions

The main conclusions resulting from this study are:

- The mean values of CV, RV and PIV for the daily maximum and monthly rainfall are approximately the same, but for the ratio between the mean daily maximum and mean monthly rainfall are significantly lower.
- Monthly rainfall increases linearly with daily maximum rainfall.
- Correlation coefficients between monthly and daily maximum rainfall are significant during all months of the year.
- Minor or steady change of rainfall pattern is observed. Pre- and post-monsoon months are getting slightly wetter, whereas other months are mostly constant.
- Variation of rainy days is not significant in terms of climate change.

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