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Precipitation evaluation based on CHIRPS and GPCC data with surface measurements in the Guamá River sub-basin in northeastern Pará, Brazil

Ivan Carlos da Costa Barbosa[I], Emerson Renato Maciel da Silva[II],
Helder José Farias da Silva[III], Luiz Gonzaga da Silva Costa[IV],
Maria Isabel Vitorino[V] e Adriano Marlisom Leão de Sousa[VI]

ABSTRACT

Rain is one of the most important variables in climate studies in te Amazon because of it is large variability in spatio-temporal scales. Many basins and sub-basins in the region are deficient in regular and uniform monitoring of data at the surface. Today, the remote sensing products available provide rainfall data for a large spatio-temporal distribution and for almost every place on the globe. This study evaluates the performance of rainfall data obtained from remote sensing for the sub-basin region of the Guamá River, northeastern Pará state, compared to data obtained from terrestrial rain gauges, as well as to identify the spatio-temporal behavior of rain in the area. The rainfall data used were measured by rain gauge (Hidroweb) and estimated by remote sensing, obtained from the high-resolution precipitation databases of the Global Precipitation Climatology Centre (GPCC) and the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS), for the period from 1988 to 2018. The data comparison showed remarkably high correlation (r = 0.99) and satisfactory agreement index (d = 0.98). The two estimated databases showed an approximate overestimation of the observed precipitation and a spatio-temporal distribution consistent with that expected for the region.

Keywords: CHIRPS; GPCC; Remote sensing

[I] Student of Postgraduate Program in Environmental Sciences in Federal University of Pará, Belém, Brazil - ivan.barbosa@ufra.edu.br
[II] Student of Postgraduate Program in Environmental Sciences in Federal University of Pará, Belém, Brazil - emersonrvs255@gmail.com
[III] Student of Postdoctoral Program in Climate Sciences in Federal University of Rio Grande do Norte, Natal, Brazil helderpa@ufrn.edu.br
[IV] Professor at Federal University Rural of Amazon, Belém, Brazil luizgonzagacosta53@gmail.com
[V] Professor of the Postgraduate Program in Environmental Sciences in Federal University of Pará, Belém, Brazil vitorino@ufpa.br
[VI] Professor of the Postgraduate Program in Environmental Sciences in Federal University of Pará, Belém, Brazil - marlisoms@yahoo.com.br

1 INTRODUCTION

Knowledge about the spatial and temporal variability of the distribution of precipitation is essential for various sectors of society, such as agriculture, energy production and control of impacts arising from extreme events (SANTOS et al., 2017). Rainfall is one of the most important variables in climate studies in the Amazon (SOUZA et al., 2017), due to its wide variability in the temporal (daily, monthly, seasonal and decadal) and spatial (local, regional, continental and global) scales (SOUZA et al., 2017). Several authors (e.g., MENEZES et al., 2015) have demonstrated through diversified observational data the occurrence of the same high variability of precipitation in seasonal and spatial patterns over the Amazon as a whole. According to Ferreira et al. (2013), some of these factors are the different atmospheric systems that act on the region, such as the South Atlantic Convergence Zone (ZCAS) and the Intertropical Convergence Zone (ZCIT), in addition to a smaller scale system in the rainfall regime called Lines of Instability (LI).

According to De Souza et al. (2016), by observing the monthly precipitation values of the annual cycle over the Amazon it is possible to identify the clear occurrence of seasonality throughout the year. The maximum value of 9 mm/day is observed between February and March, and the minimum between 2.6 and 2.2 mm/day in July and August. Still according to the authors, it is possible to characterize the months from December to May as composing the rainy season, and the June to November as the less rainy season.

Consistently with the climate of the Amazon region, it is also possible to observe high rainfall variability for the state of Pará due to the different atmospheric systems that act on the region (MENEZES et al., 2015). According to several authors (FIGUEROA; NOBRE, 1990; MARENGO et al., 2001; SOUZA; AMBRIZZI, 2003), a large part of the rainfall in Pará occurs between the southern summer and autumn, associated with the patterns of large-scale quasi-stationary atmospheric circulation linked to the ZCAS and ZCIT. According to Camponogara and Silva Dias (2011), the amount of rainfall in the state is also influenced by mechanisms of interaction between the Atlantic Ocean and the atmosphere, such as the North Atlantic Oscillation (OAN), Pacific Decadal Oscillation (ODP) and El Niño South Oscillation (ENOS). In this context, Pará is the state of the Amazon that has the largest drainage network, thus having large hydrographic basins, so that rivers acquire unique relevance in the life of the population (LOPES et al., 2013).

The most important factors affecting the hydrological behavior of river basins are rainfall, its duration, intensity, distribution and return periods (SABER et al., 2015). Many basins and hydrographic sub-basins in the Amazon region are lacking in real-time monitoring of precipitation, have a very sparse monitoring network, are bereft of precipitation data for a given area of interest, or even have inconsistent rainfall data or a large number of failures over the period (due to the lack of maintenance of the network of pluviometric stations). The insufficient number of surface rainfall stations in certain regions of Brazil (mainly in the Amazon region) negatively interferes with the development of research and climate monitoring to predict extreme weather events.

According to Araujo and Guetter (2007), in recent decades important advances have been observed in remote sensing of rain using specialized satellites for this purpose, which has led to an increase in the availability and quality of these estimates for various regions of the globe. The products currently available provide estimated rainfall data by satellites with spatial and temporal distribution in large basins and regions. The importance of information on the climate at different scales - regional and global - has generated the creation of several international programs to provide generalized information on the meteorological variables of the planet. According to Hessels (2015), it is becoming increasingly attractive to use satellites to carry out estimates of rainfall, due to the provision of continuous spatial measurements. Many of these satellite products are open source and have varying resolutions (DINKU, 2014; SHRESTHA, 2011), so their performance may vary from region to region (DUAN et al., 2016). Some of these provide precipitation data obtained from surface observation and remote sensing (DINKU et al., 2018), such as the Global Precipitation Climatology Project (GPCP) (ADLER et al., 2001), the Global Precipitation Climatology Center (GPCC) (SCHNEIDER et al., 2016), the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) (SHRESTHA et al., 2017; DINKU et al., 2018; FUNK et al., 2015), the Climate Research Unit (CRU) (BROHAN et al., 2006) and the Tropical Rainfall Measuring Mission (TRMM) (HUFFMAN et al., 2007).

Thus, the climatic conditions of a region present limiting factors for the maintenance of water availability, and accurate data are of great importance for economic, social and cultural development. The perception of the difficulty of access and logistics to the various water bodies in the region of the Guamá River sub-basin and the lack of a representative monitoring network for the area makes it essential to use rainfall databases to analyze temporal and/or spatial variability of atmospheric phenomena. Thus, this study has the main objective of evaluating the performance of rainfall data obtained from remote sensing data (GPCC and CHIRPS) for the Guamá River sub-basin region in northeastern Pará, in comparison with data directly obtained from terrestrial rain gauges (made available by Brazil's National Water Agency - ANA), in addition to identifying the spatio-temporal behavior of rain in the region, thus generating results that will enable a better understanding of the local climate and provide support for better management of the region's water resources.

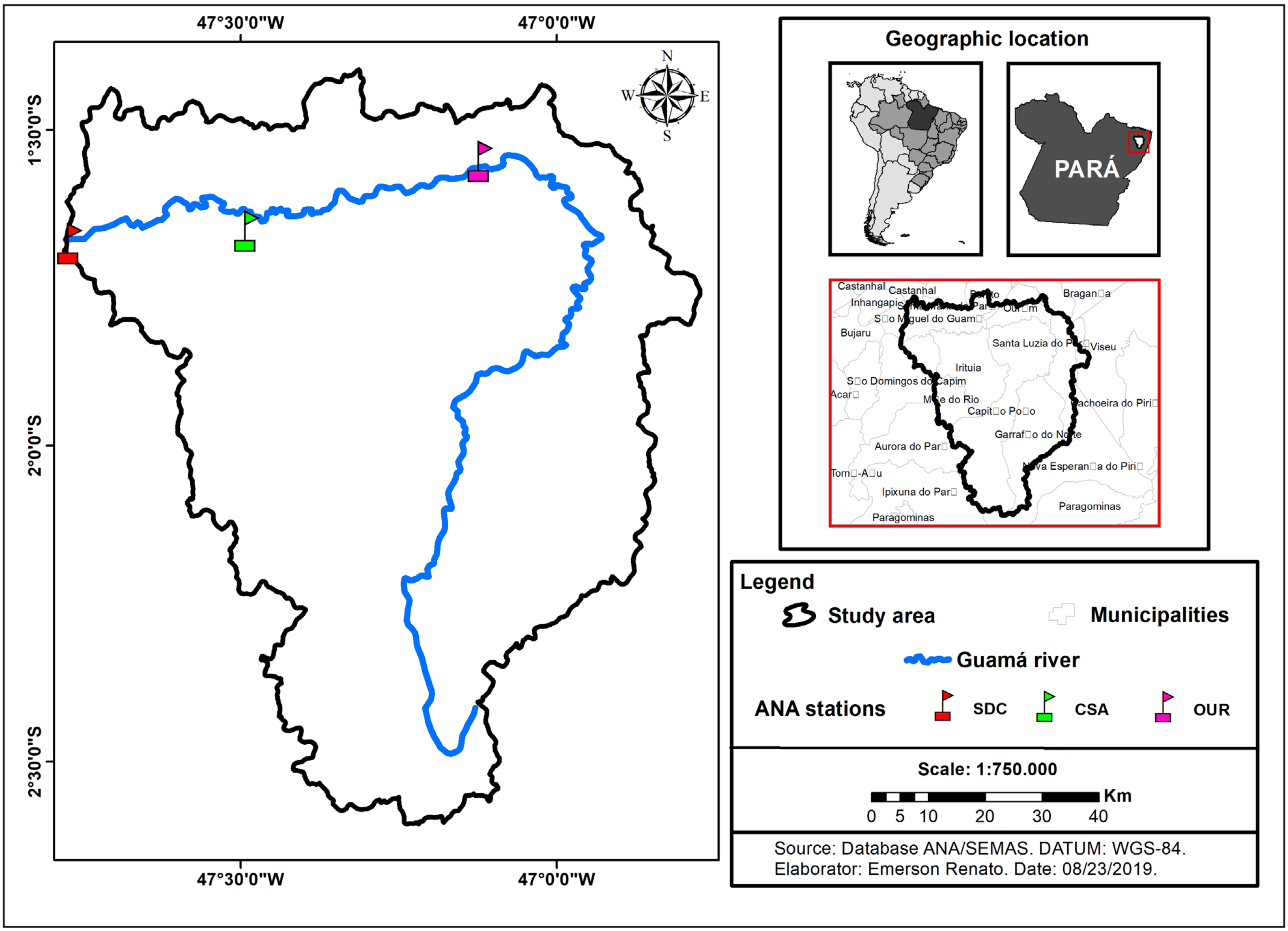
2 MATERIAL AND METHODS

2.1 Study area

The state of Pará is located in the North region of Brazil, in the Eastern Amazon, occupying an area of 1,247,954.6 km2 (Figure 1). It is the second largest Brazilian state in landmass and has 144 municipalities, with an official population in the last census of 7,581,051 inhabitants (IBGE, 2010). According to Lopes et al. (2013), in Pará, two well-defined seasons can be described from the rainfall index: a rainy season (Amazonian winter) and a less rainy season (summer). Currently, land cover in the Amazon is dominated by three types of landscape: primary forest, secondary forest various succession stages, and pasture (SALIMON et al., 2003).

The study area is composed of the Guamá River sub-basin (GRSB), located in the mesoregion of northeastern Pará and the microregion of Guamá, It covers an area of 49,637 km2, as shown in Figure 1 (TORRES, 2007). The Guamá River is one of the tributaries of the Pará River and is 700 km long. It originates in the Coroados Mountains (southern part of the municipality of Capitão Poço), running in the south-north direction until the municipality of Ourém, located on its right bank. Heading west, it meets Capim River, one of its most important tributaries. It is navigable by small boats to its first waterfall, 225 km from Belém. At its mouth, in Baía do Guajará, it reaches 900 m in width and is navigable in certain sections (BRAZ; MELLO, 2005). According to Rebello et al. (2009), the Northeaster Pará mesoregion is an important agricultural area of the state, mainly due to the practice of slash-and-burn agriculture and the formation of wide pastures.

Figure 1 – Spatial dimension of the Guamá River sub-basin (GRSB) and the location of the selected pluviometers



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The GRSB is part of the historical context of the creation of the Bragança Railroad, which connected the capital Belém to the city of Bragança and its colonization (TORRES, 2007). The municipalities contained in the GRSB are: Aurora do Pará, Bonito, Capitão Poço, Garrafão do Norte, Ipixuna do Pará, Irituia, Mãe do Rio, Nova Esperança do Piriá, Ourém, Santa Luzia do Pará, São Domingos do Capim and São Miguel do Guamá. The GRSB is part of the Western Atlantic Hydrographic Region, according to Resolution 04/2008 from the Water

Resources Council of the State of Pará (BRAZ; MELLO, 2005), which has an area of 918,822 km2 (11% of the nation's territory) and covers the states of Goiás (21%), Tocantins (30%), Pará (30%), Maranhão (4%), Mato Grosso (15%) and the Federal District (0.1%) (ANA, 2016).

The Guamá River sub-basin is located in a warm and humid tropical equatorial region, which has typically convective rains (stronger rain intensity, shorter duration and shorter coverage area) that can migrate over time to stratiform rains (spread over a large area, longer duration and intensity of medium or low precipitation) (ROCHA; CORREIA; FONSECA, 2014). The predominant climatic type in the region is Af, according to the Köppen classification, with an average annual temperature above 18 ºC (PRATA et al., 2010). According to Lopes et al. (2013), the less rainy season occurs between June and November, and the rainiest season between December to May (with annual precipitation rates greater than 2,000 mm).

The soil of the Guamá River sub-basin area is characterized by the presence of the following types: Yellow Latosol, Concrete Latosol, Fluvic Neossol, Quartzarenic Neossols and Red Yellow Argisol (ROCHA, 2017).

In its total area, equivalent to 7% of Pará (TORRES, 2007), the Guamá River sub-basin is responsible for supplying 75% of the water distributed to the population of the state capital, Belém (COSTA et al., 2015). Due to its territorial extension, it is also responsible for supplying water for various types of activities along its route. The importance of the Guamá River to the city of Belém is due to the fact that it, together with Água Preta and Bologna lakes, is part of the Utinga Water Complex, which supplies the city (BRAZ; MELLO, 2005). Water from the Guamá River is also used for cropping, livestock breeding, mineral extraction and fishing. Therefore, it is a fundamental river for local development and economic growth in Pará (COSTA et al., 2015). The GRSB has different types of occupation, varying among urban centers, small communities, farms and ranches, as well as outposts for extractive activities (coal, gravel and timber). According to Silva et al. (2016), in the mesoregion of northeastern Pará, the factors mining, human occupation (population) and agriculture stand out in land use and coverage.

Figure 1 shows the modulation of the GRSB area and indicates the geographic location of the three rain gauges that are part of the monitoring network of the National Water Agency (ANA) - with the Guamá River highlighted, flowing for 380 km in the selected reach.The three rain gauges presented were selected since they are located within the study area. They were called SDC (located in the municipality of São Domingos do Capim), CSA (located in the Colônia Santo Antônio district of São Miguel do Guamá municipality), and OUR (located in the municipality of Ourém). The SDC rain gauge is positioned at the geographical coordinates 47º46'12" W and 1º40'48" S; the CSA at 47º29'24" W and 1º39'36" S; and the OUR rain gauge at 47º7'12" W and S 1º33'0" S.

2.2 Rain data

The rain data used in this work were obtained from three different sources: rain measured by rain gauges (called observed data); and rain estimated by remote sensing and made available by the high resolution precipitation databases of the GPCC (Global Precipitation Climatology Center) and CHIRPS (Climate Hazards Group Infrared Precipitation with Station Data), for the common period between 1988 and 2018. The GPCC has a database relying on precipitation interpolated from surface observations (SANTOS et al.; 2017; RUDOLF; SCHNEIDER, 2005) and CHIRPS also uses an inverse distance weighting algorithm to process its data (DUAN et al., 2016). Thus, the two satellite precipitation sources were used to analyze the influence of spatial resolution on the observed values, among other parameters.

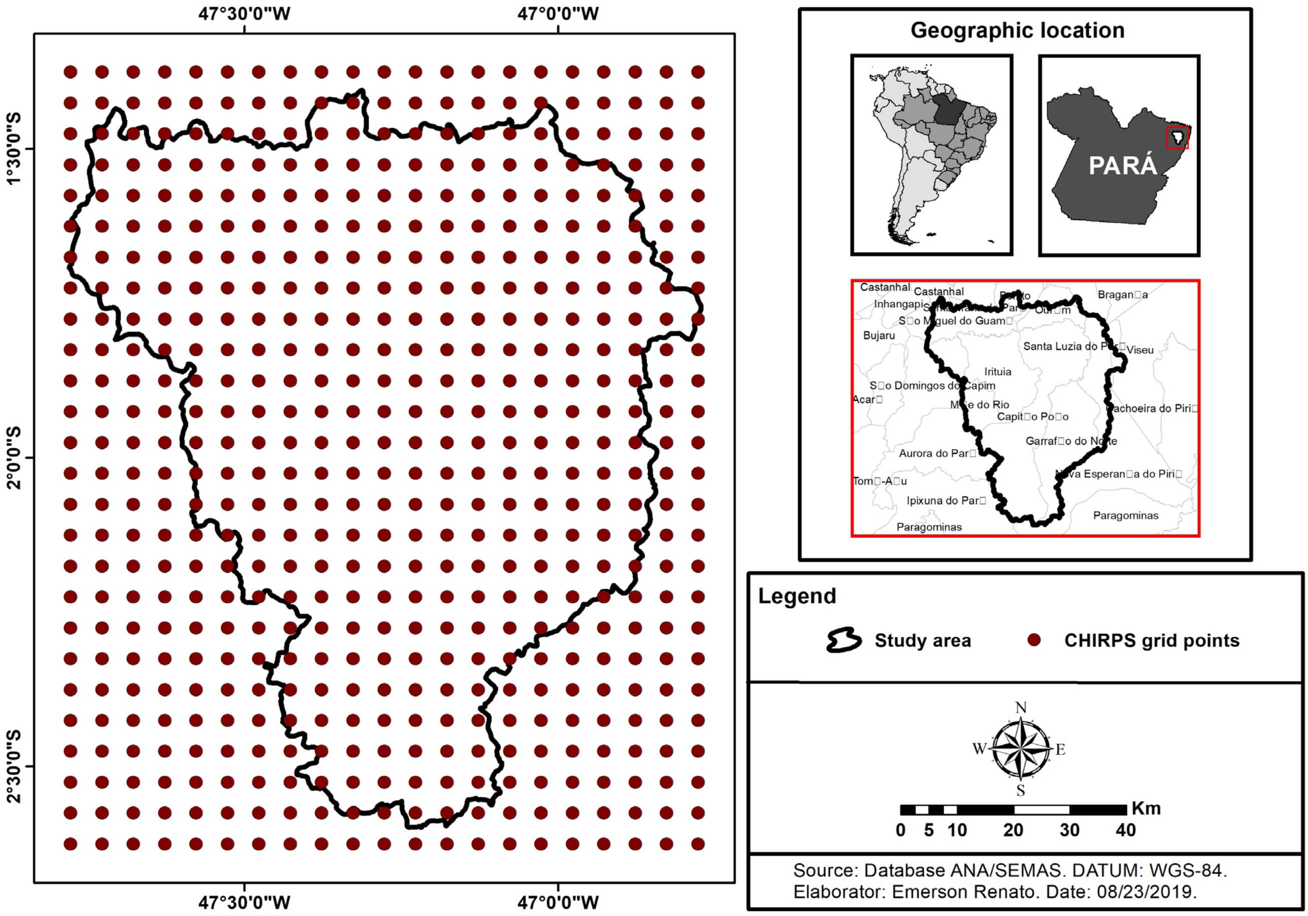
For the observed rain data, the monthly accumulated precipitation values (in millimeters or mm) were used, measured by the three pluviometers located in the Guamá River sub-basin. As previously mentioned, these rain gauges are located in the municipalities of São Domingos do Capim, São Miguel do Guamá and Ourém, being part of the surface monitoring network of the National Water Agency (ANA). The database was accessed through the Hidroweb online platform, available at: http://www.snirh.gov.br/hidroweb/apresentacao. Manual control of the quality of the pluviometric data of the earth station was carried out, because among the three pluviometers there were some gaps in the continuous data series. Despite the limited range and intrinsic error of rain stations, they remain the most direct and accurate measurement tool to date (WANG et al., 2017). Thus, soil-based measures were considered as "true precipitation" datasets for reference in this study (WANG et al., 2017; MARCIANO et al., 2018).

The estimated data were obtained through remote sensing. According to Jiménez et al. (2013), the electromagnetic radiation reflected and emitted by the planet's surface and atmosphere can be detected by sensors present in satellites. Electromagnetic radiation is interpreted in the electromagnetic spectrum according to certain wavelengths. Also according to the authors, the agencies that administer these satellites process the raw radiation data and make the remote sensing data available in a spatial raster (pixel) format in different temporal and spatial resolutions.

The CHIRPS precipitation dataset is based on the measurement of the global cold cloud duration (CDD), based on infrared thermal data stored in the CPC (Climate Prediction Center), NOAA (National Oceanic and

Atmospheric Administration) and NCDC (National Climatic Data Center), as the primary sources for calculating precipitation on a quasi-global scale (geographic coverage from 50ºS to 50ºN and all longitudes) from 1981 to the present date (DUAN et al., 2016). The first estimates are calibrated with the precipitation estimated in the product TRMM-3B42, version 7, and information from the global network of rain gauges (collected by the United Nations Food and Agriculture Organization and Global Historical Climatology Network), providing a set of precipitation data with high horizontal spatial resolution of 0.05 ° × 0.05 ° (ESPINOZA et al., 2019; FUNK et al., 2015). The data used in this work were acquired through the website https://www.chc.ucsb.edu/data/chirps/, in NetCDF, GeoTiff and Esri BIL format. For the Guamá River sub-basin area, 546 grid points were incorporated (Figure 2).

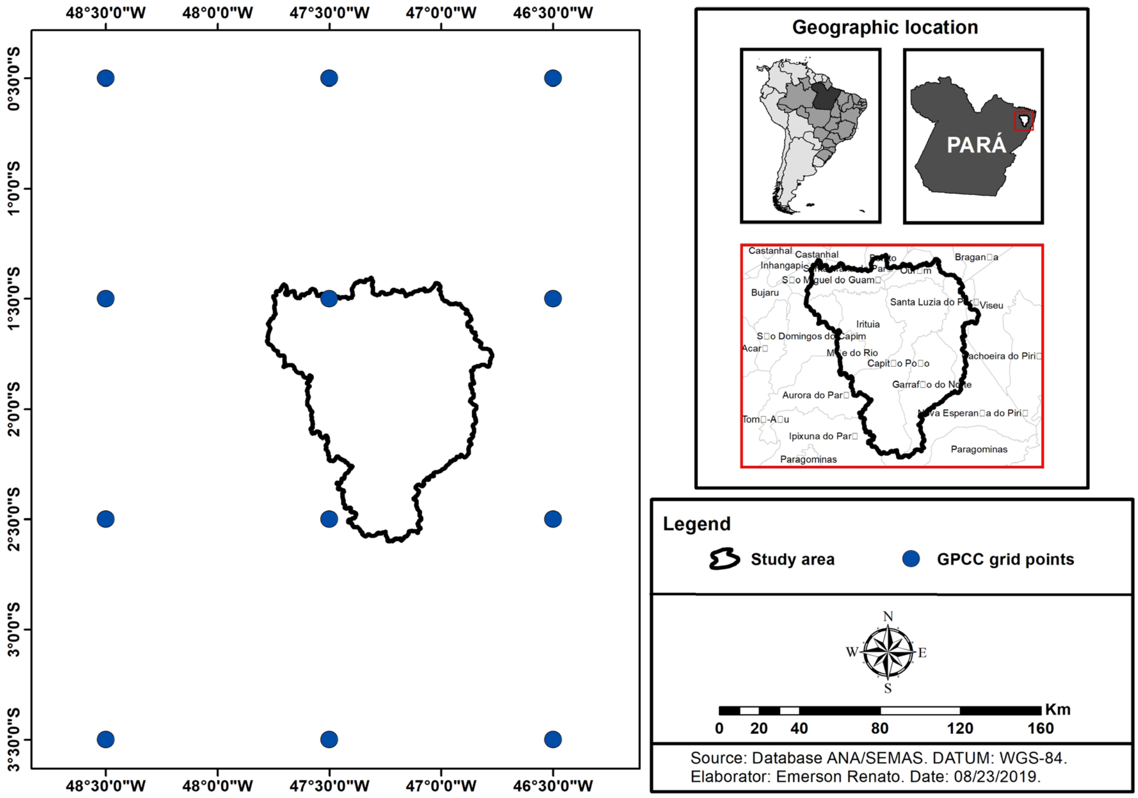
Figure 2 – Distribution of CHIRPS grid points in the Guamá River sub-basin



Source: Authors

The GPCC precipitation data were obtained with monthly temporal resolution and spatial resolution in a 1.0º x 1.0º grid (Figure 3), available at http://gpcc.dwd.de/. The GPCC dataset has 12 large points distributed in the GRSB area. The complete GPCC product is a set of monthly rainfall data in a grid for the global land surface (RAZIEI et al. 2015), controlled for quality, of 85,000 pluviometric stations almost in real time (CHANDRAN et al., 2016). According to Wang et al. (2017), the available data are based on the monthly reports of SYNOP (Surface Synoptic Observations) and CLIMAT received via GTS (Global Telecommunication System) from the WMO (World Meteorological Organization), after automatic and manual quality control. These precipitation data are generated within two months after the end of the observation month based on a combination of radiometric observations from satellites and rain gauges (AJAAJ et al., 2016).

Figure 3 – Distribution of the GPCC grid points over the Guamá River sub-basin



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2.3 Calculation of statistical metrics and interpolation of rain data

According to Xu et al. (2015), monthly rainfall events are usually subject to small scale variability, and therefore can be better validated on the smallest possible spatial scale.

In this work, a point-to-pixel analysis was performed to compare precipitation data from the monthly time series observed through the selected rain gauges with the respective grid cell to the corresponding CHIRPS and GPCC pixels. For this, four statistical metrics based on pairwise comparison were used to assess the performance of each of the satellite products (PAREDES-TREJO et al., 2016): Pearson's correlation coefficient (r), relative bias percentage (or error) (BIAS), root mean square error (RMSE), and Willmott concordance index (d). The equations are summarized in Table 1.

Table 1 – Equations of the statistical metrics of performance of the precipitation products (where: O = represents the data observed on the surface by the rain gauges; S = represents the data estimated by the CHIRPS or GPCC satellite; Ō and S̅ represent the averages of the observed and estimated data, respectively; and n represents the number of observations)

Metric name	Equation	Ideal value
Pearson's correlation coefficient (r)	$r = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{[\sum_{i=1}^{n}(O_i - \bar{O})^2][\sum_{i=1}^{n}(S_i - \bar{S})^2]}}$	1
Bias percentage (BIAS)	$PBIAS = 100\frac{\sum_{i=1}^{n}(S_i - O_i)}{\sum_{i=1}^{n}(O_i)}$	0
Root mean square error (RMSE)	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2}$	0
Willmott agreement index (d)	$d = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(\lvert S_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert)^2}$	1

Source: Authors

Pearson's correlation coefficient (r) measures the strength of the linear relationship between satellite estimates and observations of rain gauges, ranging from -1 to +1 with a desired score equal to +1 (PAREDES-TREJO et al., 2017) . According to Rivera et al. (2018), the average percentage error (or bias) measures the tendency of the estimated precipitation to be greater or less than the observed precipitation, with an ideal value of 0. Positive values indicate overestimation bias, while negative values indicate underestimation bias. The root mean square error (RMSE) value indicates the mean deviation between estimated values and actual values. The ideal value for this metric is equal to 0 and always has positive values (XU et al., 2015). The agreement index (d) used was developed by Willmott (1981). The values of this index can vary from 0, for no agreement, to 1, for perfect agreement. The results of r and d are dimensionless, while BIAS is expressed as a percentage (%) and RMSE in millimeters (mm). To perform the statistical analyses, the software R (R Core Team, 2018) was used, through implementation of the functions available in the packages base, devEMF, lattice, plyr, Rmisc, reshape and hydroGOF. The R software was also used to perform the comparison test between the datasets (observed and estimated) using the Student t-test (significance level of 5%, that is, $p \leq 0.05$). The objective of the test was to test the null hypothesis that the averages between the two groups (observed/CHIRPS and observed/GPCC) were equal to the monthly averages over the study period.

For the spatialization of rain data, the software QGIS, a geographic information system (GIS), version 2.18, was used. In processing, the average rainfall estimated by the satellite product was used as input data in the spatialization calculations. In this case, the universal Kriging interpolation method was used within the Guamá River sub-basin area. According to Gallardo (2006), the behavior of a variable in the different directions of a geographical space is explained by the kriging interpolator, which is based on a continuous function. In this way, it is possible to associate the variability of the estimation based on the distance that exists between a pair of points, through the use of a semivariogram, which allows verifying the level of similarity that exists between them, as they move away.

3 RESULTS AND DISCUSSION

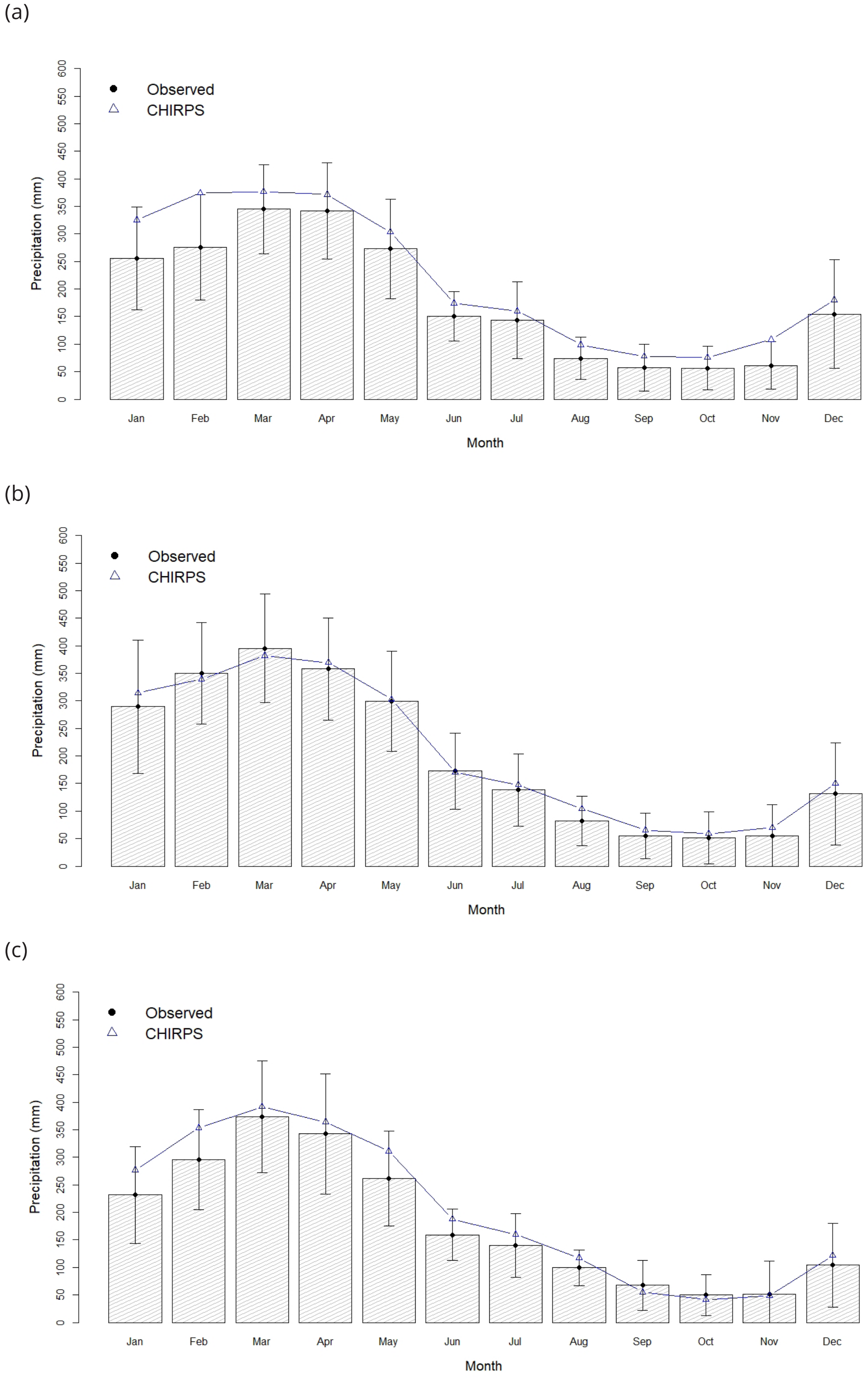
Figures 4 and 5 show the average values of accumulated precipitation obtained from data from pluviometers (vertical bars) located in São Domingos do Capim (Figure 4a), Colônia Santo Antônio district of São Miguel do Guamá) (Figure 4b) and Ourém (Figure 4c). The values estimated by the CHIRPS and GPCC products for the validation period (1988 to 2018) are also represented in Figures 4 and 5, respectively, through the solid blue line. All the rain gauges are located within the Guamá River sub-basin area (GRSB). The average accumulated precipitation data obtained from CHIRPS and GPCC were extracted from the pixel closest to each rain gauge.

It is possible to observe the same pattern of behavior of monthly precipitation in both figures during the study period. The average rainfall in the Guamá River sub-basin estimated by CHIRPS and GPCC has higher peaks than that observed by the rain gauges, but the two types of data are in phase throughout the study period. There was an increase in the amount of rain from December to a peak generally in March and a decrease in the amount of rain to the lowest value, generally observed in October. According to Costa et al. (2019), rainfall data from the CHIRPS database and its validation with data from INMET/CPTEC for the northern region of Brazil shows a rainy period between the months of November to May, and less rainfall (precipitation rates considered high compared to other regions of the country) between June and September (COSTA, 2019).

In the present study, the largest standard deviations were commonly observed between the months of December to June/July in both figures (Figures 4 and 5). These months are part of the so-called rainy season in the Amazon region. The most evident discrepancies between the average observed value (rain gauge) and the estimated average value (CHIRPS and GPCC) were commonly identified for January, February and/or March. However, in the months of lower rainfall, the data estimated by CHIRPS and GPCC show very satisfactory agreement with the data obtained by rain gauges (lower standard deviations).

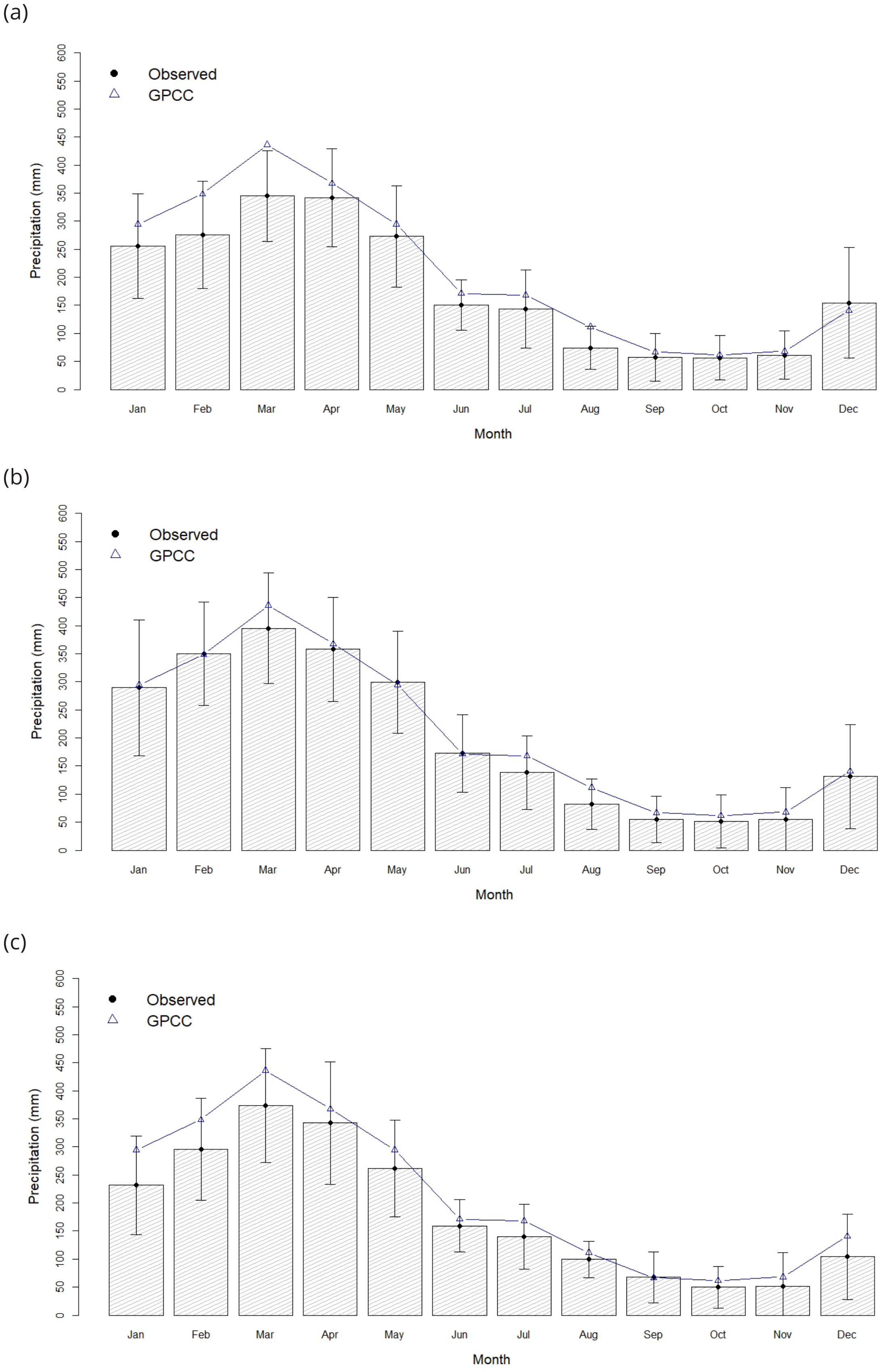
The average amount of rain, in mm, estimated by CHIRPS was commonly higher than that obtained by the rain gauge every month in São Domingos do Capim and Ourém, with some exceptions. Of particular note are the months of February and March, in São Domingos do Capim, and the months of September and October in Ourém, where the estimated amount of rain was lower than that measured in each of the pluviometers. Also noteworthy are the months of May and June, in São Domingos do Capim, and the month of November in Ourém, where the estimated rain values were the same as those measured in the rain gauges. According to Katsanos et al. (2016), the difference between the trend in rainfall measured by rain gauges and the trend in CHIRPS data is a result of incorporating TRMM estimates into this satellite product, which tend to overestimate rainfall.

Figure 4 – Annual cycle of observed average accumulated precipitation * and that estimated by the CHIRPS database for the period from 1988 to 2018 (* average observed for: (a) São Domingos do Capim rain gauge; (b): Colônia Santo Antônio rain gauge in São Miguel do Guamá; (c) Ourém rain gauge; the barb represents the ±1 calculated standard deviation)



Source: Authors

Figure 5 – Annual cycle of observed accumulated average precipitation * and that estimated by the GPCC database for the period from 1988 to 2018 (* average observed for: (a) São Domingos do Capim rain gauge; (b) Colônia Guamá River sub-basin Antônio rain gauge in São Miguel do Guamá; (c) Ourém rain gauge; the barb represents the ±1 standard deviation calculated)



Source: Authors

For the GPCC satellite database, only in December for São Domingos do Capim was the estimated average value below those observed from the rain gauge. In the remaining months for all three locations, the value estimated by the GPCC was equal to or slightly higher than that measured by rain gauges. Of particular note is the similarity between the measured and estimated rainfall for most months (with the exception of March, July and August) in the Colônia Santo Antônio region. This rain gauge is closest to grid point for which the precipitation data were extracted, approximately 18 km. While the rain gauge located in São Domingos do Capim is approximately 35 km and the one located in Ourém approximately 43 km. According to Limberger and Silva (2018), the GPCC dataset is reconstructed from observed precipitation data. Therefore, the proximity between the rain gauge and the grid point is favorable to the estimated precipitation precision.

Table 2 presents the results of the statistical metrics calculated from the comparison between the estimated data (CHIRPS and GPCC) and observed data (pluviometers).

Table 2 – Summary of statistical metrics for assessing precipitation products (CHIRPS and GPCC) on the monthly time scale (1988 to 2018) versus the values observed in rain gauges located in the Guamá River sub-basin (* SDC = São Domingos do Capim; CSA = Colônia Santo Antônio (São Miguel do Guamá); OUR = Ourém). ** Distance in kilometers between the location of the rain gauge and the closest grid point closest of the GPCC

		CHIRPS vs. observed		
Observed*	**BIAS (%)**	**r**	**RSME (mm)**	**d**
SDC	20.0	0.98	43.18	0.96
CSA	4.1	1.00	14.02	1.00
OUR	11.7	0.99	30.03	0.98
Average value	11.9	0.99	29.08	0.98
		GPCC vs. Observed		
Observed*	**BIAS (%)**	**r**	**RSME (mm)**	d
SDC (34.87 km)**	15.6	0.99	39.88	0.97
CSA (17.73 km)**	6.4	0.99	18.50	0.99
OUR (42.65 km)**	16.3	0.99	36.79	0.98
Average value	12.8	0.99	21.72	0.98

Source: Authors

All the correlation coefficients (r) were above 0.97 (97%), indicating a strong direct correlation between CHIRPS data and rainfall (SDC, CSA, OUR), and mainly between GPCC and rain gauge (SDC, CSA, OUR). In general, the mean values of the correlation coefficients (r = 0.99 for both) were similar for the two satellite products compared to the observed values.

The rain gauge located in São Domingos do Capim (SDC) presented the highest values of average percentage error (BIAS of approximately 20 and 16% for CHIRPS and GPCC, respectively). The lowest average percentage error was obtained for Colônia Santo Antônio in the approximate value of 4% overestimation for the CHIRPS/observed set. Regarding the GPCC/observed set, the lowest average percentage error was obtained for Ourém, of approximately 8%. In general, the mean BIAS value obtained for the CHIRPS/observed indicated a smaller overestimation, approximately 12%, of the precipitation data, whereas the highest mean value of approximately 13% of BIAS was found for the GPCC/observed set. In this study, no average percentage error was found indicating underestimation of the data observed by the rain gauges.

The lowest (best) RSME values were approximately 14 and 19 mm for CHIRPS and GPCC, respectively, for the Colônia Santo Antônio and São Domingos do Capim regions, while the highest RSME values were approximately 43 and 40 mm for CHIRPS and GPCC, respectively. Overall, the average value of approximately 29 mm, obtained for the CHIRPS/observed dataset was less than the average value of approximately 32 mm obtained for the GPCC/observed dataset.

Regarding the Willmott concordance indexes (d), the values were equal to or greater than 0.97. The weakest agreement rates were found for São Domingo do Capim: 0.96 and 0.97 for the CHIRPS/observed and GPCC/observed datasets, respectively. Again, the best metric values were identified for Colônia Santo Antônio, with agreement index values of 1.00 and 0.99 for the CHIRPS/observed and GPCC/observed datasets, respectively. In general, a mean value of 0.98 was obtained for both sets of precipitation data. Thus, the most favorable results of the statistical metrics were obtained both for the CHIRPS/observed dataset and for the GPCC/observed dataset at the geographical coordinates of the Colônia Santo Antônio rain gauge in São Miguel do Guamá. The most unsatisfactory results were obtained for São Domingos do Capim for both datasets. It is noteworthy that the pluviometer of this last location is at the limit of the Guamá River sub-basin, which may have impaired the precision of the precipitation data due to factors such as the influence area of the pluviometer and the topography, which influences air movement (MARCIANO et al., 2018).

Since precipitation does not differ only with geographic location, the variation related to the seasonality of the Amazon region was taken into account. Thus, Tables 3 and 4 show the comparison between the estimated (CHIRPS and GPCC) and observed (rainfall) data for the rainy season (December to May) and less rainy period (June to November) between 1988 and 2018.

Table 3 – Summary of statistical metrics for the evaluation of the CHIRPS precipitation product for the rainy and less rainy periods (1988 to 2018) versus the values observed in pluviometers located in the Guamá River sub-basin (* SDC = São Domingos do Capim; CSA = Colônia Santo Antônio (São Miguel do Guamá); OUR = Ourém)

		Rainy season (December to May)		
Observed*	**BIAS (%)**	**R**	**RSME (mm)**	**d**
SDC	17.3	0.92	54.67	0.85
CSA	1.9	0.99	15.12	0.99
OUR	13.1	0.98	38.76	0.95
Average value	10.8	0.96	26.18	0.93
		Less rainy period (June to November)		
Observed*	**BIAS (%)**	**R**	**RSME (mm)**	**d**
SDC	27.9	0.97	27.19	0.90
CSA	11.3	0.99	12.81	0.98
OUR	7.7	0.99	17.37	0.97
Average value	15.63	0.98	19.12	0.95

Source: Authors

Table 3 shows that the highest values of average percentage error were found, both in the rainy and less rainy periods, in the region of the rain gauge located in São Domingos do Capim. The lowest values changed between CSA and OUR in the rainy and less rainy periods, respectively. The average percentage error values presented a reduction of 1% of overestimation in the rainy season (average BIAS value of approximately 11%) and an increase of 4% of overestimation in the less rainy period (average BIAS value of approximately 16%). The lowest correlations were found in SDC in both seasonal periods. The average correlation coefficients for reduction in the rainy and less rainy seasons were 0.96 and 0.98, respectively. As for the RMSE, an increase of approximately 25% was observed for the rainy season and a reduction of approximately 34% for the less rainy period compared to the results of the analysis without distinction of seasonality. The highest values of RSME were in SDC and the lowest in CSA, in both seasonal periods. Finally, the agreement index fell to 0.93 and 0.95 in the rainy and less rainy periods, respectively.

Table 4 – Summary of statistical metrics for evaluating the GPCC precipitation product for the rainy and less rainy period (1988 to 2018) versus the values observed in rain gauges located in the Guamá River sub-basin (* SDC = São Domingos do Capim; CSA = Colônia Santo Antônio (São Miguel do Guamá); OUR = Ourém). ** Distance in kilometers between the rain gauge and the nearest grid point of the GPCC)

		Rainy season (December to May)		
Observed*	**BIAS (%)**	**r**	**RSME (mm)**	**d**
SDC (34.87 km)**	14.4	0.96	52.4	0.89
CSA (17.73 km)**	3.2	0.99	17.89	0.99
OUR (42.65 km)**	17.0	0.99	48.00	0.93
Average value	11.53	0.98	39.43	0.94
		Less rainy period (June to November)		
Observed *	**BIAS (%)**	**r**	**RSME (mm)**	**d**
SDC (34.87 km)**	19.2	0.98	20.85	0.95
CSA (17.73 km)**	16.9	0.97	19.09	0.96
OUR (42.65 km)**	14.3	0.99	16.06	0.97
Average value	16.80	0.98	18.67	0.96

Source: Authors

Table 4 shows similar behavior similar to that reported in Table 3 of the statistical metrics for the seasonal periods according to the precipitation estimate using the GPCC product. There was a reduction to approximately 12% in the average value of BIAS for the rainy period and an increase to approximately 17% in the less rainy period. The highest BIAS results were found for the OUR and SDC locations in the rainy and less rainy periods, respectively. The average correlation coefficient was 0.98 for both seasonal periods, lower than that previously verified without distinction of seasonality. The RMSE value also increased by approximately 24% for the rainy season compared to the analysis without distinction of seasonality. In the less rainy period there was a reduction of approximately 41% in the mean square error compared to the analysis without distinction of seasonality. The highest values of RMSE (52.4 and 20.85 mm) were in São Domingos do Capim. The agreement indexes obtained (0.94 and 0.96 for the rainy and less rainy periods, respectively) were lower than those found previously without distinguishing the seasonality of the region. The lowest values (0.89 and 0.95 for the rainy and less rainy periods, respectively) were also concentrated in São Domingos do Capim.

Thus, it was observed that, when the seasonal periods are accentuated, no relevant differences were observed in the correlations obtained between rainfall measured by pluviometers and estimated by CHIRPS or GPCC. This indicates that the amount of rain interferes minimally with the quality of the statistical metrics presented. However, quantitative rainfall statistics (BIAS, correlation coefficient, RMSE and agreement index) demonstrated efficiency and reliability of the rainfall estimates in the Guamá River sub-basin through the products generated by CHIRPS and GPCC. Several authors (COSTA et al., 2015; DUAN et al., 2016; MARCIANO et al., 2018; XU et al., 2015) have reported the need for knowledge on the quality of precipitation data, since they must have satisfactory accuracy in spatial and temporal resolution. This importance is based on the employment of these data for the strategic planning of water resource management, forecasting and evaluation of floods and droughts (FISCH et al., 1998).

The CHIRPS/observed dataset (Table 5) and the GPCC/observed dataset (Table 6) were tested for statistical significance at a p-value of 0.05, according to the paired Student t-test.

Table 5 – Student's t-test (5% significance) for the CHIRPS/dataset observed between 1988 and 2018 (* p-value ≤0.05 indicates there a significant difference between the data of the observed (rain gauge) and estimated (CHIRPS) values)

Month	P-value (CHIRPS/SDC)	P-value (CHIRPS/CSA)	P-value (CHIRPS/OUR)
January	0,006969*	0,3697	0,0652
February	0,0003007*	0,6389	0,0141*
March	0,09728	0,523	0,4022
April	0,139	0,5756	0,3438
May	0,1696	0,9007	0,03143*
June	0,06959	0,8745	0,01478*
July	0,3206	0,5052	0,09297
August	0,008718*	0,02674*	0,0315*
September	0,04721*	0,2632	0,1935
October	0,07054	0,4623	0,3017
November	0,00211*	0,2716	0,8336
December	0,287	0,4143	0,3859

Source: Authors

Table 6 – Student's t-test (5% significance) for the GPCC/dataset observed between 1988 and 2018 (* p-value≤0.05 indicates a significant difference between the data of the observed (rain gauge) and estimated (GPCC) values)

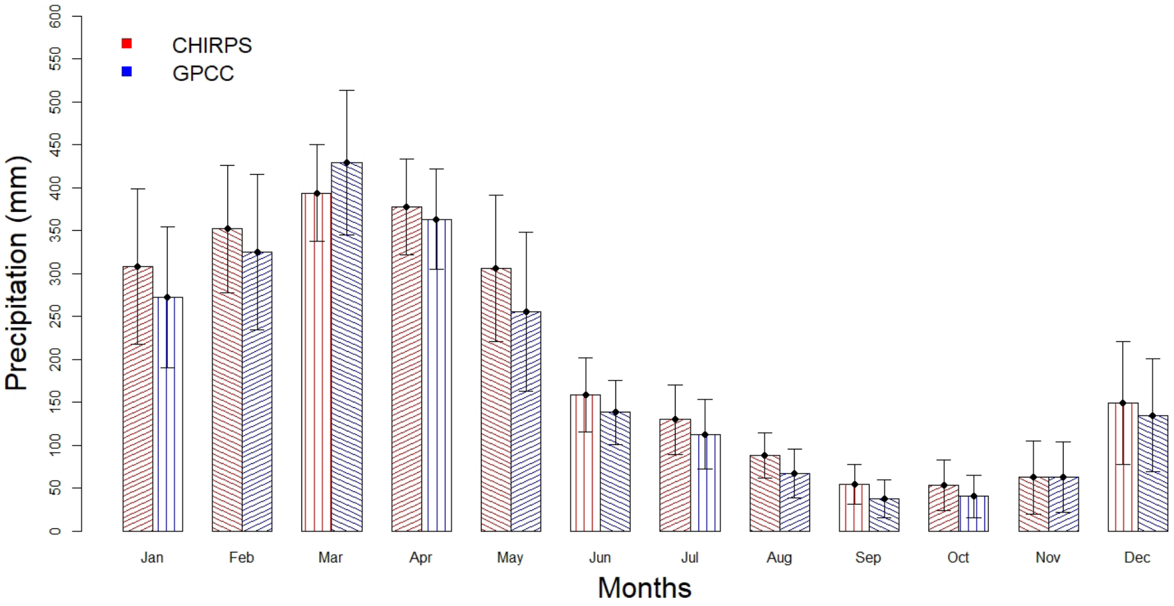
Month	P-value (GPCC/SDC)	P-value (GPCC/CSA)	P-value (GPCC/OUR)
January	0,1055	0,8418	0,006924*
February	0,009664*	0,9626	0,04692*
March	0,0002577*	0,1037	0,01731*
April	0,1932	0,6341	0,2895
May	0,3918	0,84	0,1886
June	0,07951	0,9311	0,3056
July	0,1258	0,05244*	0,04071*
August	0,0003063*	0,006783*	0,1705
September	0,3218	0,2063	0,9404
October	0,6093	0,3279	0,2041
November	0,5582	0,2997	0,2217
December	0,5596	0,6522	0,05773

Source: Authors

According to the comparison test, it is possible to reject the equality hypothesis for the CHIRPS/observed dataset, mainly for SDC, in January, February, August, September and November; and in February, May, June and August for OUR. For the values estimated by the GPCC, the rejection of the equality hypothesis for the GPCC/observed dataset occurred February, March, and August for SDC and, January, February, March and July for OUR. Thus, the months that influenced the loss of quality are identified in the statistical metrics previously presented. The higher occurrence of rejection of the hypothesis of equality between the measured and estimated value (CHIRPS or GPCC) in the rain gauges of São Domingo do Capim and Ourém influences the higher RMSE values, mainly for the rainy season. Also noteworthy is the greater occurrence of rejection of the hypothesis of equality between the measured and estimated rainfall values for the month of August in most of the sets, with the exception of GPCC/observed in Ourém.

The following is the average monthly rainfall for the period under study considering the total area of the Guamá River sub-basin. The average monthly precipitation for the period from 1988 to 2018 was satisfactorily estimated by CHIRPS (vertical bars with lines in red) and GPCC (vertical bars with lines in blue) for the study area (Figure 6).

Figure 6 – Average monthly precipitation data *, estimated by CHIRPS and GPCC, for the Guamá River sub-basin area (period 1988 to 2018) (* The barb represents the ±1 calculated standard deviation)



Source: Authors

In all months except March, the precipitation values estimated by CHIRPS for the region were higher than those estimated by GPCC. A concordance in the values only occurred for the month of November. Both databases have similar standard deviations. According to Lopes et al. (2013), variability from year to year of precipitation around average values is common.

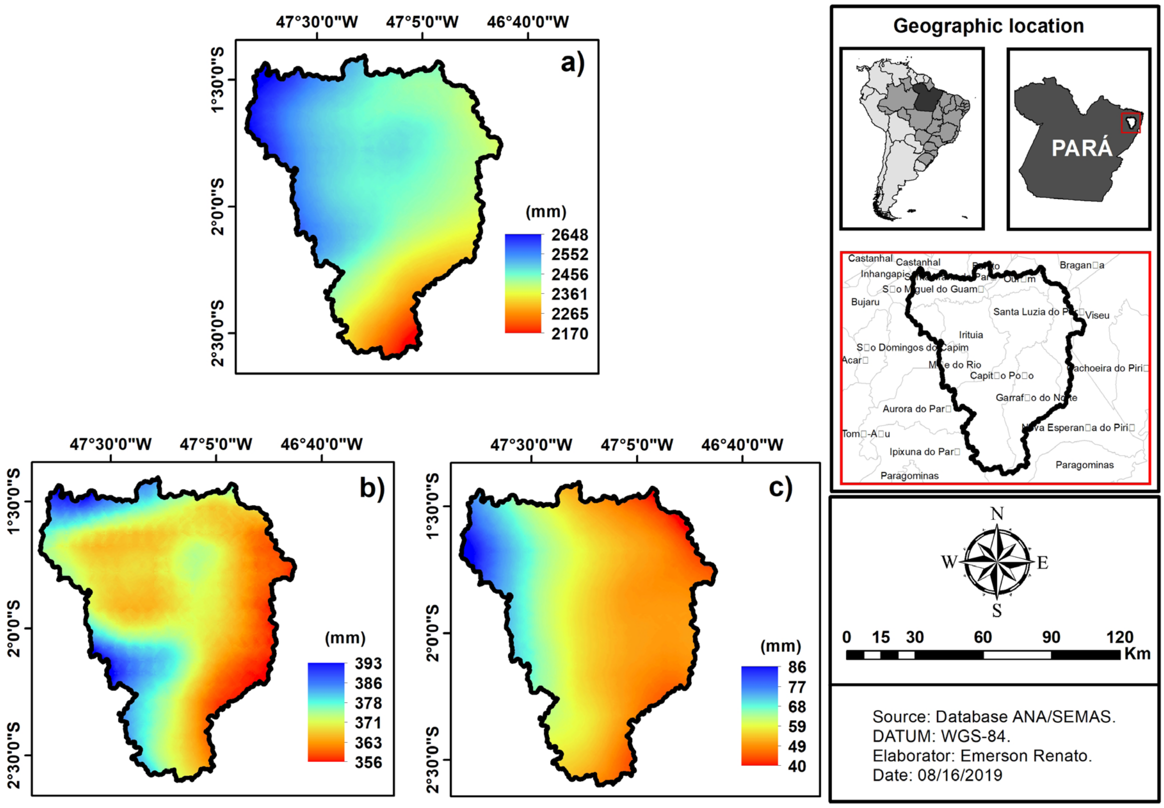
In general, both satellite databases showed the same seasonality in the GRSB area in the amount of precipitation as exists in the Amazon region in general (FIGUEROA; NOBRE, 1990; MARENGO, 1995; PAIVA; CLARK, 1995). Fisch et al. (1998) stated that the rainy period in the Amazon region comprises the months from November to March, while May to September represent the period of least convective activity (less rainy). The months not mentioned are thus transition periods between the two regimes.

The spatial distribution of rainfall data through the CHIRPS database provides a very detailed representation of climatology in the Guamá River sub-basin area. The low spatial resolution of the GPCC product generates rainfall interpolation maps with geometrical and pointed regions that are inconsistent with natural situations. Therefore, the last dataset was not used to generate the specialized distribution of precipitation in the GRSB area.

Figure 7 shows the interpolation, through universal kriging, of the annual average accumulated precipitation data provided by the CHIRPS database, for the period between 1988 and 2018 in the study area. To avoid the interference of the transition months between periods (rainy and less rainy), the interpolation of precipitation data was also carried out taking into account only the quarter with the months with highest precipitation values (February, March and April) and the quarter with the months with lowest precipitation values (September, October and November).

As shown by map with the annual accumulated average for the period (Figure 7a), the highest rainfall values (> 2,500 mm year-1) occurred in the northwestern portion and the lowest (<2,500 mm year-1) in the south/southeast of the sub-basin. According to the interpolated rainfall data, the average annual rainfall ranged from 2,170 to 2,648 mm/year and the rainfall showed a general pattern of increasing from southeast to northwest in the sub-basin area. According to Fisch et al. (1998), the value average yearly precipitation in the Amazon region is 2,300 mm. Lopes et al. (2013), in his study on the regional climatology of precipitation in the state of Pará, stated that in northeastern Pará, the highest precipitation rates were found throughout the year (values above 2,000 mm). Albuquerque et al. (2010) also presented a similar result to these last authors, attributing these high values concentrated in northeastern Pará to the occurrence of large-scale systems such as the ZCIT, strong local convection, cumulonimbus clusters and the proximity of coastal areas.

Figure 7 – Spatial distribution of CHIRPS data for (a) annual average accumulated precipitation; (b) average accumulated precipitation for the rainiest quarter (February, March, April) and (c) for the least rainy quarter (September, October and November) for the period from 1988 to 2018 (* Black outline represents the boundary of the Guamá River sub-basin area)



Source: Authors

On the other hand, the seasonal average maps consider only the months of the rainy and less rainy quarters (Figure 7b and 7c, respectively). In the rainy season, the highest precipitation values (> 380 mm year-1) were found close to the coast (north/northwest extension). The southwestern portion of the sub-basin area also showed high values in the rainy quarter (> 380 mm year-1). The lowest precipitation values (<370 mm year-1) were observed in the range from the southeast to the northwest of the sub-basin. In the less rainy quarter, the lowest values (<60 mm year-1) were found in the eastern half of the sub-basin. The highest values (> 70 mm year-1) were observed in a small portion to the northwest. In general, for the rainiest quarter (Figure 7b) the spatial distribution of precipitation increased from east to west, with peaks in the northwest and southwest portions, while in the less rainy quarter (Figure 7c), the spatial distribution of precipitation showed only an increasing pattern from east to west in the Guamá River sub-basin.

It should be noted that the distribution of rainfall was not affected by the topography of the region, since the main difference between seasonal periods was represented by the amount of rain rather than its distribution in the sub-basin area. According to Figueroa and Nobre (1990), in the eastern Amazon the annual precipitation values show a decreasing trend from the coastal region to the interior of Pará., so the phenomenon has global scale (Intertropical Convergence Zone) and mesoscale (Instability Lines), both of which have strong influence on the region's precipitation conditions (which includes the Guamá River sub-basin).

4 CONCLUSIONS

The present study evaluated the performance of CHIRPS, a new high-resolution precipitation climatology database, in northeastern Pará, specifically in the Guamá River sub-basin.

The data observed through rain gauges were strongly correlated (r = 0.99) with the rainfall estimated by satellite in the GPCC and CHIRPS databases for the period from 1988 to 2018 and also had a satisfactory agreement index (d = 0.98). The two databases overestimated of precipitation (by about 12% and 13% for CHIRPS and GPCC, respectively). In terms of seasonality, the statistical metrics between the CHIRPS/observed datasets were better for the less rainy period, despite the greater average percentage error (approximately 16%). Similar behavior was found for the statistical metrics obtained for the GPCC/observed dataset. In this case, the statistical metrics showed, through the values of BIAS and RMSE, that the proximity between the geographical location of the pluviometer and the point of extraction of the estimated precipitation contributes to obtain favorable results.

Thus, on the scale of the Guamá River sub-basin, the two satellite products, CHIRPS and GPCC, presented similar statistical metrics. This indicates that the two remote sensing databases can be used without impairment of conclusions, with more accurate results for the period with the least amount of rain in the Guamá River sub-basin.

The interpolation of precipitation data from CHIRPS demonstrated the pattern of spatial distribution along the Guamá River sub-basin consistent with the specific literature: high values (> 2,000 mm.year-1) of accumulated precipitation, seasonality during the months and growth of precipitation towards the coast (southeast to northeast in the annual accumulation and east to west in the seasonal aspect).

Finally, the satellite products studied are generated using several datasets and several different procedures for combining, mixing and correcting them. Based on the statistical metrics presented, there is a need to correct the sources of errors in order to better adapt the remote sensing precipitation data to the Guamá River sub-basin, thus obtaining more accurate grid data.

Due to the fundamental participation of this hydrographic basin in the economic and social development of the region, and the scarcity of specific works in the study area, the present study is relevant for the pluviometric monitoring of the region from other broad databases. These bases have greater regularity of measurements over a longer time scale.

With the results of the historical series of rainfall, it is possible to relate and evaluate the relationship between climatic trends found and the changes in land use and occupation in the region. Understanding how the various human activities affect the natural behavior of the hydrographic basin is important to distinguishing the anthropic effects from possible natural cycles in the region.

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REFERENCES

ADLER RF ,KIDD C, PETTY G, MORISSEY M, GOODMAN M. Intercomparison of Global precipitation products: the third precipitation intercomparison project (PIP-3). Bull. Am. Meteorol. Soc. 2001;82(7):1377-1396.

AGÊNCIA NACIONAL DE ÁGUAS (ANA), Ministério do Desenvolvimento Regional. Conjuntura dos recursos hídricos no Brasil: Informe 2017. Brasília: ANA, 2016.

AJAAJ AA, MISHRA AK, KHAN A. Comparison of BIAS correction techniques for GPCC rainfall data in semi-arid climate. Stoch. Environ. Res. Risk Assess. 2016;30:1659-1675.

ALBUQUERQUE MF, DE DOUZA EB, OLIVEIRA MCF, SOUZA JÚNIOR JA. Precipitação nas mesorregiões do Estado do Pará: climatologia, variabilidade e tendências nas últimas décadas (1978-2008). Rev. Bras. Climatol. 2010;6(6):151-168.

ARAUJO NA, GUETTER AK. Validação da chuva estimada por satélite “CMORPH” na modelação hidrológica do Alto Iguaçú. Rev. Bras. Recur. Hídricos. 2007;12(3):189-198.

BRAZ VN, MELLO VSA. Estudo temporal da qualidade da água do rio Guamá, Belém-PA. In: Congresso Brasileiro de Engenharia Sanitária E Ambiental [Internet]; 2005 Setembro 18-23; Campo Grande, Brasil. 2005 [cited 2019 jan 15]. Available from: https://pdfs.semanticscholar.org/1bb3/d85c17a2ceb9a9971120ef1cb2d a946b94ea.pdf.

BROHAN P, KENNEDY JJ, HARRIS I, TETT SFB, JONES PD. Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. J. Geophys. Res. 2006;111:D12106.

CAMPONOGARA G, SILVA DIAS MAF. Precipitação diária e estrutura vertical da atmosfera em Belém-PA. Ciênc. Nat. 2011;33 Suppl 1:263-266.

CHANDRAN A, BASHA G, OUARDA TBMJ. Influence of climate oscillations on temperature and precipitation over the United Arab Emirates. Int. J. Climatol. 2016;36:225-235.

COSTA CEAS, ARAÚJO JÚNIOR AJS, VIEIRA ASA, MATOS TR, SANJAD HC, CARVALHO BGP et al. Estudo de tendência pluviométrica na bacia do rio Guamá no período de 30 anos. In: 12º SILUSBA [Internet]; 2015 Novembro 22-27; Brasília, Brasil. 2015 [cited 2018 mar 25]. Available from: http://www.evolvedoc.com.br/silusba/download-2015-UEFQMDIwMzM5LnBkZg ==.

COSTA J, PEREIRA G, SIQUEIRA ME, CARDOZO F, SILVA VV. Validação dos dados de precipitação estimados pelo CHIRPS para o Brasil. Rev. Bras. Climatol. 2019;24(15):228-243.

DE SOUZA EB, CARMO AMC, MORAES BC, NACIF A; FERREIRA DBS; ROCHA EJP, et al. Sazonalidade da precipitação sobre a Amazônia Legal brasileira: clima atual e projeções futuras usando o modelo REGCM4. Rev. Bras. Climatol. 2016;18(12):293-306.

DINKU T. Validation of the CHIRPS satellite rainfall estimate. In: Proceedings of the 7th International Precipitation Working Group (IPWG) Workshop [Internet]; 2014 Novembro 17-21; Tsukuba, Japão. 2014 [cited 2019 jan 30]. Available from: https://sharaku.eorc.jaxa.jp/IPWG7/index.html.

DINKU T, FUNK C, PETERSON P, MAIDMENT R, TADESSE T, GADAIN H, et al. Validation of the CHIRPS satellite rainfall estimates over eastern Africa. Q. J. R. Meteorol. Soc. 2018;144(Suppl 1):292-312.

DUAN Z, LIU J, TUO Y, CHIOGNA G, DISSE M. Evaluation of eight high spatial resolution gridded precipitation products in Adige Basin (Italy) at multiple temporal and spatial scales. Sci. Total Environ. 2016;573:1536-1553.

ESPINOZA JC, RONCHAIL J, MARENGO JA, SEGURA H. Contrasting North–South changes in Amazon wet-day and dry-day frequency and related atmospheric features (1981–2017). Clim. Dyn. 2019;52:5413–5430.

FERREIRA DBS, SOUZA EB, MORAES BC. Ciclo horário da precipitação no leste da Amazônia durante o período chuvoso. Rev. Bras. Climatol. 2013;13(9):74-86.

FIGUEROA SN, NOBRE CA. Precipitations distribution over central and western tropical South American. Climanalise. 1990;5(6):36 -45.

FISCH G, MARENGO JA, NOBRE CA. Uma revisão geral sobre o clima da Amazônia. Acta Amaz. 1998;28(2):101-126.

FUNK C, PETERSON P, LANDSFELD M, PEDREROS D, VERDIN J, SHUKLA S, et al. The climate hazards infrared precipitation with stations: a new environmental record for monitoring extremes. Sci. Data. 2015;2:150066.

GALLARDO A. Geostadistica. Ecosistemas. 2006;15(3):48-58.

HESSELS TM. Comparison and Validation of Several Open Access Remotely Sensed Rainfall Products for the Nile Basin. [dissertation]. Delft: Delft University of Technolog, Netherlands; 2015. 233 p.

HUFFMAN GF, BOLVIN DT, NELKIN EJ, WOLFF DB. The TRMM Multisatellite Precipitation Analysis (TMPA): quasi-global, multi-year, combined-sensor precipitation estimates at fine scale. J. Hydrometeorol. 2007;8:38-55.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA [Internet]. Brasília: Ministério do Planejamento, Orçamento e Gestão (BR) [cited 2019 jun 02]. Censo demográfico 2010. Resultados Gerais da Amostra por áreas de ponderação. Available from: https://censo2010.ibge.gov.br/resultados.html.

JIMÉNEZ KQ, MELO TM, LOUZADA JA. Uso de dados de precipitação obtidos por sensoriamento remoto em um modelo agro-hidrológico. Irriga. 2013;18(3):496-508.

KATSANOS D, RETALIS A, MICHAELIDES S. Validation of a high-resolution precipitation database (CHIRPS) over Cyprus for a 30-year period. Atmos. Res. 2016;169:459-464.

LIMBERGER L, SILVA MES. Precipitação observada na Amazônia brasileira: comparação entre os dados das redes convencionais e dados da Reanálise I do NCEP/NCAR, CRU e GPCC. Rev. Bras. Climatol. 2018;22(14):20-37.

LOPES MNG, DE SOUZA EB, FERREIRA DBS. Climatologia regional da precipitação no Estado do Pará. Rev. Bras. Climatol. 2013;12(9):84-102.

MARCIANO AG, BARBOSA AA, SILVA APM. Cálculo de precipitação média utilizando método de Thiessen e as linhas de cumeada. Rev. Ambient. Água. 2018;13(1):e1906.

MARENGO JA. Interannual variability of deep convection in the tropical South American sector as deduced from ISCCP C2 data. Int. J. Climatol. 1995;15(9):995-1010.

MARENGO JA, LIEBMANN B, KOUSKY V, FILIZOLA N, WAINER IC. Onset and end of the rainy season in the Brazilian Amazon Basin. J. Clim. 2001;14:833-852.

MENEZES FP, FERNANDES LL, ROCHA EJP. O uso da estatística para regionalização da precipitação do Estado do Pará, Brasil. Rev. Bras. Climatol. 2015;16(11):64-71.

PAIVA EMCD, CLARK RT. Time trends in rainfall records in Amazonia. Bull. Am. Meteorol. Soc. 1995;76(11):2203-2209.

PAREDES-TREJO FJ, BARBOSA HA, KUMAR TVL. Validating CHIRPS-based satellite precipitation estimates in Northeast Brazil. J. Arid Environ. 2017;139:26-40.

PAREDES-TREJO FJ, BARBOSA HA, PEÑALOZA-MURILLO MA, MORENO MA, FARÍAS A. Intercomparison of improved satellite rainfall estimation with CHIRPS gridded product and rain gauge data over Venezuela. Atmos. 2016;29(4):323-342.

PRATA SS, MIRANDA IS, ALVES SÃO, FARIAS FC, JARDIM FCS. Floristic gradient of the northeast paraense secondary forests. Acta Amaz. 2010;40(3):523-534.

R Development Core Team [Internet]. Vienna: R Foundation for Statistical Computing (Austria) [cited 2019 abr 10]. R: A language and environment for statistical computing. Available from: http://www.R-project.org/.

RAZIEI T, MARTINS DS, BORDI I, SANTOS JF, PORTELA MM, PEREIRA LS, et al. SPI Modes of Drought Spatial and Temporal Variability in Portugal: Comparing Observations, PT02 and GPCC Gridded Datasets. Water Resour. Manag. 2015;29:487-504.

REBELLO FK, SANTOS MAS, HOMMA A KO. Modernização da agricultura nos municípios do Nordeste Paraense: determinantes e hierarquização no ano de 2006. Revista de Economia e Agronegócios. 2009;15(2):209-232.

RIVERA JA, MARIANETTI G, HINRICHS S. Validation of CHIRPS precipitation dataset along the Central Andes of Argentina. Atmos. Res. 2018;213:437-449.

ROCHA NCV. Avaliação da sustentabilidade hídrica segundo os modelos de uso e ocupação do território na bacia do rio Guamá – Pará, Amazônia Oriental [dissertation]. Belém: Universidade Federal do Pará, Belém/UFPA; 2017. 118 p.

ROCHA VM, CORREIA FWS, FONSECA PAM. Precipitation Recycling in the Amazon: a Review Study. Rev. Bras. Meteorol. 2015;30(1):59-70, 2015.

RUDOLF B, SCHNEIDER U. Calculation of gridded precipitation data for the global land-surface using in-situ gauge observations. In: 2nd Workshop of the International Precipitation Working Group [Internet]; 2005 Março 24-30; Califórnia, Estados Unidos. 2005 [cited 2019 abr 24]. Available from: https://www.researchgate.net/publication/253114707_Calculation_of_Gridded_Precipitation_Data_for_the_Global_Land-Surface_using_in-situ_Gauge_Observations/link/0deec53bbcb3a0e220000000/download.

SABER M, HAMAGUCHI T, KOJIRI T, TANAKA K, SUMI T. A physically based distributed hydrological model of wadi system to simulate flash floods in arid regions. Arab. J. Geosci. 2015;8:143-160.

SALIMON CI, VICTORIA RL, BROWN IF, STONE T, DAVIDSON EA. Mudança de cobertura da terra e fluxo de CO2 do solo para a atmosfera na Amazônia Sul Oriental. In: 11º Simpósio Brasileiro de Sensoriamento Remoto [Internet]; 2003 Abril 5-10; Belo Horizonte, Brasil. 2003 [cited 2019 mai 15]. Available from: http://marte.sid.inpe.br/col/ltid.inpe.br/sbsr/2002/11.14.10.20/doc/06_126.pdf.

SANTOS SRQ, SANSIGOLO CA, NEVES TTAT, SANTOS APP. Variabilidade sazonal da precipitação na Amazônia: Validação da série de precipitação mensal do GPCC. Rev. Bras. Geogr. Fís. 2017;10(6):1721-1729.

SCHNEIDER U, BECKER A, FINGER P, MEYER-CHRISTOFFER A, RUDOLF B, ZIESE M. GPCC Full Data Reanalysis Version 7.0: Monthly Land-Surface Precipitation from Rain Gauges built on GTS based and Historic Data [Internet]. EUA: Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory; 2016 [cited 2018 fev 15]. Available from: https://doi.org/10.5065/D6000072.

SHRESTHA MS, TAKARA K, KUBOTA T, BAJRACHARYA SR. Verification of GSMaP rainfall estimates over the central Himalayas. J. Hydraul. Eng. 2011;55:37-42.

SHRESTHA NK, QAMER FM, PEDREROS D, MURTHY MSR, WAHID SM, SHRESTHA M. Evaluating the accuracy of Climate Hazard Group (CHG) satellite rainfall estimates for precipitation based drought monitoring in Koshi basin, Nepal. J. Hydrol. Reg. Stud. 2017;13:138-151.

SILVA FL, OLIVEIRA FA, AMIN MM, BELTRÃO NES, ANDRADE VMS. Dimensões do uso e cobertura da terra nas mesorregiões do Estado do Pará. Espacios. 2016;37(5)5-24.

SOUZA EB, AMBRIZZI T. Pentad precipitation climatology over Brazil and the associated atmospheric mechanisms. Climanálise, 2003; 5(6):36-44.

SOUZA EB, FERREIRA DBS, GUIMARÃES JTF, FRANCO VS, AZEVEDO FTM, SOUZA PJOP. Padrões climatológicos e tendências da precipitação nos regimes chuvoso e seco da Amazônia Oriental. Rev. Bras. Climatol. 2017;21(13):81-93.

TORRES MF. A pesca ornamental na bacia do rio Guamá: sustentabilidade e perspectivas ao manejo [thesis]. Belém: Universidade Federal do Pará/UFPA; 2007. 287 p.

XU W, ZOU Y, ZHANG G, LINDERMAN M. A comparison among spatial interpolation techniques for daily rainfall data in Sichuan Province, China. Int. J. Climatol. 2015;35(10):2898-2907.

WANG G, ZHANG P, LIANG L, ZHANG S. Evaluation of precipitation from CMORPH, GPCP-2, TRMM 3B43, GPCC, and ITPCAS with ground-based measurements in the Qinling-Daba Mountains, China. PLoS ONE. 2017;12(10):e0185147.

WILLMOTT CJ. On the validation of models. Phys. Geogr. 1981;2(2):184-194.