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Study of a Heavy Rainfall Event in Bangladesh Using Global Satellite Mapping of Precipitation Data

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Abstract

Flood or flash flood monitoring and forecasting is a complicated tasks in densely inhabited and low-lying topography areas like Bangladesh. Recently, flash flood showed its hazardous and devastating affect in the northeastern part of the country especially Sumamganj, Kishoreganj, Netrokona due to heavy rainfall in those area and upper catchment area in India. Due to lack of rainfall data of upper catchment area in India, flash flood forecasting was not possible. Global Satellite Mapping of Precipitation (GSMaP) data can be used for flash flood forecasting. GSMaP is a high spatiotemporal resolution (0.1°×0.1°; 1 hourly) data and available four hour later after the observation. To validate GSMaP data, 3-hourly data of 35 rain gauge stations of Bangladesh Meteorological Department (BMD) used for the study period 2001-2015. Different threshold rainfall events are also studied. Several statistical analyses showed that GSMaP data are well correlated with rain gauge data. The correlation coefficients between GSMaP and BMD rain gauge for 3-hourly,and daily are found 0.71and 0.74 respectively. The Standard Deviation (SD) of 3 -hourly rainfall for G SMaP and rain gauge data are found 1.96 and 2.10 mm, respectively. According to BMD, there are five types of threshold rainfall events such as Very Heavy Rainfall (VHR > 88 mm in 24 hour), Heavy Rainfall (88 ≥ HR ≥ 43.5 mm in 24 hour), Moderate Heavy Rainfall (43.5 > MHR ≥ 22.5 mm in 24 hour), Moderate rainfall (22.5 > MR ≥ 10.5 mm in 24 hour) and Light rainfall (10.5 > LR ≥ 2.5 mm in 24 hour). The average yearly occurrence of VHR, HR, MHR, MR and LR events are found 4.1, 11.7, 17.9, 23.5 and 35.4 for BMD rain gauge data and 2.30, 8.03, 14.13, 22.56, and 42.58 for GSMaP data, respectively. The performance of GSMaP data to detect the events is 97%. So GSMaP data may be used to predict the flash flood, especially in areas where rain gauge data are limited.

Keywords: *Flash flood, Catchment area, Correlation Coefficient, Rainfall event, Prediction.*

1. Introduction

Heavy rainfall (HRF) events and their associated flooding have made tremendous impacts on human society in terms of property damage and loss of human life [1]. While HRF is possible anywhere, some areas are more susceptible or vulnerable than other areas [2]. Bangladesh, is primarily a low-lying plain country, situated on deltas of large rivers flowing from the Himalayas, has a sub-tropical humid climate and considered as a heaviest rainfall area in the world [3] which may responsible to become an agro-based economic country. Precipitation, especially rainfall has a dramatic effect on agriculture system; the rainfall pattern is momentous to healthy living plants and greens. National economy and economic development of Bangladesh is vehemently linked with rain-fed-agriculture system. So, to understand the physical mechanism and variability of precipitation, especially heavy rainfall is very important.

In Bangladesh, only 35 rain gauge station's data represent the rainfall throughout the country, which is insufficient for meteorological and hydrological study. Inadequate rain gauge

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networks throughout the country sometimes provide incomplete information about the distribution of rainfall or heavy rainfall [4]. To mitigate this problem as well as transboundary rainfall data satellite observation may play an important role for the country. Remote sensing techniques use microwave and space borne sensors that provide an excellent complement to continuous monitoring of rainfall event both spatially and temporally. So, it is a suitable chance to use Satellite-born Global Satellite Mapping of Precipitation (GSMaP) data to characterize the dynamical mechanism of rainfall over Bangladesh. There have been many studies conducted to flood or flash flood forecasting, monitoring using GSMaP data in different parts of the world [5-9] but a very few work has been carried out in Bangladesh.

This study contains the analysis of spatial distribution of heavy rainfall that occurred recently on March 28, 2017 in the northeastern part of the country especially Sumamganj, Kishoreganj, Netrokona and upper catchment area in India.

In this study GSMaP hourly data is used with the aim to predict the rainfall and/or HRF in a better and instant way. The results of this study will help to predict and forecast the rainfall related flood especially flash flood.

2. Data and Methodology

The remotely sensed observational data utilized on this work is satellite-based rainfall estimates from GSMaP product which is processed and released by Earth Observation Research Centre (EORC) of Japan Aerospace Exploration Agency (JAXA).

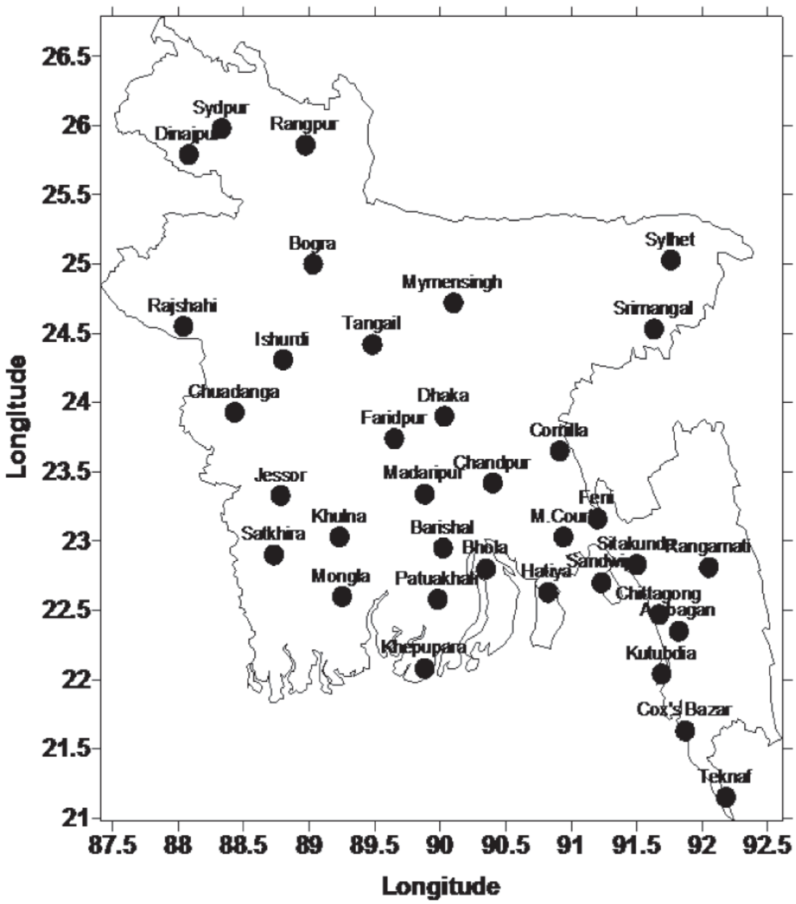

Fig. 1. Locations of the 35 rain gauge stations of BMD.

The GSM aP data, prepared from the combined geostationary infrared and many microwave radiometer satellites retrieved rain rates information, have a spatial resolution of 0.1° between 60°N and 60°S and a temporal resolution of 1 h ending on the hour in UTC. This satellite-derived GSMaP dataset is available from 2001 to present over both land and sea, in contrast to rain gauge dataset that is confirmed to land only.In the present study, we utilize fifteen years (2001-2015) rainfall data from GSMaP and three hourly BMD rain gauges, in order to describe the mean characteristics of rainfall of the study area. BMD has only35rain gaugestationsalloverthe-country. The locations of these 35 rain gauges are shown in Fig.1. In the current study, 3 hourly rain gauge data collected by BMD are utilized.

Grid Analysis and Display System (GrADS) script was used to extract rainfall from GSMaP global data at different BMD rain gauge station locations. The 3-hourly and daily rainfall is calculated from hourly rainfall data of GSMaP. Surfer mapping software tool used to observe the spatial distribution of rainfall. According to BMD [10], there are five types of threshold rainfall events such as Very Heavy Rainfall (VHR > 88 mm in 24 hour), Heavy Rainfall (88 ≥ HR ≥ 43.5 mm in 24 hour), Moderate Heavy Rainfall (43.5 > MHR ≥ 22.5 mm in 24 hour), Moderate rainfall (22.5 > MR ≥ 10.5 mm in 24 hour) and Light rainfall (10.5 > LR ≥ 2.5 mm in 24 hour). The different thresholds rainfall are also calculated and compared.

2.1. Statistical verificationformulae

According to Ebert [11], statistical method to verify accuracy of the satellite-born rainfall estimates compared with the observed rain gauge values include continuous verification statistics. The continuous verification statistics measure accuracy of a continuous variable such as rain amount or intensity. In this study, the statistics measures used include correlation coefficient (r), root mean square error (RMSE), and standard deviation (SD).

2.1.1.Correlation coefficient

The formula for the correlation (r) is

$$r = \frac{1}{(n-1)}\left(\frac{\sum\sum x-\bar{x})(y-\bar{y})}{s_x s_y}\right) \qquad (1)$$

where, n is the number of pairs of data . $\bar{x}$ and $\bar{y}$ are the sample means of all the x-values and all the y-values, respectively; and s_x and s_y are the sample standard deviations of all the x-value and y-values, respectively.

2.1.2. Root mean square error

The RMSE (also called the root mean square deviation) is a frequently used to measure of the difference between values predicted by a model and the values actually observed from the environment that is being modelled. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power.

The RMSE of a model prediction with respect to the estimated variable x_{model} is defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_{obs,i} - x_{model,i})^2}{n}} \qquad (2)$$

where, x_{obs} is observed values and x_{model} is modelled values at time/place *i*.

The calculated RMSE values will have units. In this study, BMD data is observed values and GSMaP data is modelled/reference values. The unit of RMSE is millimetre in this study.

2.1.3. Standard deviation

The standard deviation (SD) which measure that is used to quantify the amount of variation or dispersion of a set of data values. A low standard deviation indicates that the data points tend to be close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values.

The formula for standard deviation (SD) is

$$SD = \sqrt{\sum\frac{(x-\bar{x})^2}{n}} \qquad (3)$$

where, ∑means "sum of", x is a value in the data set, $\bar{x}$ is the mean of the data set and n is the number of data points.

3. Results and Discussion

3.1. Data validation

So far our knowledge this is the first attempt to use GSMaP data in Bangladesh, for this reason we validated GSMaP data with BMD rain gauge data. It is found GSMaP data are highly correlated with BMD rain gauge data. The 3-hourly and daily CC′s between BMD rain gauge and GSMaP data are found 0.71 and 0.74 using equation (1). Level of confidence of our both dataset is 95%. We also checked the average daily rainfall trend of BMD rain gauge and GSMaP data during study period (2001-2015).

3.1.1. Scattered plot of 3-hourly rainfall

Fig. 2 represents scatter plot of 3-hourly rainfall between GSMaP and BMD rain gauge for the period 2001-2015.

The value of R^2 (The Value of determinant) between GSMaP and rain gauge is found 0.5643, which means that 56% of rain gauge data can be explained by the GSMaP data. The SD of 3-hourly rainfall for GSMaP and rain gauge data are found 1.96 and 2.10 mm, respectively. RMSE between BMD and GSMaP is found 4.56 mm.

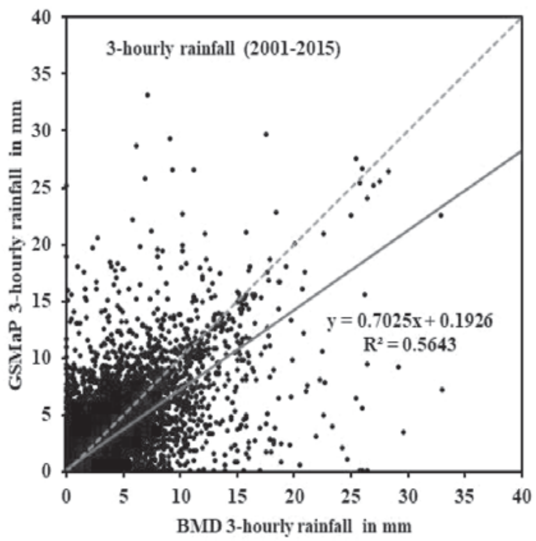

Fig. 2. Scatter plot of 3-hourly rainfall between GSMaP and rain gauge from 2001-2015. The dashed line is a 1 : 1 line and blue solid line represents linear fit (Y=a+bX)

In this figure, the dashed line (1:1) is above the blue solid line (linear fit), suggesting the negative (GSMaP < rain gauge) systematic difference is significant for higher rainfall rate. The systematic difference is small for low rainfall rate.

3.1.2. Scattered plot of daily average rainfall

Fig. 3 represents scatter plot of daily average rainfall between GSMaP and BMD rain gauge during the period 2001-2015. Horizontal and vertical axis is the average of daily rainfall of BMD and GSMaP, respectively during 2001-2015.

The value of R^2 between GSMaP and rain gauge is found 0.5435. The SD of daily GSMaP and rain gauge data are found 10.78 mm and 9.76 mm, respectively. The RMSE is found 7.62 mm between BMD and GSMaP.

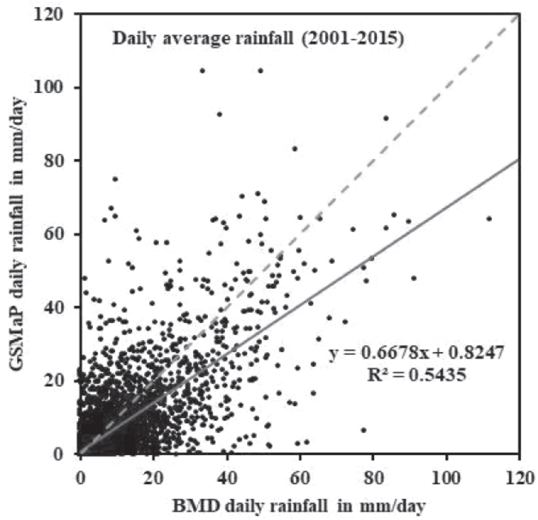

Fig. 3. Scatter plot of daily average rainfall between GSMaP and rain gauge from 2001-2015. The dashed line is a 1:1 line and blue solid line represents linear fit (Y=a+bX)

In this figure, the dashed line (1:1) is above the blue solid line (linear fit), suggesting the negative (GSMaP < rain gauge) systematic difference is significant for higher rainfall rate whereas systematic difference is small for low rainfall rate. To get the corrected GSMaP data we may use the regression equation of linear fit which leads to the real observational value.

3.1.3. Daily rainfall variation

Fig. 4 showed 15-years daily average variation of rainfall measured by rain gauge and GSMaP. The GSMaP and rain gauge measured 5.14 mm and 6.47 mm rainfall per day, respectively. It is found from figure that active and break phases of rainfall trend are well matched between GSMaP and rain gauge.

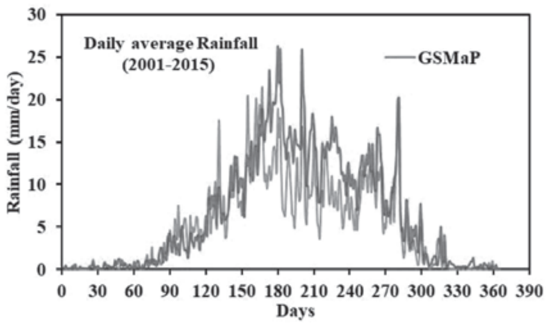

Fig. 4. Variantion of daily average rainfall from 2001 to 2015 over Bangladesh measured by GSMaP and rain gauge.

Prasad et al., [12] explained that the primary cause of these active and break spells are fluctuations (i.e. intensity and position) of the seasonal monsoon trough. Active spells occur in almost every monsoon season being without even a single active event. The break phase is characterized by a marked change in the lower tropospheric circulation over the monsoon zone, with the vorticity above the boundary layer becoming anticyclonic [13]. Monsoon trough is an extended trough of low seasonal pressure which runs across the Gangetic plains of north India and also over northwest India and Pakistan, eastern end emerging into the Bay of Bengal. In the meantime, the axis of this trough runs from Ganganagar in Rajshahi to Kolkata via Allahabad. Fig. 4 also showed that during monsoon period (around days of 160-270) GSMaP underestimated and during pre-monsoon period (around days of 65-160) GSMaP overestimated. Rafiuddin et al., [14] studied 6 - years radar data of BMD and divided the precipitation systems into arc, line and scattered types according to their shape. They showed that arc-type systems are dominated during the pre - monsoon period. Measurement of precipitation of GSMaP may be depends on the precipitation types. It may the reason for the overestimation of rainfall of GSMaP during pre-monsoon period.

3.2. Rainfall events

Fig. 5 showed the threshold rainfall events (Category) measured by GSMaP and BMD rain

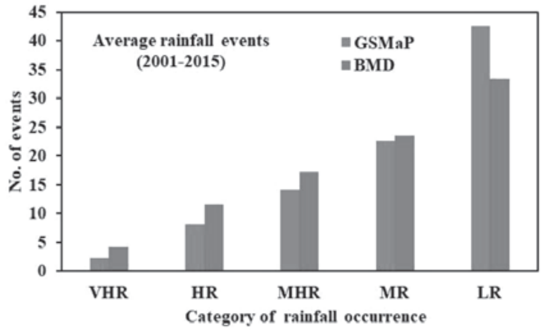

Fig. 5. Threshold rainfall events measured by GSMaP and BMD rain gauge.

The average yearly occurrence of VHR events measured by GSMaP and BMD rain gauge during the study period is 2.30 and 4.1, respectively. GSMaP and BMD detect HR events 8.03 and 11.7, respectively. In the case of MHR events, GSMaP and BMD detect 14.13 and 17.9 events, respectively. MR events are 22.56 and 23.5 measured by GSMaP and BMD, respectively. In the case of light rainfall events GSMaP measured 42.5 and BMD measured 35.4 events. GSMaP overestimated for LR events and underestimated for other events of rainfall event.

3.3. Flash flood on March, 2017

River cross-section builds up based on the catchments pattern and the amount of rainfall over it. If rainfall in the northeastern part of the country decreases and in the Meghalaya region increases, for the upstream cross sections of the rivers in the Sylhet region, this excess flow will appear as unusual over the capacity of the river cross sections, causing flash flood. It has been reported by Bangladesh Water Development Board (BWDB) that the number of flood increases now-a-days in this region [15].

Flood started on 28th March affecting six haor districts (Sylhet, Moulvibazar, Sunamganj, Habiganj, Netrokona and Kishoreganj) in the north east region [16]. Rising water overflow and breeched embankment in many places and inundated vast areas of croplands. It destroyed nearly-ready-for-harvesting boro rice in about 219,840 hectors area sand over 300,000 people without secure accommodation. Flash floods set off by heavy rains and upstream torrents from Meghalaya in India have swamped vast stretches of land in northeastern part of the country, leaving thousands of people marooned. In addition, there is a high potential to deteriorate the flood condition in Sylhet as the onrush of water from upstream is very likely to inundate most of the sub-districts located near to Indian border. As the river beds of Surma and Kushiara and their tributaries are silted up, so the prolonged water beyond danger limit might cause huge effect to six haor districts. Fig. 6 showed the spatial distribution of accumulated rainfall of March, 2017 measured by GSMaP over the north-eastern part of the country and upper catchment of area of Megalaya of India which experienced HRF (yellow-red-light blue sheded area).

This helps us to get a message about the transboundary areas rainfall which may be a warning of flood or flash flood in land areas of the Bangladesh.

Fig. 7(a-b) represent the comparison of BMD and GSMaP spatial distribution of rainfall of 1-10 days of march, 11-20 days in Fig. 7(c-d) and 21-31 days in Fig. 7(e-f). According to Skymet Weather report [17], during the middle of the March, the central part of India experienced the tight grip of heatwave conditions, which produced a cyclonic circulation over Sub-Himalayan West Bengal and adjoining areas like northeast parts of Bangladesh. These circulations bring huge moisture by the strong winds from the Bay of Bengal towards the Meghalaya and Assam regions. After cooling and condensation of the moisture due to the uplift over the Meghalaya hills, orographic HRF occurred over Meghalaya and Asham regions.

Since we have no access of rainfall data in the upper catchment area of India (Megalaya) but flash flood model needs those transboundary rainfall data, so someone may use GSMaP transboundary rainfall data to predict flash flood more accurately.

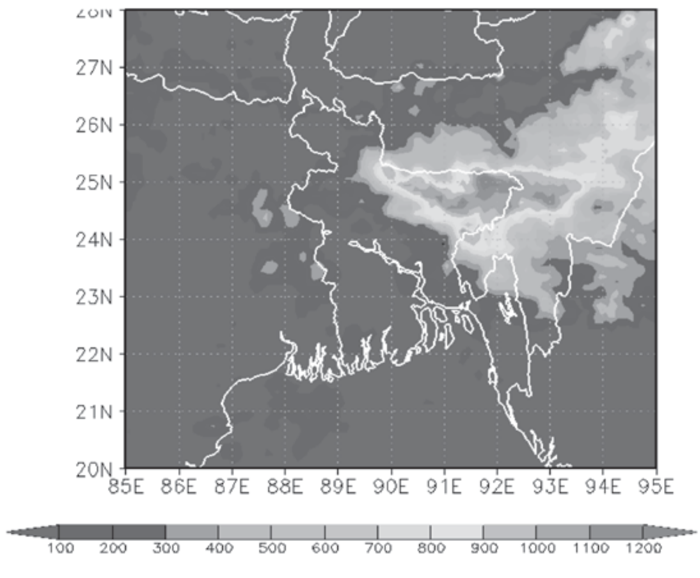

Fig. 6: Spatial distribution of accumulated rainfall of 31 days of March, 2017.

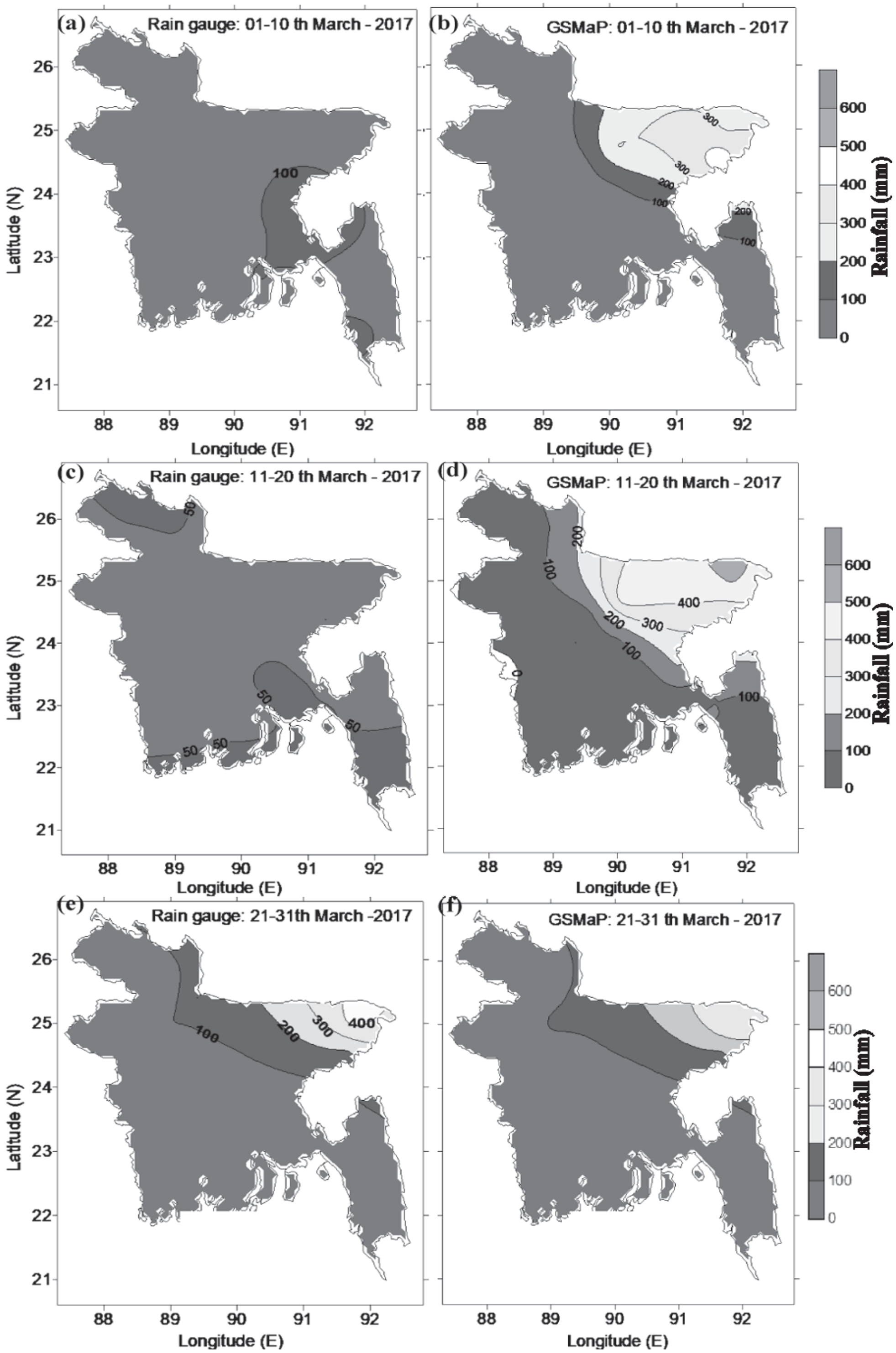

Fig. 7: Spatial distribution of rainfall of 1-10 days at (a-b), 11-20 days at (c-d) and 21-31 days at (e-f) of March, 2017 observed by BMD rain gauge and GSMaP.

4. Conclusions

From these analyses the following conclusions may be drawn:

(i) The correlation coefficients between GSMaP and BMD rain gauge for 3-hourly and daily are found 0.71, and 0.74 respectively. The Standard Deviation (SD) of 3-hourly rainfall for GSMaP and rain gauge data are found 1.96 and 2.10 mm, respectively. RMSE between both 3-hourly datasets of BMD rain gauge and GSMaP is found 4.56 mm. GSMaP product's data are well correlated with gauge data of BMD; it can be used for meteorological study in Bangladesh.

(ii) The average rainfall trend is well matched during study period and GSMaP overestimated during pre-monsoon season but underestimated during monsoon season.

(iii) The average yearly occurrence of VHR, HR, MHR, MR and LR events are found 4.1, 11.7, 17.9, 23.5 and 35.4 for BMD rain gauge data and 2.30, 8.03, 14.13, 22.56, and 42.58 for GSMaP data, respectively.

(iv) The variation of spatial distribution of rainfall measured by BMD rain gauge and GSMaP are well mached.

(v) GSMaP product can be robustly used to predict rain related flash flood or flood in Bangladesh.

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