engenharia agrícola
Journal of the Brazilian Association of Agricultural Engineering

Engenharia Agrícola

ISSN: 1809-4430 (on-line)
www.engenhariaagricola.org.br

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v38n3p376-386/2018

CLIMATOLOGICAL WATER BALANCE WITH DATA ESTIMATED BY TROPICAL RAINFALL MEASURING MISSION FOR THE DOCE RIVER BASIN

Franciane L. R. de O. Louzada[1*], Alexandre C. Xavier[2], José E. M. Pezzopane[2]

[1*]Corresponding author. Federal University of Espírito Santo/ Alegre - ES, Brazil. E-mail: francianelouzada@yahoo.com.br

KEYWORDS

orbital data, rainfall, water deficit, water availability.

ABSTRACT

The Climatic Water Balance (CLIMWB) is very used in the climatic characterization and can also offer important contribution in the identification of the water demand for irrigation of a region. For this, reliable precipitation data with good spatial coverage is required. The Tropical Rainfall Measuring Mission satellite -TRMM-3B43-v7 is a partnership between NASA (National Aeronautics and Space Administration) and Japan's Aerospace Exploration Agency (JAXA), which estimates rainfall data for the tropics region. The aim of this study is to evaluate the CLIMWB obtained by the Thornthwaite & Mather method (1955), with estimated rainfall data with the 3B43 product versus those generated with rainfall data and to map pixel-by-pixel water availability with good spatial coverage for the Doce River basin, located in the Atlantic Hydrographic Region, Southeastern Brazil, between the states of Minas Gerais and Espírito Santo. The CLIMWB variables generated with 3B43, together with the precipitation, showed a good correlation with those fed with surface rainfall data. The largest differences between the two datasets were found in some stations in the southeast and northeast of the basin. The CLIMWB variables presented a good correlation, with the best water excess (0.94), followed by water deficit (0.88), water availability (0.84) and real evapotranspiration (0.82). With TRMM - 3B43, we can characterize the CLIMWB in a similar way to that obtained with data observed by the gauges, providing much more extensive coverage. The use of the TRMM - 3B43 precipitation data allows a consistent characterization of the regional water availability, contributing to the agricultural planning and management, mainly to fill the gaps left due to the absence of rain gauges and to possible failures in the rain gauges' data series.

INTRODUCTION

The water basin area of the Doce River (WBDR) is of great importance for the agricultural sector covering an area of 86.711 km² (82% - MG and 18% - ES) and contributes to the generation of expressive borders generated by coffee exports in the states of Minas Gerais and Espírito Santo, and fruit pulp in the state of Espírito Santo, as well as by forestry and livestock.

In the WBDR, especially in the areas of the state of Espírito Santo, there is a great demand for freshwater, and a large number of allocations are registered for the irrigation of monocultures with capture in the Doce river, mainly in the municipalities of Linhares and Colatina (ANA, 2016).

The knowledge of rainfall is of great relevance for the management of the water resources of a river basin. The rain gauges are distributed on the terrestrial surface and collect information only for a small area located in its surroundings. The WBDR stations are poorly distributed and with low density.

Several studies have been studying other forms of rainfall monitoring, such as the Tropical Rainfall Measuring Mission - TRMM. This satellite is a partnership between the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency, to monitor and to study the rainfall in the tropics (Kummerow et al., 2000).

The TRMM is composed of five instruments: microwave imaging; precipitation radar; non-visible and infrared sensors; sensor for the imaging of lightning and; radiant and cloud energy sensor (NASA, 2014).

[2] Federal University of Espírito Santo/ Alegre - ES, Brazil.
Received in: 8-19-2016
Accepted in: 10-7-2017

The version seven (v7) is the last of the TRMM products and according to Xue et al. (2013), there was an improvement in precipitation estimation when compared to the v6. The 3B43-v7 product is the result of the combination of two products, the 3-hour estimate of the 3B42-v7 algorithm and the precipitation observed by rain gauges from the Global Precipitation Climatology Center project and the Climate Assessment and Monitoring System on a monthly basis.

Studies have been developed with TRMM precipitation data, applying them in several areas, such as drought monitoring (Du et al., 2013; Zhang & Jia, 2013; Li et al., 2013; Leivas et al., 2014, Santos et al., 2017), productivity (Silva-Fuzzo et al., 2015), weather forecast (Ferreira et al., 2012), hydrological models (Xue et al., 2013; Li et al., 2012; Tuo et al., 2016; Wang, et al., 2016), rain estimation (Soares et al., 2016), evapotranspiration (Mateos et al., 2013), incidence of fire (Alves & Perez-Cabello, 2017) and characterization of groundwater.

Validation studies with the TRMM 3B43 have been carried out in recent decades, such as those of As-Syakur et al. (2013) in Indonesia, which compared data obtained with the TRMM with five rain gauges. Feidas (2010), in Greece, compared six satellite products at three different space resolutions and Dinku et al. (2007), in Ethiopia, evaluated ten products from different satellites, the 3B43 being the one that presented the best performance.

However, there is a lack of studies using rainfall data estimated by this satellite as input to the Climatological Water Balance (CLIMWB), mainly with the Thornthwaite & Mather method, such as the studies of Mahmud (2014) and Quirino et al. (2015). Mahmud (2014) used the rainfall data from the TRMM satellite and evapotranspiration estimated by the Satellite-based Daily Evapotranspiration to calculate water availability in the Malaysian Peninsula. Quirino et al. (2015) analyzed the response of the CLIMWB proposed by Thornthwainte & Math (1955) with data from the TRMM in regions of the state of Goiás.

The CLIMWB consists of the quantification of the inputs and outputs of water of a given soil volume, and it allows the estimations of the actual evapotranspiration of the area represented by the accounting and has been used as a priority in the regional climatic characterization. This can help in several areas of agriculture such as characterization of dry periods, irrigation, agroclimatic zoning and climatic characterization. The main inputs and outputs for CLIMWB are precipitation and evapotranspiration, respectively.

The aim of this study is to compare the climatic water balance obtained by the method of Thornthwaite & Mather (1955), with precipitation data estimated by the 3B43 product versus rainfall data, and to generate the pixel-by-pixel water availability mapping with good spatial coverage for the water basin of the Doce river.

MATERIAL AND METHODS

The water basin of the Doce River (WBDR) is located in the states of Minas Gerais and Espírito Santo. The boundary of the basin adopted for this study follows the Integrated Water Resources Plan of the Doce River Basin (Souza et al., 2010), which encompasses the Barra Seca river basin, for management purposes (Figure 1).

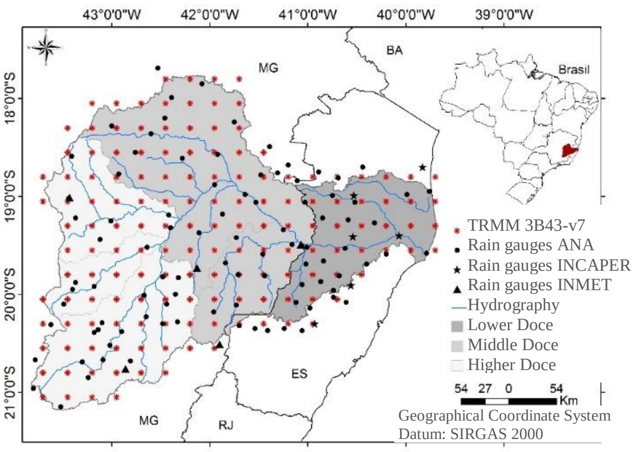

FIGURE 1. Location of the water basin of the Doce River; Rain gauges represented in blue color and the center point of the pixels of the 3B43 - v7 product in red.

The region is influenced by the oceans, causing higher air temperatures (Ta) in Baixo Guandu, Espírito Santo, Aimorés, Governador Valadares and Vale do Aço (Timóteo, Coronel Fabriciano and Ipatinga) in Minas Gerais. It presents spatial and seasonal variability of Ta (Cupolillo et al., 2008). The largest area of WBDR presents annual Ta between 20 and 26°C. The warmest period is found in the months from December to March, being recorded the highest Ta in the lower Doce river, region of the state of ES. In the west part, most of the upper Doce River, even in the summer, the average Ta does not surpass 26°C, being, therefore, the region with the milder Ta, corroborating with the study of Cupolillo et al. (2008). In the regions bordering the basin, especially in the mountainous areas, Serra do Caparaó to the southeast, Serra da Mantiqueira to the southwest and Serra do Espinhaço to the west, the Ta arrives at 5°C in the coldest month of the year, July (May to August).

The climatic water balance (CLIMWB) uses easily obtained parameters, such as local air Temperature (Ta), Precipitation (P) and local Latitude (Lat). The Ta was estimated by multiple linear regression equations; the monthly and annual P data were estimated by the TRMM satellite from the 3B43-v7 product with regular grid-point in the ASCII format on the NASA site (NASA, 2013); the observed P data (OBS) came from the rain gauges of the National Water Agency - ANA, of the National Institute of Meteorology - INMET and the Capixaba Institute for Research, Technical Assistance and Rural Extension (INCAPER). An overview of the processes carried out can be obtained by the flowchart in Figure 2.

The observed monthly data of P of 80 rain gauges, located in the basin and 25 bordering ones, totaling 105, were used for preliminary analysis, as directed by Bertoni & Tucci (2004).

The fault-filling was carried out using the regional weighting method and the consistency analysis by the Double Mass method developed by the Geological Survey (USA) (Bertoni & Tucci, 2004). For the regional weighting method, a series of 30 years (1983 to 2012) was used as recommended by the World Meteorological Organization (Pereira et al., 2002).

The monthly P data estimated by the TRMM satellite come from the 3B43 product and other sources of monthly precipitation products, version 7 (3B43-v7). The 3B43-v7 combines two products, the estimation every 3 hours of the 3B42-v7 algorithm and the precipitation observed by rain gauges from the Global Precipitation Climatology Center (GPCC) project and the Climate Assessment and Monitoring System on a monthly basis.

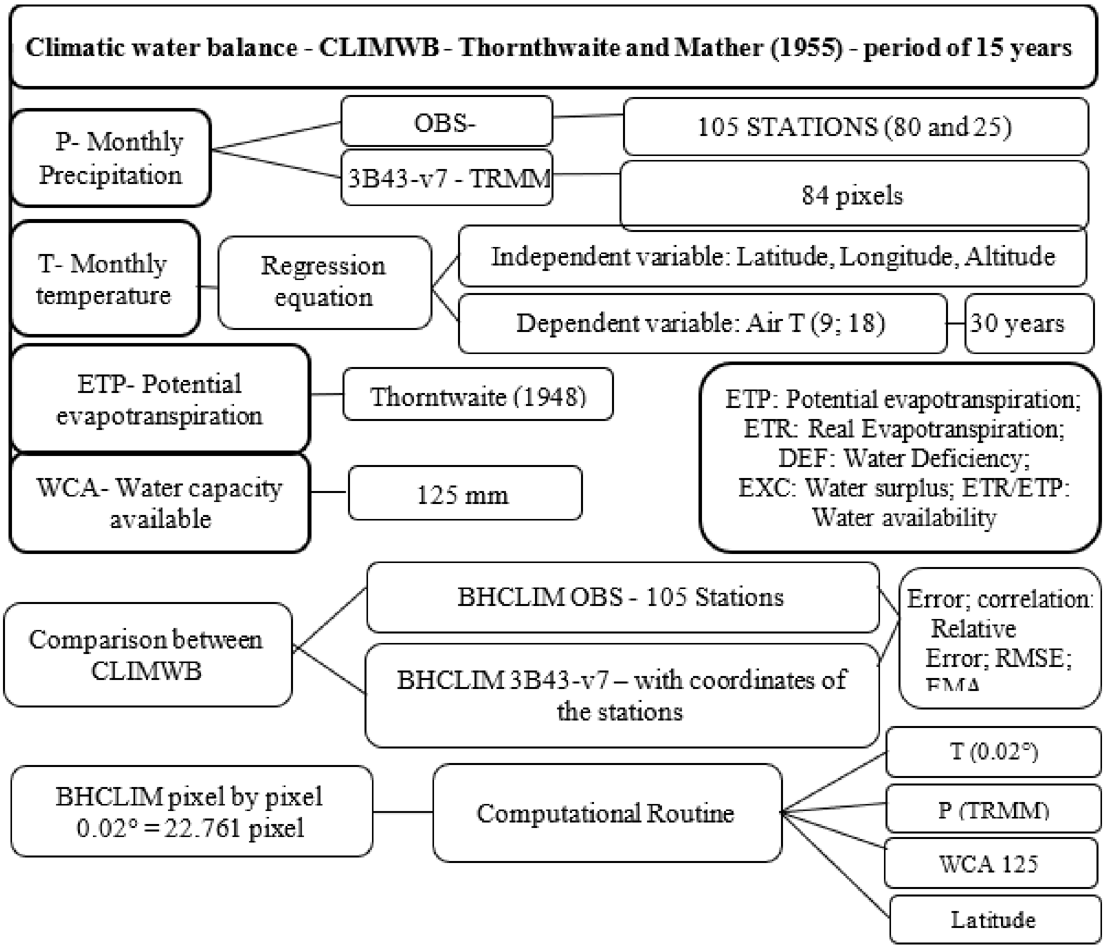

FIGURE 2. Flowchart overview of the procedures developed at study. (Error: difference originated by the nature of the P values of a rain gauge with those of the TRMM; r: correlation; RMSE: root mean square error; AAE: Absolute average error).

The data are available free of charge from NASA's TRMM website at 0.25° x 0.25° resolution. The data were acquired covering the entire WBDR boundary, totaling 150 pixels central points (Figure 1). Of these, only the pixels in which there were rain gauges in their area of coverage were used, totaling 84 pixels.

The determination of the CLIMWB for WBDR was carried out according to methodology proposed by Thornthwaite & Mather (1955). One with input data from P gauges (OBS) and one with P from 3B43-v7. The average of the historical series of the monthly P was 15 years (1998 to 2012), due to the availability of the 3B43-v7 P data be from 1998.The Thornthwaite & Mather method was developed to determine the water regime of a given site, without requiring direct measures of soil conditions.

The CLIMWB was carried out using the "BHnorm" program, elaborated in EXCEL worksheet by Rolim et al. (1998). The available soil water capacity (AWC) was 125 mm, as indicated for perennial crops by Pereira et al. (2002), since this region is a major producer of coffee, fruit growing and forestry.

The CLIMWB started with the estimation of potential evapotranspiration (ETP) by the Thornthwaite method (1948) due to its simplicity of determination of potential evapotranspiration and is widely used, as in studies by Silva et al. (2013). This method was chosen because it requires only the air temperature (Ta) as input data and also because it presents small estimation deviations, as compared to the Penman-Monteith standard method, as observed by Sentelhas et al. (2008).

The air temperature (Ta) was estimated by applying multiple linear regression equations with independent variables the altitude (Alt), the latitude (Lat) and the longitude (Long) of the gauges. Nine stations were used within the WBDR and 18, around the border of the same, being 12 in MG, 1 in RJ and 14 in ES with a historical series of 30 years (1983-2012). Castro et al. (2010)

verified a good coefficient of determination for Ta, from 0.94 to 0.97.

The adjusted coefficient of determination (R^2) and the significance of the regression coefficients were obtained by Student's t-test at 5% of probability.

After the CLIMWB was carried out for the 105 rain gauges (OBS) of the WBDR with P data of the gauges, the CLIMWB with P data of the 3B43-v7 were processed for the same locations of the gauges, for later comparison. The P value for the central point of the pixel corresponds to the rainfall of an area of approximately 27 X 27 km^2. Therefore, the analysis was carried out with the data of the gauge that is in the area of comprehension of the pixel and the value of the center point of the same one.

The comparison between the CLIMWB was carried out using the calculation of Error (Bias), in which the variables generated by CLIMWB were subtracted from the variables generated by the CLIMWB with the 3B43-v7 (3B43-v7 - OBS). The relative error was calculated to verify the percentage of how much the values underestimated or overestimated in relation to the observed, in which the Relative Error was calculated by the expression (ER) = 100x (OBS-TRMM)/OBS. We also used: Correlation of Person (r) and root mean square error (RMSE), as used by Quirino et al. (2015) and also the average absolute error (AAE).

In order to map the WBDR water availability with good spatial coverage and potential for application in agrometeorology, a pixel-by-pixel CLIMWB was carried out, with rainfall data estimated by 3B43-v7 and Ta estimated by the linear regression equations.

The pixel-by-pixel CLIMWB was carried out through a computational routine based on the methodology of Thornthwaite & Mather (1955). Lat., Long. and Alt. were used of the WBDR and the WCA of 125 mm. For the Alt. data, a digital elevation model (DEM), obtained by the SRTM (Shuttle Radar Topography Mission) radar data made available by the Brazilian Agricultural Research Corporation - Embrapa (Miranda, 2005). The 15 scenes used were mosaic and submitted to a refinement process. The generated DEM provided the geographic coordinates and the Alts. necessary to estimate the Ta. The spatial resolution of output was 0.02 °, equivalent to a spatial resolution of approximately 2.2 km.

RESULTS AND DISCUSSION

The results of the statistical analyzes between the CLIMWB and the data estimated by the TRMM satellite product 3B43-v7 versus observed data (OBS) of the rainfall gauges for WBDR are shown in Figure 3 and Table 1 (variables: P, ETR, DEF, EXC and ETR/ETP), along with the maximum and minimum values of each variable. The positive signals in error (E) and relative error (ER) indicate that satellite overestimated and the negative underestimated. 105 comparisons were made.

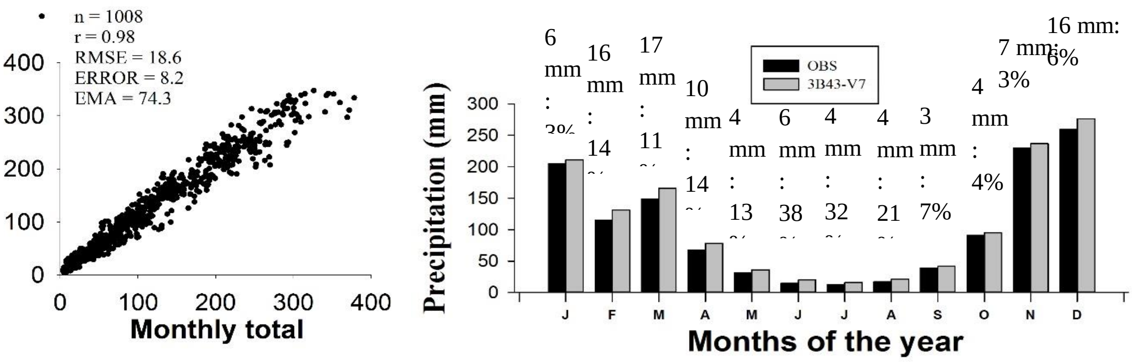

FIGURE 3. Comparison between TRMM precipitation data (3B43) and rain gauges (OBS) for the water basin area of the Doce river, between 1998 and 2012. a. Scatter chart. B. P index and their respective error values (TRMM-OBS) and Relative Error (100x (OBS-TRMM)/OBS).

The TRMM rainfall data presented good performance with r of 0.98, RMSE 18.6, ERROR 8.2 and EMA 74.3, with a tendency to overestimate P in this basin (Figure 3.a and b). However, the opposite was found by As-Syakur et al. (2011) in Bali - Indonesia for the period of 1998-2002. Li et al. (2012) in their study, observed, in the 6 years analyzed, that the TRMM underestimated in the first three years and overestimated in the other three. This demonstrates that the TRMM does not have a standard, presenting different results in each basin. This confirms the importance of validating this data in each region.

TABLE 1. Statistical analysis of annual comparisons between CLIMWB variables generated with rainfall data estimated by the TRMM and rain gauge for the basin of the Doce River.

	r	RMSE (mm)	E (Bias) (mm)	EMA (mm)	ER (%)		TRMM (mm)		OBS (mm)	
					Avg.	Max. Min.	Avg.	Max. Min.	Avg.	Max. Min.
P	0,92	18	8	75	8		110	348-5	102	378-3
ETR	0,82	88	54	102	6	41 a -6,2	1046	1297 a 764	993	1327 a 754
DEF	0,88	87	-54	90	-22	74 a -99,9	174	433 a 0	228	573 a 23
EXC	0,94	92	54	195			288	813 a 0	238	1073 a 0
ETR/ETP	0,84	0,06	0,04	0,06	6	41 a -6,2	0,9	1 a 0,7	0,8	1 a 0,6

ETR = real evapotranspiration; DEF = water deficiency; EXC = water excess; ETR/ETP = water availability; r = coefficient of correlation; RMSE: Root of the mean square error. E (Bias) = average error; EMA = absolute mean error; ER = relative error; TRMM = with rainfall estimated by Tropical Rainfall Measuring Mission satellite; OBS = with the rain. observed by the rain gauges.

The TRMM data responds to seasonal climatic conditions in the region where the rainfall in the dry season is low and in the rainy season, is high (Figure 3), following the variations of the gauges, as can be observed in Figure 3.b. A seasonal pattern was also observed by As-Syakur et al. (2013) in the archipelago of Indonesia and Silva-Fuzzo & Rocha (2016) in the state of Paraná.

The correlation values were above 0.82. Values of r near this value were found by Quirino et al. (2015) for three cities of Goiás (Aragarças, Catalão and Formosa) for monthly values of 2013. The authors also evaluated ten-days values with another TRMM product, the Real Time - RT daily. According to the authors, this last product presented excellent performance, but less than the monthly, and proved to be useful for monitoring the water balance in near real time.

The analyzes for the ETR, DEF, EXC variables were: the RMSE with 88 and 92 mm; Error of 54 mm, overestimating the variables, less for the DEF, where the 3B43-v7 underestimated. This was due to the P influence, which in this basin tends to overestimate, as can be observed in previous data analysis; the EMA was from 90 to 195 mm, showing higher value in the EXC. Quirino et al. (2015) observed this pattern in their study in GO, in which two-thirds of the comparisons overestimated. The relative error shows that the satellite overestimated on average 6% for the ETR and ETR/ETP, but the DEF was underestimated, 22%.

The EMA for ETR/ETP is 0.06 mm, a similar value was found by Castro et al. (2010), when they evaluated different interpolators for this variable in the state of Espírito Santo. It is a low value, the station with the highest absolute error is 0.25 and the lowest is 0.01. These low values are justified because the ETR/ETP values vary between 0 and 1. The closer to 1 the lower will be the climatic risk of non-water supply.

The 3B43-v7 product underestimated the ETR in 15% of the comparisons. Among the 85% that overestimated, 14% are in the class of 10 and 20% and 4% in the class of 20 and 40%. Therefore, 84% presented an error within ± 10% of the OBS value.

The regions that obtained the highest errors in the annual RTE, above 10%, were the Baixo Guandu (ER = 40%) and Aimorés (ER = 35%) regions followed by Colatina, Santa Tereza, Conselheiro Pena, Laranja da Terra, Itaguaçu, Tarumirim and Tumiritinga. In this region, the satellite overestimated the P. Since the value of P minus the ETP was less than zero (P-ETP <0), the ETR was estimated by summing P plus Altitude (ALT), causing this difference.

It is important to note that the negative values for P-ETP represent a potential loss of water in the analyzed months, indicating, in these cases, dry months and soil with restricted water storage, while the positive ones indicate excessive rainfall (Pereira et al., 2002).

According to Cecílio et al. (2012), there is a tendency to occur the highest values of ETR in the vicinity of the coast, with a consequent reduction towards the west of the state, which indicates marked influence of the longitude, the ocean and, mainly, the relief. The errors of ETR and DEF, EXC and ETR/ETP were higher in the region near the coast, in Lower Doce (ES) and part of theg Doce (MG).

The DEF and EXC are very important variables, since the deficit can cause problems for agriculture and the EXC can increase the recharge in the aquifers and also generate problems in agriculture. According to the comparisons, the satellite data underestimated the DEF in 85% of the comparisons. As the 3B43-v7 overestimated the P, it underestimated the DEF and overestimated the EXC. The highest percentage of DEF error is in the -29 to 0% class and only 33% have errors above the 30% class. These classes are in the coastal region, in Jaguaré and Linhares, and also in Afonso Cláudio, Baixo Guandu and Laranja da Terra.

Due to the importance of the ETR/ETP relation, in which the climatic risk of non-water supply of a region can be known, it was decided to space the monthly and annual relative errors (Figures 4a and 4b, respectively) to verify where and when they occurred the biggest mistakes.

In the rainy months, there were minor relative errors, between November and March, between -10% and + 10%, practically throughout the basin. However, from January onwards, the presence of errors between 10 and 50% was observed. It was evident that in November and December the satellite data underestimated (up to 10%) across the basin and in January overestimated (up to 10%). In the months of February and March, it underestimated (up to 10%) in the region of Higher Doce and overestimated (up to 10%) in the Middle and Lower Doce.

In the dry months, the largest relative errors occurred in most of the basin, as can be observed in Figure 4a, with the highest percentage in July, when the satellite data overestimated over 100%. The region where the greatest errors occurred was between the Middle Doce and the Lower Doce. In this region, there were also larger errors in relation to P of 3B43-v7 and OBS, showing the influence of the overestimation of the P satellite data that may be related to the entry of cold air masses, affecting the region and influencing the estimation of precipitation due to rain shadow.

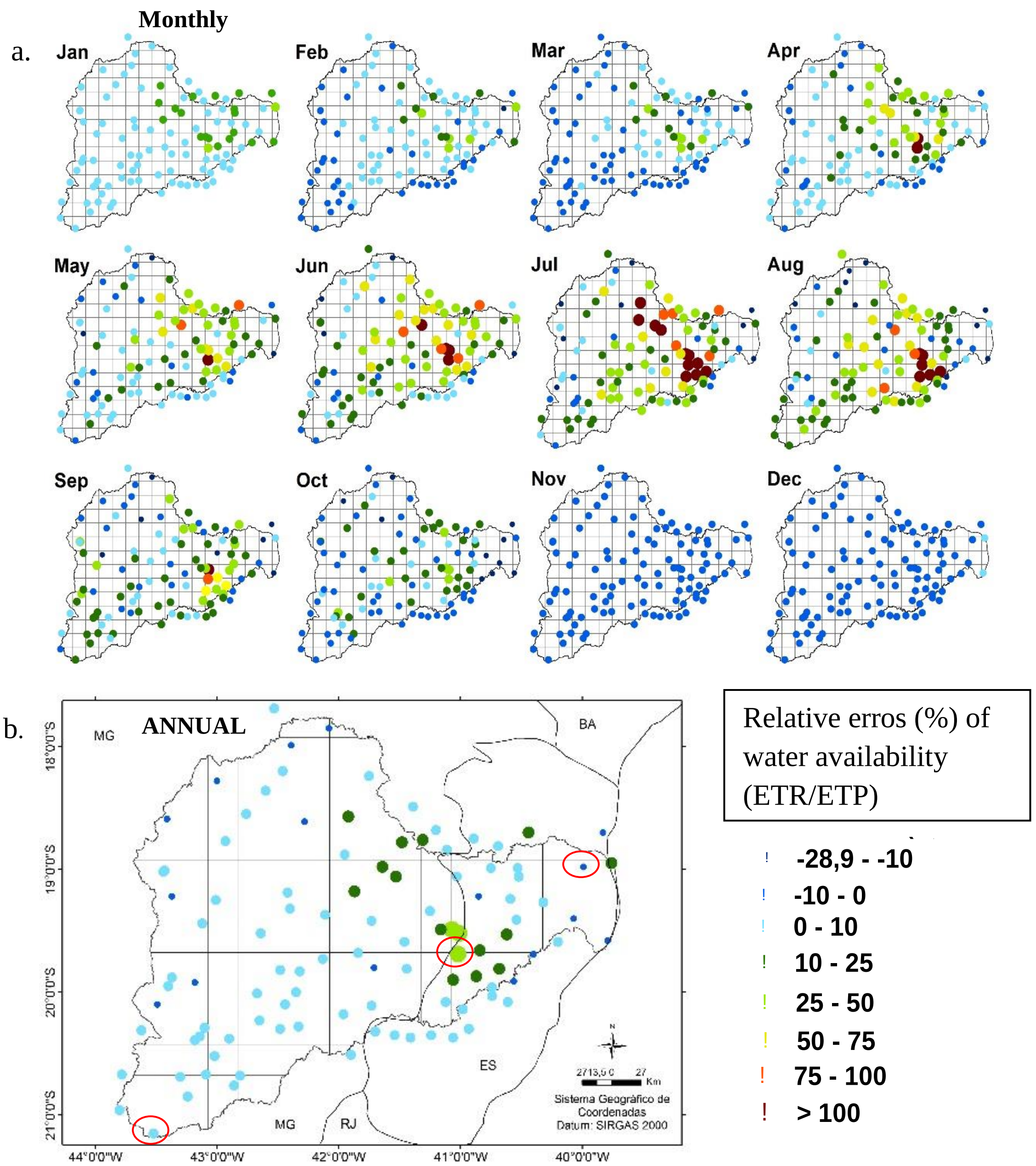

FIGURE 4. Spatial distribution of relative errors (RE) of water availability (ETR/ ETP) performed with the two sources of rainfall data, satellite (3B43-v7) and rain gauge (OBS). A. Monthly ER; B. ER annual. Red circles: Baixo Guandu, Jaguaré and Desterro de Melo.

Figure 5 shows graphical examples of the comparison of estimated CLIMWB for the WBDR, showing the difference between the two data sources.

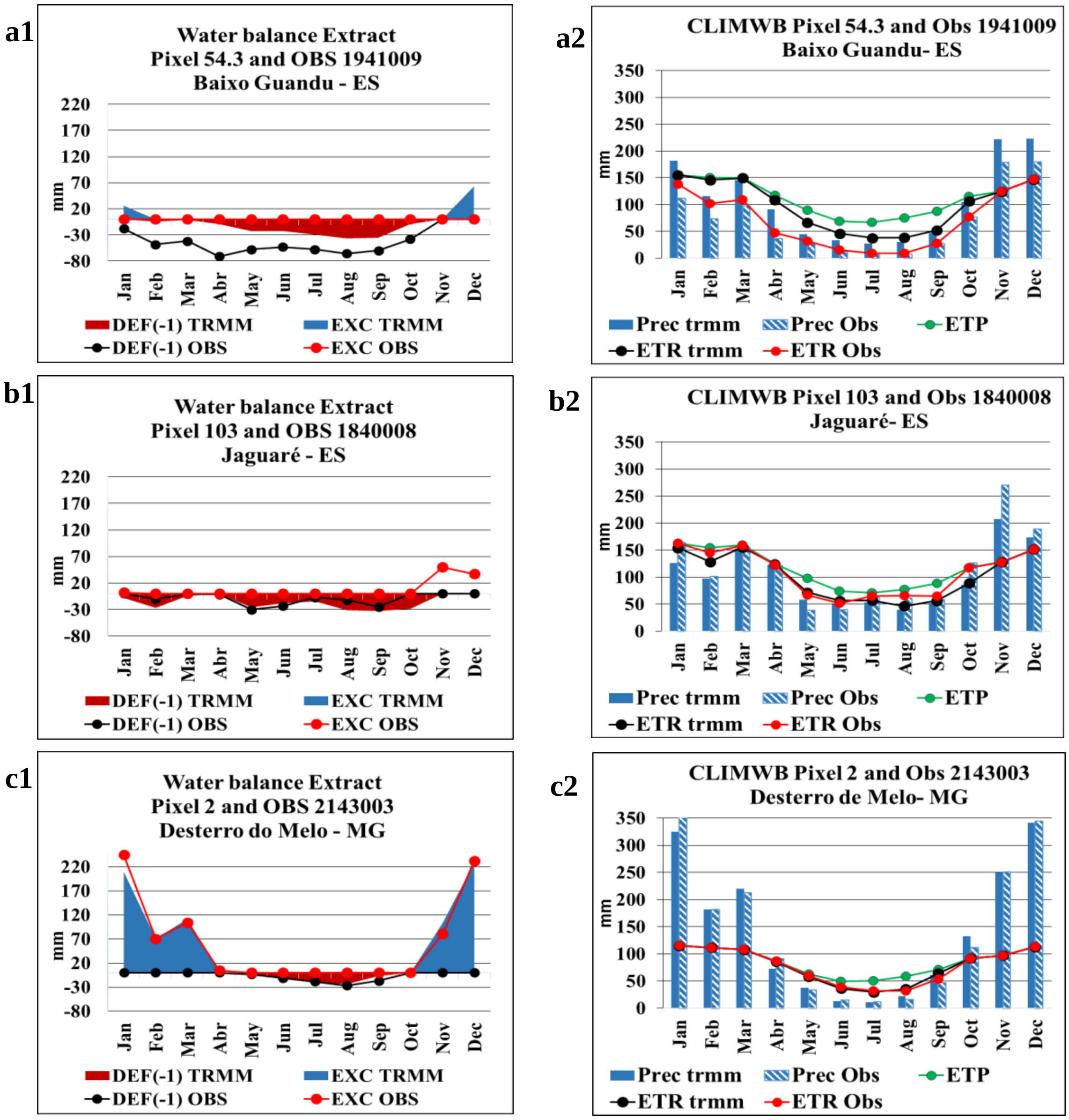

FIGURE 5. Comparison of climatic water balance extract with rainfall data (P) estimated by TRMM - 3B43-v7 (a1, b1, c1) and CLIMWB with the P data from rain gauge (DEF and EXC) and data ETP and ETR (a2, b2, c2).

Three locations were chosen: Baixo Guandu - ES with an Alt. of 160 m (pixel 54.3 and OBS 1941009); Jaguaré - ES, East of the basin with Alt. of 47 m (pixel 103 and OBS 1840008) - coastal and; Desterro do Melo - MG, south of the basin, with an Alt. of 780 m (pixel 02 and OBS 2143003). The location of these points can be seen in Figure 4b in highlights with red circles.

Figure 5 shows the comparison of the simple extracts of the water balance, where there is the DEF and/or EXC during the year and the P data of the rain gauges and the data of P, ETP and ETR. In the graphical interpretation of the comparisons of the points located in the cities of Desterro do Melo - MG and Jaguaré - ES (Figure 5b and 5c), the 3B43 - v7 data presented homogeneity in relation to OBS, corroborating with the study of Quirino et al. (2015), who also observed homogeneity in their graphs.

The city of Baixo Guandu (Figure 5a) presented a greater discrepancy in the results of CLIMWB among the 105 analyzes. The 3B43-v7 underestimated the DEF, less for the months of November and December (Figure 5a). Although the satellite overestimated the P in all months, the ETR of November and December was equal. This is because P is greater than ETP in both months and therefore the ETR is equal to ETP.

The comparison of the annual water balance the components shows that the different P data sources can change the value of the water balance components, but usually they meet the needs of the practical application, taking into account that in winter there is less ETR and less need of water resources.

Getirana et al. (2011) used the TRMM as input to the hydrological model for large basins of the Instituto de Pesquisas Hidráulicas (MGB-IPH) for the Negro River basin and observed that it can reproduce the hydrological cycle reasonably well, even though it underestimated the precipitation. Li et al. (2012) evaluated the TRMM P as input to the hydrological model distributed to a basin in China (Xinjiang). They have noted that its use is feasible for the simulation of discharges and it has the potential to be an appropriate data source for poor data basins or without gauges. Mahmud (2014) used the rainfall data from the TRMM satellite and evapotranspiration estimated by the Satellite-based Daily Evapotranspiration to calculate water availability in the Malaysian Peninsula.

The results of the CLIMWB pixel-by-pixel for the WBDR using the 3B43-v7 data are represented in Figure 6 (a, b, c, d, e, f), with ETP, ETR, DEF, EXC, ETR/ETP relation known as water availability and precipitation, on an annual scale, respectively.

Due to the fact that ETP (Figure 6a) is dependent on Ta, the regions that are located in Lower Doce, close to the Costal, and in the Middle Doce region have the highest values, between 1.300 and 1.500 mm. In the south and west region of the basin, in Higher Doce, the annual values that predominate remain around 1.000 to 1.200 mm.

The ETR/ETP relation (Figure 6c) presented lower water availability in the central-north region of the basin, with values between 0.60 and 0.80 mm and DEF reaching 450 mm (Figure 6d). This DEF is the result of low water availability and high evaporative demand. In the border region to the south and southeast and the border between the ES and MG states, the ETR/ETP relation is higher than 0.90 mm, indicating that this region has a low risk of non-water supply. In the southeast portion, where the Serra do Caparaó is, the values are above 0.95 mm. Pezzopane et al. (2006) found similar results in the Lower Doce region.

The annual EXC (Figure 6e) for the WBDR is shown in Figure 6.e, where it is possible to observe the large difference in the area of the basin. The upper part of the basin, East (coastal) and North, presents 0-100 mm, indicating little volume of water supplying the water table during the year. Castro et al. (2010) also observed this in the area of Lower Doce - in the state of Espírito Santo. In the lower part of the basin, South-Southwest, high excesses were obtained reaching 800-900 mm. This is due to the higher water availability and lower evaporative demand. It is evident that in the upstream of the basin, there is a greater water excess in relation to the downstream.

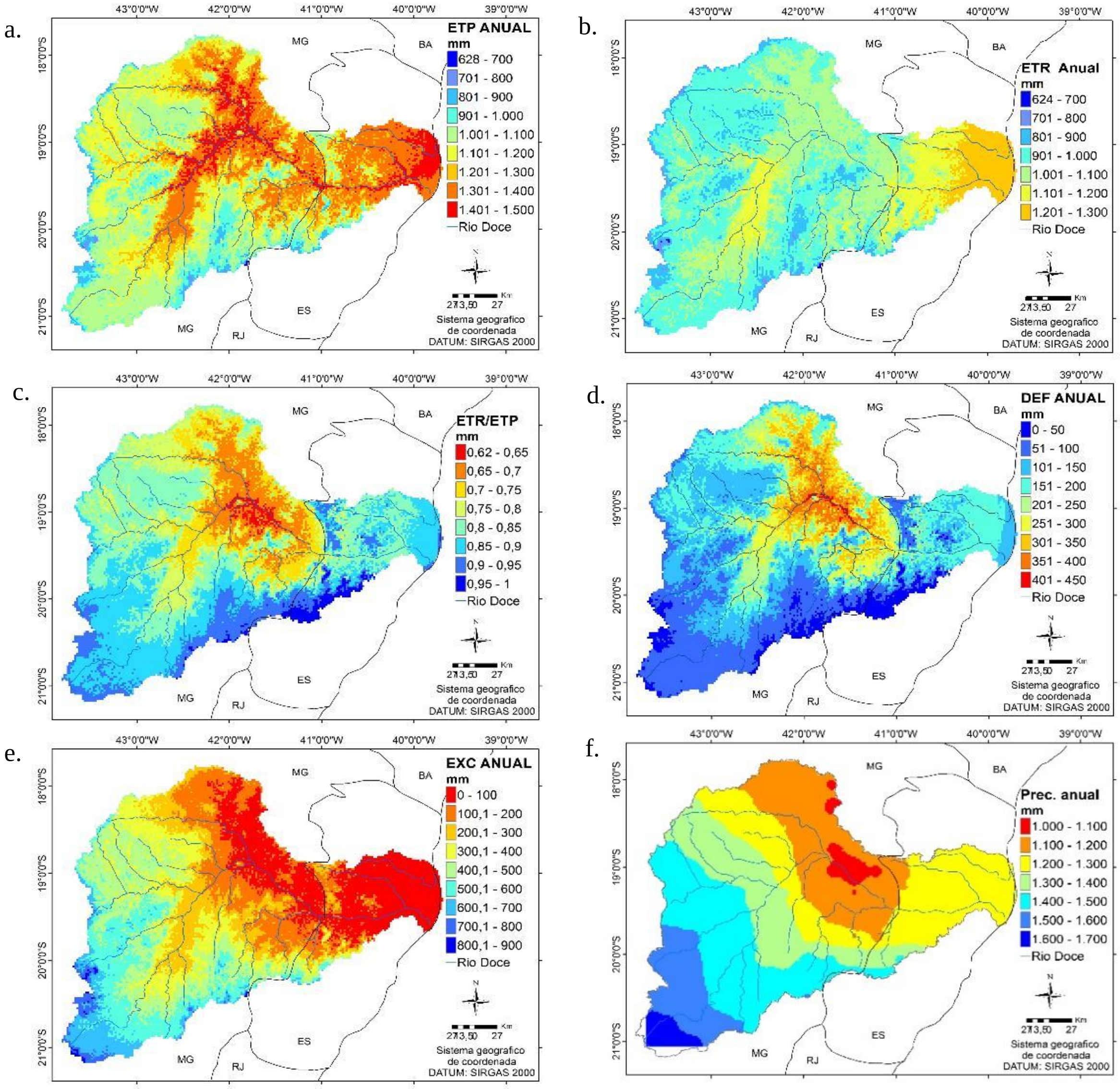

FIGURE 6. Resulting maps of water balance climatological pixel-by-pixel using rainfall data estimated by the TRMM satellite (3B43-v7) for the water basin of the Doce River. a. Evapotranspiration potential (ETP) annual accumulated; b. real evapotranspiration (ETR) annual accumulated; c. annual water availability (ETR / ETP); d. annual water deficit (DEF); e. annual water surplus (EXC); f. precipitation annual (Prec).

The rainfall regime has two well-defined periods: rainy, from October to April, and dry, from May to September. The annual precipitation (Figure 6.f) is characterized by a west-east direction in the rainy season, a meaningful flow of the mountainous regions of Espinhaço and Mantiqueira to the coastal, being influenced by the air mass of Equatorial Continental. In the dry period it is inverted, being the P greater from east to the west, being influenced by the air mass that comes from the south, Tropical Atlantic and Polar Atlantic air mass.

Figure 7 shows the monthly water availability (ETR/ETP). The months from November to March presented the lowest climatic risks of non-water supply, with values above 0.9 mm. In April, it began to present greater risks in the Northeast region. As the months go by, the area with the greatest risks increases, reaching practically the entire basin in the months of July and August. In the dry season, the coastal and southeastern region has a lower climatic risk of non-water supply in relation to the rest of the basin.

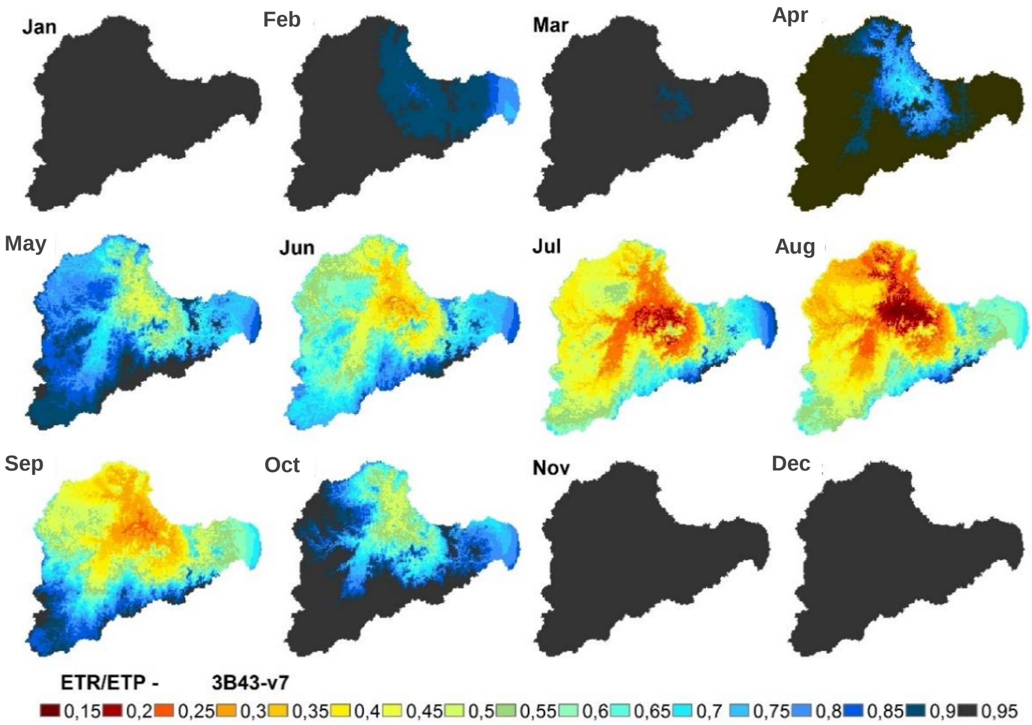

FIGURE 7. Monthly water availability in the basin of Doce River, using rainfall data estimated by the TRMM satellite (3B43-v7).

The use of precipitation data estimated by the TRMM 3B43-v7 satellite can be taken as an important tool in the characterization of regional water availability, thus contributing to agricultural planning and management, mainly because it fills the gaps left due to the absence of rain gauges in this basin area.

CONCLUSIONS

According to the results obtained, we can conclude that:

The Climatological water balance with the TRMM 3B43-v7 showed a significant correlation, with a value above 0.82.

The highest percentage errors were found in some stations in the Southeast and Northeast of the basin (in the Lower Doce and Middle Doce).

The 3B43-v7 product data characterized the climatological water balance in a similar way to the data observed by the gauges.

The TRMM 3B43-v7 precipitation data showed good performance, responded to the seasonality of the region climate and overestimated the monthly precipitation in this water basin.

The precipitation estimated by 3B43-v7 provided the realization of the climatic water balance of the Doce river basin with good coverage.

REFERENCES

ANA - Agência Nacional de Águas Ministério do Meio Ambiente (2016) Encarte Especial sobre a Bacia do Rio Doce: Rompimento da barragem em Mariana/MG, Conjuntura dos Recursos Hídricos no Brasil, Informe 2015. Superintendência de Planejamento de Recursos Hídricos – SPR, Brasília.

Alves DB, Pérez-Cabello F (2017) Multiple remote sensing data sources to assess spatio-temporal patterns of fire incidence over Campos Amazônicos Savanna Vegetation Enclave (Brazilian Amazon). Science of The Total Environment 601-602(1):142-158. DOI: http://dx.doi.org/10.1016/j.scitotenv.2017.05.194

As-Syakur AR, Tanaka T, Prasetia R, Swardika IK, Kasa IW (2011) Comparison Of TRMM multisatellite precipitation analysis (TMPA) products and daily-monthly gauge data over Bali. International Journal of Remote Sensing 32(24):8969-8982. DOI: http://dx.doi.org/10.1080/01431161.2010.531784

As-Syakur A, Tanaka T, Osawa,T, Mahendra M (2013) Indonesian rainfall variability observation using TRMM multi-satellite data. International Journal of Remote Sensing 34(21):7723-7738. DOI: http://dx.doi.org/10.1080/01431161.2013.826837

Bertoni JC, Tucci CE (2004) Precipitação. In: Tucci CE. Hidrologia: ciências e aplicação. Porto Alegre, Editora da UFRGS/ABRH, 3 ed. 174p.

Castro FS, Pezzopane JE, Cecílio RA, Pezzopane JR, Xavier AC (2010) Avaliação do desempenho dos diferentes métodos de interpoladores para parâmetros do balanço hídrico climatológico. Revista Brasileira de Engenharia Agrícola e Ambiental 14(8):871-880.

Cecílio RA, Silva KR, Xavier AC, Pezzopane JR (2012) Método para a espacialização dos elementos do balanço hídrico climatológico. Pesquisa agropecuária brasileira 47(4):478-488.

Cupolillo F, Abreu ML, Vianello RL (2008) Climatologia da bacia do Rio Doce e sua relação com a topografia local. GEOgrafias 4(1):45-60. Available in: http://www.igc.ufmg.br/portaldeperiodicos/index.php/geografias/article/view/467.

Dinku T, Ceccato P, Grover-Kopec E, Lemma M, Connor S, Ropelewski C (2007) Validation of satellite rainfall products over East Africa’s complex topography. International Journal of Remote Sensing, 28(7):1503-1526. DOI: http://dx.doi.org/10.1080/01431160600954688

Du L, Tian Q, Yu T, Meng Q, Jancso T, Udvardy P, Huang Y (2013) A comprehensive drought monitoring method integrating MODIS and TRMM data. International Journal of Applied Earth Observation and Geoinformation 23:245-253. DOI: https://doi.org/10.1016/j.jag.2012.09.010

Feidas H (2010) Validation of satellite rainfall products over Greece. Theoretical and applied climatology 99(1-2):193-216. DOI: https://doi.org/10.1007/s00704-009-0135-8

Ferreira S, Varone F, Alves R (2012) Uso do TRMM para a correção estatística da chuva prevista pelo modelo BRAMS. ANAIS. In: Simpósio Brasileiro de Ciências Geodésicas e Tecnologias da Geoinformação, Recife, Universidade Federal de Pernambuco, Anais...

Getirana A, Espinoza J, Ronchaile J R (2011) Assessment of different precipitation datasets and their impacts on the water balance of the Negro River basin. Journal of Hydrology 204(3-4):304-322. DOI: https://doi.org/10.1016/j.jhydrol.2011.04.037

Kummerow C, Simpson J, Thiele O, Barnes W, Chang ATC, Stocker E, Adler RF, Hou A, Kakar R, Wentz F, Ashcroft P, Kozu T, Hong Y, Okamoto K, Iguchi T, Kuroiwa H, Im E, Haddad Z, Huffman G, Ferrier B, Olson WS (2000) The status of the tropical rainfall measuring mission (TRMM) after two years in orbit. Journal of Applied Meteorology 39:1965-1982. DOI: https://doi.org/10.1175/1520-0450(2001)040<1965:TSOTTR>2.0.CO;2

Leivas JF, Andrade RG, Victória DC, Torresam FE, Bolfe EL (2014) Monitoramento da seca 2011/2012 no nordeste brasileiro a partir do satélite SPOT-Vegetation e TRMM. Engenharia na Agricultura 22(3): 211-221.

Li X, Zhang Q, Ye X (2013) Dry/Wet Conditions Monitoring Based on TRMM Rainfall Data and Its Reliability Validation over Poyang Lake Basin, China. Water 5:1848-1864. DOI: https://doi.org/10.3390/w5041848

Li XH, Zhang Q, Xu CY (2012) Suitability of the TRMM satellite rainfalls in driving a distributed hydrological model for water balance computations in Xinjiang catchment, Poyang lake basin. Journal of Hydrology 426:28-38. DOI: https://doi.org/10.1016/j.jhydrol.2012.01.013

Mahmud M (2014) Space based observations: A state of the art solution for spatial monitoring tropical forested watershed productivity at regional scale in developing countries. 8th International Symposium of the Digital Earth (ISDE8). IOP Conf. Series: Earth and Environmental Science 18:1-6. DOI: https://doi.org/10.1088/1755-1315/18/1/012191

Mateos L, González-Dugo M, Testi L, Villalobos F (2013) Monitoring evapotranspiration of irrigated crops using crop coefficients derived from time series of satellite images. I. Method validation. Agricultural Water Management 125:81-91. DOI: https://doi.org/10.1016/j.agwat.2012.11.005

Miranda EE (2005) Brasil em Relevo. Campinas, Embrapa Monitoramento por Satélite. Available in: http://www.relevobr.cnpm.embrapa.br. Accessed: Mar 20, 2013.

NASA - National Aeronautics and Space Administration (2013) Landsat Data Continuity Mission: Continuously Observing Your World. Available in: http://ldcm.gsfc.nasa.gov/mission_details.html. Acesso em 02 de julho de 2014.

NASA - National Aeronautics and Space Administration (2014) Tropical Rainfall Measurement Mission (TRMM) Home Page. Greenbelt: GSFC. Disponível em: http://trmm.gsfc.nasa.gov. Accessed: Jul 2, 2014.

Pereira AR, Angelocci LR, Sentelhas P (2002) Agrometeorologia: fundamentos e aplicações práticas. Guaíba, Livraria e Editora Agropecuária. v1, 478p.

Pezzopane JE, Santos EA, Santos AR, Silva GS, Reis EF (2006) Delimitação de zonas agroclimáticas no estado do Espirito Santo. Revista Brasileira de Agrometeorologia 14(2):149-156.

Quirino DT, Casaroli D, Pereira RM, Oliveira RA, Almeida RT (2015) Avaliação das estimativas de precipitação do satélite TRMM (algoritmo 3B42 Versão 7 e Real Time) utilizadas no balanço hídrico climatológico no Estado de Goiás. In: Simpósio Brasileiro de Sensoriamento Remoto, João Pessoa, Instituto Nacional de Pesquisas Espaciais, Anais...

Rolim G, Sentelhas P, Barbieri V (1998) Planilhas no ambiente EXCEL para os cálculos de balanços hídricos: normal, sequencial, de cultura e de produtividade real e potencial. Brasileira de Agrometeorologia 6:133-137.

Santos CA, Brasil Neto RM, Passos JS, Da Silva R M (2017) Drought assessment using a TRMM-derived standardized precipitation index for the upper São Francisco River basin, Brazil. Environmental monitoring and assessment 189(6):250. DOI: https://doi.org/10.1007/s10661-017-5948-9

Sentelhas P, Santos DD, Machado R (2008) Water deficit and water surplus maps for Brazil, based on FAO Penman-Monteith potential evapotranspiration. Revista Ambiente e Água 3(3):28-42. DOI: https://doi.org/10.4136/1980-993X

Silva KR, Cecílio RA, Xavier AC, Pezzopane J R, Garcia G (2013) Zoneamento edafoclimático para a cultura da seringueira no Espírito Santo. IRRIGA 8(1):1-12. DOI: http://dx.doi.org/10.15809/irriga.2013v18n1p01

Silva-Fuzzo DF, Rocha JV (2016) Validação dos dados de precipitação estimados pelo TRMM, para o estado do Paraná e sua contribuição ao monitoramento agrometeorológico. Revista Formação (ONLINE) 3(23):301-316. ISSN: 2178-7298. ISSN-L: 1517-543X.

Silva-Fuzzo D, Prela-Pantano A, Camargo MB (2015) Modelagem agrometeorológica para estimativa de produtividade de soja para o Vale do Médio Paranapanema-SP. IRRIGA - Brazilian Jornal of Irrigation and Drainage, 20(3), pp. 419-501. DOI: http://dx.doi.org/10.15809/irriga.2015v20n3p490

Soares AS, Paz AR, Piccilli DG (2016) Avaliação das estimativas de chuva do satélite TRMM no Estado da Paraíba. Revista Brasileira de Recursos Hídricos 21(2):288-299. DOI: http://dx.doi.org/10.21168/rbrh.v21n2.p288-299

Souza PI, Carvalho AE, Kotzian HB, Marciel Junior P, AlE (2010) Plano integrado de recursos hídricos da bacia hidrográfica do Rio Doce: Relatório final (Vol. II). Consórcio ECOPLAN - LUME.

Thornthwaite CW (1948) An approach towards a rational classification of climate. Geographycal Review London (38)55-94.

Thornthwaite C, Mather J (1955) The water balance. Publications in Climatology. New Jersey, Drexel Institute of Technology, 144p.

Tuo Y, Duan Z, Disse M, Chiogna G (2016) Evaluation of precipitation input for SWAT modeling in Alpine catchment: A case study in the Adige river basin (Italy). Science of the total environment 573(15):66-82. DOI: https://doi.org/10.1016/j.scitotenv.2016.08.034

Wang W, Lu H, Yang D, Sothea K, Jiao Y, Gao B, Peng X, Pang Z (2016) Modelling Hydrologic Processes in the Mekong River Basin Using a Distributed Model Driven by Satellite Precipitation and Rain Gauge Observations. PLoS ONE 11(3)e0152229:1-19. DOI: https://doi.org/10.1371/journal.pone.0152229

Xue X, Hong Y, Limaye AS, Gourley JJ, Huffman GJ (2013) Statistical and hydrological evaluation of TRMM-based Multi-satellite Precipitation Analysis over the Wangchu Basin of Bhutan: Are the latest satellite precipitation products 3B42V7 ready for use in ungauged basins? Journal of Hydrology 499:91-99. DOI: https://doi.org/10.1016/j.jhydrol.2013.06.042

Zhang A, Jia G (2013) Monitoring meteorological drought in semiarid regions using multi-sensor microwave remote sensing data. Remote Sensing of Environment 134:12-23. DOI: https://doi.org/10.1016/j.rse.2013.02.023