

Analogy of Ground Based Rainfall Observations to Satellite Based Observations from TRMM and GPM

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ABSTRACT: Rainfall is one of the paramount factors for the global hydrological cycle and has large socio-economic impacts. Therefore, study of the rainfall becomes important. Generally, Rain gauge stations are used to find the intensity of rainfall. One of major issue is estimation of the rainfall at the ungauged stations or the remote areas where the installation of rain-gauge stations is not possible. Improved technical knowledge assists us to use satellite data to find precipitation. Our study focuses on preliminary analysis of the potential for using satellite derived rainfall data through a comparison with available gauge-based precipitation for Tungabhadra lower basin located in southern India. The rain gauge data from Andhra Pradesh and Karnataka meteorological department is collected and is compared with the National Aeronautics and Space missions Global Precipitation Measurement (GPM) and Tropical Rainfall Measuring Mission (TRMM) satellite-based precipitation data products. Tropical Rainfall Measuring Mission (TRMM) 3B42V7 and GPM satellites precipitation product offers an opportunity to monitor precipitation at high spatiotemporal resolution. However, it has several inherent errors related to observation, instrument, and rainfall retrieval algorithms. It is, therefore, essential to validate it with ground-based measurements. Different skill scores are computed for GPM and TRMM 3B42V7 data products to evaluate the performance of these satellite estimates. However, in terms of bias TRMM satellite has almost overestimated and GPM satellite has underestimated values when compared with ground rainfall observation also root mean square error values are high for TRMM observations when compared in an average with GPM observations. However, both TRMM and GPM products shows almost similar variations compared to ground rainfall observations.

KEYWORDS: Hydrological cycle, Gauge based precipitation, Satellite based precipitation.

I. INTRODUCTION

The significant contribution of Indian economy is from agriculture, which is contributed by rural areas. The area of study is covering the region of Andhra Pradesh and Karnataka. Agriculture in Andhra Pradesh is the chief source of economy and provides occupation for 60% of the people also in Karnataka, farmers and agricultural labourers forms around 56% of the work force. Fresh water availability for irrigation is majorly rainfall. Therefore, focus on the rainfall which contributes to major part of irrigation is important. So Real time recording of monsoon rainfall is required. Tropical rainfall accounts for about two thirds of the global rainfall and has large socio-economic impacts. Continuous monitoring of rainfall is essential. As precipitation varies highly in space and time dimensions, its irregular patterns pose multitude challenges for its precise measurement. The most effective way of direct measurement of rainfall are observed to be Rain Gauges whereas establishing an evenly distributed in-situ precipitation measurement network is infeasible considering the geographical diversity of the planet. Therefore, there is a requirement of satellites counter this.

The first satellite dedicated for meteorological precipitation is the Tropical Rainfall Measurement Mission (TRMM), launched in 1997, was capable to measure moderate and heavy tropical precipitation with reasonable accuracy, strengthened our understanding of weather systems and real-time observations of monsoons and extreme weather

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events. The TRMM Microwave Imager measured microwave energy emitted by the Earth and its atmosphere to quantify rainfall intensity in the atmosphere. Out of various data products given by the satellite 3B42 V7 gives precipitation data. The resolution of TRMM precipitation data product is 0.25° . With the magnificent success of TRMM, the Global Precipitation Measurement (GPM) Core Observatory was launched in February 2014 to provide next-generation next generation global observations of rainfall with a resolution of 0.1° . The GPM carries an advanced 13-channel passive microwave radiometer specifically Ku/Ka-band Dual-frequency Precipitation Radar (DPR) and a multi-channel GPM Microwave Imager. The DPR instrument provides three dimensional measurements of precipitation structure over 78 and 152 miles. This served as a benchmark to unify and advance precipitation estimates made by a constellation of research and operational microwave sensors. The Ka-band in DPR is more sensitive than TRMM precipitation radar in low rainfall and high-latitude snowfall measurements. Also, the DPR is able to detect and estimate extreme precipitation more accurately, which would be critical to study their impacts in the global climate models in order to better understand the global water cycle.

In the present study, an attempt is made to inter-compare the GPM rainfall products, 3B42V7 of TRMM and rainfall products from the ground rain gauge stations. Also, the data is evaluated to find out any differences and improvements, with cross-evaluation against the gridded gauge-based data sets over the Tungabhadra lower sub basin region during the monsoon season 2018(July-2018). To quantify the performance of the satellite measurements, several statistical skill scores are computed and inter-compared. Thus, this project targets to contribute an improved understanding of errors in satellite estimates arising due to the interaction of precipitation-topography over the Tungabhadra lower sub basin region, thereby helping in shaping up of advanced satellite rainfall products in the future.

II. LITERATURE REVIEW

Precipitation is one of the predominant measures in determining the weather and climate conditions of a region. It is extremely useful to have knowledge about the quantitative rainfall information and its distribution over time since these are fundamental factors to perform climatic zoning and to determine the agricultural aptitude of a given area. In addition, continuous monitoring of rainfall is important to identify the need for additional irrigation of several crops and the design of dams and also to predict events such as floods and cyclones. (Massagli et.al., 2011).[6],(Wang et al.,2012).[10]For monsoon modelling, High-quality monsoon rainfall estimates are a possible source of information. Therefore, it is essential to have genuine daily and monthly rainfall datasets over the Indian region, to understand the monsoon rainfall and its variability in a better way. Rainfall data set is made from the rain gauges and ground-based radars. (Muralikrishna et al., 2017)[7]. Also, in land surface hydrological system, the foremost atmospheric input is the precipitation data. (Nijssen et al., 2004) [9]. Traditionally rainfall measurement is performed using ground rain gauges; however, these instruments have deficiencies in the representation of rainfall distribution in larger areas, because they are unevenly distributed and are limited in space. Therefore, to accurately represent the rainfall behavior of a region, a high density of rain gauges would be required which, for countries with huge areas it becomes unfeasible due to the high costs of rainfall monitoring. (Xie and Arkin 1995)[11], (Collischonn et al., 2008) [1]. On the other hand, a wide range of remote sensing products in rain estimation are available in increasingly detailed spatial and temporal resolutions Thus, remote sensing can contribute to the continuous representation of the distribution of rainfall events. (Huffman et al., 2010)[5]. Further the rainfall estimates from satellite are more cost effective and provide a more continuous and consistent data set than ground-based weather stations. (Han et al., 2011) [2]. Satellite measurements provide high temporal resolution and near real-time rainfall estimation over a wide area. A number of multi-satellite precipitation products such as Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA), and GPM. Precipitation Estimation from Remotely Sensed Information is available. (Huffman et al., 2014)[4]. The first dedicated meteorological precipitation satellite – the Tropical Rainfall Measuring Mission (TRMM), launched in late 1997, was capable to measure moderate and heavy tropical precipitation with reasonable accuracy from last 17 years and enhanced our understanding of weather systems and real-time monitoring of monsoons and extreme weather events. With the splendid success of TRMM, the Global Precipitation Measurement (GPM) Core Observatory was launched in February 2014 to provide next-generation global rain as well as snow observations in near-real-time (Yong et al., 2015)[12]. To evaluate the multi-satellite rainfall estimates against IMD gauge-based observations,

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several continuous metrics such as bias, relative difference, correlation coefficient, and root-mean-square error (RMSE) of the selected multi-satellite precipitation estimates against IMD gauge-based observations are computed. (Nasrollahi et al., 2015) [8]. In addition to distributional analysis, four categorical metrics based on a 2x2 contingency table such as probability of detection (POD), false alarm ratio (FAR), frequency bias index (FBI), critical success index (CSI) and accuracy are computed to assess the capability of multi-satellite rainfall estimates in detection of precipitation events as compared to IMD gauge-based observations. (Hogan et al., 2010) [3].

STUDY AREA

The current study considered the area of Krishna Basin which extends over Andhra Pradesh, Maharashtra and Karnataka having a total area of 2,58,947km² which is nearly 8% of the total geographical area of the country. It is bounded by Balaghat range on the north, by the Eastern Ghats on the south and the east by Western Ghats on the west. The Krishna rises from the Western Ghats on the west and is further divided into 7 sub basins namely Bhima lower sub basin, Bhima Upper Sub Basin, Krishna Lower Sub Basin, Krishna Middle Sub Basin, Krishna Upper Sub Basin, Tungabhadra Lower Sub Basin, Tungabhadra Upper Sub Basin. Out of the above 7 Tungabhadra Lower Sub Basin is being selected for study which is shown in fig 1.

Tungabhadra Lower Sub Basin stretches over an area of 41542.29km² in both the riparian states of Karnataka and Andhra Pradesh and finally joins Krishna that flows into Bay of Bengal. It is the largest tributary of the River Krishna. The area covers ten districts and forty-three taluks of Karnataka, two districts and forty-eight mandals of Andhra Pradesh. The area falls in geographical co-ordinates of 13°N-17°N and 73°E-77°E. The elevation range in the region varies from 200-1020m. Average temperature in Tungabhadra region around 26 degrees Celsius. Mean annual rainfall in the Tungabhadra basin is 884 mm. The major crops grown are paddy, jowar, sugarcane, cotton and Ragi (millets). The South West Monsoon sets in the middle of June and withdraws by the middle of October and about 90% of annual rainfall is received during the Monsoon period, of which more than 70% occurs during July, August and September. Hence, the period of study is from 1st July 2018-31st July 2018.



Figure 1: Study Area Map.

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III. METHODOLOGY

The flow chart shown in fig 4.1 gives the brief outline of the methodology used

Methodology involves three major steps:

1. Data collection.
2. Visual & Statistical analysis.
3. Categorical Analysis

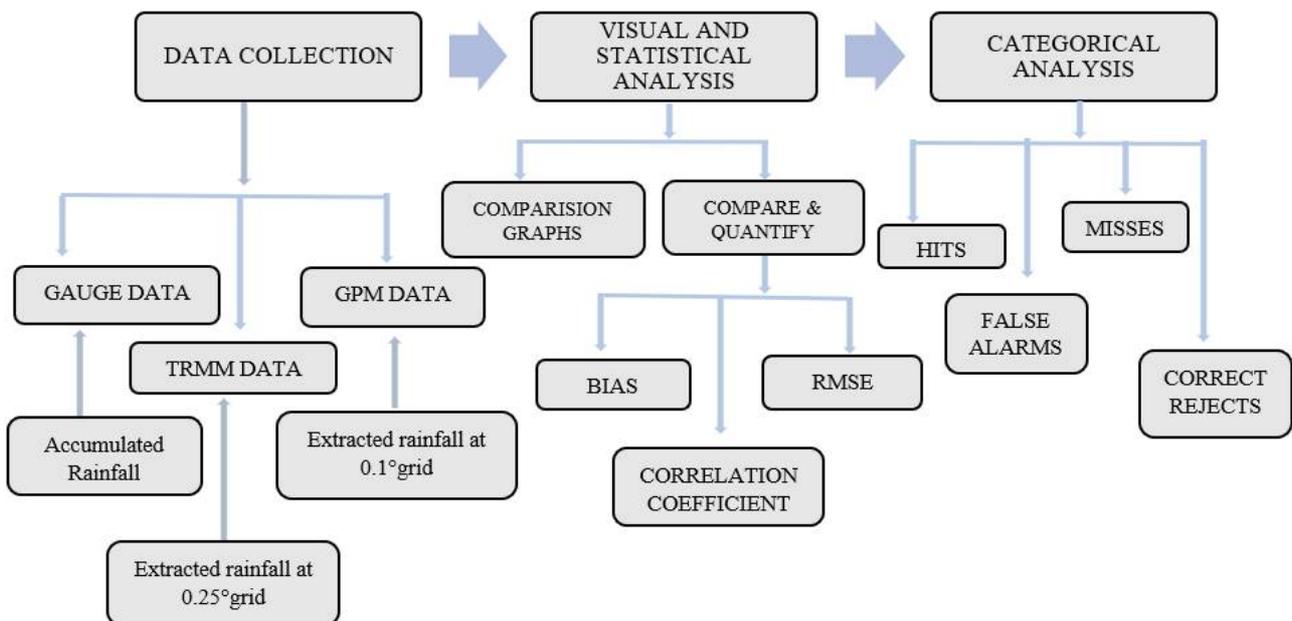


Figure 2: Methodology Flowchart.

DATA COLLECTION:

Data collection involves collection of rainfall observations from both ground and satellites (TRMM and GPM). The study area of Tungabhadra lower sub basin covers a total of 92 stations in both the Karnataka and Andhra Pradesh states. The precipitation data for Karnataka state is obtained from the Karnataka State Natural Disaster Monitoring Centre i.e., <https://www.ksndmc.org/> and The Precipitation data for Andhra Pradesh state is obtained from the state Development Planning Society website i.e., http://www.apsdps.ap.gov.in/pages/reports_web/reports_daily_mandalwise.html. Rainfall data from the satellites (TRMM & GPM) is extracted from raster images which are imported from NASA website i.e., <https://pmm.nasa.gov/> in ARC MAP 10.5.

VISUAL AND STATISTICAL ANALYSIS:

Visual & Statistical analysis is the measure of performance criteria which measures the strength of statistical relationship between observed and predicted values. The comparison results are evaluated using three indicators. The

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standard statistical metrics like bias, correlation coefficient, and root-mean-square error have been used extensively in validation studies.

BIAS:

BIAS indicates how the estimates of rainfall by satellite are related to the measurements obtained by the rain gauges or calculating bias ratio provides information on the ability of TRMM to describe the actual rainfall on the ground. Bias can be calculated using the below formula:

$$bias = \frac{1}{N} \sum_{i=1}^N (E_i - O_i)$$

E_i designates estimated value by the satellites, O_i Observed value from the raingauge stations at a given cell and N thenumber of samples.

Negative BIAS values mean, the satellite overestimates the measure obtained by rain gauges while Positive BIAS values mean, the satellite underestimates the measure obtained by rain gauges.

ROOT MEAN SQUARE ERROR:

Root Mean Square Error (RMSE) is the standard deviation of the residuals (prediction errors). Residuals are a measure of how far from the regression line data points are. In other words, it tells you how concentrated the data is around the line of best fit. It evaluates the error from the square of the differences between the satellite data and the rain gauge.

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^n (P_i - O_i)^2 \right]^{1/2}$$

where n is the number of observations, O_i is observed value from ground stations, P_i is the predicted value by satellites.

CORRELATION COEFFICIENT:

A correlation is a single number that describes the degree of relationship between two variables. It is good measure of linear association which can be calculated using the below formula:

$$r = \frac{\sum_{i=1}^N (E_i - \bar{E})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^N (E_i - \bar{E})^2} \sqrt{\sum_{i=1}^N (O_i - \bar{O})^2}}$$

CATEGORICAL ANALYSIS:

Visualising categorical data presents a comprehensive overview of graphical methods for discrete data-count data, cross-tabulated frequency tables and discrete response data. In the gridded data, precipitation is estimated and observed as discrete values. Therefore, categorical or descriptive statistics methods have been applied to determine how good satellite estimates are. In general, contingency tables are used as statistical methods. Commonly, forecast verification data in contingency tables are characterized using relative accuracy measures.

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TABLE 1: CONTINGENCY TABLE

CONTINGENCY TABLE		Observed values _rain gauge data	
		YES	NO
Observed values_ satellite data	YES	HITS (a)	FALSE ALARMS(b)
	NO	MISSES (c)	CORRECT REJECTS(d)

TABLE 2: CATEGORICAL METRICS FOR VALIDATION OF RAINFALL AREA PREDICTIONS

Metric	Formula	Range	Optimum Value
Probability Of Detection	$\frac{a}{a + c}$	0-1	1
Frequency Bias Index	$\frac{a + b}{a + c}$	0-∞	1
False Alarm Ratio	$\frac{b}{a + b}$	0-1	0
Critical Success Index	$\frac{a}{a + b + c}$	0-1	1
Accuracy	$\frac{a + d}{a + b + c + d}$	0-1	1

IV. RESULTS

VISUAL AND STATISTICAL ANALYSIS

The least value of RMSE when TRMM satellite data is compared with ground based rainfall data is observed as 2.09 mm/day and it is observed at Uravakonda station of Anantapur district, Andhra Pradesh, whereas when GPM satellite data is compared with the ground based data the least error observed is 1.06 mm/day and it is observed at Kalyanadurg station of Anantapur district, Andhra Pradesh. The highest error is observed at Mudigere station of Chikkamagalur district, Karnataka for both TRMM satellite data and GPM satellite data whose values are 28.6 mm/day, 24.3 mm/day respectively. The RMSE values for the various stations over the entire region is plotted as a spatially map as shown in figure 3.

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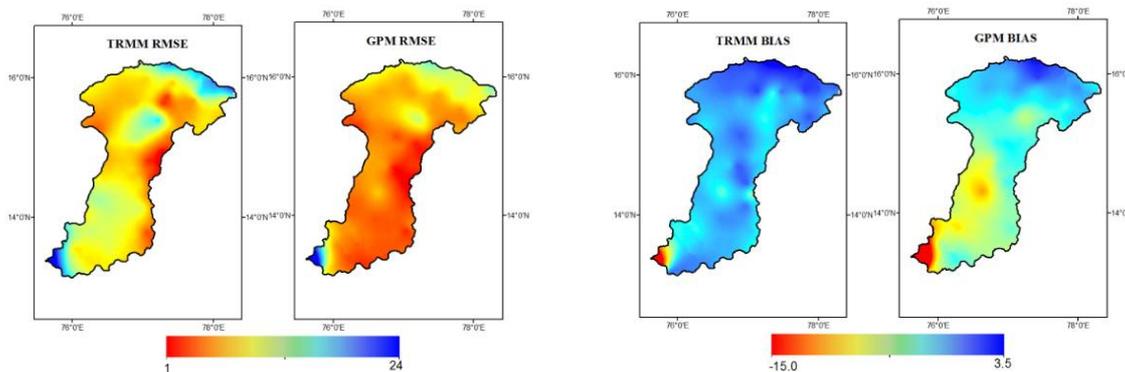


Figure 3: Spatial Distribution of Root Mean Square Error (RMSE) and BIAS for TRMM and GPM Satellites during July 2018 Over Tungabhadra Lower Sub Basin.

The gauge-based precipitation data is analysed for RMSE with satellite-based (TRMM & GPM) precipitation data for the 92 stations in the study area, out of which 40 stations fall under RMSE of 6 mm/day with reference to TRMM and 77 stations with reference to GPM. The RMSE for the entire study area in accordance to TRMM satellite observations is recorded as 7.21 mm/day while GPM satellite observations records a value of 4.49 mm/day. The above alterations in the values of RMSE is mainly due to the disparity in the elevation.

The TRMM and GPM satellite-based observations when correlated with ground-based rainfall observations it was observed that TRMM satellite has overestimated the rainfall whereas the GPM satellite has underestimated the rainfall occurred. Out of the 92 stations in the study area the TRMM satellite has underestimated the rainfall only in 9 rain-gauge stations and overestimated the remaining 83 stations while GPM satellite has underestimated the rainfall for 37 stations and overestimated in the 55 stations which is shown as spatial distribution of bias over the entire region in figure 3.

The correlation coefficients are computed for TRMM satellite data and GPM satellite data for all the 92 stations. The maximum value of correlation coefficient is observed at Hosapet station, Bellary district, Karnataka, for both TRMM and GPM satellite data (0.79, 0.87 respectively). The number of stations where correlation coefficient is less than 0.3 for TRMM satellite data are 48, whilst GPM satellite data recorded 52 stations as correlation values less than 0.3.

ANALYSIS FROM CONTINGENCY TABLE

The satellite data from TRMM and GPM is set side by side with data from rain gauges and evaluated for various parameters. For Probability of Detection (POD) it is observed that TRMM records higher values in almost all the stations. POD is greater than 0.6 for 41 stations for TRMM data and for GPM 32 stations fall in this range. The POD for the entire region in accordance to TRMM satellite data is 0.56 and for GPM satellite data is 0.51 as shown in figure 4. The False Alarm Ratio (FAR) for the entire study area is shown in figure 4 and is noticed to be low in case of GPM satellite data when compared with TRMM satellite data. The number of stations accounting for FAR less than 0.5 are 51 for GPM and 34 for TRMM.

The Critical Success Index (CSI) for the entire study area is same for both TRMM and GPM satellites and it is observed to be 0.34. With regards to Frequency Bias Index (FBI) it is observed that both the satellites had over forecasted the rainfall occurrences. But the GPM satellite gave better results when compared with TRMM satellite. The figure 4 shows the spatial distribution of Critical Success Index (CSI) and Frequency Bias Index (FBI) for TRMM and GPM satellites during July 2018 over the study area.

The Accuracy of detection for the entire study area is higher for GPM satellite. The accuracy of detection is greater than 0.7 for 39 stations when observations are in accordance to TRMM satellite and 54 stations when observations are in accordance to GPM satellite. Spatial distribution of accuracy for TRMM and GPM Satellites during July 2018 over study area is shown in figure 5.

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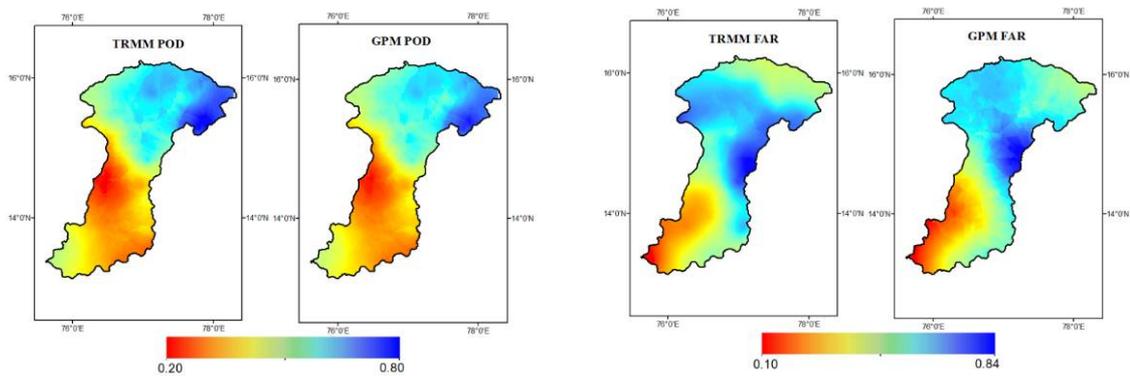


FIGURE 4: Spatial Distribution of Probability of Detection (POD) and False Alarm Ratio (FAR) for TRMM and GPM Satellites during July 2018 over Tungabhadra Lower Sub Basin.

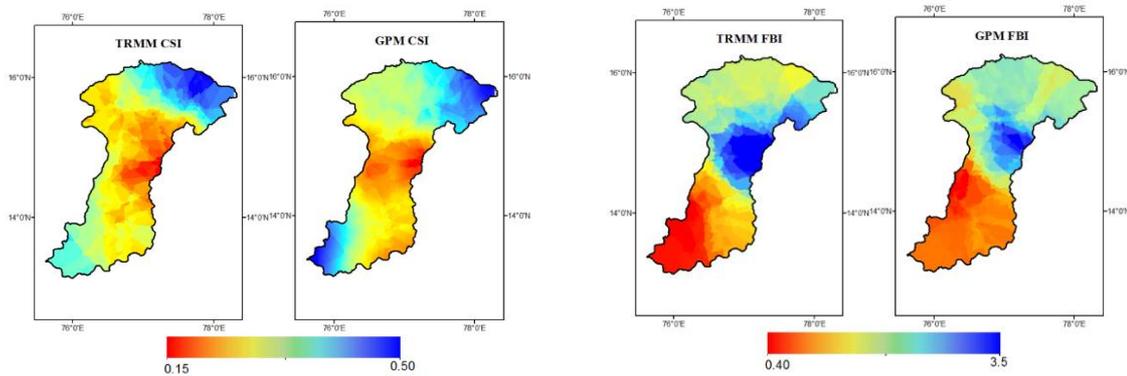


FIGURE 5: Spatial Distribution of Critical Success Index (CSI) and Frequency Bias Index (FBI) for TRMM and GPM Satellites during July 2018 over Tungabhadra Lower Sub Basin.

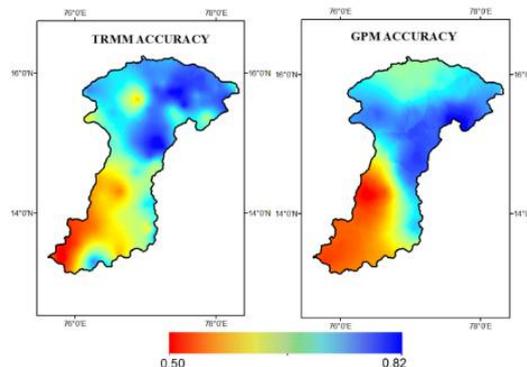


FIGURE 6: Spatial Distribution of Accuracy for TRMM and GPM Satellites during July 2018 over Tungabhadra Lower Sub Basin.

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V. CONCLUSIONS

The Root Mean Square Error for the entire region in accordance to TRMM satellite is 8.55. while the error for GPM satellite is 6.60. GPM captures the frequency of rain events for low-intensity while TRMM overestimates the frequency of the low intense rain events. The accuracy of detection of rainfall by TRMM is about 62%. The accuracy of detection of rainfall by GPM is about 70%. For the entire region it is observed that GPM satellite has negative bias (i.e., underestimates) whereas the TRMM satellite has positive bias (i.e., over estimates). And the value of bias for GPM satellite is less than that of the TRMM satellite.

The inter comparison of two satellite precipitation product were also done. This shows that the GPM has slightly better result than the TRMM product. The estimation bias for TRMM is almost double of the GPM but in positive side (-0.56 and 0.99 respectively) which indicates the under estimation by GPM product and over estimation by TRMM product. Rainfall values from the rain gauge stations are uniformly distributed. The reliability of daily satellite precipitation products is dependent on the topography of the basin. Both the satellites were able to differentiate days with precipitation and days without precipitation but the GPM satellite is found more accurate. TRMM daily average precipitation overestimates the rain amount for low rain intensities over the entire area. The error strongly depends on the change in elevation. Both TRMM and GPM satellites overestimates for higher elevation value.

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