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Comparison of Diurnal Variation of Rainfall of GSMaP and Rain Gauge Data in Bangladesh

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ABSTRACT

The diurnal variation of rainfall across Bangladesh is evaluated using data from the Global Satellite Mapping of Precipitation (GSMaP). GSMaP data has a temporal resolution of 1 hour and a spatial precision of 0.1 degree. GSMaP data is combined with three hourly rain gauge data from 35 sites of Bangladesh Meteorological Department (BMD). The diurnal variation of rainfall and their spatial distribution are compared in daily, monthly and yearly scales during the period of 2001-2015. It is observed that GSMaP data is well correlated with BMD rain gauge data. The correlation coefficients between GSMaP and BMD rain gauge for 3-hourly, daily, monthly and yearly rainfall are found 0.71, 0.74, 0.82 and 0.66, respectively. The GSMaP measured daily maximum rainfall over Bangladesh at 0300 LST (Local Standard Time) with a secondary maximum peak at 1500 LST, whereas, rain gauge got primary peak at 0600 LST with a secondary peak at 1500 LST. The diurnal variation of rainfall observed by GSMaP is well matched with rain gauge observation during the pre-monsoon, post-monsoon and winter season. During monsoon season, the primary peak of rainfall is measured at 1500 LST by GSMaP whereas rain gauge is found at 0600 LST. The maximum rainfall is found in the southern, western, eastern and central regions of the country during 1200-1500 LST. In the southeastern region of Bangladesh the maximum rainfall is found during 0600-0900 LST. The maximum rainfall is observed in the northwestern and northeastern regions of the country during 0300-0600 LST.

Keywords: *Diurnal variation, Correlation Coefficient, Maximum rainfall, Spatial distribution*

1. Introduction

Precipitation, especially rainfall (RF) is one of the most important climatic variables having a direct effect on many kinds of human activity like to grow healthy living plants and greens. The RF regime affects water management, agriculture, water transport and also human’s everyday life.The weather of a certain region is highly dominated by different diurnal processes and the diurnal variation (DV) of RF is their direct result. The nature of RF DV is influenced by a number of factors, including the nature of the related ground surface, geographical location, time of year, and rainfall type.

Over land and adjacent coastline, the land-sea-breeze circulation and the thermal characteristics of the land surface persuaded by the contrast of the ocean surfaces and land can interpret much of the diurnal variation of rainfall. Bangladesh has the world's heaviest rainfall [1], making it ideal for studying the DV's physical mechanics. The diurnal cycle of RF influences the RF effectiveness in agriculture, because a large part of the rainwater during the warmer part of the day is lost through the process of evaporation. So, to understand the physical mechanism of DV of RF is very important to us.

Just 35 rain gauge stations of the Bangladesh Meteorological Department (BMD) represent the RF across the country, which is insufficient for meteorological and hydrological research. Inadequate rain gauge networks over the country sometimes provide partial information about the spatial distribution of rainfall [2]. To mitigate this problem 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 RF amount both spatially and temporally. As a result, it is a good opportunity to describe the DV of RF across Bangladesh using satellite-borne Global Satellite Mapping of Precipitation (GSMaP) data. Many studies on diurnal variation of RF utilizing GSMaP data have been conducted in various parts of the world, but only a handful have been conducted in Bangladesh. The goal of the current work is to presentGSMaP data in order to compare it to traditional rain gauge data.

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2. Data and Methodology

The satellite-based rainfall estimates from GSMaP product which is processed and released by Earth Observation Research Centre of Japan Aerospace Exploration Agency (JAXA) is used in this research.

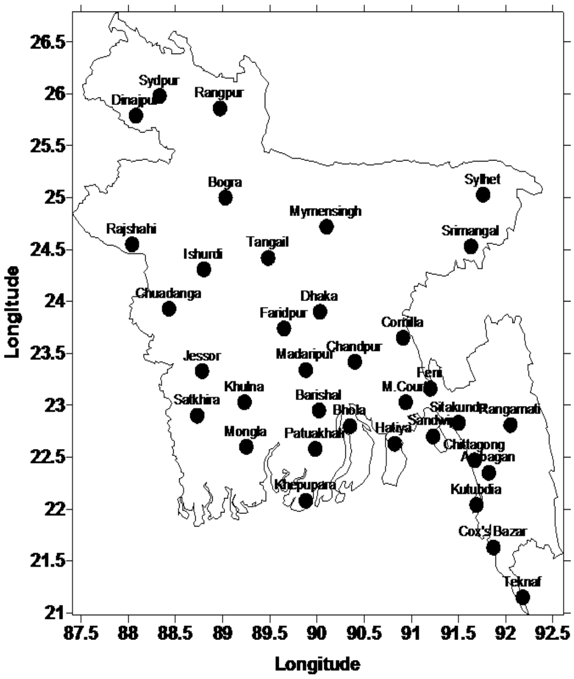

Fig. 1: Locations of the 35 rain gauge stations of BMD.

The GSMaP data have a temporal resolution of 1 hour and a spatial resolution of 0.1° by 0.1° from 60°N to 60°S. Using a combination of geostationary infrared and microwave radiometer satellites, GSMaP was able to gather information on rain rates. The GSMaP dataset included both land and marine data, but the rain gauge dataset only included data from the land.In order to summarize the mean characteristics of rainfall over Bangladesh, we used fifteen years (2001-2015) of RF 1 hourly data from GSMaP and three hourly RF data from 35 BMD rain gauge stations.The locations of 35 rain gauge stations are shown in Figure 1.

Grid Analysis and Display System (GrADS) script was used to extract rainfall data from GSMaP global data at different BMD rain gauge stations location. 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.

2.1. Statistical verification

Continuous verification statistics, according to Ebert [3], are a statistical tool for verifying the accuracy of satellite-born RF estimates compared to observed rain gauge data. Continuous verification statistics assess the consistency of a continuous variable, such as rainfall. Here, the correlation coefficient (r) and root mean square error (RMSE), and standard deviation (SD) were used as statistical metrics.

2.1.1. Correlation coefficient

The mathematical formula for the correlation coefficient is

$$r = \frac{1}{(n-1)} \sum_{i=1}^{n} \left(\frac{x_i - \bar{x}}{S_x}\right)\left(\frac{y_i - \bar{y}}{S_y}\right) \qquad (1)$$

where n is the number of data pairs . $\bar{x}$ is the mean of all the x-values and $\bar{y}$ is the mean of all the y values; and s_x is the standard deviation of all the x-values s_y is the standard deviations of all the y-values.

2.1.2. Root mean square error

The RMSE is for calculating the difference between a model's projected values and the actual collected values being modelled. Residuals are the differences between each pair of values, and the RMSE assembles them into a single measure of predictive power.

The RMSE is defined as the square root of the mean squared error:

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

where x_{pre} is modeled predicted values at time/place i and $x_{act}$is the actual observed values.

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

Any dataset's fluctuation or dispersion is explained using the SD. The SD number is low if the data points are near to the mean. The value of SD, on the other hand, is high if the data points cover a wide range. SD is calculated using the formula

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

where $\sum$ means "sum of", n is the total number of data points, $\bar{x}$ is the average of data points and x is individual values of data points.

3. Results and Discussion

3.1. Data validation

There have been a few studies in Bangladesh that have used GSMaP data, thus we used BMD rain gauge data to validate GSMaP data. GSMaP data are found to be substantially correlated with BMD rain gauge data. Using equation (1), the 3-hourly and daily correlations between BMD rain gauge and GSMaP data are 0.71 and 0.74, respectively (1). The level of confidence in our two datasets is

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95%. During the study period (2001-2015), we also looked at the average daily rainfall pattern of the BMD rain gauge and GSMaP data.

3.1.1. Scattered plot of 3-hourly rainfall

Figure 2 represents scatter plot of 3-hourly rainfall between GSMaP and BMD rain gauge data for the period 2001-2015.The value of R^2(value of determinant) between GSMaP and BMD rain gauge data is found 0.5643, which means that 56% of rain gauge data can be explained by the GSMaPdata. The SD of 3-hourly rainfall for GSMaP and rain gauge data are found 1.96 and 2.10 mm, respectively. The RMSE value between rain gauge and GSMaP data is found 4.56 mm.

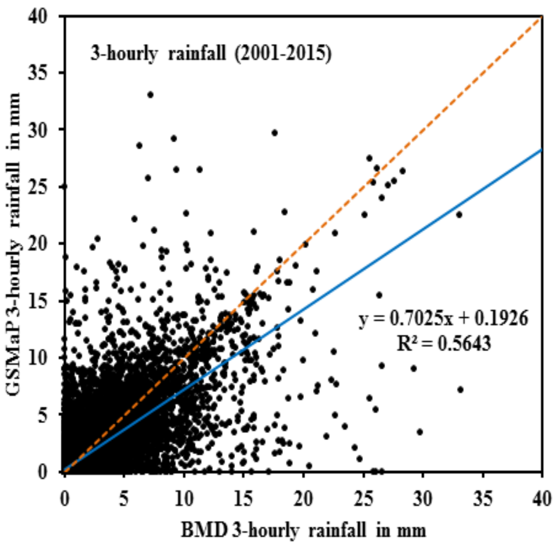

Fig. 2: Scatter plot of 3-hourly rainfall between GSMaP and rain gauge from 2001-2015. The red line depicts a 1:1 relationship, while the blue line represents a linear fit (Y=a+bX).

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

3.1.2. Scattered plot of daily rainfall

Figure 3 represents scatter plot of daily rainfall between GSMaP and BMD rain gauge data during the period 2001-2015. Horizontal and vertical axis is the average for daily RF of BMD rain gauge and GSMaP, respectively.The value of R^2 between GSMaP and BMD 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 value is found 7.62 mm between BMD and GSMaP.In the 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 RF rate whereas systematic difference is small for low rainfall rate. To get the corrected GSMaP data we may use the regressionequation of linear fit which leads to the real observational value.

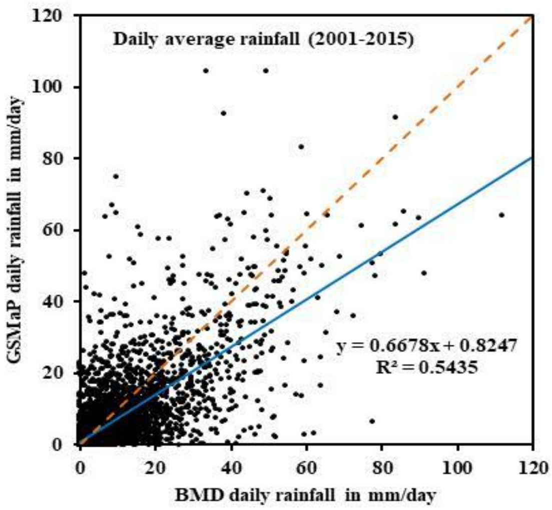

Fig. 3: Scatter plot of daily average rainfall between GSMaP and rain gauge from 2001-2015. The red line represents 1:1 line and blue line is the linear fit (Y=a+bX).

3.1.3. Daily rainfall variation

Figure 4 **shows** the variation of 15-years daily average RF measured by rain gauge and GSMaP data. 5.14 mm and 6.47 mm RF per day were measured by the GSMaP and rain gauge, respectively. The active and break phases of the RF trend are well matched with GSMaP and BMD rain gauge data, as seen in this diagram.

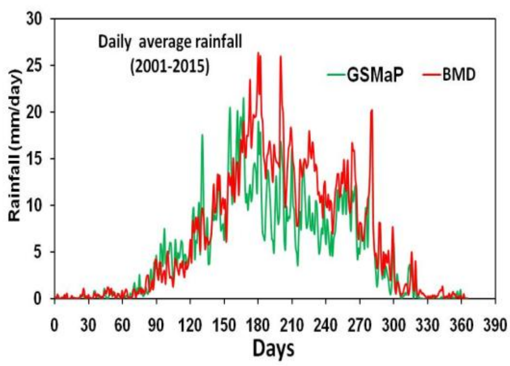

Fig. 4: Variation of daily average rainfall during study period over Bangladesh measured by GSMaP and rain gauge.

Prasad et al. [4] illustrated that the fluctuation of the seasonal monsoon trough is the primary cause of these active and break phases. 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 atmospheric circulation over the monsoon region, with the vortices over the boundary layer fitting anticyclone [5].The extended trough of low

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seasonal pressure is known as monsoon trough. It runs over Bay of Bengal, northwest India, Gangetic plains of north India and Pakistan.

Figure 4 also **shows** that during monsoon period (around days of 160-270) GSMaP are underestimated and during pre-monsoon period (around days of 65-160) these are overestimated. According to the shape of the precipitation system Rafiuddin et al., [6] divided them into three classes such as arc, line and scattered types. Ref. [6] showed that arc type precipitation 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. Seasonal diurnal variation of rainfall

Seasonal diurnal variation of rainfall during pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and winter (December to February) seasons are described in this study.

3.2.1. Diurnal variation of rainfall during Pre-Monsoon season

Figure 5 represents the DV of rainfall during pre-monsoon. In this season both BMD rain gauge and GSMaP are found well matched two maximum Rainfall Peaks (RFP) at 1500 LST (Primary Peak-PP) and 2100 LST (Secondary Peak-SP). RF dominates from afternoon to early night during pre-monsoon season. Though GSMaP is well captured the RFPs but the amount was overestimated than that of BMD rain gauge. Thunderstorms which known as ‘Kalbaisakhi’ or ‘Nor’westers are the main source of pre-monsoon RF over Bangladesh [7]. Norwesters mainly come from the north westerly direction (and hence the name) which is land based phenomena. This thunderstorm season begins in the eastern and northeastern parts of Bangladesh in early March during post noon period of the day. These thunderstorm season activities gradually move westward, and become effective in the westernpart of Bangladesh before the arrival of the summer monsoon [8].

In this season, daytime heating triggers by high temperatures and tower type clouds build up which is mainly tall, high echo top and deep convection clouds such as cumulonimbus, cumulus, that is more vertical in nature and mostly come up during late afternoon and early evening or night hours and form often an arc-shape squall line type and intense rainfall which usually gets the thunderstorms after the post-noon period [9]. Generally in a day which begin with a transparent sky and high temperature from the afternoon, rain starts occurring and intense rain with squally cooled winds (sometime along with hail) results fall in temperature, which help to procreate a diurnal cycle of rainfall during this season.

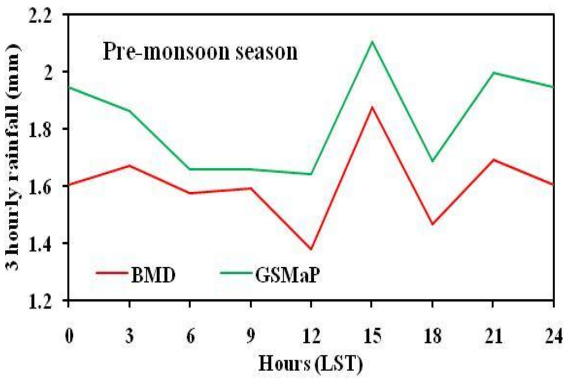

Fig. 5: DV of RF of pre-monsoon during study period between BMD rain gauge and GSMaP.

It is synonymous with heat and humidity with uncomfortable conditions throughout the day and night [10]. Besides these, various weather systems (say troughs) bring in moisture and thermal instability during this season due to condensation which is also responsible to afternoon’s maxima of rains [11].

3.2.2. Diurnal variation of rainfall during Monsoon season

Figure 6 shows the DV of rainfall of monsoon during study period. It is observed by BMD rain gauge measured dual RFPs at 0600 LST (PP) and 1500 LST (SP). On other hand, GSMaP found this twin peaks at 0300 LST and 1500 LST. These findings are almost similar to yearly average sketch of DV of rainfall. So it is clear, monsoon rainfall has a strong effect on the annual RF in Bangladesh. The quantity of RF which measured by GSMaP is underestimated than that of BMD rain gauge. In the monsoon season, rain can commence any time of the day, generally the preferred time of maximum RF at late night to early morning and late noon. During this monsoon, the atmosphere over Bangladesh is very unstable due to the large amount of moisture present in the lower atmosphere, and only a small perturbation is sufficient to produce low-level clouds, primarily nimbostratus and stratiform clouds, which are mainly widespread or continuous layers of clouds [9, 11]. Depths of these clouds are less but the layers are thick and moisture laden which contain a very big amount of water droplets and result in precipitation especially rain which mainly occur after post noon session. This is why, during monsoon days’ most afternoons experience heavy RFs [9].

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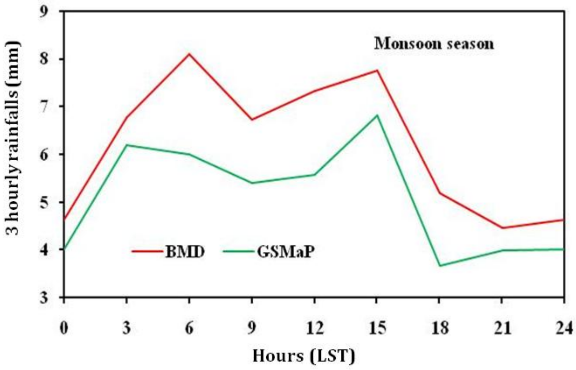

Fig. 6: DV of RF of monsoon during study period between BMD rain gauge and GSMaP.

Furthermore, mesoscale circulations such as mountain valley winds, katabatic-anabatic winds, land sea breezes, and others can influence the rain regime and cause a diurnal cycle or fluctuation [12, 13]. Actually, the ground heat due to insolation is the dominant forcing for diurnal variation of rainfall during the monsoon period. Generally, convective cells formed over sea and moved toward the land results maximum rainfall over land in the late night to early morning. Terao et al., [14] found that monsoon rainfall peaks between 0030 to 0060 LST over Bangladesh, particularly in the northeastern section of the country. The southeasterly advanced in the lower atmosphere throughout the afternoon, then wind direction changed to a clockwise direction during the night. The nocturnal jet, which coincides to the peak of rainfall in the northeastern region of the country from midnight to early morning, occurs due to increased wind blowing against the southern border of the Meghalaya Mountains.Besides this, post-noon tidal water of rivers may accountable to these phenomena, because during this time huge water moisture come or grow from river water.

3.2.3. Diurnal variation of rainfall during Post-monsoon season

Figure 7 shows the DV of rainfall of post-monsoon season during study period. BMD rain gauge and GSMaP observed a SP at 0600 LST and PP at 1500 LST. So, it reveals that in post-monsoon season maximum RF occurred at afternoon and early night. The diurnal pattern of rainfall measured by both GSMaP and rain gauge is almost similar. These results are similar to the findings of Islam et al. [15].

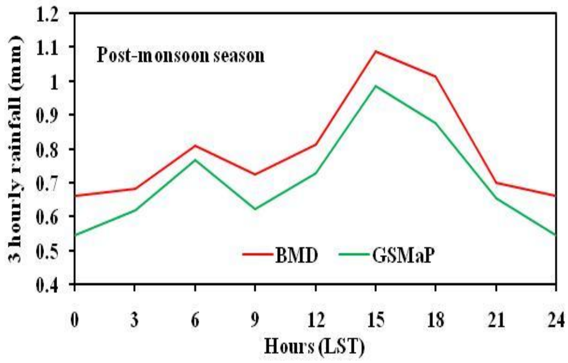

Fig. 7: DV of RF of post-monsoon season during study period between BMD rain gauge and GSMaP.

During post-monsoon, high temperature and low pressure in the Bay of Bengal causes to bring cool, dry and intense air masses to many regions of the country. Winds spill across the Himalayas and flow to the southwest and north-easterly direction across the country [16], resulting in clear, sunny skies and sometimes depression or cyclone form in the Bay of Bengal resulting the evening hour with a significant amount rainfall. The mean rainfall decreases sharply from October to November and slowly from November to December. The gradients of mean monthly rainfall are maximum over the northeastern and southwestern parts of Bangladesh during evening period [17].

3.2.4. Diurnal variation of rainfall during winter season

Figure 8 represents the DV of RF of winter season of the study period. The peak of the rainfall is observed at 0300 LST by both GSMaP and rain gauge. Since Bangladesh is a rainfall dominated climate country and maximum rainfall occur during monsoon season, only 2% or less rainfall of the annual occurs during winter season [18]. In winter, the solar radiation falls obliquely which may not to conducive making a remarkable to generate the thermal properties of sea and land let alone to create a diurnal cycle of RFs.

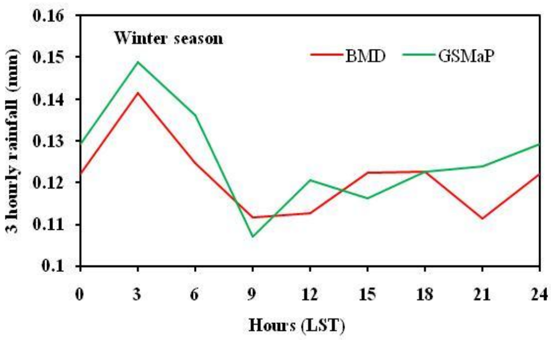

Fig. 8: DV of RF of winter season during study period between BMD rain gauge and GSMaP

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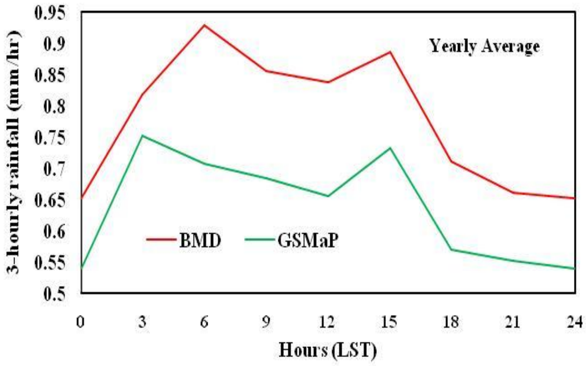
A centre of high pressure exists over Bangladesh and northwestern part of India during the winter season. From this high pressure a current of dry and cold air flows eastward and enters Bangladesh over its northeast part by propagating clockwise, almost right-angle. This cod and dry wind is the main part of the winter monsoon formation over the South Asian countries. Wind over Bangladesh commonly has a northerly component (flowing toward south and southeast) which is not helpful creating a significant rainfall during the winter season [18].

3.2.5. Diurnal variation of rainfall of yearly average

Figure 9 (Top) represents the average yearly diurnal variation of rainfall which is measured by BMD rain gauge and GSMaP. BMD rain gauge detects a PP at early morning (0600 LST) and a SP at afternoon (1500 LST). On other hand GSMaPalso measured dual peaks; one at late night (0300 LST) and other in the afternoon (1500 LST).



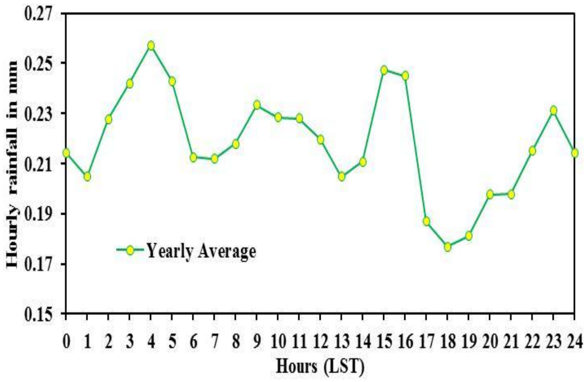


Fig. 9: Top: DV of RF of yearly average during study period. Bottom: DV of RF of yearly average of GSMaP yearly data

Due to available of hourly data of GSMaP, we also sampled the hourly DV of rainfall which represents in Figure 9(Bottom). From this figure, it is found that four peaks ofRF, but distinctly twin maxima of rainfall; one at 0400 LST another at 1500 LST. Using Radar data from BMD, Islam et al. [19] observed rainfall echoes exhibit two peaks, one in the morning (~0600 LST) and other in the afternoon (~1500 LST). On contrary using Japanese Geostationary Meteorological Satellite (GMS-5) they also found two peaks at morning (~0300 LST) and afternoon (~1700 LST). Bhuiyan et al. [20] used three hourly rainfall data and found dual peak one from noon to afternoon (1200 to 1500 LST) and other from late night to early morning (0300 to 0600 LST) over Bangladesh. This research also show that BMD rain gauge measured the day time's rainfall is 48.42 % and nighttime's rainfall is 51.58%. On other hand GSMaP measured the daytime's and nighttime's rainfall is 48.25% and 51.65%, respectively. Thus it is clear that in Bangladesh more rainfall occurs in nighttime than daytime.

3.2.6. Spatial distribution of occurrence time of maximum yearly average rainfall during study period

Spatial distribution of occurrence of maximum yearly RF measured by rain gauge and GSMaP is illustrated in Figure 10 and 11. The pattern of distribution of time of maximum rainfall (MRF) of BMD rain gauge and GSMaP is almost same. BMD rain gauge showed the northern part of the country experiences MRF at 0600 LST and middle part of the country experiences MRF at 1500 LST. Whereas, GSMaP observed the MRF in the northern part at 0300 LST and in the middle portion of the country at 1500 LST. Islam et al. [21] divided the total radar coverage area into nine sectors and showed that the north part and northeastern part of the Bangladesh experiences the MRF at 0000-0600 LST, which is the impact of the Shillong hill.

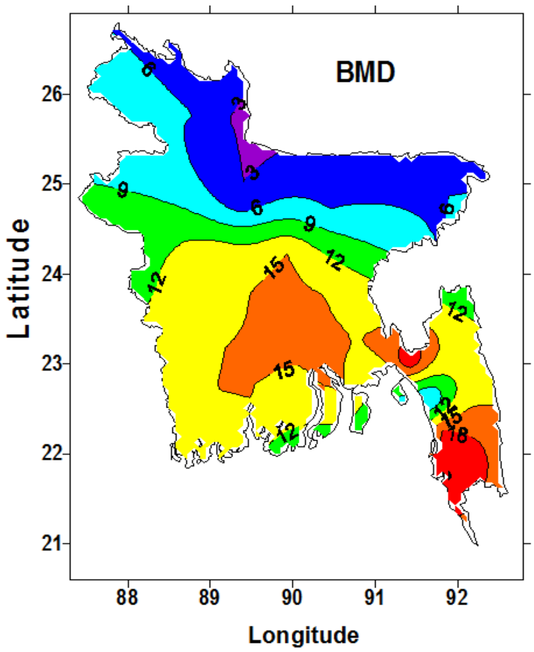


Fig. 10: Spatial distribution of maximum occurrence time of yearly average over Bangladesh between BMD

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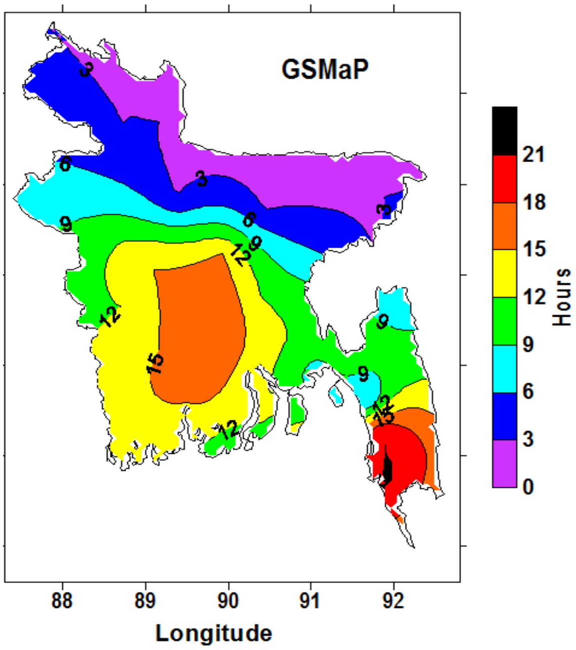

Fig. 11: Spatial distribution of maximum occurrence time of yearly average over Bangladesh between BMD

The MRF occurred in the western part at 0900-1200 LST, which may the influence of the land characteristics of the India especially Megalaya. Rainfall at 1200-1500 LST is dominated in the coastal region of the south and southeastern part of the country. The eastern part of Bangladesh shows the MRF in the morning at 0300-0600 LST, which is diversified from the Indian subcontinent and hilly areas. Northern region and some part of eastern region observed MRF at 0300-0600 LST, which is possibly related to the many effects, for example land-sea-breeze circulation, structure of complex terrain, life cycle of mesoscale convective systems etc. [22]. Near coastlines and over land the characteristics of land sea breeze circulation and the thermal features of the land surface induced by the contrast between the ocean surfaces and land can explain the main mechanism of the diurnal cycle of rainfall. MRF comes at morning over the country and at its northern parts experiences MRF from midnight to early morning [23]. Ohsawa et al. [24] and Prasad [4] suggested that the moisture content of the air and its ascent rate are the dominating factor for the amount of rainfall. The ascent rate of moisture content of air is governed by the low level convergences, which depends on local orographic features. Terao et al [14] suggested that the development of convective systems governed by the lower atmosphere wind acceleration over northeastern part of Bangladesh during midnight to early morning.

4. Conclusions

From these analyses and realization the following conclusions are 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 SD of 3-hourly RF for GSMaP and rain gauge data are found 1.96 and 2.10 mm, respectively. RMSE value between both 3-hourlydatasets of BMD rain gauge and GSMaP is found4.56 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 under estimated during monsoon season.

(iii) DV of yearly RF during study period showed two peaks of MRF. Rain gauge detected maximum rainfall at 0600 LST(PP) and 1500 LST(SP) whereas GSMaP found these peaks at 0300 LST(PP) and 1500 LST(SP) but hourly data of GSMaP showed the peaks of RF at 0400 LST(PP) and 1500 LST(SP).

(iv) From yearly average it is found that north and north-eastern part of the country experienced MRF at 0300-0600 LST whereas central and southern part of the country at 1200-1500 LST but coastal part of Chittagong at 1800 LST.

Several types of analyses between GSMaP and BMD rain gauge data over Bangladesh **show** that GSMaP has lower bias. So, GSMaP data might be useful for different meteorological purpose in Bangladesh.

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