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## SPACIALIZATION OF RAINS IN A HYDROGRAPHIC BASIN IN THE SEMIARID OF PARAÍBA

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### Abstract

The northeastern semi-arid region of Brazil has high temperatures associated with low rainfall, which occur intensely and are poorly distributed throughout the geographical space. From this perspective, there is a need to understand the dynamics of rainfall in the dry perimeter in order to substantiate the various forms of water resources management. However, the availability of rainfall data in this region is sometimes scarce, which implies interpolation as a way of understanding the distribution or spatialization of rainfall in various spatial cutouts. Quantitative analysis of rainfall data allows us to understand the dynamics and relationship with the main precipitation systems of a given study area. Thus, the objective of this work is to quantify and spatialize the rainfall data correlating them with the rain producing systems between the wettest and driest year of the Piranhas River Upper Course drainage basin, Semi-arid - PB between January 1996 and December 2016. Given the above, it was identified that the year 2008 was the wettest and 2012 the driest in the series, and that ITCZ's performance varies year-on-year according to SSM temperature.

**Keywords:** Semi-arid; Precipitation; Spatialization.

### ESPACIALIZAÇÃO DAS CHUVAS EM UMA BACIA HIDROGRÁFICA NO SEMIÁRIDO DA PARAÍBA

#### Resumo

O semiárido nordestino do Brasil apresenta altas temperaturas associadas a baixos valores pluviométricos, que ocorrem de forma intensa e mal distribuída no espaço geográfico. Nessa perspectiva, existe a necessidade de compreensão da dinâmica das chuvas no perímetro seco no intuito de fundamentar as diversas formas de gestão dos recursos hídricos. No entanto, a disponibilidade de dados pluviométricos nessa região por vezes é escassa, o que implica a interpolação como meio de compreensão da distribuição ou espacialização das chuvas em diversos recortes

espaciais. As análises quantitativas dos dados de chuva permitem compreender a dinâmica e relação com os principais sistemas de precipitação de determinada área de estudo. Sendo assim, o objetivo deste trabalho é quantificar e espacializar os dados de chuva correlacionando-os com os sistemas produtores de chuva entre um ano mais chuvoso e outro seco da bacia de drenagem do Alto Curso do Rio Piranhas, Semiárido (PB) entre janeiro de 1996 e dezembro de 2016. Dado o exposto, foi possível identificar que o ano de 2008 foi o mais chuvoso e 2012 o mais seco da série, e que a atuação da ZCIT varia interanualmente nos respectivos anos de acordo com a temperatura da TSM.

**Palavras-chave:** Semiárido; Precipitação; Espacialização.

### ESPACIALIZACIÓN DE LA LLUVIA EN UNA CUENCA HIDROGRÁFICA EN LA SEMIÁRIDA DE PARAÍBA

#### Resumen

La región semiárida del noreste de Brasil tiene altas temperaturas asociadas con bajos valores de lluvia, que ocurren de manera intensa y mal distribuida en el espacio geográfico. Desde esta perspectiva, es necesario comprender la dinámica de las precipitaciones en el perímetro seco para apoyar las diversas formas de gestión de los recursos hídricos. Sin embargo, la disponibilidad de datos pluviométricos en esta región a veces es escasa, lo que implica la interpolación como un medio para comprender la distribución o espacialización de la lluvia en diferentes áreas espaciales. Los análisis cuantitativos de los datos de lluvia nos permiten comprender la dinámica y la relación con los principales sistemas de precipitación en un área de estudio determinada. Por lo tanto, el objetivo de este trabajo es cuantificar y espacializar los datos de lluvia correlacionándolos con los sistemas productores de lluvia entre un año más lluvioso y un año más seco en la cuenca de drenaje del curso superior del río Piranhas, semiárido (PB) entre enero 1996 y diciembre de 2016. Dado lo anterior, fue posible identificar que 2008 fue el año más lluvioso y 2012 fue el más seco de la serie, y que el rendimiento de ZCIT varía año tras año en los años respectivos de acuerdo con la temperatura del TSM.

**Palabras-clave:** Semiárido; Precipitación; Espacialización.

## 1. INTRODUCTION

The climate is usually determined by the way in which the general circulation of the atmosphere occurs. The circulation patterns of the atmosphere redistribute heat, humidity and wind direction across the globe (FERREIRA; MELLO, 2005). From a climatic point of view, the northeastern semi-arid region has high insolation and air temperature values characteristic of the tropical region, where it is also marked by low annual rainfall values, with irregular and intense distribution in time and space (ALVES et al., 2015). These conditions of the climatic elements associated with the geological characteristics of a mostly crystalline substrate provides less availability of water resources for the region with direct negative effects for the population that inhabits it (ZANELLA, 2014).

The atmospheric circulation over the semiarid region is closely related to thermodynamic variations, mainly over the ocean basin of the Tropical Atlantic. With that said, positive or negative anomalies may occur and that are related to the variations in the amount and intensity of rainfall over the region, taking into account that the semiarid region is inserted close to the global low latitudes, that is, a low pressure zone that converges hot and humid ascending air over the equator and forming clouds through the condensation process as it loses heat through the adiabatic cooling of the air (FERREIRA; MELLO, 2005).

Precipitation is a type of atmospheric phenomenon in the form of rain, hail or snow. The material used in its collection is called pluviometer, and the beaker allows the measurement of the quantity that occurs in a certain time interval (BARBOSA, 2006). Therefore, aridity does not correspond to the amount of precipitation that occurs in a given area, but its index is calculated based on the relationship between precipitation and evapotranspiration. It is important to emphasize that drought cannot be confused with aridity index, because while the first consists of prolonged drought (SILVA; MOURA, 2018), the second refers to the precipitation / evaporation ratio according to the classification proposed by Thornthwaite (CAVALCANTI et al., 2006).

The main mechanisms that dictates the rain regime in the region are the Sea Surface Temperature, Trade Winds, AICZ (Atlantic Intertropical Convergence Zone), Cold Fronts (mainly the zones of repercussion when more intense) and the UTCS (Upper Tropospheric Cyclonic Circulation Systems) (RIBEIRO; ARAGÃO; CORREIA, 2013).

Among the systems that cause precipitation in the northeastern semiarid, Atlantic Intertropical Convergence Zone is the main supplier of rainfall and can be defined as a set of clouds that accompanies the Earth's equator (FERREIRA; MELLO, 2005), and operates from February to May reaching the Sententrional States of the Brazilian Northeast. It is formed by the confluence of the NE and SE trademarks in a zone of low pressure and high temperatures at sea level, reaching the northeastern areas during the summer season in the southern hemisphere (ZANELLA, 2014). It normally migrates between latitudes 14°N between August and October and 4°S between February and April. Such displacement is closely related to the sea surface temperature, because the Atlantic Intertropical Convergence Zone is more significant over the oceans and for this reason the

sea surface temperature is a major factor in its position and intensity (FERREIRA; MELLO, 2005).

The high level cyclonic vortices are closed cyclonic circulations, where the center is colder than its surroundings, causing the subsidence of the air and inhibiting the formation of clouds in its central part, with hot and humid peripheries, generating the ascension / condensation of the air and consequently precipitation (VAREJÃO-SILVA, 2006), and they transform potential energy into kinetic by the downward movement in the cold center and upward in the periphery (KOUSKY; GAN, 1981).

According to Chan (1990) it was from the studies of Riehl (1945) in the Caribbean region that the East Waves were identified through the observation of oscillations in the pressure and wind fields moving from east to west in the lower troposphere. It was Yamazaki and Rao (1977) who discovered that east waves or east wave disturbances can occur in the Atlantic Ocean region adjacent to the Northeast coast of Brazil. The East Waves are conglomerates of convective clouds that move to the West, form over the Ocean, losing strength as it enters the continental mass and can last from one to two weeks (VAREJÃO-SILVA, 2006).

Barbosa (2006) states that precipitation is one of the most widely used geostatistical climatic elements to systematize and classify the various climatic types, as it is among the most discussed in atmospheric weather. A correct analysis of the distribution of rainfall is of fundamental importance for the planning of water resources in drainage basins, providing support for climatological and meteorological studies (MARCUIZZO; ANDRADE; MELO, 2011). Therefore, the importance of water resources and the knowledge of the locations of their greatest occurrences for considerable management is considerable. As it is a random natural element, the distribution of precipitation in space does not repeat exactly the same in different annual periods in a quantitative perspective, although it points to the places where its greatest frequencies and incidences should be expected (SALGUEIRO; MONTENEGRO, 2008).

Generally, the most used process to represent the amount of rain in a given area occurs through isoiets, which are traced or curved that unite the points of homogeneous precipitation in a certain period of time (MARCUIZZO; ANDRADE; MELO, 2011). However, statistical analysis allows understanding of individual or integrated elements (depending on the researcher's objective) of the climate (BARBOSA, 2006).

A quantitative assessment of rainfall is always important in any physical context, especially when it comes to issues such as culture, management of water resources, environmental assessment, identification of rainy periods, etc. It is important to note that the cost of having a large network of instruments installed that support the collection of data on precipitation is high (RIGHI; BASSO, 2016), making it necessary to use spatial data interpolation procedures to obtain data in non-spatial areas. sampled (CARVALHO; QUEIROZ, 2002).

Interpolation methods are tools generally used to generate distributed data for a given variable from point data, as they contribute to spatial understanding of attributes without having to collect data across the study area, as this rainfall deficit is recurrent where the interpolation is seen as a mathematical

process responsible for generating intermediate data between existing point values (RIGHI; BASSO, 2016).

The spatial representation models have in the interpolation methods an improvement of data and techniques of analysis of the reality that do not have sample data. In this perspective, among the several interpolators existing in GIS environments (Geographic Information System - computer programs), Krigagem can be understood as an estimator based on regression analysis techniques, linear or not, with the purpose of minimizing the variance estimated (NOGUEIRA; AMARAL, 2009).

The Kriging tool assumes that the spatial variation of the represented phenomenon is statistically homogeneous over the entire surface, that is, it is based on a continuous function that explains a given variable in different directions on the geographic surface, allowing combining the variability of the combination with the base of the distance that exists between two points, thanks to the semivariogram (GALLARDO, 2006. Apud. RIGHI; BASSO, 2016). Thus, the objective of this work is to quantify and spatialize the rain data and to identify the rain-producing systems between the rainiest and driest years of the drainage basin of the Upper Course of the Piranhas River, Semi-Arid (PB).

## 2. METHODOLOGY

### 2.1. Study area

This study has as its research area the Upper Course of the Piranhas River basin located in the Paraíba interior, occupying an area with 35 municipalities that among the main ones are: Cajazeiras, Souza and Pombal. The exutory point of the Upper Course of the Piranhas River is at the confluence with the Piancó River and the main channel is 174.22 km long. The area of the basin is approximately 5995 km<sup>2</sup>, in the interior of Paraíba, having physical characteristics similar to a good part of the Brazilian Northeastern semi-arid. The Paraíba hinterland is organized around the Borborema Plateau, and is the result of morphology inherited from morphostructural processes, where in these flattened areas the denudational processes surpass the pleasant ones, forming vast erosive surfaces (MAIA; BEZERRA; SALES, 2010) (Figure 1).

It should be noted that the Upper Course of the Piranhas River will act as a receiver and passage of the waters received by the North Axis of the São Francisco River Integration Project, as it has a regulatory framework that establishes delivery flow at the state border between Paraíba and Rio Grande do Norte, which will perpetuate it completely. Therefore, studies on precipitation are essential for understanding its dynamics, which allows the development of better measures / management of water resources available during the year.

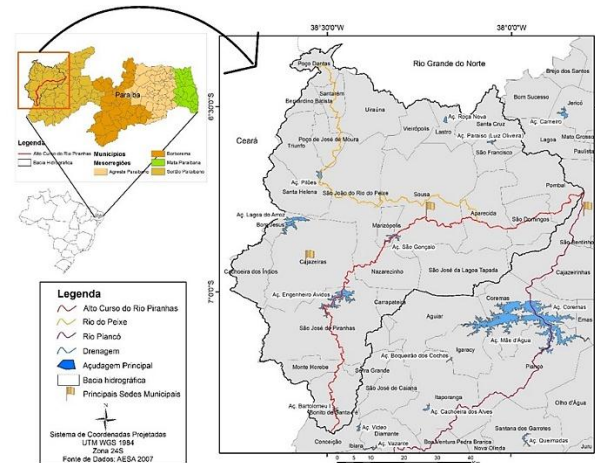


Figure 1 – Location map of the Upper Course Basin of the Piranhas River. Data source: AESA (2019). Elaboration: Author (2019).

The basin was delimited using SRTM raster data provided by the USGS (United States Geological Survey). The shapes of the Municipalities, Northeast region, Weirs and main drainage were obtained at the Geoportal of the Executive Water Management Agency of the State of Paraíba (AESA).

From the SRTM data it was also possible to generate the Digital Elevation Model that reflects the terrain's topography, which combined with the line vector referring to the annual rainfall totals provided by Geoportal AESA, allowed to identify the amount of rain according to the topographic position in the basin (Figure 2).

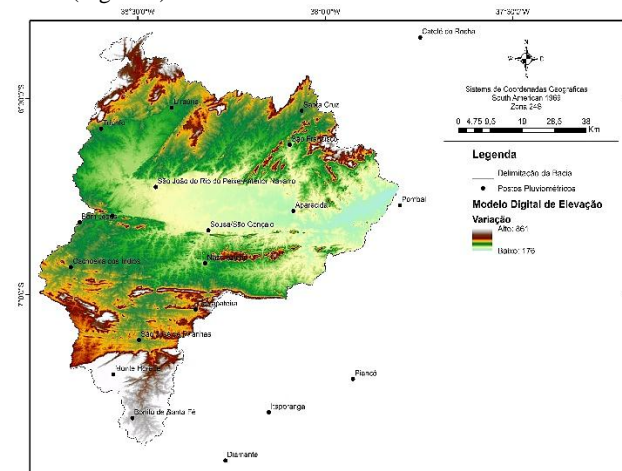


Figure 2 – Location of stations and Digital Elevation Model. Source: AESA (2019). Elaboration: Author (2019).

Figure 2 also indicates the 20 rainfall stations that were selected according to the pattern of corresponding collection years between them. The stations are distributed throughout the basin and are located at different altitudes. Five stations were selected outside the perimeter of the basin due to the need for the interpolation method that required better spatialization of the

point precipitation data. Subsequently to the result of the interpolation, data from the internal part of the basin area were extracted.

## 2.2. Procedures for spatialization of rain

In order to specialize the rains and understand their dynamic in the Upper Course of the Piranhas River basin, it was necessary first to define the annual totals of the historical series, followed by the definition of the rainiest and least rainy year. The third stage consists of identifying the rainy season and the dry season. Finally, the definition of more and less rainy years in the basin will be associated with the sea surface temperature according to the months of the dry and rainy season, in order to understand the importance of this variable in the rain-forming systems in the region.

In the first stage, daily precipitation data were used between January 1996 and December 2016. These data were treated in the Microsoft Excel program, which made it possible to define the annual totals and the respective monthly averages of 20 pluviometric stations, 15 within the basin area, and 5 out. It is important to note that the database used is the maximum limit of time available for the area under study, where the data presents standardization without fail in the years of collection in all the stations that were worked on.

The tabulation of the data in order to generate the annual totals by season of the pluviometric series was an important step for spatialization, as it allowed to define the rainiest and driest year in the series. The organization of the monthly average data for all seasons in the series made it possible to understand the distribution of the amount of rain per month, that is, what are the rainiest and driest months, making it possible to identify the rainy and dry season. The tabulated data was organized in a spreadsheet in .xls format because the processing of information in the GIS works with this extension.

For the second stage, Esri's ArcMap 10.5 software was the geoprocessing program used to use the Linear Kriging method that allowed interpolating the data and generating precipitation values for the areas that did not have data, attributing the spatialization of the monthly average rainfall information analyzed from cartographic representation. This processing allows interpolating data and specializing rain information for the entire study area.

The use of this method required pluviometric data from stations outside the basin area, as the stations located inside the basin did not comprise the totality of the analyzed area, considering the variation of rain in space and time, that is, to obtain a close result reality.

Information on sea surface temperature was obtained from the FUNCEME database, both for the wettest year and also for the driest year. This database identifies the sea surface temperature through 16 buoys over the Atlantic Ocean. With that, it is possible to correlate the variations on the sea surface temperature with the seasons of the basin.

Finally, the satellite image bank of the Satellite and Environmental Systems Division of the Center for Weather Forecasting and Climate Studies (CPTEC - *Centro de Previsões e Tempo de Estudos Climáticos*) and the National Institute for Space Research (INPE - *Instituto Nacional de Pesquisas*

*Espaciais*) made it possible to obtain satellite images for the rainiest month and driest for both the wettest and driest years. These images served as the basis for identifying the most active system in the selected periods.

## 3. RESULTS AND DISCUSSION

The rains in the Upper Course of the Piranhas River basin do not occur homogeneously annually, because they both vary in annual precipitation levels and spatiality. Thus, to represent the variation in rainfall annually, the average annual rainfall for the study area was used (Figure 3). To represent the quantitative variations in space, it was necessary to define the wettest and driest year, showing the amount of rain in contrasting years for each season (Figure 4).

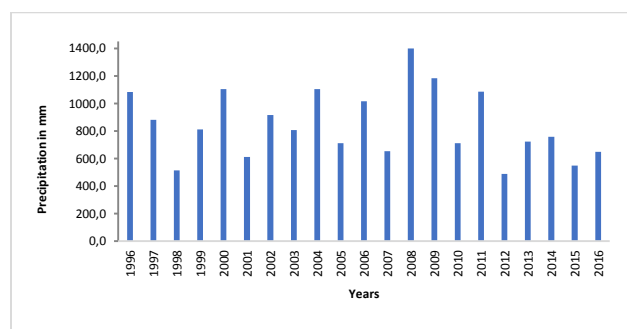


Figure 3 – Average rainfall per year in the Upper Piranha River Basin. Source: AESA (2018). Elaboration: Author (2019).

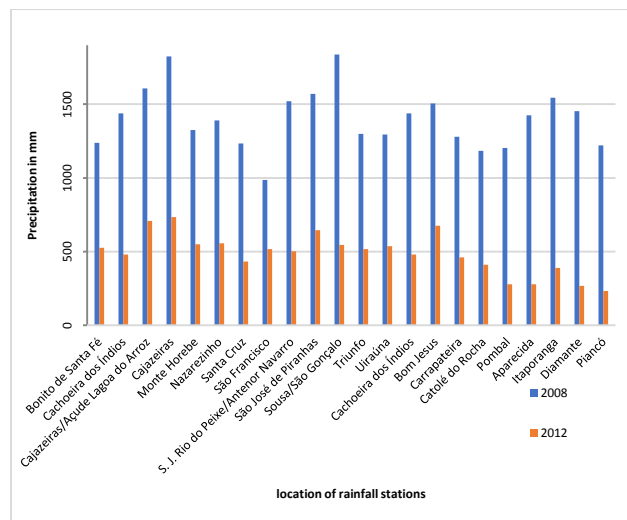


Figure 4 – Amount of rain in the rainiest (2008) and driest (2012) year of the historical series for each station analyzed in the Upper Course of the Piranhas River and adjacent stations analyzed. Source: AESA 2018. Elaboration: Author (2019).

Through Figure 3, it was possible to note that the year of 2008 presented rainfall values above 1400 mm, while the year 2012 presented a little more than 500 mm. In this perspective, the difference in the amount of rain between 2008 (rainiest year) and

2012 (driest year) was almost three times greater. Through the definition of the wettest and driest year, it was possible to identify the amount of rain per season for each of these years as seen in Figure 4.

In 2008, the station with the highest amount of rain was the Souza / São Gonçalo station at an altitude of around 250 m, with precipitation values above 1700 mm; the season with the lowest rainfall in 2008 is that of San Francisco at an altitude of around 350 m with rainfall totals below 1000 mm. In 2012 it is the Cajazeiras station with 734 mm at an approximate altitude of 400 m that presents the largest amount of rain; the season with the least amount of rain for this dry year is Piancó with 232 mm, located at an altitude of 312 m.

It is important to note that the Piancó station is outside the hydrographic limits for reasons of interpolation. In this perspective, it is important to note that the rainfall values for both the rainiest and the driest year indicate that there are variations in the total annual amount according to the location of the seasons.

In order to understand the dynamics of rainfall and its relationship with the temperature of the sea surface, it was necessary to graph the average monthly rainfall (Figure 5) and spatialize the monthly precipitation data (Figure 6) in order to identify the most frequent months. rainiest and driest in the series of years analyzed.

Thus, Figure 5 shows that the first 5 months of the year (from January to May) correspond to the rainy season in the basin, as the first 4 months manage to exceed 100 mm of monthly rainfall. Conversely, the other months of the year remain below 50 mm (with the exception of May), especially the months of August and September, which are the driest months in the basin. Thus, based on the rain data, it was possible to generate the spatial map of rainfall in the Upper Course of the Piranhas River basin (Figure 6).

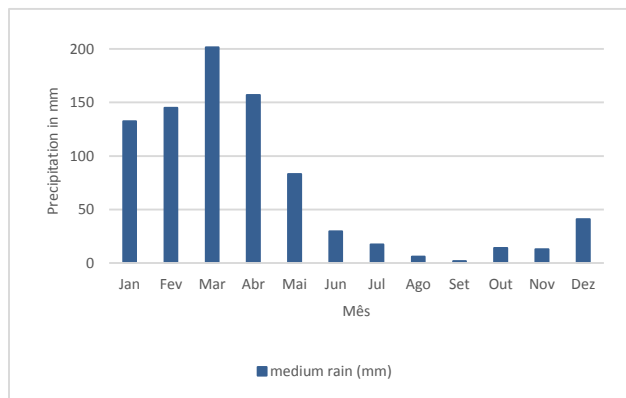


Figure 5 – Average monthly values for all stations in the series from 1996 to 2016. Source: AESA (2019). Elaboration: Author (2019).

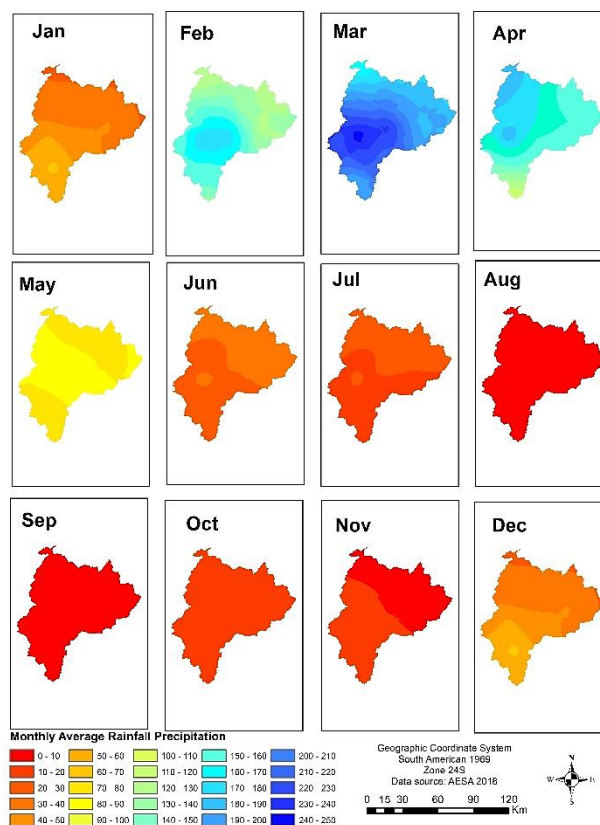


Figure 6 – Spatialization of monthly rainfall data in the Upper Course of the Piranhas River basin from January 1996 to December 2016. Elaboration: Autorial (2019).

Figures 5 and 6 indicate that March is the rainiest month among the first five months of the year (rainy season in the basin). On the other hand, September is the driest month of the dry season, showing the interannual contrast of the amount of rain that occurs in the basin. The performance of the rains in the first months of the year is due to the fact that in this season the South Atlantic is hotter in relation to the North Atlantic (Figure 7), implying a weakening of the South Atlantic Semi-fixed Anticyclone, where such depression thermal pushes the air masses in a vertical north-south direction reaching the central parts of the Brazilian Northeast (NIMER, 1966).

From the definition of March as the rainiest month of the year and September as the driest, it was possible to correlate these notes with the rain forming systems for the studied basin region. According to the sea surface temperature data provided by FUNCEME (*Fundação Cearense de Meteorologia e Hídricos*), the sea surface temperature is more heated in March and less heated in September for the South Atlantic, both for 2008 and 2012 (Figure 7).

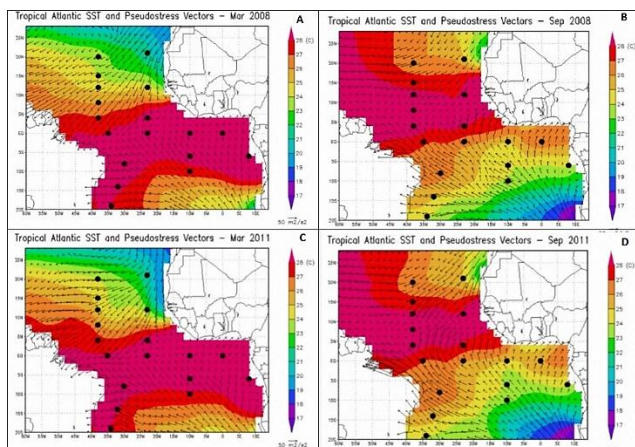


Figure 7 – Sea Surface Temperature Variation in March 2008 (A) and September 2008 (B) referring to the rainy season; March 2012 (C) and September 2012 (D) referring to the dry season. Source: FUNCEME (2019).

Through the satellite images provided by DSA (*Divisão de Satélites e Sistemas Ambientais*) - CPTEC / INPE, it was possible to have access to Meteosat 9 / Eumetsat images, of rectangular projection for South America, which makes it possible to visually identify the rain systems acting in the region for the dry and rainy periods of 2008 and 2012 (Figure 8).

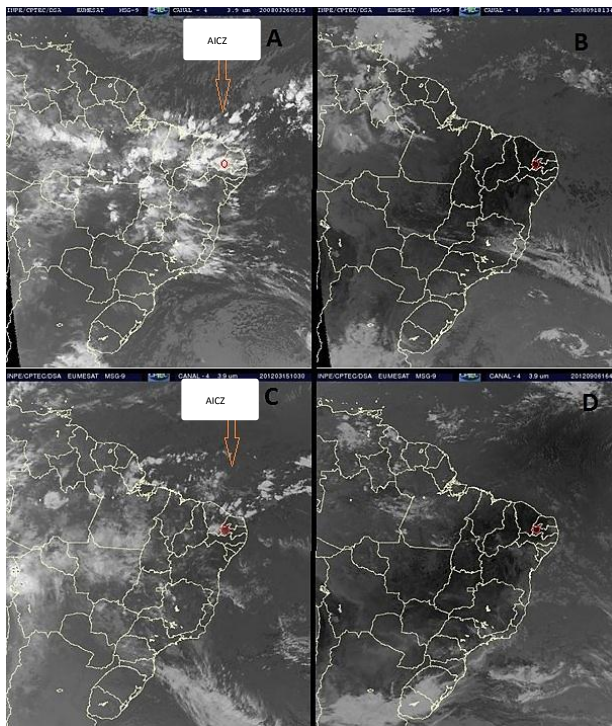


Figure 8 – Spatial representation of the Intertropical Convergence Zone for the months of May and September of the years 2008 (Rainy) and 2011 (Dry). A - March 24, 2008; B - September 10, 2008; C - May 15, 2012; D - September 6, 2008.

The red circle corresponds to the location of the study area. Source: CPTEC / INPE 2019.

According to Chung (1982), the increase in the temperature of the sea surface of the South Atlantic weakens the semi-fixed anticyclone of the South Atlantic and allows the displacement of the Intertropical Convergence Zone further south, which consequently causes more intense rains in the Northeast of Brazil. In this way, the performance of the Intertropical Convergence Zone is concentrated from February to May (ZANELLA, 2014), which makes it possible to infer that this period associated with the performance of the High Level Cyclonic Vortexes in January (XAVIER; MACIEL; SILVA, 2016) refers to if to the rainy season of the hydrographic basin of the Upper Course of the Piranhas River, considering that the total of rains are considered high if compared with the dry months.

The Intertropical Zone of Convergence is the macro-scale system and the main responsible for the rains that occur in the Upper Course of the Piranhas River between the months of January to April, with greater intensity in the month of March. However, this intensity can vary annually, where in a rainier year the Intertropical Convergence Zone can present itself with considerable concentration of clouds over the region as can be seen in part A of Figure 8, which corresponds to the month of March of the year of 2008, in contrast to the month of March of 2012 in part C of Figure 8, which presents less clouds than the rainy year of 2008. This variation can be associated mainly to the Dipole of the Atlantic, where the waters of the Atlantic Ocean can to have favored mainly the year 2008, because the dipole is a phenomenon that occurs through the ocean-atmosphere relationship that identifies a possible anomalous change in the temperature of the tropical Atlantic sea surface (BARBOSA, 2016).

Another factor for the difference in cloud concentration between the month of March 2008 (rainy) and the month of March 2012 (dry), which is the moment of greatest performance in the Intertropical Convergence Zone over the Alto Piranhas basin, may be associated with positive anomalies in the values of the Temperature of the Surface of the Sea of the Pacific Ocean, this generating a phenomenon of global scale denominated like El Niño (BARBOSA, 2016).

It is important to note that the East Waves operating mainly in the month of June are not able to generate considerable amounts of rain in the basin, because the continentality factor prevents the air masses coming from the ocean to arrive with enough force to generate large precipitations in the interior of the continent (RIBEIRO; ARAGÃO; CORREIA, 2013), considering that the basin is located about 300 km from the eastern continental coast of the State of Paraíba.

#### 4. CONCLUSIONS

The Upper Course of the Piranhas River basin located in a semi-arid environment has variation in the distribution and amount of rain, both spatial and temporal. Thus, rainfall totals can vary both monthly and annually, depending on the conditions and influences of the precipitation-forming systems in the area. The first five months of the year are the rainiest, given that precipitation is mainly attributed to the performance of the Intertropical Convergence Zone in this period of the year.

However, the performance of the Intertropical Convergence Zone depends on other factors, mainly the Sea Surface Temperature, which indicates the thermodynamic variation of the ocean waters and, consequently, the extent of the influence of the expansion / retraction of the South Atlantic Semi-fixed Anticyclone.

The application of quantitative methods in order to understand the dynamics of rainfall is an essential tool for analysis, allowing the identification of rainy days, months or periods, as well as less rainy ones. However, the lack of data in some regions makes it difficult to obtain data, making it necessary to use interpolation methods that allow inferring data about the deficit areas. This method is accessible and generally manages to achieve objectives, as occurred in this research. However, it is important to consider that the objective must be consistent with the proposed interpolation, allowing the researcher to achieve the interpretation of his object of study.

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