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Comparison of Satellite Derived Rainfall Estimations: CMORPH, IMERG and GSMaP with Observed Precipitation

Deepa Roy*, Sharmin Banu

Department of Mathematics, Jashore University of Science and Technology, Jashore, Bangladesh
Email: *deeparoy707@gmail.com

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Abstract

Being largely dependent on agriculture, the overall development and water resource management of Bangladesh are greatly influenced by the accurate estimation of precipitation. Different satellite derived precipitation products, covering a large area, are very useful for rainfall estimation. In this study, three different satellite precipitation datasets namely Climate Prediction Center MORPHING (CMORPH), the global Satellite Mapping of Precipitation (GSMaP), and the Integrated Multi-satellitE Retrievals for GPM (IMERG) daily data are spatially analyzed and compared with the observed rainfall data from 20th May 2020 to 21st May 2020. It is observed that the satellite products matched well with the observed data set but the amount varied. Also, the spatial distribution of CMORPH and GSMaP with the observed precipitation is represented for 02 May 2019.

Keywords

CMORPH, IMERG, GSMaP

1. Introduction

In developing countries like Bangladesh, many human activities and socio-economic stability are strongly influenced by the availability and variability of precipitation (UN, 2009). Rainfall data plays a very important role in weather forecasting and in various climate studies. With its good temporal and spatial coverage, rainfall data help to make decisions regarding hydrological matters as it is the main input in hydrological models. Precipitation is also crucial in water resources planning and management, and directly links to agriculture, disaster mitigation, and preparedness.

Due to the geographical position, Bangladesh experiences the highest amount of rainfall among the SAARC region. The economic development largely depends on agriculture. Accurate rainfall prediction plays a vital role in overall economic growth of this country. Conventional rain gauge networks provide relatively accurate point measurements of precipitation. However, the uneven distribution of gauges and their limited sampling area imposes a substantial problem when dealing with efficient spatial coverage as well as in representing areal means (Xie & Arkin, 1996). Ground-based weather radars provide fairly continuous coverage in space and time, but the quantitative range of their measurements is generally limited to 150 km or less (Feidas, 2010). Most importantly, both rain gauges and radars provide incomplete coverage over remote and undeveloped land areas and particularly over the sea, where such instruments are virtually not available. In contrast, rainfall observations derived by meteorological satellites became an attractive option due to their high spatial and temporal resolution. In addition, they offer complete spatial coverage and provide rainfall measurements over remote land and oceanic areas. The alternative source of such rainfall data is remotely-sensed satellite-based rainfall estimates (SREs), which have the advantage of providing large spatial and temporal rainfall data coverage. These SREs include among others, Famine Early Warning Systems Network Rain Fall Estimation (FEWS-Net RFE) (Herman et al., 1997), Tropical Rainfall Measuring Mission (TRMM) sensor package (Kummerow et al., 1998), Climate Prediction Center (CPC) Morphing Technique (CMORPH) (Joyce et al., 2004), and Precipitation Estimates from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN) (Sorooshian et al., 2000).

There are a number of efforts to compare and validate different satellite rainfall products with other rainfall measurements on global and regional scales. Many of these studies focus on the validation and intercomparison of the Tropical Rainfall Measuring Mission (TRMM) standard products as well as of the TRMM Multi-satellite Precipitation Analysis (TMPA) products for various regions, e.g., Africa (Nicholson et al., 2003; Adeyewa & Nakamura, 2003), south and southeast Asia (Kozu et al., 2002; Islam & Uyeda, 2005; Chokngamwong & Chiu, 2007) North and South America (Fisher & Huffman, 2001; Lettenmaier & Su, 2007; Villarini & Krajewski, 2007), and for the globe (Shin et al., 2001; Chiu et al., 2004). Some global and regional validations have also been carried out for other satellite rain products. An extensive inter-comparison of monthly gauge observations and various satellite estimates for global grid domains of 2.50 latitude/longitude for a 3-year period was carried out by Xie and Arkin (1995). Yin et al. (2004) compared two monthly global precipitation products over land and ocean over a 23-year period (1979-2001). Four global products produced by various international data centers were validated over the Sahel for the period of 1986-2000 by Ali et al. (2005). Dinku et al. (2007) used a relatively dense station network over the Ethiopian highlands to perform an extensive validation and intercomparison of ten satellite rainfall products at different spatial and temporal scales. Recently, a detailed comparison of operational rain products at the daily scale has been carried out for the continental US, Europe, and Australia by Ebert et al. (2007).

Among several available precipitation products, it is still unclear which one is more accurate over different regions. For example, Nesbitt et al. (2008) found that the CMORPH and PERSIANN estimate higher rainfall rates relative to TRMM in the Sierra Madre Occidental (i.e. the western Mexico mountain range running approximately north-south) whereas Dinku et al. (2008) found that the TRMM and CMORPH performance is better in Ethiopia and Zimbabwe. In contrast, de Goncalves et al. (2006) found PERSIANN performance is better than TRMM in South America. For this satellite derived precipitation products need to be validated and deeply analyzed to improve the accuracy and timely prediction of rainfall as they can differ due to geographical location, topography, and climate (Meng et al., 2014; Xue et al., 2013). Therefore, inter-comparison is very crucial for the selection of better and more accurate rainfall estimation among various alternatives. The aim of this study is to compare the two satellite derived rainfall products CMORPH and IMERG with the observed data to evaluate the better one for further use in different rainfall estimation processes.

2. Study Region and Data Sets

2.1. Study Region

The study was conducted over Bangladesh setting the latitude 18˚N - 28˚N and longitude 84˚E - 96˚E.

2.2. Data Sets

2.2.1. Rain Gauge Data

Daily rainfall data of 20th May 2020 at different stations in Bangladesh are collected from the Storm Warning Centre (SWC) of Bangladesh Meteorological Department (BMD).

2.2.2. CMORPH

CMORPH (Climate Prediction Center MORPHING technique) produces global precipitation analyses at very high spatial and temporal resolution. It was developed at the NOAA Climate Prediction Center (CPC). This technique uses precipitation estimates that have been derived from low orbiter satellite microwave observations exclusively, and whose features are transported via spatial propagation information that is obtained entirely from geostationary satellite IR data. This method is highly flexible as it allows the incorporation of any rainfall estimate from PM satellites. The CMORPH V1.0 product has been available as three-hour data since 1st January 1998, at a 0.25˚ × 0.25˚ spatial resolution, and with a 60˚N - 60˚S overall coverage.

2.2.3. IMERG

The Integrated Multi-satellite Retrievals for GPM (IMERG) algorithm combines information from the GPM satellite constellation to estimate precipitation over the majority of the Earth's surface. This algorithm is particularly valuable over the majority of the Earth's surface that lacks precipitation-measuring instruments on the ground. Now in the latest Version 06 release of IMERG, the algorithm fuses the early precipitation estimates collected during the operation of the TRMM satellite (2000-2015) with more recent precipitation estimates collected during operation of the GPM satellite (2014-present). Rainfall estimates in IMERG are processed on a 0.1˚ grid every 30 min. The IMERG algorithm builds on the satellite merging techniques applied in its predecessor TMPA (Huffman et al., 2007; Huffman et al., 2010).

2.2.4. GSMaP

Global Satellite Mapping of Precipitation (GSMaP), was established by the Japan Science and Technology Agency (JST) in 2002 to produce global precipitation products with high resolution and high precision (Ushio et al., 2009), provides a global hourly rain rate with a 0.1 × 0.1 degree resolution. GSMaP is a product of the Global Precipitation Measurement (GPM) mission, which provides global precipitation observations at three hour intervals. Values are estimated using multi-band passive microwave and infrared radiometers from the GPM Core Observatory satellite and with the assistance of a constellation of other satellites. GPM's precipitation rate retrieval algorithm is based on a radiative transfer model. The gauge-adjusted rate is calculated based on the optimization of the 24 h accumulation of GSMaP hourly rain rate to daily precipitation by NOAA/CPC (National Oceanic and Atmospheric Administration/Climate Prediction Centre) gauge measurement. This dataset is processed by GSMaP algorithm version 6 (product version 3).

3. Methodology

The three satellite derived rainfall products CMORPH, IMERG and GSMaP from 20th May 2020 to 21st May 2020 were spatially analyzed along with observed gauge rainfall data. Station wise rainfall amounts of rain gauges were then compared with the three different satellite estimate rainfall amounts. For spatial distribution of the three-satellite derived rainfall, the rainfall products are analyzed using GrADS (Grid Analysis and Display System) version: 2.2.1.

4. Results and Discussion

Spatial distributions of observed rainfall of 20th May 2020 and 21st May 2020 are shown in **Figure 1** and **Figure 2** respectively. On 20th May 2020, due to cyclone "AMPHAN", Khulna division, Barishal division, some districts of Rajshahi and Mymensingh divisions experienced heavy rainfall. Among these divisions, Khulna division experienced the highest amount of rainfall. On 21st May 2020, as the intensity of "AMPHAN" decreases, the rainfall amount also decreased except some areas of southeastern and northwestern parts of Bangladesh. **Figures 3-5** represent the satellite derived rainfall on 20 May 2020 for CMORPH, IMERG and GSMaP respectively. If we take a closer look at these figures, we can observe

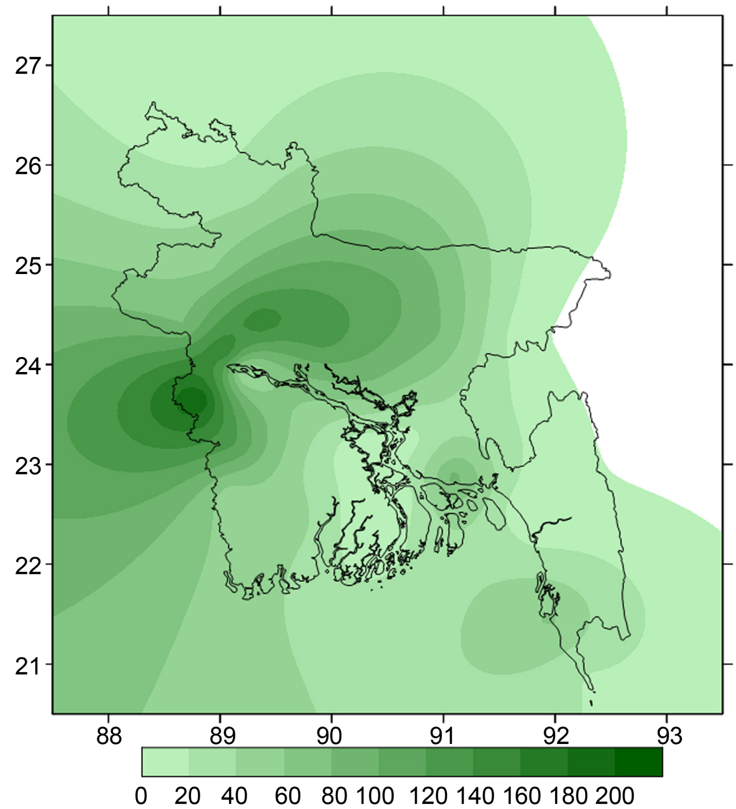

Figure 1. Observed rainfall on 20 May 2020.

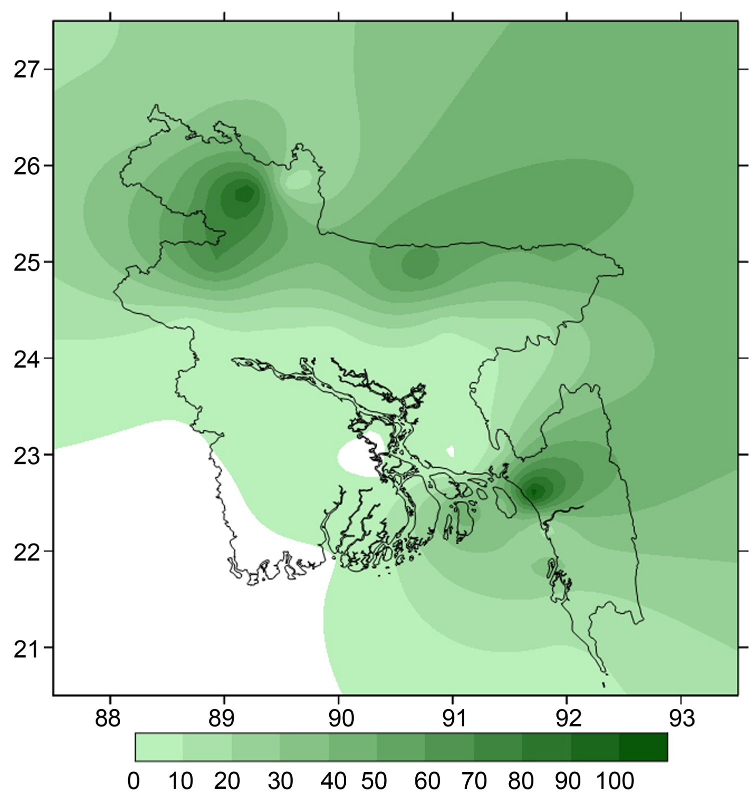

Figure 2. Observed rainfall on 21 May 2020.

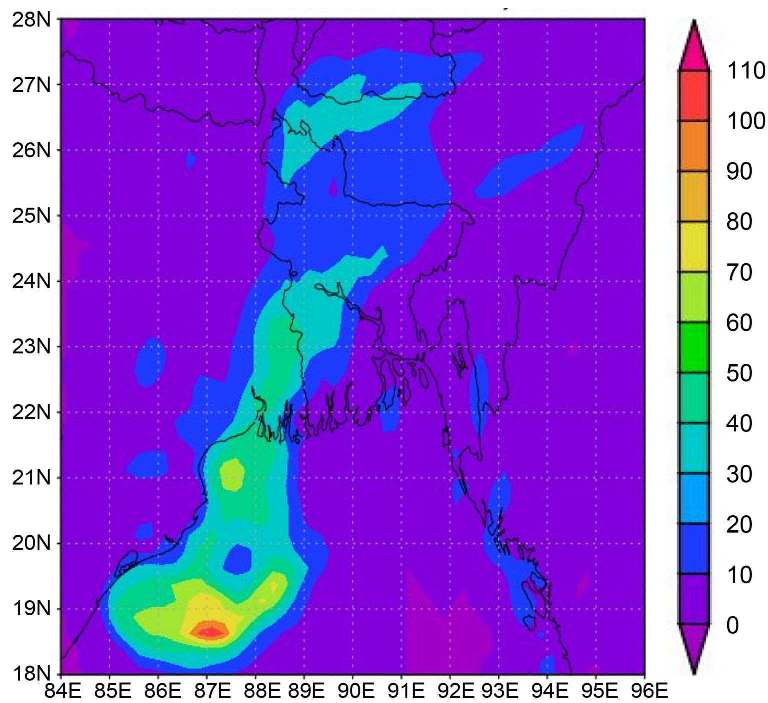

Figure 3. CMORPH rainfall on 20 May 2020.

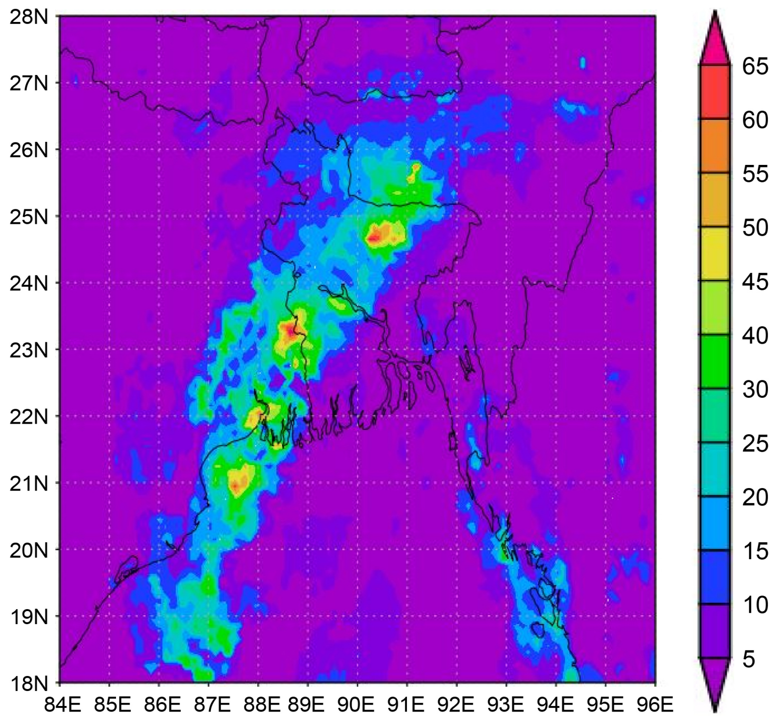

Figure 4. IMERG rainfall on 20 May 2020.

that IMERG agreed much than the other products but did not show any significant rainfall amount on the southeastern parts of the country. In case of CMORPH, it captured rainfall but did not agree much with the observed rainfall distribution well. On the other hand, GSMaP underestimated the rainfall amount on that very day although all the rainfall products showed moderate rainfall in various parts of the country.

Figures 6-8 shows the satellite derived rainfall on 21st May 2020 for CMORPH, IMERG, and GSMaP respectively. All the products did not show any significant amount of precipitation on that day although GSMaP and CMORPH showed a little amount of precipitation in the northeastern parts of the country.

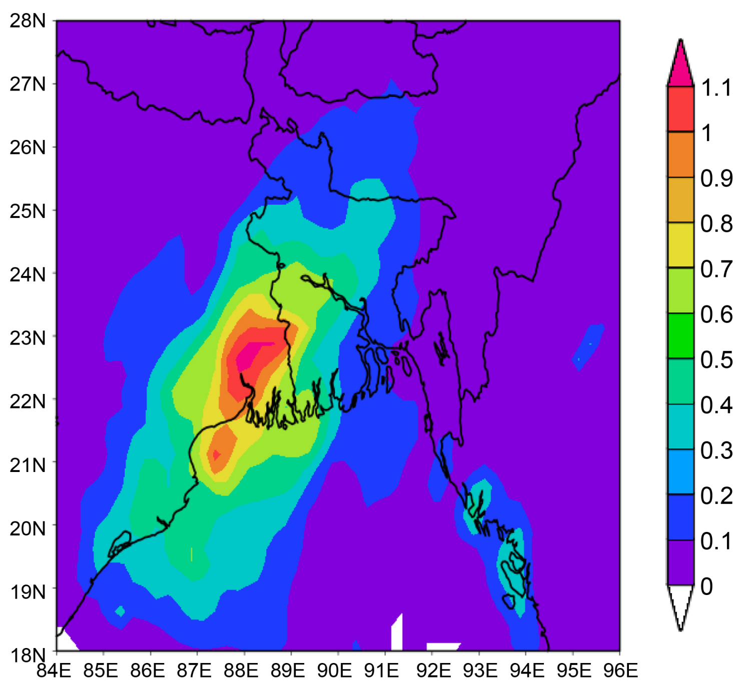

Figure 5. GSMaP rainfall on 20 May 2020.

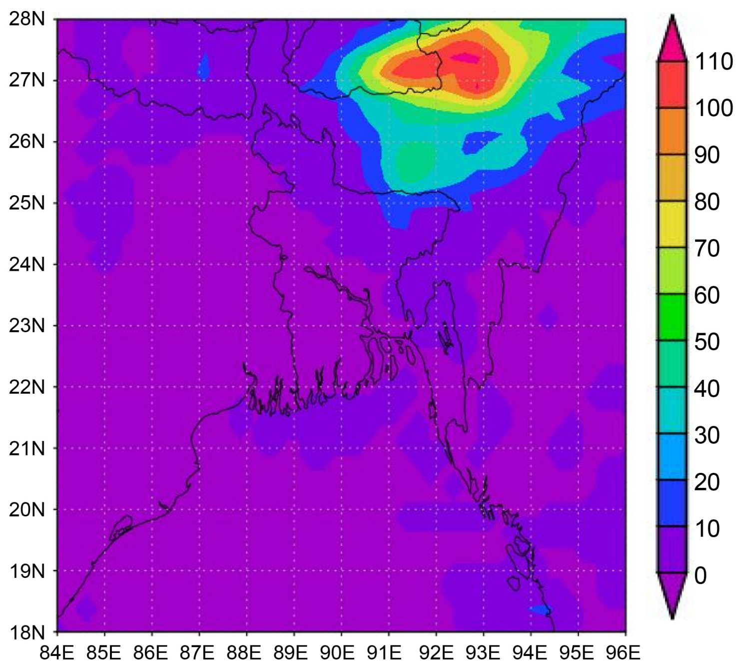

Figure 6. CMORPH rainfall on 21 May 2020.

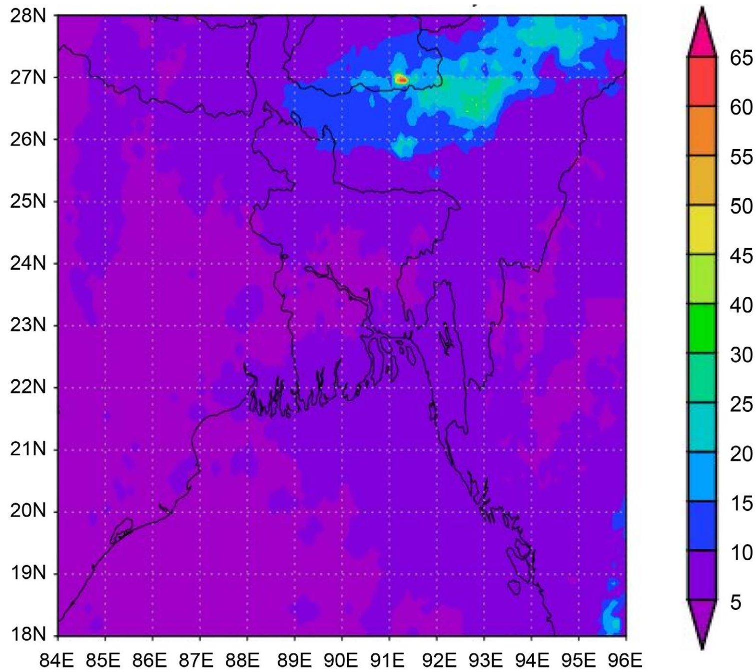

Figure 7. IMERG rainfall on 21 May 2020.

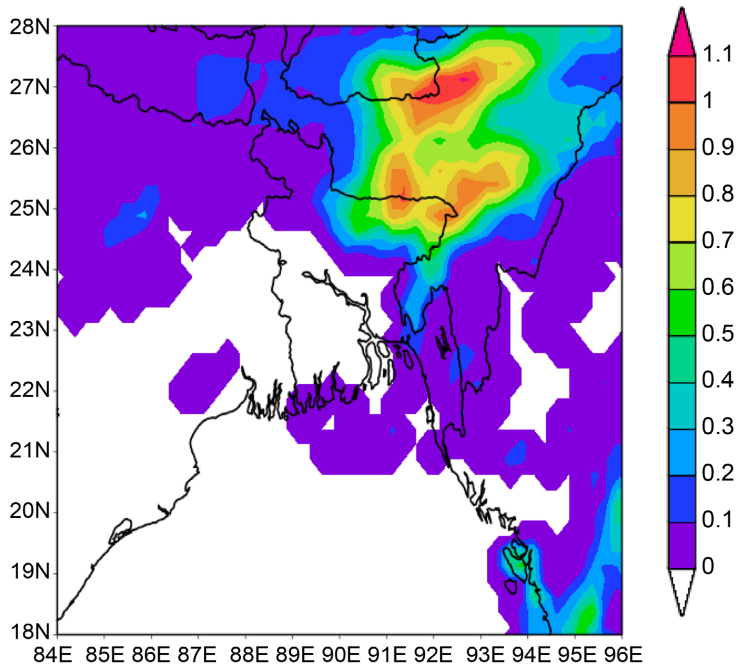

Figure 8. GSMaP rainfall on 21 May 2020.

For better understanding, the observed rainfalldata along with the satellite derived precipitation amount for CMORPH, IMERG and GSMaP are given in Figure 9. From this figure, we can see that all the satellite derived rainfall products underestimated the amount of precipitation compared to observed data. In some cases, CMORPH matched reasonably well but GSMaP estimations always remained far behind. Being newly introduced, IMERG captured precipitation well but not satisfactory. Therefore, it can be said that none of the three satellite derived rainfall products did not estimate the amount of precipitation well.

Figures 10-12 represent the rainfall above 20 mm on 20th May 2020 respectively. It can be easily observed that compared to CMORPH and IMERG,

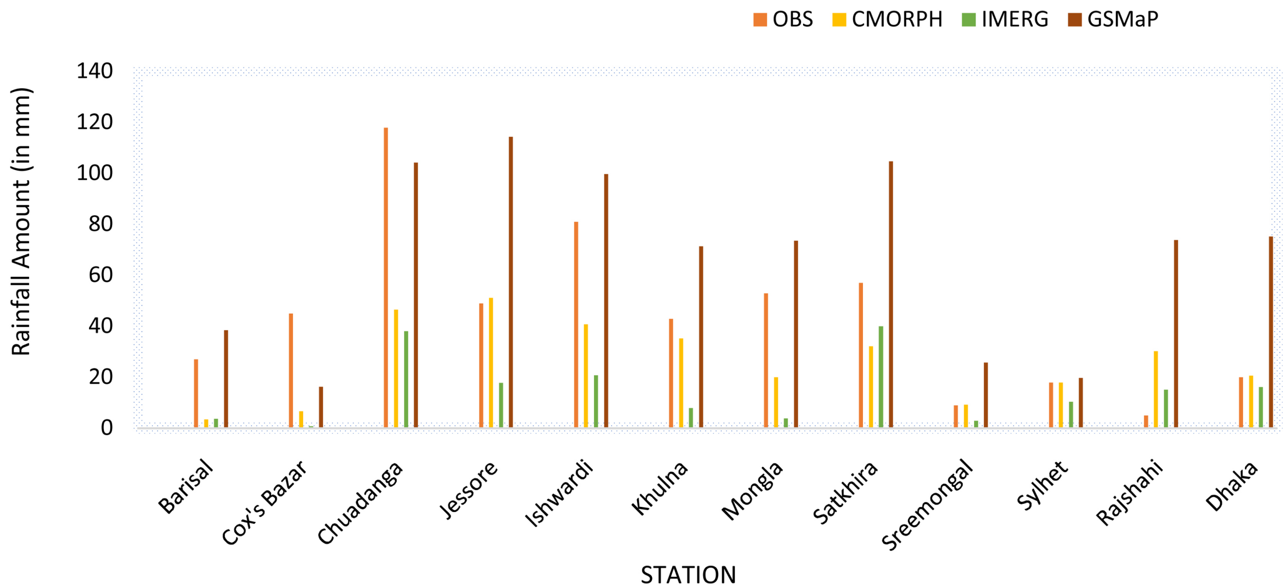

Figure 9. Rainfall amount for different stations on 20 May 2020.

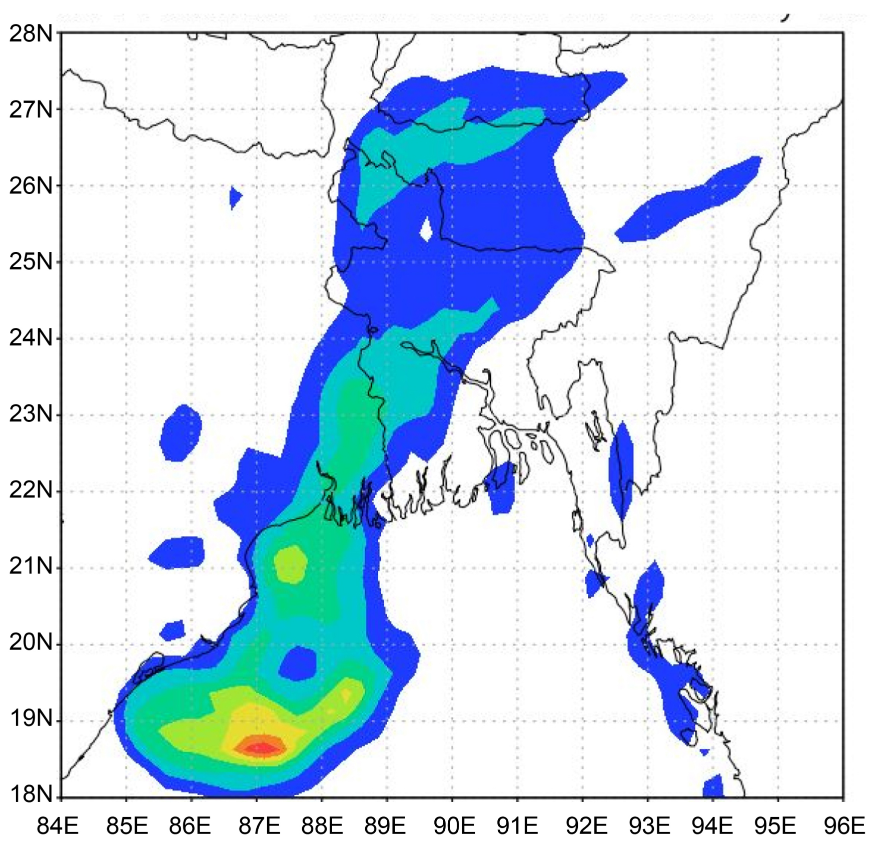

Figure 10. CMORPH rainfall above 20 mm on 20 May 2020.

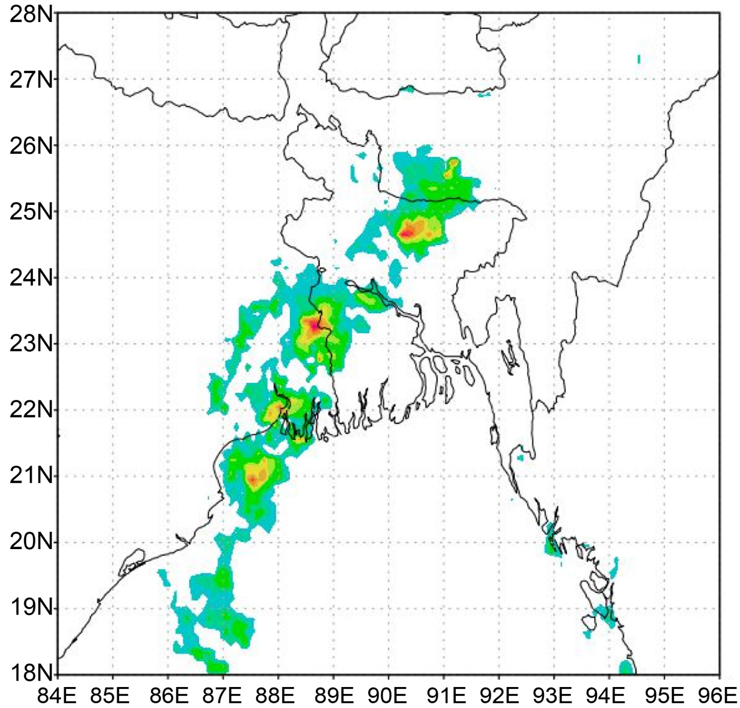

Figure 11. IMERG rainfall above 20 mm on 20 May 2020.

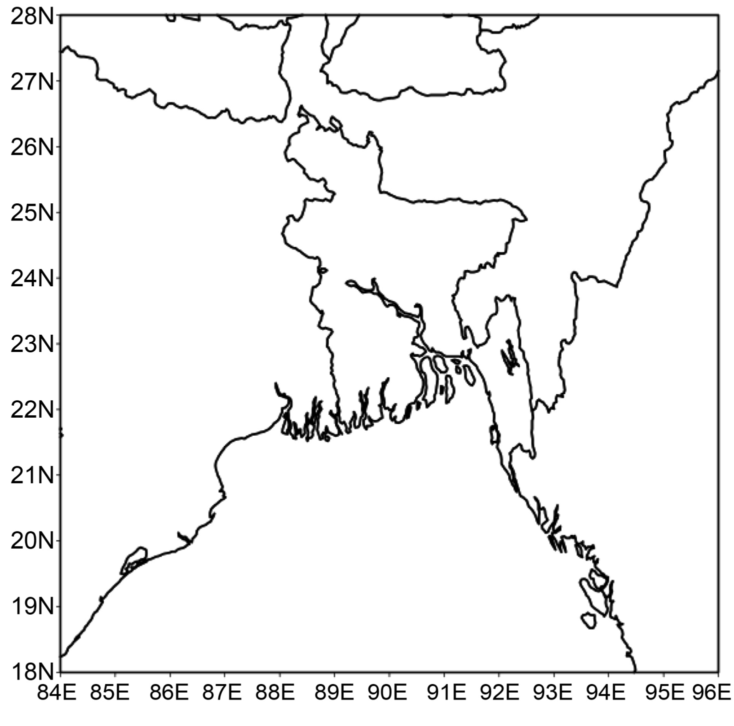

Figure 12. GSMaP rainfall above 20 mm on 20 May 2020.

GSMaP did not show any rainfall amount above 20 mm on any parts of the country where some south-western parts of Bangladesh experienced significant rainfall on that very day. Moreover IMERG agreed with observed precipitation but sometimes over estimated. Among all these three, spatial distribution of

CMORPH agreed reasonably well with the observed data.

Another comparison had made by representing the spatial distributions of three mentioned satellite derived rainfall estimations for 01 May 2019 during the time of cyclone "FANI". These are shown in Figures 13-15 respectively. It can be observed that GSMaP did not show any significant rainfall on that day although there was rainfall on the southern parts of the country. On the other hand, CMORPH showed a significant amount of rainfall but not very close to

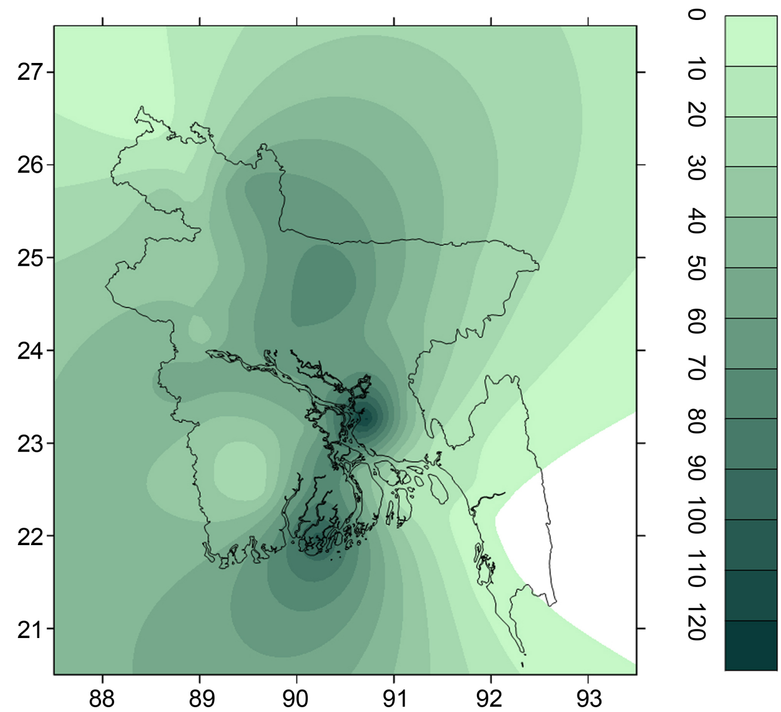

Figure 13. Spatial distribution of observed rainfall (mm) on 03 May 2019.

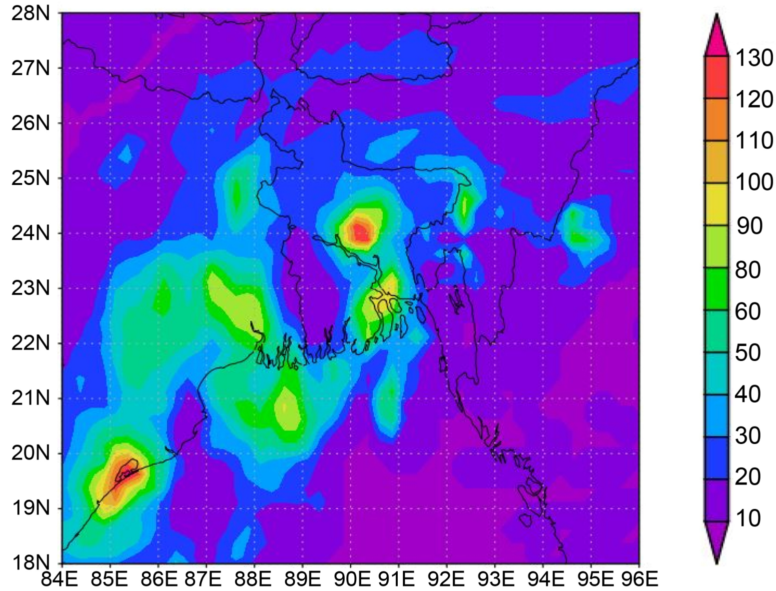

Figure 14. CMORPH rainfall on 03 May 2019.

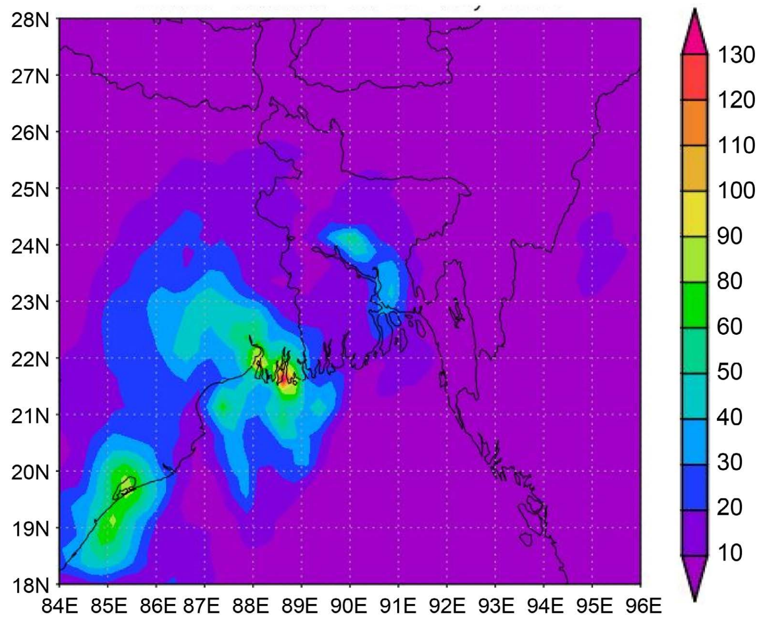

Figure 15. GSMaP rainfall on 03 May 2019.

the observed rainfall distribution.

5. Conclusion

The purpose of this study was to assess the accuracy of the three satellite derived rainfall products CMORPH, IMERG, and GSMaP for estimating the amount of precipitation during the time of cyclone "AMPHAN". These satellite derived rainfall products have been evaluated regionally. But there are significant differences in their performances and this is due to the geographical location, climate, and rainfall regime. In some cases, these products completely agree with the observed precipitation while in other cases they significantly vary. Among the products, CMORPH performed and IMERG performed reasonably well but not up to the mark while GSMaP showed the poorest performance of them all. In the case of spatial distribution, IMERG performed well but for estimating the amount, it stayed far from the observed values. CMORPH also did the same but it estimated the precipitation amount quite close to the observed values. GSMaP did not show a good performance in both spatial distribution and amount estimation when compared with the CMORPH and IMERG. Satellite derived rainfall could be a good source of rainfall estimation where observation facilities are not available but they need to be validated more deeply. Further study is needed for the evaluation of other satellite derived rainfall products for accurate rainfall estimation and timely prediction. Further study is needed for the evaluation of other satellite derived rainfall products for accurate rainfall estimation and timely prediction.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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