ASSESSMENT OF THE ACCURACY OF SATELLITE PRECIPITATION PRODUCTS WITH GROUND OBSERVED STATIONS IN THE NORTH-EAST REGION OF BANGLADESH

Omar Al Maimun*[1], Md. Tofiquzzaman[2] and Md. Shahabuddin[3]

[1] *Senior Scientific Officer, River Research Institute, Bangladesh, e-mail: engrmaimun@gmail.com*
[2] *Senior Scientific Officer, River Research Institute, Bangladesh, e-mail: tofiqrri@gmail.com*
[3] *Senior Scientific Officer, River Research Institute, Bangladesh, e-mail: shahabuddin061@gmail.com*

***Corresponding Author**

ABSTRACT

Bangladesh is a low-lying riverine country located in South Asia with three sides east, west and north is surrounded by India and south by the Bay of Bangle. Bangladesh has one of the richest and largest floodplain systems in the world. The north-eastern part of Bangladesh is one of the most low-lying regions of the country. The upper area of this region is the Meghalaya State of India with mountain ranges and one of the world's most rain-prone areas, namely, Cherrapunji is situated here. Cherapunji receives an annual rainfall of 11,371mm. This substantial rainfall from the mountain ranges drained downstream into Bangladesh through numerous major and minor channels resulting in frequent severe flash floods and threatening agriculture, industry, lives and properties. The channels predominantly have their catchment areas situated in India causing the unavailability of ground-based precipitation data for Bangladeshi authorities, which hinders effective flood forecasting in the lower part of the basin.

Therefore, it is promising to use satellite precipitation data for analyzing the hydrological processes of the area. In this study, the quality of three satellite precipitation products (SPPs) such as IMERG-final (IMERG-F), TMPA version 7 (3B42V7) and Climate Forecast System Reanalysis (CFSR) was statistically evaluated using statistical parameters with the five ground rainfall observe stations located in North-Easter region of Bangladesh to explore the feasibility of employing SPPs for the hydrological analysis of the region.

The analysis of the spatial pattern of precipitation in the North-East region of Bangladesh demonstrates that all three SPPs follow an increasing trend from south to north and west to east. Moreover, the statistical evaluation of the three SPPs against the ground precipitation observations within the region shows that CFSR demonstrates the best quality followed by 3B42V7 and IMERG-F.

Keywords: *GPM; TMPA; IMERG; CFSR; Satellite Precipitation*

1. INTRODUCTION

2. STUDY BACKGROUND

Bangladesh is a low-lying, mainly riverine country located in South Asia with three sides east, west and north is surrounded by India and south by the Bay of Bangle. Bangladesh has one of the richest and largest floodplain systems in the world (Tsai et al., 2011).

The major sources of water in Bangladesh are rainfall, river and groundwater are closely related. Much of Bangladesh, nearly 60 percent, is less than six meters above mean sea level, and is located within the flood plains of the three great rivers, the Ganges, the Brahmaputra and the Meghna (Hofer & Messerli, 1997). Bangladesh is crisscrossed by over 200 rivers which form a complex and ever-changing pattern. These rivers cover some seven percent of the land area (Haggart, 1994). These river systems drain water from a total catchment area of about 1.72 million square kilometers laying in India, China, Nepal, Bhutan and finally Bangladesh, of which only eight percent of the catchment area lies within the country itself (Ahmed & Nicholls, 1994). As a result, massive inflows of water enter the country during the rainy season (July -September) on their way to the Bay of Bengal. About 90 percent of annual rainfall also occurs in period (Chowdhury & Haque, 2010).

One of the most low-lying regions of the country is located in the north-eastern part of Bangladesh. The upper area of this region is Meghalaya state of India which mostly consists of Mountain ranges and world one of the most rain prone areas is located here which is known as Cherrapunji. Cherapunji receives an annual rainfall of 11,371mm (*Starkel & Singh, 2004*). This huge rainfall from the mountain ranges drained to its downstream of Bangladesh through many numbers of Rivers. This flow formed a unique characteristic in the north-eastern part of Bangladesh which physically is a bowl or saucer-shaped shallow depression, also known as a Haor in the local language. Haors are frequently affected by the flash floods due to hilly topography and steep slope of the Mountain ranges situated in Meghalaya. These flash floods overflow onto the low-lying floodplains in the area, inundating crops, causing land erosion, damaging infrastructure, and often resulting in the loss of lives and properties. Climate change is exacerbating the situation.

The precipitation data from the catchment area is crucial for the hydrological analysis of the region. However, the location of the catchment area in a foreign country renders the data unavailable to Bangladesh, thereby hindering effective flood forecasting in the region. Consequently, there exists an excellent opportunity to utilize satellite data for the analysis of hydrology of the area.

3. LITERATURE REVIEW

Precipitation is a key component of the planetary water and energy cycle, helping to regulate the surface hydrological fluxes between land and the atmosphere. It is also an essential input for land surface and hydrological model. Water resource management, drought monitoring, and flood forecasting and warning depend on accurate precipitation observation or estimation. Rain gauges used as a direct physical tools for precipitation measurement. The development of satellite-based precipitation products (SPPs) has undergone two important stages, namely, the Tropical Rainfall Measuring Mission (TRMM)*(Hou et al., 2014)* and the Global Precipitation Measurement (GPM) *(Huffman et al., 2007)*. NASA and the Japan Aerospace Exploration Agency (JAXA) officially launched the GPM mission in February 2014, and the TRMM mission was terminated in April 2015, symbolizing the beginning of a new era for SPPs, that is, the GPM era *(Huffman et al., 2007)*. As a global successor of TRMM, GPM comprises an international satellite constellation (1 core observatory satellite and approximately ten partner satellites). Its core observatory satellite is equipped with an advanced Dual-Frequency Precipitation Radar (DRP, the Ku-band at 13.5 GHz and Ka-band at 35.5 GHz) and a multi-channel GPM MW IMAGER (GMI) (frequency of 10–183 GHz)

(Gebregiorgis et al., 2018). NASA released its first GPM-era global precipitation products IMERG in March 2014. IMERG provides global precipitation estimates at finer spatiotemporal scales (0.1°× 0.1° and 30-min interval) and more expensive quasi-global coverage (60°N-60°S) than TMPA products *(Huffman et al., 2007)*.

Satellite precipitation products from the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement (GPM) mission are the critical data source for hydrological applications in ungauged or data-sparse regions/ basins. IMERG includes three products with different latencies: the near real-time "Early" and "Late" run (IMERG-E and IMERG-L, respectively) and the post-real-time "Final" run (IMERG-F) *(Gebregiorgis et al., 2018)*. Many previous studies demonstrated that IMERG SPPs generally present a relatively higher accuracy in comparison with TMPA in many regions, such as the conterminous USA*(Gebregiorgis et al., 2018)*, Brazil *(Rozante et al., 2018)*, West and East Africa *(Dezfuli et al., 2017)*, the northern highlands of Pakistan *(Anjum et al., 2018)*, Malaysia *(Tan & Santo, 2018)*, India *(Prakash et al., 2016, 2018)*; the Mekong River basin*(Wang et al., 2017)*, Iran *(Khodadoust Siuki et al., 2017; Sharifi et al., 2016)*, South Korea*(J. P. Kim et al., 2016)*, Japan*(K. Kim et al., 2017)*, Mainland China*(Guo et al., 2016; Tang et al., 2016)*, the Qinghai-Tibet Plateau *(Xu et al., 2017)*, the Mishui basin*(S. Jiang et al., 2018)* and the Yellow River source region*(Yuan et al., 2017)* of China.

For instance, in the Ganjiang River Basin of China, *(Tang et al., 2016)* highlighted that IMERG-F version 03(V03) performs similarly to the ground precipitation data in daily discharge simulations and outperforms TMPA version 7 (V7) near-real-time product (3B42RT) and post-real–time product with gauge-based bias-correction (3B42V7) in many cases. *(D. Jiang et al., 2017)* further proved that the gauge-corrected radar precipitation estimates and rain gauge-interpolated data exhibit better hydrological performance in hourly streamflow simulations in the Ganjiang River basin compared with IMERG-F V03. *(Yuan et al., 2017)* demonstrated that IMERG-F V03 and 3B42V7 are feasible in daily discharge simulations in the Chindwin River basin in Myanmar, in which 3B42V7 is more suitable than IMERG-F in terms of Nash-Sutcliffe model efficiency coefficient (NSE) and relative bias of total runoff.

After ascertaining the importance of the different SPPs from different sources, this study evaluated the quality of three satellite precipitation products (SPPs) such as IMERG-final (IMERG-F), TMPA version 7 (3B42V7) and Climate Forecast System Reanalysis (CFSR) was statistically evaluated using statistical parameters with the five weather ground stations located in North-East region of Bangladesh.

4. METHODOLOGY

5. TRMM MULTI-SATELLITE PRECIPITATION ANALYSIS (TMPA VERSION 7)

The TRMM is a joint US–Japan space programme designed to measure tropical rainfall worldwide with the regular spatial and temporal distribution. This program is established and regulated by the National Aeronautics and Space Administration (NASA). Since its inaugural launch in 1997, TRMM has gathered a huge collection of rainfall data, widely employed globally in diverse climate and hydrological models. TRMM estimates precipitation from space utilizing advanced instruments across five categories (Liu et al., 2012), including the Precipitation Radar, TRMM Microwave Imager, Visible Infrared Scanner, Lightning Imaging Sensor, and the Clouds and Earth's Radiant Energy System. However, due to extreme spatial and temporal variability of the rainfall parameter, a substantial and well-defined global validation programme has been developed on the basis of some pre-specified site measurements for validation of TRMM data. There are 10 ground sites with a representative variety of rain regimes worldwide selected by the TRMM Science Team of NASA for validation in this aspect over the years, continuous effort has been made to improve the performance of the TRMM algorithm in the estimation of precipitation. Furthermore, NASA acquires each standard TRMM rainfall product following strict testing, evaluation, and calibration procedures, ensuring a high level of precision accuracy. The version (version 7: V7) of TRMM products was recently developed with improved algorithms and additional datasets. Today, TRMM is extensively utilized not just as an important source of precipitation data but also for validating simulated rainfall outcomes. For example, (Agnihotri & Dimri, 2015) applied TRMM products to verify simulated rainfall values in a weather research and forecasting model. The TRMM 3B42V7 rainfall product used in this study comprises 0.25∘ × 0.25∘grid cell data at a continuous 3 h interval and with spatial coverage of −180 ∘ W to +180 ∘ E extending from 50 ∘ S to 50 ∘ N latitude (http://trmm.gsfc.nasa.gov/).

In this study, the 3B42V7 daily SPPs from 1 January 2001 to 31 December 2013 were downloaded from the PMM website. TRMM data download in NetCDF format, then the data read and write in excel format as needed using MATLAB coding. There were 35 grid stations to cover study watershed. Firstly, Satellite precipitation products downloaded from the USGS website, Then the data was processed to extract the required data and then the data compared with the ground data using various statistical parameters.

6. INTEGRATED MULTI-SATELLITE RETRIEVALS FOR GPM (IMERG FINAL)

The Global Precipitation Measurement (GPM) project, an international partnership between NASA and the Japan Aerospace Exploration Agency (JAXA), produces IMERG, a multi-satellite global precipitation estimates. On 27 February 2014, the GPM core satellite was launched. IMERG employs a highly adaptable architecture to use as many satellites of opportunity as feasible. IMERG produces and archives the data in the HDF5 file format. The IMERG HDF5 files contain variables that describe the surface precipitation rate and the phase of the precipitation reaching the Earth's surface. In the HDF5 files, the precipitation rate is expressed in mm per hour. The data is stored in a rectangular latitude-longitude grid that has 3600 columns for longitude and 1800 rows for latitude. This grid covers the globe (90°S to 90°N and 180°W to 180°E) at 0.1° resolution. The temporal resolution of the products is: 3IMERGHH: half-hour and 3IMERGM: month. The half-hour period for the 3IMERGHH is driven by the basic observational interval for the geo-IR data.

The detailed IMERG estimation procedure is described at the https://pmm.nasa.gov/sites/default/files/document_files/IMERG_doc.pdf.

In this study, IMERG half-hourly data was download in netCDF format using wget code in the command window and adjusted with local time and converted to daily data using the method proposed by(Yuan et al., 2017). There were 70 grid stations to cover the study watershed.

7. CLIMATE FORECAST SYSTEM REANALYSIS (CFSR) DATA

The Climate Forecast System Reanalysis (CFSR) of the National Centers for Environmental Prediction (NCEP) was finished over the course of 36 years, from 1979 to 2014. A global high resolution, coupled atmosphere-ocean-land surface-sea ice system was developed from the CFSR project to provide the best estimation over the period. This website allows to download daily CFSR data (precipitation, wind, relative humidity, and solar) for a given location and time period.
For this study, CFSR data was downloaded from 1 January 2001 to 2013 for the watershed. The statistical evaluation for CFSR satellite precipitation products with the observe precipitation data has done with observed data.

8. STATISTICAL PARAMETERS

In this Study, several statistical indexes have been used to quantitatively measure the consistency of SPPs against observed ground precipitation suggested by (Yuan et al., 2018a). Pearson coefficient of correlation (CC) evaluates the difference between the simulated and observed data Equation (1); in this study, "simulated data" refers to SPPs, and "observed data" refers to observations of ground precipitation. Similar bias (Prejudice) implies the systemic bias of the simulated data Equation (2). Root mean square error (RMSE) is the average magnitude of absolute error between the data being simulated and observed Equation (3). To measure the contingency of satellite precipitation estimates, probability of detection (POD), false alarm ratio (FAR), and critical success index (CSI) were selected.POD denotes the proportion of precipitation events that are correctly detected by satellites among all real precipitation events Equation (4). FAR describes the fraction of false events among all the rain events identified by the satellites Equation (5). CSI denotes the overall proportion of precipitation events that are correctly identified by the satellites Equation (6). These diagnostic indices are expressed as follows:

Table 1: List of the diagnostic statistics for evaluating satellite precipitation products

Equ. No	Diagnostic Statistics	Equation	Perfect value	Unit
1	Relative bias (BIAS)	$BIAS = \frac{\sum_{i=1}^{n}(P_i^S - P_i^O)}{\sum_{i=1}^{n} P_i^O} \times 100\%$	0	%
2	Pearson coefficient of correlation (CC)	$CC = \frac{\sum_{i=1}^{n}\left(P_i^O - \overline{P^O}\right)\left(P_i^S - \overline{P^S}\right)}{\sqrt{\sum_{i=1}^{n}\left(P_i^O - \overline{P^O}\right)^2}\sqrt{\sum_{i=1}^{n}\left(P_i^S - \overline{P}^S\right)^2}}$	1	-
3	Root mean square error (RMSE)	$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(P_i^S - P_i^O\right)^2}{n}}$	0	mm
4	Probability of detection (POD)	$POD = \frac{H}{H+M}$	1	-
5	False alarm Ratio (FAR)	$FAR = \frac{F}{H+F}$	0	-
6	Critical success index (CSI)	$CSI = \frac{H}{H+M+F}$	1	-

Here: n, sample size of the satellite or gauge-based precipitation time series; P_i^S, satellite precipitation samples; P_i^O, gauge-based precipitation samples; $\bar{P}^S$, mean value of the satellite precipitation sample; $\bar{P}^O$, mean value of the gauge-based precipitation samples; H, number of real precipitation events correctly detected by the satellite; M, number of real precipitation events that failed to be detected by the satellite; F, number of precipitation events detected by the satellite that did not occur; the threshold for identifying a precipitation event is 0.1 mm/d.

Five observed ground precipitation stations of North-Eastern region of Bangladesh considered in this study; those ground stations are Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet. Details information of the observation station is mentioned in the Table 2.

Table 2: Observed Ground Precipitation Stations of North-Eastern Region of Bangladesh

Sl. No	Station Name	Geographic Position (Degree Decimal)	
		Latitude	Longitude
	Mymensingh	24.30 N	91.73 E
	Netrokona	24.90 N	91.88 E
	Sreemangal	24.73 N	90.42 E
	Sunamganj	24.88 N	90.73 E
	Sylhet	25.03 N	91.40 E

9. RESULTS AND DISCUSSIONS

10. COMPARISON AMONG THE SPPS WITH OBSERVED PRECIPITATION

The three satellite precipitation data 3B42V7 daily, IMERG-final half-hourly (converted to daily) and CFSR daily were plotted and compared with the observed precipitation data in the monthly scale of the year 2001 to 2013.

There are five nearest ground stations of the North-Eastern region of Bangladesh in this study; those ground stations are Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet Figure 1.

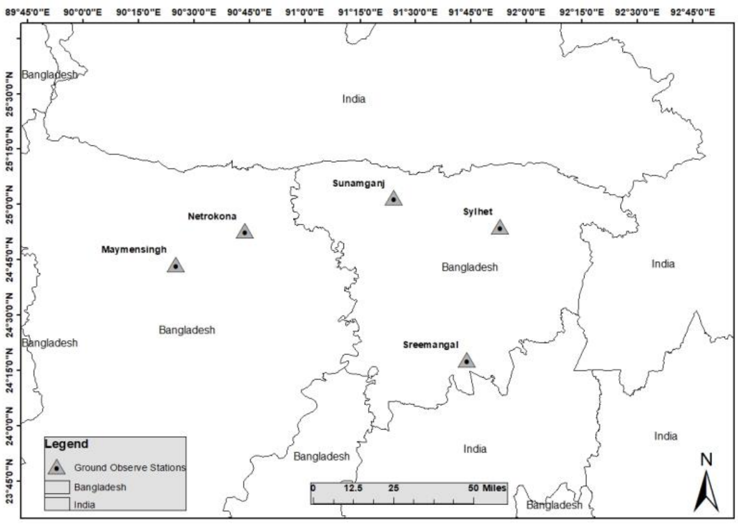


Figure 1: Location of Ground observe stations

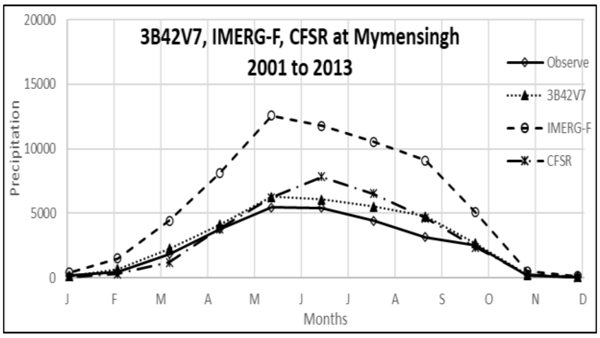
Figure 2(a) demonstrates SPPs 3B42V7, IMERG-F and CFSR along with observed precipitation at Mymensingh ground observe station. At this ground station, maximum total monthly rainfall was observed 5447mm in June and two SPPs 3B42V7 and CFSR estimates little over than observed precipitation. CFSR precipitation is slightly underestimated upto March on the other hand it was overestimated at a later stage. The TRMM data 3B42V7 was slightly overestimated over the years. However, IMERG-F shows an extremely overestimation of precipitation at the station compared with the observed precipitation over the years. IMERG-F estimates 12557mm rainfall in June of the year 2001 to 2013.

Figure 2(b) shows comparative precipitation estimation of three SPPs 3B42V7, IMERG-F and CFSR with the observed precipitation at Netrokona ground station. This observe station found maximum precipitation 7483.9mm in June. In this ground observe station precipitation estimation by SPPs 3B42V7 and CFSR is proximate to observe precipitation as like previous Mymensingh station. But it could be explained that CFSR is initially underestimated and overestimated from about June over the years. Other IMERG-F SPPs overestimates the precipitation at the Netrokona ground observe stations compare with the observed precipitation over the months of the years.

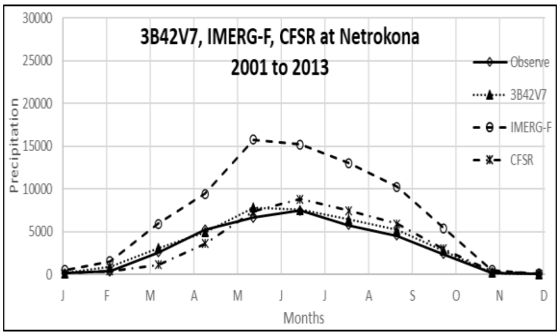
Figure 2(c) shows three SPPs 3B42V7, IMERG-F and CFSR comparison with observed precipitation at Sreemangal ground observe station. Satellite precipitation estimation of 3B42V and CFSR is following the trend of the observed precipitation of the ground station. To explain specifically, TRMM 3B42V7 is overestimated from May to September than the observed precipitation and CFSR underestimated before May and overestimated after May for the years. IMERG-F satellite precipitation data is exaggerated over the year than the observed precipitation data.

The comparison of three SPPs 3B42V7, IMERG-F and CFSR with precipitation at observed ground station Sunamganj, it is demonstrated in Figure 2(d). The figure shows SPPs 3B42V7 and CFSR is underestimated in order to observed precipitation data and IMERG-F precipitation estimation is excessively overestimated at the station. The maximum total precipitation over the years was in the month of July, i.e. 15364.2mm, 12290mm, 25404.3mm and 10962.4mm at observe station, 3B42V7, IMERG-F and CFSR precipitation respectively.

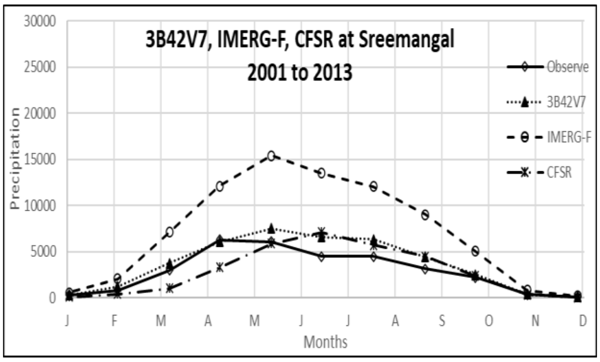
Relation among the three SPPs 3B42V7, IMERG-F and CFSR with observe precipitation at Sylhet ground observe station is graphically represented in Figure 2(e). The plot demonstrated that 3B2V7 is closely follow the observed precipitation at the station over the years but CFSR SPP slightly underestimated the rain up to the middle of June. However, IMERG-F SPPs is overestimated in comparison with the observed precipitation at the Sylhet observe station. The maximum summation of monthly precipitation over the years was 9559mm, 9748.9mm, 19387.9mm and 7988.2mm at observed station, 3B42V7, IMERG-F and CFSR SPPs respectively.



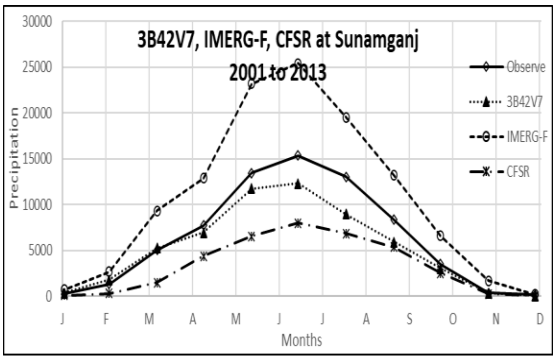
(a)



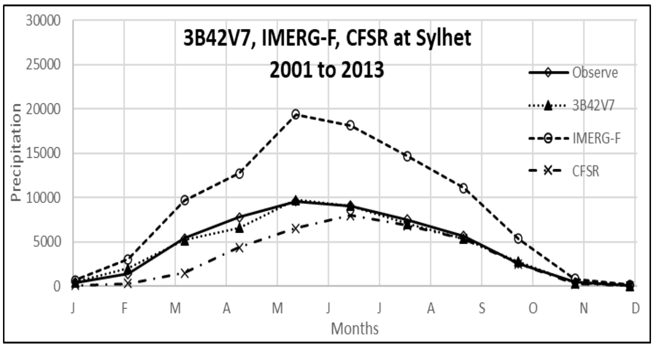
(b)



(c)



(d)



(e)

Figure 2: The comparison of three SPPs 3B42V7, IMERG-F and CFSR with observe precipitation (2001 to 2013) at observed stations (a) Mymensingh, (b)Netrokona, (c)Sreemangal, (d)Sunamganj and (e) Sylhet;

If a close look has done at all plots of above three SPPs and observes rainfall from five observe stations and consider the following **Figure 3**, here, the observe station was organized from north to south, as shown in the location map **Figure 1**. Sreemangal observe station is located on the east side of other stations. From the presentation of the **Figure 3** each estimation of precipitation i.g. observed, 3B42V7, IMERG-F and CFSR are in decreasing order from north to south and east to west.

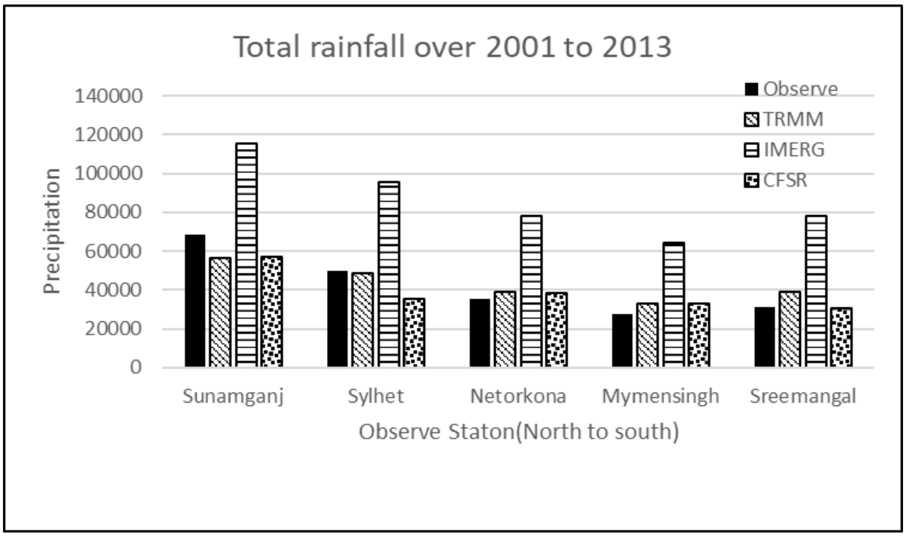


Figure 3: The comparison of three SPPs 3B42V7, IMERG-F and CFSR with total precipitation with observe data (2001 to 2013)

11.DISCUSSION OF STATISTICAL PARAMETERS OF SPPS

Statistical parameters of three satellite precipitation products 3B42V7, IMERG-Final and CFSR are evaluated with some standard statistical parameters (Yuan et al., 2018b). That value of statistical parameters is plotted in the following Figure 4(a to e).

Figure 4(a) demonstrates the percent of BIAS or PBIAS of the SPPs at five different observation stations. It is seen satellite precipitation data 3B42V7 is overestimated by 19.43%, 10.63% and 25.08% in three observe stations Mymensingh, Netrokona and Sreemangal respectively and other two station is underestimated by -17.27% and -2.28%. SPPs CFSR is overestimated in two stations Mymensingh and Netrokona stations by 22.96% and 9.06%. CFSR underestimated at Observe stations Sreemangle, Sunamganj and Sylhet by -1.26%, -14.91% and -27.5% respectively. Satellite precipitation estimation by 3B42V7 is quite reasonable. But precipitation estimation by IMERG-F is excessively overestimated at all five observe stations. Precipitation estimation of IMERG-F for observes station Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet by 133.87%, 119.84%, 148.83%, 68.26% and 92.48% respectively.

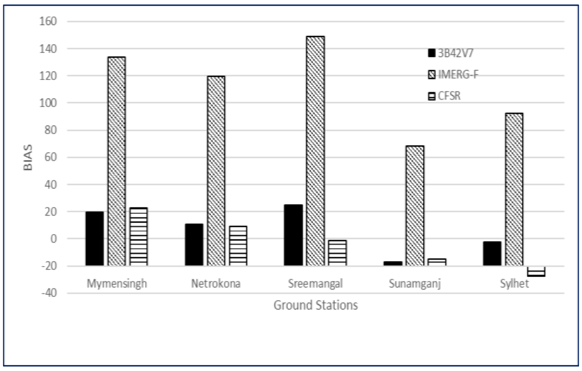
Pearson Correlation Coefficient (CC) of SPPs is demonstrated in Figure 4(b) for five observe station Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet. The value of CC for SPP 3B42V7 for Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet are 0.27, 0.33, 0.21, 0.37 and 0.30 respectively. IMERG-F estimated precipitation data gives CC value 0.14, 0.18, 0.04, 0.32 and 0.17 for five observe station respectively. CFSR data seems little better correlation coefficient value. 0.34, 0.40, 0.27, 0.36 and 0.31 is the calculated CC value for CFSR satellite data. The maximum correlation coefficient value 0.40 was calculated from CFSR data at Sunamganj observe station.

Root mean square error (RMSE) of the SPPs 3B42V7, IMERG-F and CFSR at five observe stations is demonstrated in Figure 4(c). RMSE value for the satellite precipitation estimation 3B42V7 is 19.5mm, 21.6mm, 22.08mm, 33.41mm and 27.13mm at observe stations Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet respectively. Precipitation estimation of IMERG-F is the maximum value of RMSE among the SPPs at all observe stations. The RMSE of the stations is 33.72mm, 37.9mm, 39.11mm, 48.69mm and 45.08mm for IMERG-F. Sunamganj stations have the maximum RMSE value of 48.69mm. CFSR satellite data calculate RMSE 19.19mm, 18.43mm, 19.61mm, 30.85mm 24.21mm for five observe stations Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet respectively.

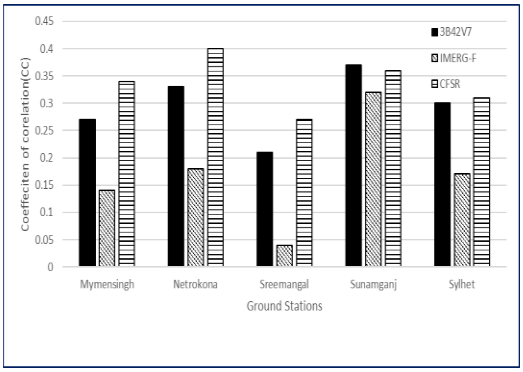
To evaluate the quality of the satellite precipitation estimation another important statistical parameter was considered are Probability of detection (POD), False alarm ratio (FAR) and Critical success index (CSI). For perfect detection or estimation of satellite data POD and CSI value is to 1.0 and the FAR value is 0.0. POD for SPPs is demonstrated in Figure 4(d) at five observe stations. The POD value was estimated by 0.65, 0.75, 0.72, 0.76 and 0.76 for SPP 3B42V7 at observe stations. The IMERG-F satellite data gives POD value 0.75, 0.84, 0.80, 0.89 and 0.83 at the observing stations in the previous sequence. The maximum calculated POD value was 0.93 by CFSR at Sunamganj observe station. For other stations value is 0.82, 0.91, 0.81, 0.93 and 0.80 at the observe stations Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet respectively.

False alarm ratio or FAR for the satellite precipitation estimation for 3B42V7 at five different observe stations Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet is 0.40, 0.48, 0.31, 0.26 and 0.26 respectively. The minimum FAR value is 0.26 at Sunamganj and Sylhet. Three lowest FAR value for IMERG-F satellite precipitation data is 0.27, 0.33 and 0.35 at Sylhet, Sreemangal and Sunamganj observe stations. In the same way, the lowest three FAR calculated for CFSR SPPs at Sylhet Sreemangal and Sunamganj.

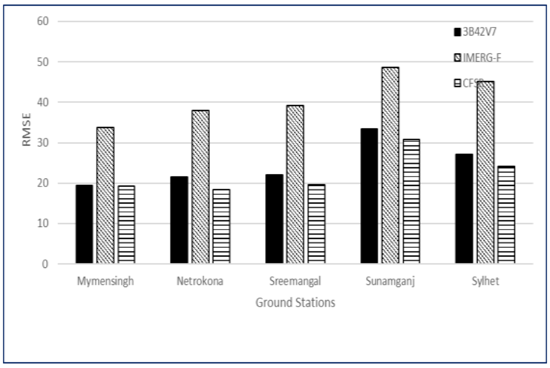
Critical Success Index (CSI) value for 3B42V7 SPPs was 0.46, 0.44, 0.54, 0.60 and 0.60 at five observe stations Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet respectively. The CSI value for IMERG-F 0.48, 0.45, 0.57, 0.60 and 0.63 for observe stations at previous mentioned sequence. CFSR satellite precipitation data gives the highest CSI value at every observed station. The CSI value for CFSR SPPs was estimated by 0.56, 0.49, 0.61, 0.68 and 0.67 for the ground stations Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet respectively.



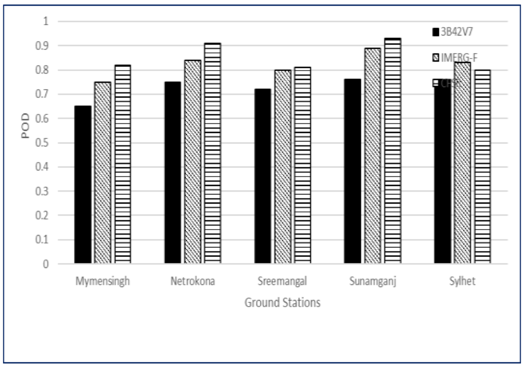
(a)



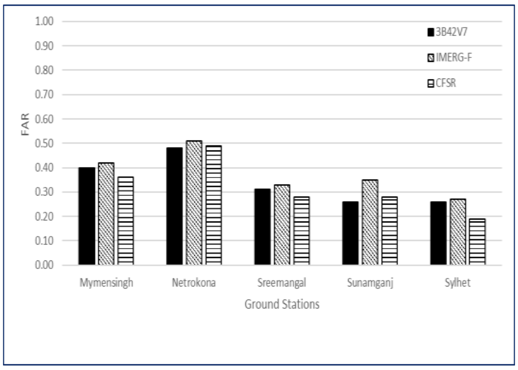
(b)



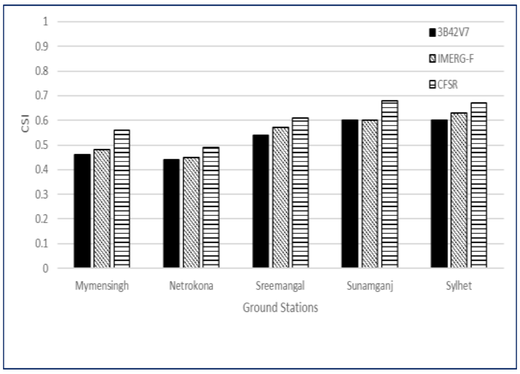
(c)



(d)



(e)



(f)

Figure 4: Statistical Parameters of SPPs (a.PBIAS, b.Pearson Correlation Coefficient (CC), c. Root mean square error (RMSE), d. Probability of detection (POD), e.False alarm ratio (FAR) and f. Critical Success Index (CSI)

The statistical evaluation provides a brief idea on the quality on satellite precipitation estimation at five ground observe stations. Precipitation was over or underestimated at all observe stations. But this amount of distortion of precipitation estimation by 3B42V7 and CFSR was not very notable in accordance with IMERG-F precipitation estimation. Precipitation estimation by all three SPPs was more efficient at Sunamganj observe station among the five observe stations. CFSR precipitation estimation is the closest precipitation estimation; 3B42V7 estimation also keeps its good quality next to CFSR. But precipitation estimation by IMERG-F is not quite so good in quality at five observe stations although Sunamganj observe station maintain better among other observe stations estimation.

12.CONCLUSIONS

In this study, the quality of three satellite precipitation products (SPPs) IMERG-final, TMPA version 7 (3B42V7) and Climate Forecast System Reanalysis (CFSR) was evaluated using statistical parameters in five observe stations Mymensingh, Netrokona, Sreemangal, Sunamganj and Sylhet located in North-East region of Bangladesh. The findings of the study are as follows:

(1) Rainfall estimation by IMERG-F is overestimated at all ground observe stations considered in this study. The other two SPPs 3B42V7 and CFSR are better in the estimation of precipitation in comparison with observe precipitation. Although 3B42V7 and CFSR are slightly underestimated at Sunamganj ground station.

(2) Precipitation is increasing from south to north and west to east in the north-east region of Bangladesh. It implies precipitation should be higher in the watershed than that of observe stations we considered.

(3) Precipitation estimation by all three SPPs was more efficient at Sunamganj observe station among the five observe stations. CFSR precipitation estimation is the closest precipitation estimation to observe rainfall; 3B42V7 estimation also keeps its good performance next to CFSR. But precipitation estimation by IMERG-F is not quite so good in quality at five observe stations although Sunamganj observes station maintain better among other observe stations estimation.

This study found from the SPPs statistical diagnostic IMERG-F precipitation estimation is inferior. Therefore, the GPM scientific team should further refine the retrieving algorithms and improve the accuracy of IMERG-F in the north-eastern region of Bangladesh as well as its upstream i.e Meghalaya State of India with mountain ranges, where local precipitation is sparsely gauged and timely precipitation data are urgently needed for study on flood control and disaster mitigation.

13.ACKNOWLEDGEMENTS

We extend our sincere gratitude to my co-authors, Md. Tofiquzzaman, for his invaluable contributions to this research endeavour. His collaboration and dedication significantly enriched the scientific rigor and depth of our work. We also acknowledge the support of Md. Shahabuddin for his assist in the completion of this study.

REFERENCES

Agnihotri, G., & Dimri, A. (2015). Simulation study of heavy rainfall episodes over the southern Indian peninsula. *Meteorological Applications*, *22*(2), 223–235.

Ahmed, K., & Nicholls, D. (1994). *The impact of non-financial company characteristics on mandatory disclosure compliance in developing countries: The case of Bangladesh*.

Anjum, M. N., Ding, Y., Shangguan, D., Ahmad, I., Ijaz, M. W., Farid, H. U., Yagoub, Y. E., Zaman, M., & Adnan, M. (2018). Performance evaluation of latest integrated multi-satellite retrievals for Global Precipitation Measurement (IMERG) over the northern highlands of Pakistan. *Atmospheric Research*, *205*, 134–146.

Chowdhury, m. S. K., & haque, m. A. (2010). Climate change impacts in coastal zones: context bangladesh. *Coastal zones and climate change: assessing the impacts and developing adaptation strategies*, 141.

Dezfuli, A. K., Ichoku, C. M., Huffman, G. J., Mohr, K. I., Selker, J. S., Van De Giesen, N., Hochreutener, R., & Annor, F. O. (2017). Validation of IMERG precipitation in Africa. *Journal of Hydrometeorology*, *18*(10), 2817–2825.

Gebregiorgis, A. S., Kirstetter, P., Hong, Y. E., Gourley, J. J., Huffman, G. J., Petersen, W. A., Xue, X., & Schwaller, M. R. (2018). To what extent is the day 1 GPM IMERG satellite precipitation estimate improved as compared to TRMM TMPA-RT? *Journal of Geophysical Research: Atmospheres*, *123*(3), 1694–1707.

Guo, H., Chen, S., Bao, A., Behrangi, A., Hong, Y., Ndayisaba, F., Hu, J., & Stepanian, P. M. (2016). Early assessment of integrated multi-satellite retrievals for global precipitation measurement over China. *Atmospheric Research*, *176*, 121–133.

Haggart, K. (1994). *Rivers of life*. Bangladesh Centre for Advanced Studies.

Hofer, T., & Messerli, B. (1997). *Floods in Bangladesh: Process understanding and development strategies*.

Hou, A. Y., Kakar, R. K., Neeck, S., Azarbarzin, A. A., Kummerow, C. D., Kojima, M., Oki, R., Nakamura, K., & Iguchi, T. (2014). The global precipitation measurement mission. *Bulletin of the American Meteorological Society*, *95*(5), 701–722.

Huffman, G. J., Bolvin, D. T., Nelkin, E. J., Wolff, D. B., Adler, R. F., Gu, G., Hong, Y., Bowman, K. P., & Stocker, E. F. (2007). The TRMM multisatellite precipitation analysis (TMPA): Quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. *Journal of Hydrometeorology*, *8*(1), 38–55.

Jiang, D., Zhang, H., & Li, R. (2017). Performance evaluation of TMPA version 7 estimates for precipitation and its extremes in Circum-Bohai-Sea region, China. *Theoretical and Applied Climatology*, *130*, 1021–1033.

Jiang, S., Ren, L., Xu, C.-Y., Yong, B., Yuan, F., Liu, Y., Yang, X., & Zeng, X. (2018). Statistical and hydrological evaluation of the latest Integrated Multi-satellitE Retrievals for GPM (IMERG) over a midlatitude humid basin in South China. *Atmospheric Research*, *214,* 418–429.

Khodadoust Siuki, S., Saghafian, B., & Moazami, S. (2017). Comprehensive evaluation of 3-hourly TRMM and half-hourly GPM-IMERG satellite precipitation products. *International Journal of Remote Sensing*, *38*(2), 558–571.

Kim, J. P., Jung, I. W., Park, K. W., Yoon, S. K., & Lee, D. (2016). Hydrological utility and uncertainty of multi-satellite precipitation products in the mountainous region of South Korea. *Remote Sensing*, *8*(7), 608.

Kim, K., Park, J., Baik, J., & Choi, M. (2017). Evaluation of topographical and seasonal feature using GPM IMERG and TRMM 3B42 over Far-East Asia. *Atmospheric Research*, *187*, 95–105.

Liu, Z., Ostrenga, D., Teng, W., & Kempler, S. (2012). Tropical Rainfall Measuring Mission (TRMM) precipitation data and services for research and applications. *Bulletin of the American Meteorological Society*, *93*(9), 1317–1325.

Prakash, S., Mitra, A. K., AghaKouchak, A., Liu, Z., Norouzi, H., & Pai, D. (2018). A preliminary assessment of GPM-based multi-satellite precipitation estimates over a monsoon dominated region. *Journal of Hydrology*, *556*, 865–876.

Prakash, S., Mitra, A. K., Rajagopal, E., & Pai, D. (2016). Assessment of TRMM-based TMPA-3B42 and GSMaP precipitation products over India for the peak southwest monsoon season. *International Journal of Climatology*, *36*(4), 1614–1631.

Rozante, J. R., Vila, D. A., Barboza Chiquetto, J., Fernandes, A. de A., & Souza Alvim, D. (2018). Evaluation of TRMM/GPM blended daily products over Brazil. *Remote Sensing*, *10*(6), 882.

Sharifi, E., Steinacker, R., & Saghafian, B. (2016). Assessment of GPM-IMERG and other precipitation products against gauge data under different topographic and climatic conditions in Iran: Preliminary results. *Remote Sensing*, *8*(2), 135.

Starkel, L., & Singh, S. (2004). *Rainfall, runoff and soil erosion in the globally extreme humid area, Cherrapunji region, India* (Vol. 191). IGiPZ PAN.

Tan, M. L., & Santo, H. (2018). Comparison of GPM IMERG, TMPA 3B42 and PERSIANN-CDR satellite precipitation products over Malaysia. *Atmospheric Research*, *202*, 63–76.

Tang, G., Ma, Y., Long, D., Zhong, L., & Hong, Y. (2016). Evaluation of GPM Day-1 IMERG and TMPA Version-7 legacy products over Mainland China at multiple spatiotemporal scales. *Journal of Hydrology*, *533*, 152–167.

Tsai, C. F., Ali, M. Y., Ahsan, K., & Alam, S. S. (2011). *Household fish consumption in relation to fishing practices and fish production in flood plains of Bangladesh*.

Wang, Z., Zhong, R., Lai, C., & Chen, J. (2017). Evaluation of the GPM IMERG satellite-based precipitation products and the hydrological utility. *Atmospheric Research*, *196*, 151–163.

Xu, R., Tian, F., Yang, L., Hu, H., Lu, H., & Hou, A. (2017). Ground validation of GPM IMERG and TRMM 3B42V7 rainfall products over southern Tibetan Plateau based on a high-density rain gauge network. *Journal of Geophysical Research: Atmospheres*, *122*(2), Article 2.

Yuan, F., Wang, B., Shi, C., Cui, W., Zhao, C., Liu, Y., Ren, L., Zhang, L., Zhu, Y., Chen, T., Jiang, S., & Yang, X. (2018a). Evaluation of hydrological utility of IMERG Final run V05 and TMPA 3B42V7 satellite precipitation products in the Yellow River source region, China. *Journal of Hydrology*, *567*, 696–711. https://doi.org/10.1016/j.jhydrol.2018.06.045

Yuan, F., Wang, B., Shi, C., Cui, W., Zhao, C., Liu, Y., Ren, L., Zhang, L., Zhu, Y., Chen, T., Jiang, S., & Yang, X. (2018b). Evaluation of hydrological utility of IMERG Final run V05 and TMPA 3B42V7 satellite precipitation products in the Yellow River source region, China. *Journal of Hydrology*, *567*, 696–711. https://doi.org/10.1016/j.jhydrol.2018.06.045

Yuan, F., Zhang, L., Win, K., Ren, L., Zhao, C., Zhu, Y., Jiang, S., & Liu, Y. (2017). Assessment of GPM and TRMM Multi-Satellite Precipitation Products in Streamflow Simulations in a Data-Sparse Mountainous Watershed in Myanmar. *Remote Sensing*, *9*(3), Article 3. https://doi.org/10.3390/rs9030302