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Tropical Rainfall Measuring Mission Performance in the Measurement of Precipitation for the Muriaé Sub-basin

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Abstract: Correct precipitation data are essential for a hydrological study. However, the pluviometric stations provide us quite doubtful data. More satellites have explored this area. Therefore, the spatial estimates of precipitation can be extremely useful, since they present data of the whole surface, since the pluviometers do not exist in areas of difficult access. The objective of this work is to analyze the precipitation data obtained by the rain gauges and the Tropical Rainfall Measuring Mission (TRMM) satellite for the Muriaé sub-basin, which belongs to the Paraíba do Sul Basin. It was used Thissen method and free software R for the manipulation of the data and its comparison. The results were satisfactory, showing that the estimates of this satellite can be an alternative source of data.

Key words: Precipitation, TRMM, satellite.

1. Introduction

Proper information on rainfall and its variability in space and time is required for efficient watershed planning and management [1]. Precise observation of rainfall is a challenging task owing to its wide variability in space-time scales, especially in countries like Brazil having diverse geographic features and developing economic status.

The principal indicator of climate variability is the rainfall; also, it is an important environmental parameter that regulates the water availability. It is traditionally measured by ground-based meteorological stations, however, sometimes such measurements are difficult to be obtained over oceanic, remote, or high-altitude areas where only sparse or no rain gauge stations are available [2].

Remote satellite sensing applied to Water Resources has gained visibility. Mostly these rainfall estimation satellite techniques have emerged as a potential alternative to ground-based rainfall measurements. Among its attributions, it is possible to carry out flood and drought monitoring. One of these satellites is the Tropical Rainfall Measuring Mission (TRMM), which studies clouds, precipitation, heat flux, lightning and other aspects of the water cycle contributing to climate research at various locations around the world. It presents almost real-time images and they change every three hours and their resolution is 25 km [3].

The main advantage of satellite-based rainfall estimation over rain gauge-based estimation is that they provide homogenous rainfall information in space and time over a region. Also, the data can be collected for inaccessible areas, consequently reducing the time and cost of observation [4].

TRMM satellite derived rainfall data have been used for various applications in the field of climatology, atmospheric, environmental, and agricultural sciences, and watershed management [5-7]. It has been used for applications such as rainfall-runoff modelling [8], daily hydrological modelling [9, 10], to assess the diurnal variability of

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rainfall over a region [11], for water balance computations in a catchment [12], for soil moisture estimation [13], to determine the vegetation characteristics [14], to determine the climatic characteristics of rainfall [15], to understand the hydrology of a region [16], for hydro-meteorological applications [17], and for validation of satellite data to gauge data [18-20].

However, some authors report that TRMM can underestimate the total monthly or yearly precipitation since the satellite radar does not detect very low rainfall rates (< 0.7 mm·h^{-1}) [21] and low to moderate levels of snowfall rate. Also, the same happens in high elevation and mountainous terrains [22].

Because it is relatively new and, in ascendancy, few studies have been published analyzing its performance, especially in Brazil. According to Araújo and Guetter [23], who compared estimates of low orbit satellites with soil measurements in small and medium basins in Paraná, concluded that there is good adherence of the estimates. Similarly, Ref. [24] showed that the TRMM precipitation estimate is very accurate for the upper São Francisco basin. According to Ref. [25], Satellite Precipitation Estimates (SREs) are more reliable in flat surface areas with convective precipitation, such as in tropical oceans and South America.

In worldwide, Ref. [26] found a satisfactory performance of the monthly and daily TRMM rainfall product over Greece. Also, Ref. [27] demonstrated that the TRMM 3B43 precipitation product provides a new data source that can be used for reliable drought monitoring in the middle and lower reaches of the Yangtze River Basin. Although, in southwest coast and Himalayan region of India, northeast parts of USA, Lake Victoria in Africa, La Plata basin in South American the TRMM estimates are found to be inconsistent [28].

Shukla et al. [28] studied the applicability of TRMM estimates over the Upper Ganga Basin (Himalayan catchment) by comparing against the gauge-based India Meteorological Department (IMD) gridded precipitation records. It was found that TRMM precipitation is fairly correlated with IMD rainfall, so it can be used in various climate analyses and hydrological water balance-based studies in this region.

The study in Ref. [2] presents the evaluation of the performance of the monthly TRMM rainfall product (3B43-v7) in capturing the rainfall patterns, on the geographic area of the central Mediterranean during 1998-2017. It was shown a satisfactory accuracy of the examined satellite products in capturing seasonal and annual rainfall patterns, having rather high correlation coefficients.

This work aims to analyze the performance of the data obtained by Tropical Rainfall Measuring Mission comparing them with the average rainfall data of the rainy season (Soil Measurements) calculated for the study basin by the Thissen method, using data from the National Agency of Water (ANA). For this purpose, free software R routines were developed. The study area is the basin bounded by the Itaperuna river post (58940000) belonging to the Muriaé River, a tributary of Paraíba do Sul, in southeast Brazil.

2. Method and Materials

The object of study is the basin defined by the Itaperuna fluviometric post, as presented in Fig. 1, which has 5,725.25 km^2 and bathes the states of Minas Gerais and Rio de Janeiro. The Muriaé River rises in the Serra do Brigadeiro, where it has an altitude of 900 m; however in the cities where the posts are located the altitudes are lower.

Within this area we have six rainfall stations, namely Bicuiba (2042014), Carangola (2042000), Porciúncula (2042027), Fazenda Umbaúbas (2142004), Patrocínio do Muriaé (2142002) and Itaperuna (2141004). The dataset is developed using the stations' observed daily rainfall data provided by the ANA (National Water Agency) website. The historical rainfall series obtained from the rainfall stations for the period 2000 to 2016 were used. This

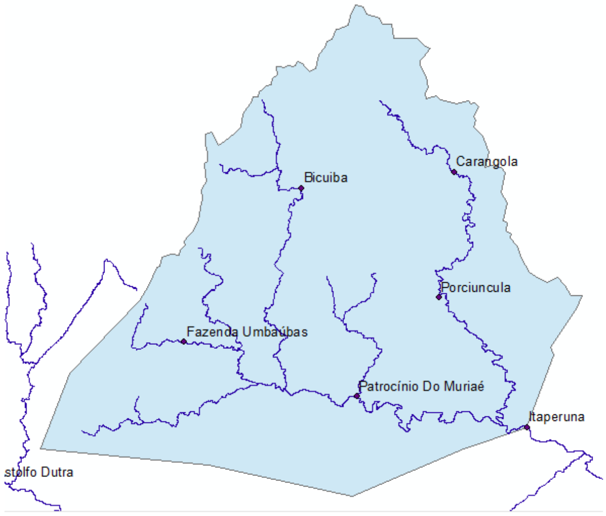

Fig. 1 Study area and rainfall stations.

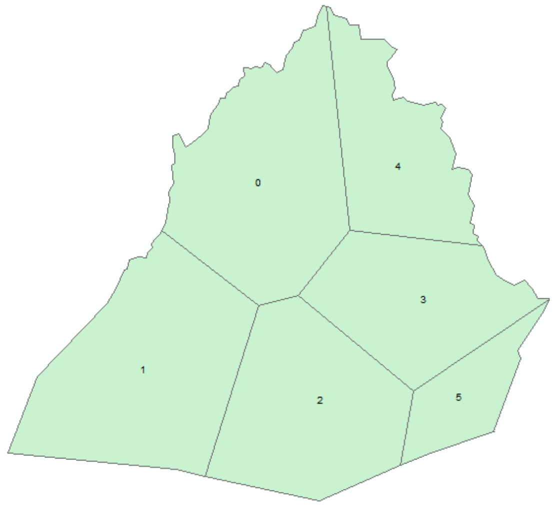

Fig. 2 Areas generated by the Thissen method.

duration was chosen due to the limited information of the TRMM satellite.

The monthly average rainfall in the basin was determined by the Thissen method. In this way, we obtain a subdivision of the basin according to the area of influence of each rainfall station (Fig. 2).

After obtaining the average monthly precipitation, it was possible to calculate the annual accumulated precipitation. This will be used in the comparison.

The TRMM 3B42RT (daily) data were downloaded through the satellite's digital platform. They were obtained in NetCDF format at daily time steps. It was necessary to decode its information using a routine created in the free software R. Then it was possible to generate maps and spreadsheets with monthly and annual averages.

Within the basin area, sixteen points were found in a 4 × 4 mesh, 25 km resolution, where each one was considered a rainfall station. Thus, an arithmetic average was made to obtain the basin's daily average precipitation, consequently also the basin monthly average and the basin annual accumulated. Fig. 3 shows two plots of daily rainfall along with the considered TRMM mesh in the study area, which is between latitude -20 to -21 and longitude -42 to -41. A map was generated for each day.

As can be seen in the plots, the TRMM rainfall is not homogeneous over the entire study area. In the second plot, there is a small portion with 40 mm accumulated rainfall but most of the area presents 0 mm accumulated rainfall. It is an unsurprising fact since Brazilian Southeast is characterized by the distribution of highly irregular rainfall in space and time, marked by great inter and intra-annual variability [29]. The rainy season starts in October and ends in March. Fig. 3 plot dates are 02/05/2000 (upper) rainy season and 06/03/2000 (lower) dry season. Most of the TRRM measurements that are not in the rainy season are shown all red, which means 0 accumulated rainfall.

3. Results and Discussions

From the data manipulation of the rainfall stations (ANA) and TRMM it was possible to observe, according to Fig. 4 and Table 1, that the values are similar. However, in five years (2000, 2010, 2012, 2013 and 2016), there was a significant disparity, reaching a 37% percentage difference in the year 2016. In these five events, the TRMM has continuously underestimated the rainfall volume. Also, ANA's accumulated rainfall was higher than that presented by TRMM in 70.6% of the time.

The correlation between the values is equal to 0.70 which means a good similarity between the two curves.

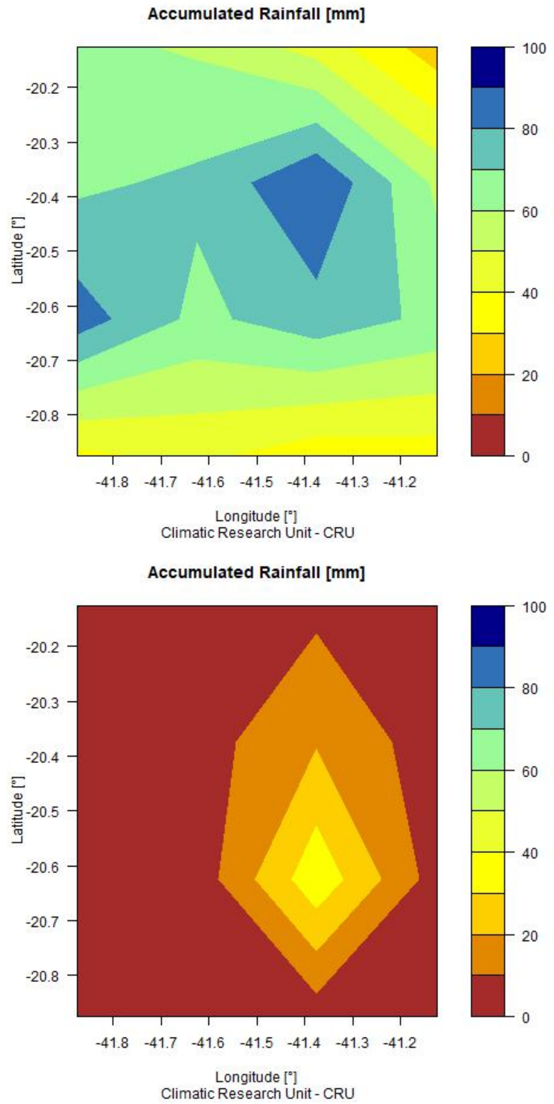

Fig. 3 Sub-basin map showing accumulated rainfall.

These differences may be due to systematic errors which are susceptible to the pluviometers. We can consider data losses due to equipment wetting, evaporation and aerodynamic effects [30]. In addition, the measurement is executed manually which makes it susceptible to human failure. Another problem is the scarcity and reliability of the data, being some or even several days without measurement, which can change actual values and thus possible studies.

Table 1 Basin average annual accumulated precipitation (mm) from the rainfall soil stations (ANA) and TRMM data.

Date	Annual acummulated rainfall (mm)		
	TRMM	ANA (THISSEN)	Percentage of variation
2000	1100,99	1484,90	26%
2001	1389,68	1498,22	7%
2002	1546,39	1652,54	6%
2003	1484,13	1450,78	-2%
2004	1794,19	1823,16	2%
2005	1650,50	1541,03	-7%
2006	1420,97	1546,23	8%
2007	1463,61	1403,22	-4%
2008	1860,72	1962,15	5%
2009	1720,42	1793,61	4%
2010	1442,78	1688,05	15%
2011	1456,52	1547,25	6%
2012	1184,53	1475,33	20%
2013	1669,51	1324,91	-26%
2014	898,44	961,01	7%
2015	1156,39	1065,18	-9%
2016	1536,99	1121,02	-37%

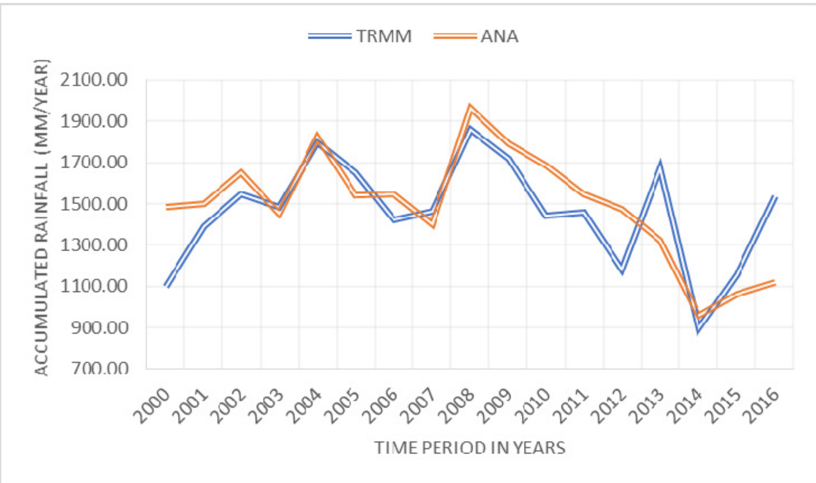

Fig. 4 Comparative graph of basin average annual accumulated precipitation (mm) from the rainfall soil stations (ANA) and TRMM data.

The spatial distribution of pluviometers is also a significant factor. In South America, this distribution is denser along with major river courses and the mainland [31], which may lead to possible distortions [32].

Additionally, it must be considered that the satellite can present errors due to the overlap of clouds because it considers the cloud's reflectance and this fact can result in some imprecision [1].

4. Conclusions

With the ability to remotely estimate rainfall events, the satellite-based rainfall measurement missions have emerged as a potential source for various hydro-climatic studies across the world, such as rainfall-runoff modeling, temporal and spatial variability analysis of rainfall, water balance components estimation. These are advantageous for inaccessible regions and a sparse network of in-situ measurement stations.

However, before applying these techniques it is necessary to validate and make proper corrections whenever necessary since TRMM rainfall estimates are found to be inconsistent at some locations, especially those with high elevation.

In the present study, it was possible to verify that the data of Tropical Rainfall Measuring Mission are satisfactory when used in the Paraíba do Sul basin, because they can reproduce with certain fidelity the rainfall regime registered by the rainfall stations of the Muriaé region. Only five years, which are 2000, 2010, 2012, 2013 and 2016, presented a huge disparity between the values. It was found that most of the time the TRMM average annual rainfall was underestimated.

However, it should be emphasized that some errors should be verified and considered, such as poor measurement of the soil rainfall station and satellite reflectance errors. Also, the region presents a stable altitude.

It is noteworthy that the numbers of failures in satellite time series are much lower than those found in rainfall stations. They occur in days or even a month, while in some soil rainfall stations, they can reach years.

Thus, the results of this work show that rainfall data obtained through TRMM may be an efficient alternative for future hydrological studies in regions with scarce rainfall data.

Future studies should analyze the performance of TRMM in spatial distribution over a region. So, it will be possible to check which rainfall station presents an error and be able to correct it.

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