Satellite Rainfall Estimation in the South-Eastern Part of Bangladesh

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Abstract—In case of sufficient moistures contamination from BOB, the rain forecasting is challenging for the meteorologists over south and south-eastern part of Bangladesh, especially in monsoon and post-monsoon period. Real time rainfall information is necessary for early warning rainfall which triggered hazards such as floods and landslides. Slow dissemination of measured rainfall information was considered as a serious obstacle in terms of the use of such information for early warning purpose. Satellite based rainfall estimation had been considered as an alternative to fulfill that demand. This research was addressed to estimate the satellite-based rainfall by using Tropical Rainfall Measuring Mission (TRMM) satellite data. Then, estimated rainfall was made to compare with surface-based rain gauge rainfall which was acquired from 08 weather stations over Bangladesh for the years of 2001-2009. At first, daily rainfall was estimated by satellite. Then, monthly, seasonally and yearly rainfall was also determined and compared it with surface rainfall. Temporal and spatial analysis was performed by estimated (TRMM) and observed (RG) rainfall and at same time for the assessment of accuracy some statistical parameters such as correlation coefficients, regression equations, biases and mean absolute errors were deermined for all stations. The TRMM overestimated rainfall during pre-monsoon and underestimated during monsoon while alike during post-monsoon period. Overall, TRMM underestimated rainfall in the heavy-rainfall regions of Bangladesh.

Index Terms—Bangladesh, Comaprison, Rain Gauge, Rainfall, TRMM, Temporal and Spatial Analysis

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1. INTRODUCTION

THE geographical location of Bangladesh is highly discussed for generating weather phenomena and disasters. Bangladesh is a deltaic land at the end of the funnel shaped Bay of Bengal (Figure 1). This special geographical configuration is dominating for the formation of cyclones, floods, droughts, tornadoes, heavy rainfall and so on. Floods and cyclones are very common disaster and almost every year the country is affected by these two disasters. But the miracle is that these two disasters are directly related to heavy rainfall. Even most of the disasters like landslides, hill slides, river erosion, flash floods, draught etc are directly or indirectly related to precipitation. Last 05 years, there caused landslides in south and south-eastern part of the country and large number of people were killed by it (landslides) which are created by heavy rainfall upon this regions. Bangladesh Meteorological Department

(BMD) is responsible organization for proving all kinds of weather forecast over the country. For precipitation measurement, BMD has only 35 rain gauges over the entire country. But in order to save human life and property, advance system of estimation is very essential over the region of the country. For this regard satellite based estimation can give better result for early warning. So, in this project, my main purpose is to find out a good forecasting means which will be helpful for flood forecasting, heavy rainfall estimation as well as early warning of harsh weather.

2 STUDY AREA AND DATA USED

2.1 Study Area

In order to estimate satellite rainfall, the south-eastern part of Bangladesh is selected. This part of the country is actually remote regions, islands and coastal belt. The Bay of Bengal (BOB) is directly dominated in this region for generating weather phenomena and disasters or water orientated disasters. Since this part of the country is situated near the BOB, the BOB plays an important role for cloud formation. Specially in monsoon period, sufficient amount of moisture is contaminated upon this region which frequently creates deep clouds and as a result of it huge amount of rainfall is occurred in monsoon and sometimes also in pre-monsoon and post-monsoon period.

Fig. 1 Geographical Location of Bangladesh in Asia and World Map

Fig. 2 Study areas (yellow color in Bangladesh map) and site map of the region.

2. 2 Data Used

2.2.1. Rain Guage Data

In the current analysis, the rain gauge data is mainly used to validate satellite rainfall estimates and assess their accuracy. Rain gauge data over the study area of the country were provided by Bangladesh Meteorological Department (BMD) for a certain time period of from 2001 to 2009. The data included observations of both 03 hourly and daily rainfall accumulations at several rain gauge sites were collected from BMD stations. There are 35 Meteorological Stations available throughout Bangladesh under BMD. More than 80% of these stations are First Class Observatory (FCO). I have actually collected ground-base rainfall data or rain gauge data from FCOs. It is noted that each gauge represents a near-point sampling site and can be geo-referenced with a certain satellite pixel.

2.2.2. TRMM Satellite Data

Recent years have witnessed significant developments in the field of satellite rainfall estimation. Last 10-20 years, several research works also successfully completed about related purpose in Bangladesh. Of particular interest is the development of estimation algorithms that can generate high-resolution rainfall products by merging infrared (IR) and microwave (MW) satellite observations. The concept behind most of these algorithms is to use the more accurate (but infrequent) MW estimates to calibrate the more frequent (but indirect) IR estimates so that the strengths of these individual sensors maintained and the weaknesses are alleviated. One recent algorithm, which is the focus of the current study, was developed at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and is based on the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA). The TMPA dataset consists of fields of 3-hourly rainfall rates over a 0.25° x 0.25° grid within the global latitude belt ranging between 50° north and 50° south.

3 MODEL DEVELOPMENT AND METHODOLOGY

3.1. Model Development

The principle of the technique depends on the cloud properties and temperature observed from the space. We can understand the cloud properties from visible reflectivity. If the visible reflectivity is brighter, it means that the cloud is thicker which causes heavier rainfall and if it is dark, it means that the cloud is thinner which causes less or no rainfall. For infrared brightness temperature, if temperature is colder, it means that the cloud is deeper which causes heavier rainfall and if temperature is warmer, it means that the cloud is thinner which causes less or no rainfall. The oldest and still useful precipitation-estimation technique is cloud indexing method. It rests on the observation to identify cloud types in satellite images. The precipitation would be assigned by each cloud types. The method of cloud indexing assigns a rainfall rate to each cloud type. The amount of rain at a particular location, R, is written by

$$R = \sum r_i f_i$$

Where, r_i is rain rate assigned to cloud type i, and f_i is the fraction of the time and space the point is covered with cloud type i. before making the calculations, the satellite image has to be classified.

According to the cloud indexing method, a Simulink model (Figure 3) is prepared for satellite estimation. It is a simple model and works easily for estimation of rainfall. We can easily estimate satellite rainfall if we can know the rain rate
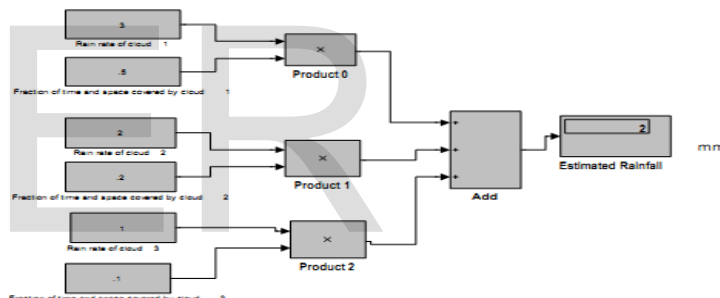

Fig. 3 Simulink Model for Rainfall Estimation

and the amount of cloud is covered by the sky in a specific time. And using the model, it was found of satellite rainfall monthly, seasonally and yearly. The yearly total rainfall is shown by (Table 1).

TABLE 1
YEARLY TOTAL OBSERVED (GAUGE) AND ESTIMATED (SATELLITE)
RAINFALL OVER 08 STATIONS (2001-2009)

Stations	Year 2001		Year 2002		Year 2003		Year 2004		Year 2005		Year 2006		Year 2007		Year 2008		Year 2009	
	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated
Cox'sBazar	4014	3426	3918	3458	4113	3560	3282	2936	3384	2994	3529	3246	4006	3696	4144	3835	3383	3222
Hatiya	4431	3632	3384	3125	3664	3256	4005	3285	3814	3324	2941	2755	3955	3540	3531	3198	3280	3046
Kutubdia	2320	2634	2389	2224	2468	2234	2541	3014	2827	2676	2967	2814	3162	3012	3171	2758	2658	3029
Sandwip	5895	3468	2031	2568	_	2470	4670	3456	3067	2812	3111	2632	4305	3824	3702	3321	3614	3365
Sitakunda	2726	2644	4361	3244	2976	2684	3247	3022	3030	2688	2031	2866	4004	3634	2945	2780	3119	2718
Teknaf	4595	3677	3929	3470	4451	3298	4141	3568	3928	3259	4232	3326	4465	3955	5412	4245	4287	3227
Rangamati	2056	2246	2784	2265	2474	2188	3113	2832	2124	2478	2316	2658	3076	2934	1780	2142	2285	2488
Ambagan	2288	2458	2764	2456	2696	2242	2924	2815	2331	2528	2375	2812	4340	3844	3270	2876	3130	2912

In this project, 09 years satellite rainfall was estimated using this model. Then satellite estimated rainfall was compared with surface-based rain gauge observations.

3.2. METHODOLOGY

The method for satellite rainfall estimation over the selected areas can be summarized as follows:

1. Acquisition of rain gauge and satellite data from Bangladesh Meteorological department (BMD) and Space Research and Remote Sensing Organization (SPARSO).

2. Estimation of Satellite-based rainfall over the selected regions of Cox'sbazar, Teknaf, Sandwip, Kutubdia, Hatia, Sitakunda, Ambagan (Chittaging) and Rangamati in Bangladesh. At first, the daily rainfall was estimated and then monthly and seasonally (pre-monsoon, monsoon, post-monsoon and winter). The period of estimation covers from 2001 to 2009.

3. Spatial geo-referencing and temporal synchronization of gauge and satellite observations: both datasets were geo-referenced using Geographical Information System (GIS). The latitude and longitude locations of each gauge were linked to certain satellite pixel. Similarly, gauge and satellite datasets were temporally synchronized by accumulating both datasets into daily and monthly time scales.

4. Analysis of annual rainfall spatial distribution: this analysis will focus on constructing maps of annual rainfall over the selected areas to establish a long- term average of rainfall patterns from satellite estimates. This will provide insight into the ability of satellite data to reproduce climatologically different rainfall patterns over the selected regions.

5. Analysis of rainfall seasonal cycle: this analysis will use satellite rainfall data from several years to examine the seasonal cycle of rainfall, if exits, over each of the selected areas. This investigation will indicate whether satellite rainfall estimates can discern among various characteristics of rainfall over different regions.

6. Statistical assessment of satellite rainfall estimates: this analysis will focus on assessment of accuracy of satellite estimates by comparison against available raingauge data. The following statistical metrics are calculated.

$$\text{Bias} = \frac{\sum R_S}{\sum R_g}$$

$$\text{Pearson's Correlation Coefficient, } R^2 = \frac{\overline{(R_S - \bar{R}_S)(R_g - \bar{R}_g)}}{\sigma_S \sigma_g}$$

$$\text{Mean Absolute Error (MAE)} = \frac{\sqrt{|R_S - R_g|}}{n}$$

Where R_s and R_g represent the spatially collocated temporally synchronized satellite and rain gauge values, σ_s and σ_g represent their standard deviations, and the bar symbol represents an arithmetic average. In these metrics, the bias provides a measure of systematic deviation of satellite estimates from the corresponding gauge values (a value of 1 represents no bias, a value larger than 1 represents overestimation by the satellite, and a value smaller than 1 represents an underestimation). The correlation coefficient provides a measure of linear association and ranges from 0 to 1, with 1 being a perfect correlation. The mean absolute error (MAE) provides a measure of the average absolute deviation of satellite estimates from the corresponding gauge measurements.

4 RESULTS

4.1. Analysis of Temporal Rainfall Pattern

Rainfall estimates from the TRMM-TMPA dataset and the corresponding gauge observations were analyzed to investigate the seasonal cycle and variations over the study areas. This analysis was performed over the study areas of Cox'sbazar, Teknaf, Sandwip, Kutubdia, Hatia, Sitakunda, Ambagan (Chittaging) and Rangamati in Bangladesh. Figure (4) and Figure (5) show the monthly and seasonal cycle of rainfall established over the selected eight locations. The figure includes the seasonal variations of monthly rainfall based on the TRMM-TMPA satellite estimates as well as based on the gauges. It should be noted that while the satellite dataset is completed for time period of 1998-2009, the corresponding gauge data are available only for the years of 2001-2009. While the satellite dataset shows different magnitudes of monthly rainfall than those shown by the gauges, it is noted that the TRMM- TMPA data exhibits a similar seasonal pattern of monthly rainfall to that of the gauges. In order to more analysis, seasonal total rainfall is also estimated by satellite and at same time it is compared with seasonal measurement of gauge network. In Figure 19, there are showing the seasonal comparison of gauge and satellite. Pre-monsoon, monsoon, post-monsoon and winter total rainfall are analyzed in this part.

From the graphical analysis of monthly and seasonal rainfall over eight stations and satellite, it is clear that satellite and gauge are performing good matching in seasonal rainfall pattern. In monthly analysis, there are showing more discrimination between satellite and gauge and this discrimination is more for the month of heavy precipitation such as June, July and August. In these three months, satellites always underestimated rainfall compared to gauge for maximun stations. The only exception is Rangamati (sometimes Sandwip) in which satellite overestimated. So, it is clear that satellite estimation is more accurate for long-term basis calculations.
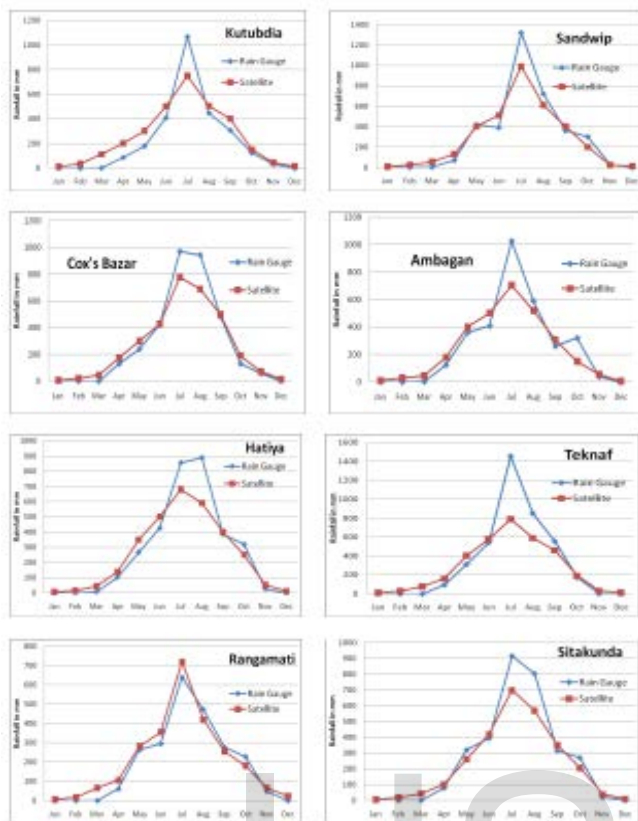
Fig. 4 Graphical comparison of time serries of monthly TRMM estimation and gauge observations (2009).
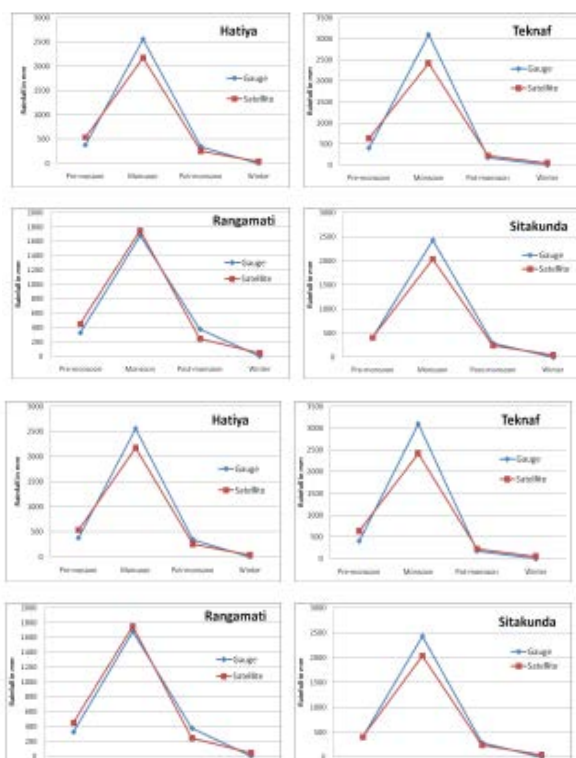
It is also interesting to see that TRMM-TMPA satellite estimation is overestimated the precipitation in the period of Premonsoon (March-May) comparing with gauge observations and satellite is underestimated the precipitation for South-West monsoon or Monsoon period (June-September). But satellite is showing good matching (not so difference) in Postmonsoon period (October-November) and it is again overestimated rainfall for North-East monsoon or Winter period (December February). The gauges show similar patterns, but with different monthly magnitudes. Differences in the magnitudes of monthly averages could be attributed to two factors: long-term bias in the satellite estimates, and the fact that the averages were established based on different number of years (12 years for the TMPA data, and 09 years for the gauges).

In order to understand the yearly precipitation pattern, yearly total rainfall is also estimated by satellite over all stations and compared it with surface rainfall. The yeearly variations between satellite and gauge are performed by time series analysis (Figure 6). From this analysis, we see that satellite underestimated rainfall almost every year and all stations, but only exception is Rangamati. In this station, satellite overestimated

Fig. 5 Graphical comparison of time series of seasonal rainfall of Gauge and TRMM.
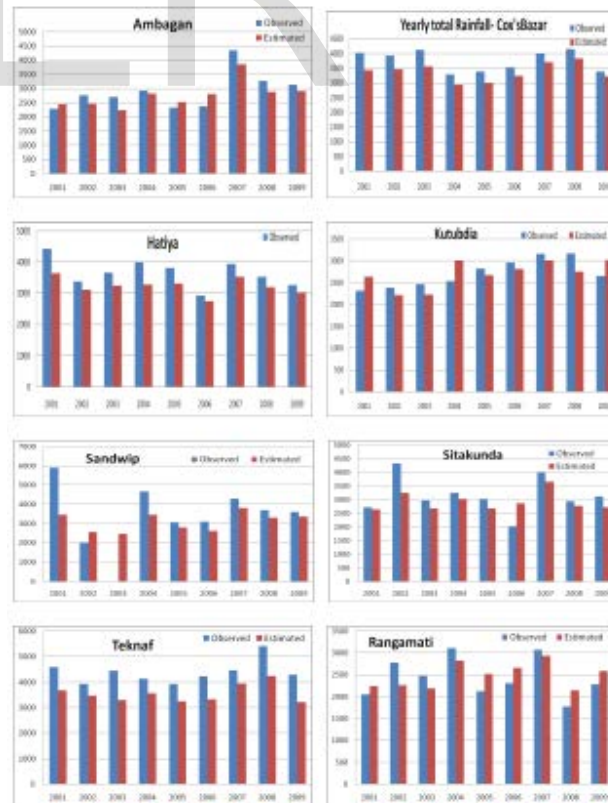

Fig. 6 Time series analysis of total annual rainfall from satellite estimates and gauge observations.

most of the year and sometimes also in Sandwip it is overestimated. It is noted that rain gauge data is totally missing for 2003 and partially missing for 2002 over Sandwip. In order to specify the climatological pattern of rainfall, long-term precipitation analysis is essential. So, time series analysis of rainfall can expose the long-term variations of precipitation. These types of time series analysis were performed over 08 meteorological stations in Bangladesh. According to this analysis, we see that the variation between TRMM-TMPA estimation and gauge measurement is not more. So, TRMM-TMPA estimation is acceptable for the selected study region.

4.2. Analysis of Spatial Rainfall Pattern

The spatial rainfall patterns are also performed over the study area. Figure 7 (a) and Figure 7(b) show some examples of long-term accumulated rainfall spatial patterns over 08 stations of the study areas of Cox'sBazar, Teknaf, Sandwip, Kutubdia, Hatia, Sitakunda, Ambagan (Chittaging) and Rangamati (including the rest of Bangladesh). In this analysis, rainfall was accumulated for each TRMM 0.25° x 0.25° pixel and each of year within the 1998- 2009 TRMM record.
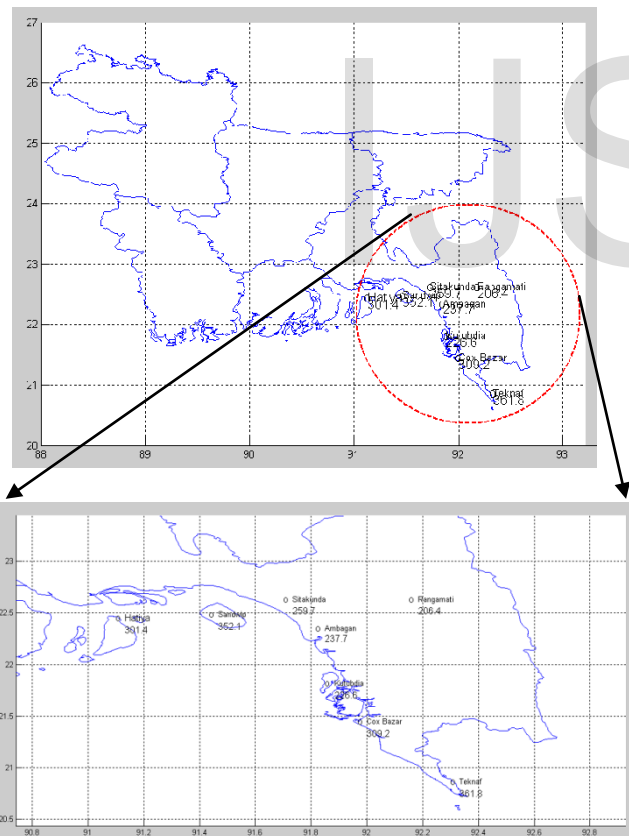

Fig. 7 Spatial Representation of the monthly average rainfall over the study area

The accumulative map for Bangladesh including the selected study areas is based on the average of total rainfall accumulat-

ed over the period of 1998-2009. It is clearly seen that the TRMM-TMPA estimates are capable of reproducing a spatial presentation of long-term rainfall patterns that are in agreement with climatologically known information about the regions.

TRMM rainfall seasonal climatology from 1998 to 2003 (Figure 32) represented the similar pattern of long range precipitation over the country and study area. The global rainfall for the season of DJF (December-January-February), MAM (March-April-May), JJA (June-July-August) and SON (September-October-November) are distributed by this presentation of TRMM satellite. In this seasonal accommodation of rainfall is also matching to our estimation of satellite rainfall. So, long-term basis analysis is more effective in this region.
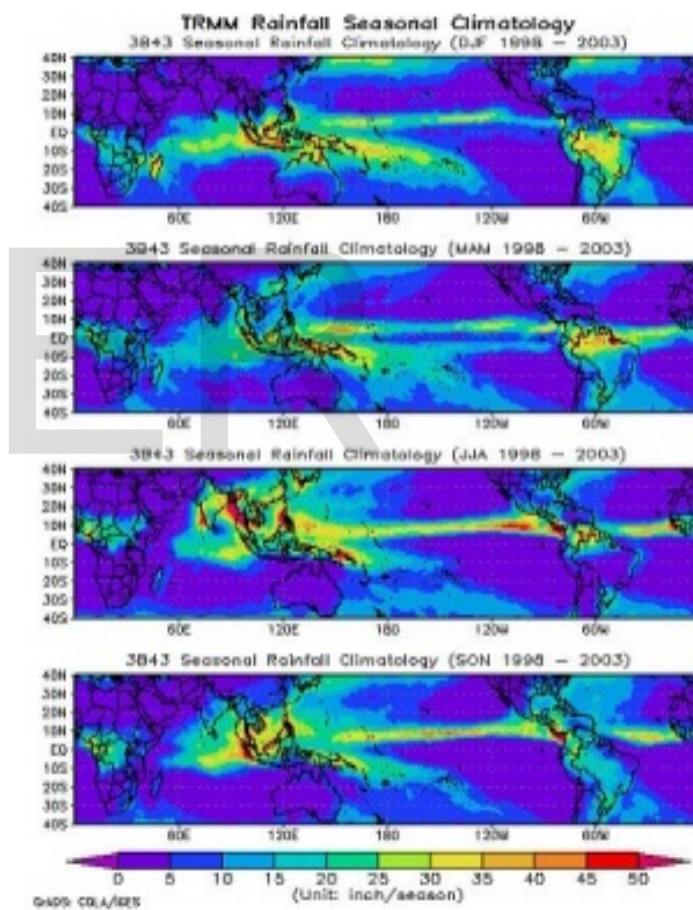

Fig. 8 TRMM global long-term accumulation of precipitation (1998-2003)

4.3. Accuracy Assessment of Satellite Rainfall Estimation

A ground validation analysis for the NASA TRMM- TMPA satellite rainfall was conducted by comparison against surface rain gauge observations over the study areas of Cox'sbazar, SaTeknaf, Sandwip, Kutubdia, Hatia, Sitakunda, Ambagan

Sadwip, Teknaf, Hatiya, Kutubdia, Sitakunda, Ambagan (Chittaging) and Rangamati regions. The validation analysis included graphical comparisons such as scatter plots (Figure 9), time series plots (Figure 4, 5 & 6) and statistical assessment using three measures, they are bias, correlation coefficient, and mean absolute error; Table (2).
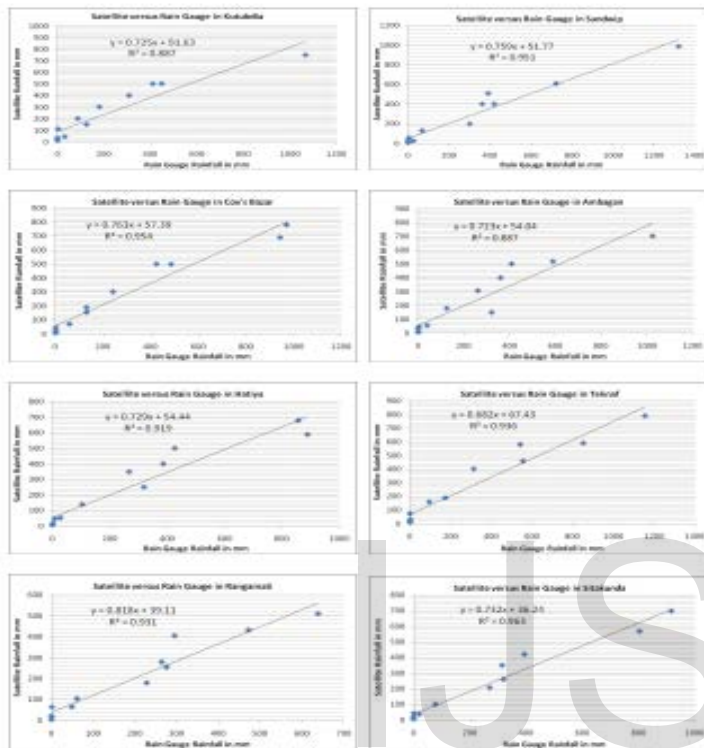

Fig. 9 Scatter plot comparisons of monthly rainfall from Satellite estimated versus the corresponding monthly Rain gauge observed rainfall over all stations.

The scatter plot comparisons show significant scatter of monthly rainfall amounts between satellite estimates and rain gauge values. However, the time series plots indicate a relatively good match between the timing and, to a lesser degree, the magnitudes of annual, seasonal and monthly rainfall amounts. The comparison is partially matching between the satellite estimates and rain gauge measurements. But for the regions of Teknaf and Cox'sBazar, there are showing more discrepancy between the gauge and satellite estimates. Only for Rangamati, TRMM overestimated but underestimated for all other stations. It should be noted that gauge observations are usually subject to several sources of uncertainty that may impact their data quality (such as undetected breakdown of gauges, human errors in logging-in the collected observations, data transmission problems). These issues can contribute to the discrepancy observed between the gauge and satellite estimates. The statistical analysis shown in Table (2) indicates good levels of correlation between the gauge and satellite estimates.

Figure 33 shows the relationship between the satellite and

gauge rainfalls. For all 08 stations the linear regresion equations take the form,

$$y = mx+c$$

where, y = Satellite rainfall
x = Gauge rainfall
m = slope (Corelation coefficient) and
c = constant (MAE)

Stations	Regression Equation	Correlation Coefficient	Mean Absolute Error (mm)	Bias (ratio)
Ambagan	y=0.723x+54.04	0.93	1.36	0.95
Cox'sBazar	y=0.763x+57.39	0.97	3.39	0.89
Hatiya	y=0.729x+54.44	0.94	4.41	0.88
Sandwip	y=0.769x+51.77	0.97	2.86	0.91
Sitakunda	y=0.732x+36.24	0.98	2.42	0.92
Teknaf	y=0.682x+67.43	0.96	8.59	0.79
Kutubdia	y=0.725x+91.63	0.93	0.12	0.98
Rangamati	y=0.818x+39.11	0.96	0.43	1.03

Using this linear equation we can find out the relationship between satellite and rain gauge rainfall for all stations.

For Ambagan: SAT = (0.93) Gauge + 1.36
For Cox'sBazar: SAT = (0.97) Gauge + 3.39
For Hatiya: SAT = (0.95) Gauge + 4.41
For Kutubdia: SAT = (0.93) Gauge + 0.12
For Sandwip: SAT = (0.97) Gauge + 2.86
For Sitakunda: SAT = (0.90) Gauge + 2.42
For Teknaf: SAT = (0.96) Gauge + 8.59
For Rangamati: SAT = (0.96) Gauge + 0.43

i.e. in general:
Satellite rainfall = CC* Surface rainfall + MAE

This means that the satellite rain value was m-times larger than the surface rain value plus the constant value of c (in this project 0.9) used in our study. With this equation the satellite rain can be estimated from surface data.

According to the assessment of satellite estimation with gauge measurement, it is clear that TRMM satellite provided good result for the selected regions of Bangladesh. The correlation

coefficients of all stations are between 0.90 and 0.98 (where 1.0 means absolute matching) means that satellite performance is matching with surface observations. The mean absolute errors (MAE) and biases are also good matching between TRMM and Gauge. The values of bases are between 0.85 to 1.05 for all stations, which means that there are no more discrimination between satellite and gauge. According to bias (ratio), we see that satellite underestimated rainfall for all station but only exception is Rangamati. In here, satellite overestimated compare to true measurement. But the interesting point is that satellite and gauge are good matching in Rangamati (MAE 0.43). The values of MAE of these stations are also good and acceptable. So, we see that these underestimation or overestimation is not so far from surface measurement.

5. CONCLUSION

The present study is discussed satellite rainfall estimation in the south-eastern part of Bangladesh. For rainfall estimation the Tropical Rainfall Measuring Mission (TRMM) TMPA algorithm was utilized and analyzed over the south-eastern part of Bangladesh like Cox'sbazar, Teknaf, Sandwip, Kutubdia, Hatia, Sitakunda, Ambagan (Chittaging) and Rangamati regions. For ground- validation purposes, observations from several surface gauge stations were also used. Analysis of seasonal rainfall patterns indicated that the satellite algorithm was able to reproduce and discern among climatologically different rainfall regimes in the regions under consideration. The satellite rainfall seasonal patterns were mostly similar to those based on the gauges. Analysis of 12 years record of satellite data (1998-2009) showed that satellite techniques can provide valuable quantitative representation of spatial rainfall variability and patterns over wide scales in these regions. Statistical analysis of satellite rainfall estimates versus gauge observations showed remarkable agreement in rainfall timing and successful detection for some of the gauges; however, relatively considerable differences were reported by the bias and mean absolute errors. Such differences can be attributed to the low quality of rain gauge data that are commonly encountered in remote areas, which complicates the task of quantifying uncertainties associated with satellite algorithms. Further challenges are caused by limited number and records of rain gauges available in the selected regions. Therefore, it is strongly recommended that local research and operational authorities establish experimental rain gauge sites in selected regions with rigorous quality control measures and frequent maintenance to ensure data integrity and continuity. Such experimental facilities will provide valuable ground datasets that are necessary for validation of satellite rainfall techniques.

6. ACKNOWLEDGEMENT

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