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Prediction of Rainfall over Southeastern part of Bangladesh during Monsoon Season

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Abstract

An attempt has been made to understand the state of affairs of monsoon rainfall and associated heavy rainfall with different scales over southeastern part of Bangladesh. It is found that the trends of station averaged rainfall over southeastern part of Bangladesh in June, July, August and September are +2.78, -0.993, +1.01 and +3.11 mm/year respectively but the trend of monsoon rainfall is found is +7.28 mm/year during the observed period. For better understanding the amounts of rainfall is divided into different category (Cat). The average frequency of Cat-I, Cat-II, Cat-III, Cat-IV and Cat-V rainfall are 35.3, 16.1, 13.9, 12.0 and 6.6. The trend of Cat-IV rainfall frequency is negative but the trends for other categories are positive. Weather Research and Forecasting (WRF) Model (version: 3.2.1) is used to simulate 16 heavy rainfall events occurred over southeastern part of the country during 2010 and analyzed for prediction. The correlation coefficients (CC) between the simulated rainfall at rain gauge locations with observed and version 7 product of Tropical Rainfall Measuring Mission (TRMMV7) rainfalls are 0.43 and 0.67 respectively. The CC of simulated station averaged rainfall with observed and TRMMV7 rainfalls are 0.42 and 0.47 and the CC of simulated maximum rainfall with observed and TRMMV7 rainfalls are 0.53 and 0.58 respectively. The ratio between station averaged model and observed rainfall is 1.04 but the ratio between station averaged model and TRMMV7 rainfall is 0.78. Similarly, the ratio between maximum simulated and observed rainfall is 0.86 but the ratio between maximum model and TRMMV7 rainfall is 1.09. The predicted location specific, station average and the maximum rainfall over southeastern part of Bangladesh may therefore be estimated by the best fitted regression equations. The standard errors of estimation for the set up equations are quiet low.

Key words: Heavy rainfall, monsoon, prediction, simulation and WRF Model

1. Introduction

Monsoon is the main rainy season in Bangladesh which accounts for about 72 percent of the annual rainfall [1]. Agriculture is the foundation of the economy in Bangladesh which largely depends on the rainfall from the monsoon. The life and livelihood of the inhabitants of Bangladesh depend directly or indirectly on the monsoon rainfall as the fertility of cultivable land depends highly on the activities of the monsoon. Most of the development endeavors especially those of physical infrastructure like roads, flood control dams, irrigation canals and so on are dictated by the monsoon and most of natural disasters are also associated with the behavior of the monsoon. Thus, the economy of the country and fate of the people are closely tied up with the good monsoon rain which occurs during June to September. Monsoon acts as a life line to the agrarian society of Bangladesh. Hence, the joys and sorrows of the peoples of Bangladesh are linked with the variability of the monsoon rainfall. Moreover, the monsoon season is characterized by the occurrence of heavy rainfall causing extensive damage to crops, livestock's and properties associated with the loss of valuable lives.

Bangladesh is situated at the interface of two different environments, with the Bay of Bengal to the South and Himalayas to the north. Due to its geographical position, Bangladesh experiences highest

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amount of country averaged monsoon and annual rainfall among SAARC countries [2]. The rainfall of Bangladesh is mainly governed by the activities of monsoon system (i.e., position and intensity of monsoon trough, monsoon depression, etc.), tropical cyclonic disturbances, local land origin weather systems (land depressions, thunderstorms and meso-scale convective systems) and sub-tropical western disturbances. The Khasi-Jaintia-Garo hill complex and the plateau of Shillong and Arakan Mountains and Mizo hills play important role in modifying the rainfall pattern in northeast and southeast part of the country [3, 4].

The duration of monsoon is also an important factor for rainfall distribution over Bangladesh. The onset and withdrawal dates of monsoon in Bangladesh as well as over southeastern parts of Bangladesh vary from year to year. It generally begins over southeastern part of Bangladesh by late May or early June and withdraws by the middle of October. The normal date of onset of monsoon over southeastern part of Bangladesh is June 1. The mean onset dates of summer monsoon in Bangladesh in the extreme south-eastern coastal part and in the extreme north-western part are 2 June and 15 June respectively. The mean withdrawal dates of the summer monsoon from the northwestern and south-eastern part are 30 September and 17 October respectively; the standard deviations (STD) of the onset and withdrawal dates in different parts vary from 7 days to 10 days. The zone of high variability in both cases being located in the area that extends from southeastern to northeastern part of the country. The mean duration of summer monsoon varies from about 107 days in the extreme northeastern to about 137 days in the extreme southeastern part of the country [5]. The southeastern part of Bangladesh is therefore very much susceptible for monsoon rainfall and its variability.

Recent studies have shown that the rainfall of Bangladesh has been increasing during the recent decades [6, 7]. Nehrin *et al*. reported the existence of temporal oscillations with timescales of 2-3 years, 4-7 years and around 20 years [8]. The variability of rainfall (>22 mm/day) for summer monsoon has been studied by Mannan and Karmakar and indicated the increasing trend of monsoon rainfall over Bangladesh [7]. An analysis on summer monsoon rainfall over Bangladesh has been done by some authors, which focused on flood disasters [1].

Rahman *et al*. used trend analysis to study the changes in monsoon rainfall of Bangladesh and found no significant change [9]. Shamsuddin Shahid has analyzed rainfall variability and the trends of wet and dry periods in Bangladesh over the time period 1958-2007 using the rainfall data recorded at 17 stations of BMD distributed over the country. The result shows a significant increase in the average annual and pre-monsoon rainfall of Bangladesh. The number of wet months is found to increase and the dry months are found to decrease in most parts of the country. Seasonal analysis of wet and dry months shows a significant decrease of dry months in monsoon and pre-monsoon [10]. A number of studies have been carried out on rainfall patterns [5, 9, 10, 11] but only very few works have been found on rainfall trends and extremes in Bangladesh. Moreover, the study of the variability of monsoon over southeastern part of Bangladesh is very limited and it requires study.

Hence, the present study focuses on the spatial and temporal (intra-seasonal and inter-annual) variability and trends of monsoon rainfall over southeastern part of Bangladesh by using up-to-date data sets. The study also contains the analysis of 16 heavy rainfall events that occurred over southeastern part of Bangladesh during monsoon season of 2010 using Numerical Weather Prediction (NWP) Technique Weather Research and Forecasting (WRF) model with the aim to predict the rainfall in a better way. The results of this study will help improving the understanding of rainfall variability of southeastern part of Bangladesh.

2. Data Used and Methodology

The daily rainfall data of 7 selected stations of Chittagong, Cox's Bazar, Kutubdia, Rangamati, Sandwip, Sitakundu and Teknaf under Bangladesh Meteorological Department (BMD) during 1 June to 30 September for the period of 1981-2014 are collected and used in this study. The amounts of rainfall are classified and defined as category (Cat) for calculating the monthly and seasonal rainfall and the frequency of classified monthly and seasonal rainfall over these locations as well as over the southeastern part of Bangladesh following the criteria given in Table 1 [7]. Visual inspection on the recorded data has been done and the suspected data are deleted and marked as blank. The suspected data points and missing entries were filled up by inverse square distance weighted interpolation technique. The location of the rain gauge stations under this study is shown in Fig. 1. The trends of the frequency of categorized rainfall are calculated and analyzed.

Table 1: Categorization of rainfall for calculation of frequency [7]

Sl No	Amounts of rainfall recorded in 24 hours	Defined category	Class used in Bangladesh	Comments
1.	1-10 mm	Category-I (Cat-I)	Light	World Meteorological Organization (WMO) Classification
2.	11 - 22 mm	Category-II (Cat-II)	Moderate	
3.	23 - 43 mm	Category-III (Cat-III)	Moderately heavy	
4.	44 - 88 mm	Category-IV (Cat-IV)	Heavy	
5.	>88 mm	Category-V (Cat-V)	Very Heavy	

WRF ARW model (version 3.5.1) with the grid resolution of 9 km is used to diagnose the 16 heavy rainfall events occurred on 12, 13, 14, 15, 19, 26, 29 June, 11, 12, 25, 30 July, 10, 11, 14, 27 August and 10 September 2010 WRF Single-Moment 3 Class (WSM3) microphysics (MP) schemes with the combination of Kain-Fritsch (KF) cumulus scheme (CP). The coverage area of the model domain is 12-30ºN and 80-100ºE. The topographic data used in the model is obtained from USGS land covers data set. NCEP data have been provided at every 6 hours as initial and boundary conditions. The model has been run for 24 hours continuously with 19 sigma levels in the vertical direction from the ground to the 100 hPa level during the dates of heavy rainfall over southeastern part of Bangladesh to simulate the events. The parameters of convective rain and non-convective rain are extracted on daily basis for analyzing through GrADS. Simulated rainfalls are also compared with the Tropical Rainfall Measuring Mission (TRMM) rainfall (version 7 products) which is denoted as TRMMV7.

Regression is a statistical empirical technique that utilizes the relation between two or more quantitative variables on observational database so that an outcome variable can be predicted from the others. Regression use two methods simple linear regression and multiple linear regression models. Regression produces a polynomial describing the relationship between any set of inputs and corresponding output [12]. The linear regression line has been fitted using the most common method of least squares. This method calculates the best fitting line for the predicted rainfall by minimizing the sum of the squares of the deviations from each simulated rainfall to the line. If a simulated rainfall lies exactly on the straight line then the algebraic sum of the residuals is zero [13].

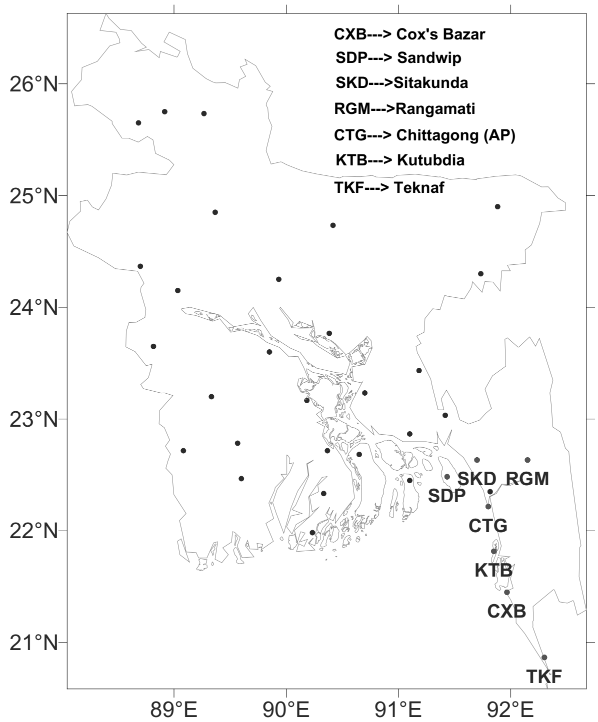

Fig. 1: Locations of rain gauge stations of BMD in Bangladesh: rainfall of the labeled and red point marked rain gauge locations are used under this study.

Residuals are defined as the difference between simulated rainfall at a point in time and the rainfall read from the trend line at that point in time. The simulated rainfall that lies far from the line has a large residual value and is known as an outlier or an extreme value. The equation of a linear regression line is given as

$$y = a + bx \text{..................................}(1)$$

Where, y is the predicted rainfall as the dependent variable and x is the simulated rainfall as the independent variable; 'a' is the intercept of the line on the vertical axis and 'b' is the slope of the line. The estimation of the intercept 'a' and the regression coefficient 'b' by the least square method is as follows:

$$\hat{a} = \bar{y} - \hat{b}\bar{x} \text{..................................}(2)$$

and

$$\bar{b} = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sum (x - \bar{x})^2} \text{..................}(3)$$

The coefficient of determination, R^2 = (Sum Square due to Regression)/ (Total SS)

$$R^2 = \frac{\sum (\hat{Y} - \bar{Y})^2}{\sum (Y - \bar{Y})^2} \text{........................}(4)$$

In order to fit regression lines, a large number of simulated rainfall (dependent variables) associated with heavy rainfalls are required and plotted. Linear regression line is then fitted to determine the predicted rainfall. The drawing of the diagrams and the fitting of the regression line is done in Microsoft Excel. Finally, the standard error of estimates for prediction of rainfall over southeastern part of Bangladesh is calculated.

3. Results and Discussion

3.1 Variability of monsoon rainfall over southeastern part of Bangladesh

In June, the monthly rainfall at rain gauge locations varies from 499.2 to 1019.4 mm but the recorded minimum and maximum monthly rainfalls during the observed period are 132.0 (Chittagong) and 3017 mm (Sandwip). The station averaged rainfall over southeastern part of Bangladesh varies between 304.4 to 1290.6 mm. The station averaged rainfall and its standard deviation (STD) are 735.0 and 221.6 mm. The trends of monthly rainfall at all of the rain gauge locations are positive and accordingly the trend of station averaged rainfall is +2.78 mm/year during the observed period (Fig. 2a).

In July, the monthly rainfall at rain gauge locations varies from 546.7 to 1107.9 mm but the recorded minimum and maximum monthly rainfall amount during the observed period are 134.0 (Sitakundu) and 2040 mm (Teknaf) respectively. The station averaged rainfall over southeastern part of Bangladesh varies between 487.8 to 1312.0 mm. The station averaged rainfall and its STD are 812.5 and 222.7 mm. The trends of monthly rainfall at Chittagong, Rangamati and Sitakundu are negative but the trends at Cox's Bazar, Kutubdia, Sandwip and Teknaf are positive. As a result, the trend of station averaged rainfall is -0.993 mm/year during the observed period (Fig. 2b). In August, the monthly rainfall at rain gauge locations varies from 411.2 to 898.3 mm but the recorded minimum and maximum monthly rainfall amount during the observed period are 71.0 (Sitakundu) and 1517.0 mm (Teknaf). The station averaged rainfall over southeastern part of Bangladesh varies between 225.6 to 1234.3 mm. The station averaged rainfall and its STD are 621.4 and 220.5 mm. The trends of monthly rainfall at Chittagong and Rangamati are negative but the trends at Cox's Bazar, Kutubdia, Sandwip, Sitakundu and Teknaf are positive. Consequently, the trend of station averaged rainfall is +1.01 mm/year during the observed period (Fig. 2c). In September, the monthly rainfall at rain gauge locations varies from 255.9 to 481.4 mm but the recorded minimum and maximum monthly rainfall amount during the observed period are 100.0 (Rangamati) and 1826.0 mm (Sandwip). The station averaged rainfall over southeastern part of Bangladesh varies between 203.9 to 724.0 mm. The station averaged rainfall and its STD are 375.9 and 131.9 mm. The trends of monthly rainfall at all of the stations are positive and therefore the trend of station average rainfall is +3.11 mm/year during the observed period (Fig. 2d).

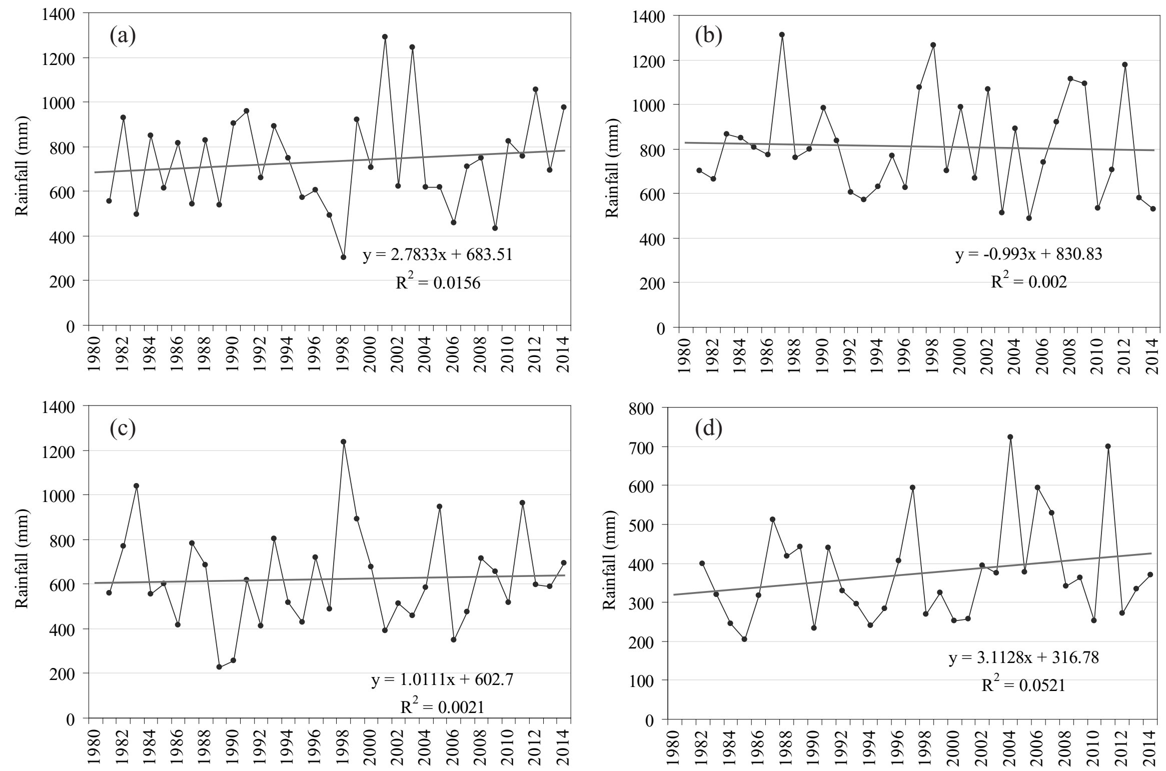

Fig. 2: Temporal variation of station averaged rainfall for (a) June, (b) July, (c) August and (d) September over southeastern part of Bangladesh during 1981-2014.

During monsoon, the average rainfall at rain gauge locations varies from 1736.3 to 3432.2 mm but the recorded minimum and maximum monthly rainfall amount during the observed period are 1025.0 (Rangamati) and 4716.0 mm (Teknaf). The station averaged rainfall over southeastern part of Bangladesh varies between 2005.9 to 3122.9 mm. The station averaged rainfall and its STD are 2526.4 and 316.5 mm. The trends of monsoon rainfall at all of the stations are positive with the deviation of magnitude and thus the trend of station average monsoon rainfall is +7.28 mm/year during the observed period. Comparison of monthly average rainfall and their STD reveals that the variability of monthly rainfall is higher in each of the monsoon months but it is quiet low as a whole in the monsoon season though the rainfall amount in the monsoon season is very high over southeastern part of Bangladesh.

3.2 Variability of categorized rainfall over southeastern part of Bangladesh

In June, the frequency of Cat-I rainfall is the highest and the frequency of Cat-V is the lowest. The average frequencies of Cat-I, Cat-II, Cat-III, Cat-IV and Cat-V rainfall are 7.4, 3.5, 3.7, 3.4 and 2.1. The variability (measured through STD) of the frequency of Cat-I rainfall is the highest and then comes Cat-IV and Cat-V (Fig. 3a). The trend of Cat-II rainfall frequency is negative but the trends for other categories of this month are positive (Table 2). In July, the frequency of Cat-I rainfall is the highest and the frequency of Cat-V rainfall is the lowest. The average frequencies of Cat-I, Cat-II, Cat-III, Cat-IV and Cat-V rainfall are 9.0, 4.3, 4.0, 3.9 and 2.4. The frequency of Cat-III, Cat-IV and Cat-V of this month are higher than other monsoon months. The variability of the Cat-I rainfall frequency is the highest and then comes Cat-IV and Cat-II (Fig. 3b). The trends of Cat-I and Cat-V rainfall frequencies are positive but the trends for other categories of this month are negative (Table 2).

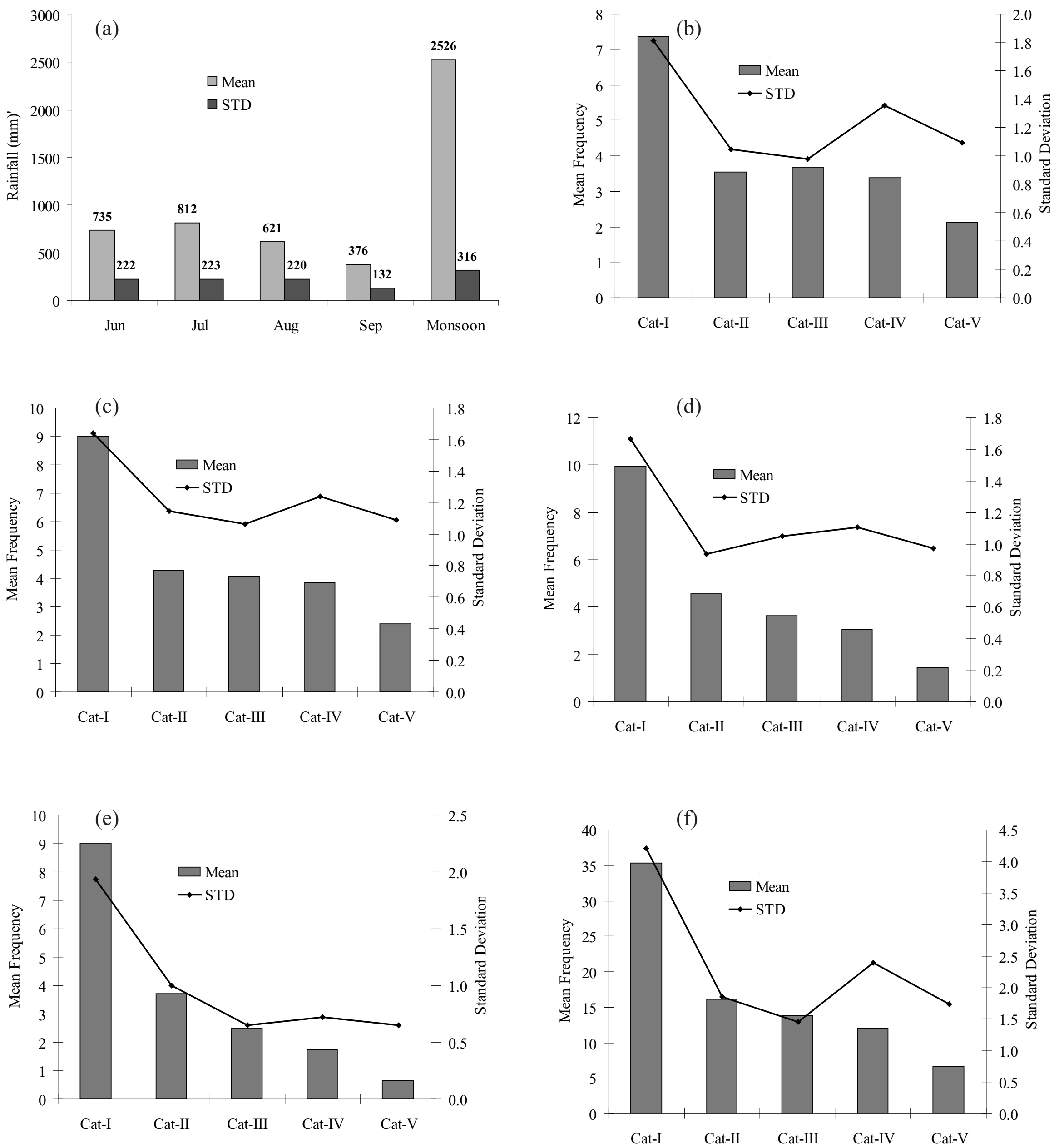

Fig. 3: (a) Mean and STD of rainfall; Frequency and STD of categorized rainfall of (b) June, (c) July, (d) August, (e) September, (f) monsoon season over southeastern part of Bangladesh during 1981-2014.

In August, the frequency of Cat-I rainfall is the highest which is also the highest among all other monsoon months and the frequency of Cat-V is the lowest. The average frequencies of Cat-I, Cat-II, Cat-III, Cat-IV and Cat-V rainfall are 10.0, 4.5, 3.6, 3.0 and 1.4. The frequency of Cat-II rainfall of this month is higher than other monsoon months. The variability of the Cat-I rainfall frequency of this month is the highest and then comes Cat-IV and Cat-III (Fig. 3c). The frequency of all the categories of rainfall depicts positive trend (Table 2). In September, the frequency of Cat-I is the highest and the frequency of Cat-V is the lowest. The average frequencies of Cat-I, Cat-II, Cat-III, Cat-IV and Cat-V rainfall frequencies are 9.0, 3.7, 2.5, 1.8 and 0.7. The variability of the Cat-I rainfall frequency is the highest and then come Cat-II and Cat-IV (Fig. 3d). The trends of Cat-III and Cat-IV rainfall frequencies are negative but the trends for other categories of this month are positive (Table 3e). Therefore, the frequency of Cat-I is the highest and the frequency of Cat-V is the lowest over southeastern part of Bangladesh during the monsoon season. The average frequency of Cat-I, Cat-II, Cat-III, Cat-IV and Cat-V rainfall are 35.3, 16.1, 13.9, 12.0 and 6.6. The variability of the Cat-I rainfall frequency is the highest and then comes Cat-IV and Cat-II (Fig. 3f). The trend of Cat-IV rainfall frequency is negative but the trends for other categories during monsoon season are positive (Table 2).

Table 2: Trends of categorized rainfall of southeastern part of Bangladesh

Category of rainfall	June	July	August	September	Monsoon
Cat-I	+0.039	+0.033	+0.051	+0.071	+0.194
Cat-II	-0.017	-0.024	+0.018	+0.045	+0.021
Cat-III	+0.004	-0.010	+0.009	-0.001	+0.002
Cat-IV	+0.006	-0.017	+0.012	-0.007	-0.006
Cat-V	+0.023	+0.013	+0.004	+0.018	+0.061

3.3 Simulation of heavy rainfall events occurred over southeastern part of Bangladesh

3.3.1 Spatial distribution of simulated rainfall occurred during heavy rainfall

Simulated rainfall of heavy rainfall events occurred during 12, 13, 14, 15, 19, 26, 29 June, 11, 12, 25, 30 July, 10, 11, 14, 27 August and 10 September of 2010 are shown in Fig. 4. Fig. 4 depicts that the signatures of high amounts of rainfall in most of the cases are over the land sea contrast zone of southeastern part of Bangladesh. But the zones of maximum rainfall are found either over Sitakundu region and adjoining Bay areas or Cox's Bazar-Teknaf region and adjoining coastal areas (Fig. 5). As per the simulated rainfall at selected station location, the average distance between the simulated and observed maximum rainfall is about 79 km.

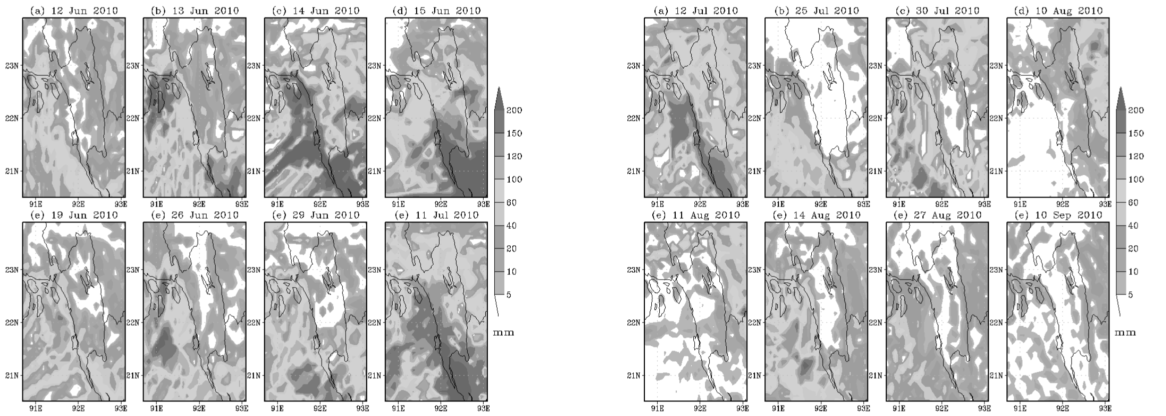

Fig. 4: Spatial distribution of simulated rainfall on (a) 12 June, (b) 13 June, (c) 14 June, (d) 15 June, (e) 19 June, (f) 26 June, (g) 29 June, (h) 11 July, (i) 12 July, (j) 25 July, (k) 30 July, (l) 10 August, (m) 11 August, (n) 14 August, (o) 27 August and (p) 10 September 2010 over southeastern part of Bangladesh

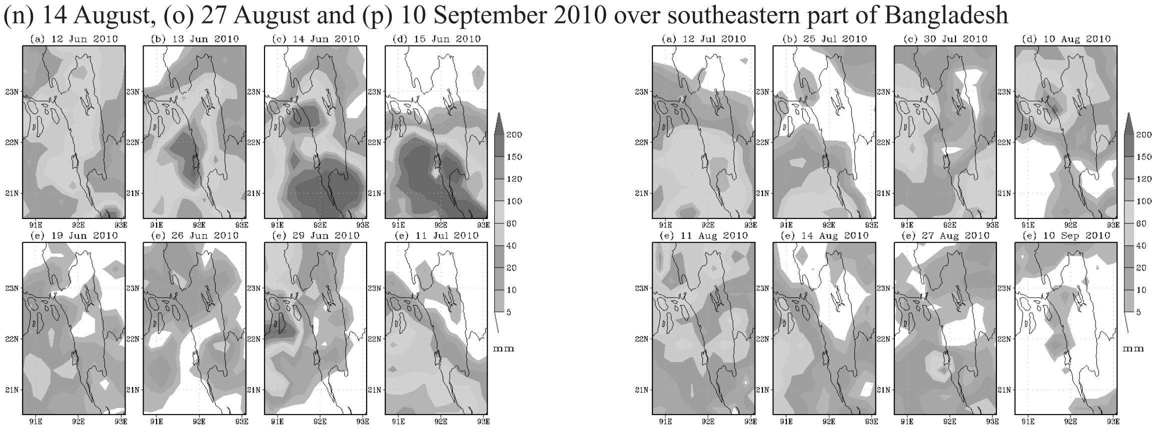

Fig. 5: Spatial distribution of TRMMV7 rainfall on (a) 12 June, (b) 13 June, (c) 14 June, (d) 15 June, (e) 19 June, (f) 26 June, (g) 29 June, (h) 11 July, (i) 12 July, (j) 25 July, (k) 30 July, (l) 10 August, (m) 11 August, (n) 14 August, (o) 27 August and (p) 10 September 2010 over southeastern part of Bangladesh

3.3.2 Comparison of simulated rainfall with observed and TRMM rainfall

Analysis reveals that the station averaged simulated rainfalls are higher than observation in 50% events; it is lower in 31% events and near to observation in 19% events. Model rainfalls are also higher than TRMMV7 rainfall in 37% cases; lower in 44% events and near to TRMMV7 in 19% cases (Fig. 6a). Similarly, the maximum rainfalls simulated during the dates of heavy rainfall occurrences are higher in 56% cases; lower in 38% cases and near to observation in 6% cases. On the other hand simulated maximum rainfalls are higher than TRMM in 38% cases but lower in 68% cases (Fig. 6b). The

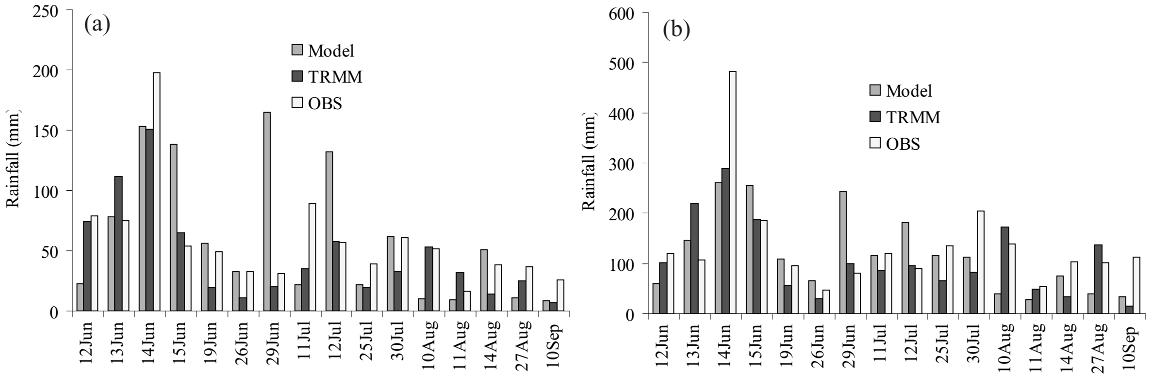

Fig. 6: Comparison of model rainfall (simulated) with TRMMV7 and observed rainfall of (a) station averaged and (b) maximum amounts on the dates of the occurrence of heavy rainfall over southeastern part of Bangladesh

maximum correlation coefficient (CC) of 0.98 is found between simulated and observed rainfall at rain gauge locations on the dates of occurrences of heavy rainfall but the maximum CC between simulated and TRMMV7 rainfall is 0.95. The CC between simulated maximum rainfall among the selected station locations with observed and TRMMV7 maximum rainfall are 0.53 and 0.70. The ratio between station averaged simulated and observed rainfall is 1.04 but the ratio between simulated and TRMMV7 rainfall is 0.76. The ratio between station averaged maximum simulated and observed rainfall is 0.86 but the ratio of simulated and TRMMV7 rainfall is 0.79.

Predicted rainfall at rain gauge locations of southeastern part of Bangladesh has therefore been calculated through the establishment of a linear regression equation between simulated and observed rainfall at the same locations where continuous rainfall observation is available. The established linear regression equation between observed and simulated rainfall at station locations on the dates of the occurrence of heavy rainfall is given in equation 5 and illustrated in Fig. 7a.

$$R_{predict} = 0.46 \times R_{stimulated} + 33.96 \quad (5)$$

Where, $R_{predict}$ indicates the predicted rainfall at the rain gauge locations of southeastern part of Bangladesh and $R_{stimulated}$ indicates the simulated rainfall at the rain gauge locations of southeastern part of Bangladesh.

Similarly, the best fitted linear regression equation between observed and TRMMV7 rainfall at station locations over southeastern part of Bangladesh on the dates of the occurrence of heavy rainfall is depicted in equation 6 and illustrated in Fig. 7b.

$$R_{predict} = 0.37 \times R_{TRMMV7} + 23.34 \quad (6)$$

Where, $R_{predict}$ indicates the predicted rainfall on the basis of simulated rainfall at the rain gauge locations of southeastern part of Bangladesh; R_{TRMMV7} indicates the simulated rainfall at the rain gauge locations of southeastern part of Bangladesh.

The standard error of estimation for predicted rainfall at rain gauge locations over southeastern part of Bangladesh is 40.0 mm for simulated rainfall but it is 32.9 mm for TRMMV7 rainfall.

The established linear regression equation between observed and simulated station average rainfall during the dates of the occurrence of heavy rainfall over southeastern part of Bangladesh is given in equation 7 and shown in Fig. 8a.

$$R_{predict} = 0.32 \times R_{stimulated} + 38.87 \quad (7)$$

Where, $R_{predict}$ indicates the predicted station averaged rainfall over southeastern part of Bangladesh & $R_{stimulated}$ indicates the simulated station averaged rainfall over the same area.

The developed linear regression equation between observed and simulated maximum rainfall over the southeastern part of Bangladesh during the dates of heavy rainfall is given in equation 8 and shown in Fig. 8b.

$R_{predict} = 0.67 \times R_{stimulated} + 57.17$ .... (8)

Where, $R_{predict}$ indicates the maximum predicted rainfall over southeastern part of Bangladesh and $R_{stimulated}$ indicates the maximum simulated rainfall over the same area.

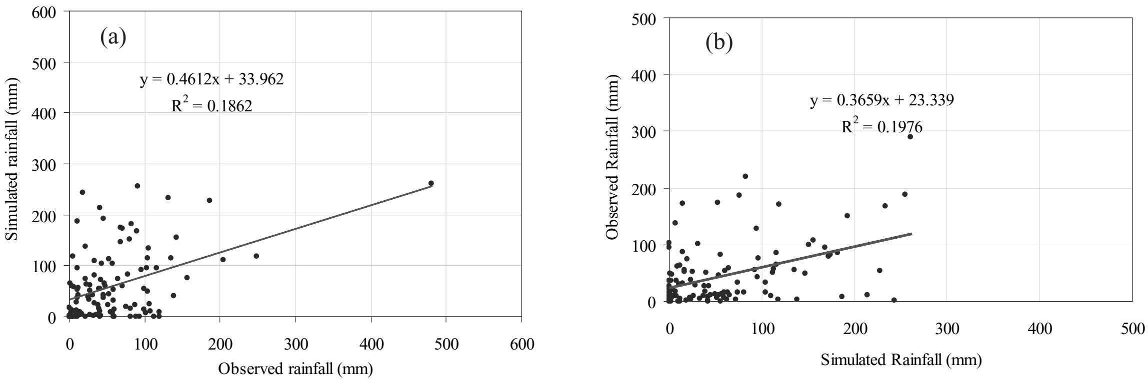

Fig. 7: Comparison of model rainfall with (a) observed rainfall and (b) TRMMV7 rainfall at station location on the dates of the occurrence of heavy rainfall over southeastern part of Bangladesh

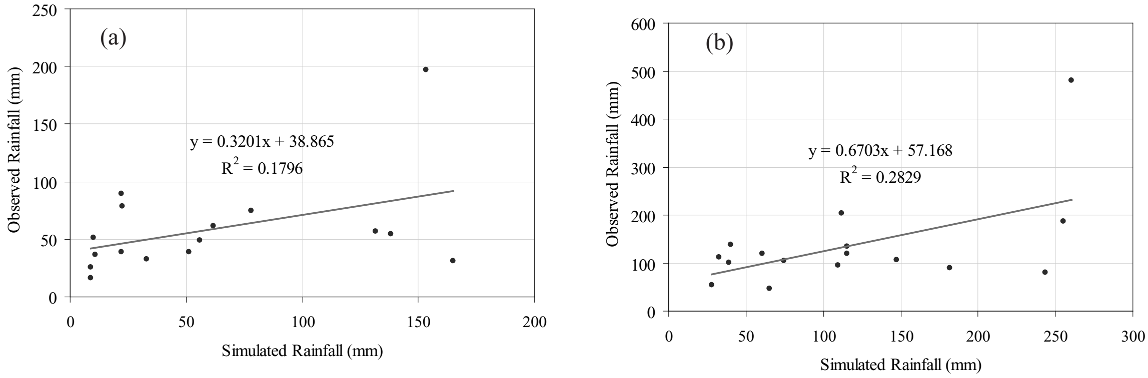

Fig. 8: Comparison of station average model rainfall with (a) observed rainfall and (b) TRMMV7 rainfall on the dates of the occurrence of heavy rainfall over southeastern part of Bangladesh

The standard error of estimation for predicted station average rainfall over southeastern part of Bangladesh is 26.1 mm but it is 56.2 mm for predicted maximum rainfall.

4. Conclusion

From the analysis the following conclusions may be drawn:

(i) The trends of station averaged rainfall over southeastern part of Bangladesh during June, July, August and September are +2.78, -0.99, +1.01 and +3.01 mm/year respectively. Accordingly, the trend of station averaged monsoon rainfall is +7.28 mm/year during the observed period.

(ii) The trend of Cat-II rainfall frequency of June is negative but the trends for other categories are positive. The trends of Cat-I and Cat-V rainfall frequencies of July are positive but the trends of other categories are negative. The frequencies of all the categories of rainfall of August depict positive trends. The trends of Cat-III and Cat-IV rainfall frequencies in September are negative but the trends for other categories positive.

(iii) The average frequencies of Cat-I, Cat-II, Cat-III, Cat-IV and Cat-V rainfall over southeastern part of Bangladesh during monsoon season are 35.3, 16.1, 13.9, 12.0 and 6.6. The frequency Cat-IV rainfall indicates negative trend but other categories indicate positive trends.

(iv) Simulated station averaged rainfalls are higher than observation in most of the cases. Simulated maximum rainfalls at rain gauge locations are also higher in most of the occurrences heavy rainfalls over southeastern part of Bangladesh.

(v) The maximum CCs between simulated and observed rainfall at rain gauge locations, simulated station average and observed and simulated maximum and observed rainfall during the dates of occurrence of heavy rainfall are 0.98, 0.53 and 0.79. The ratio between station averaged simulated and observed rainfall is 1.04 but the ratio between station averaged maximum simulated and observed rainfall is 0.86.

(vi) For prediction of rainfall over southeastern part of Bangladesh, regression equations for prediction of location specific, station averaged and maximum rainfall over southeastern part of Bangladesh during the dates of occurrence of heavy rainfall have been developed. These equations will be useful for prediction purposes.

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