

Climate variability and extreme events occurrence in Petrolina-PE municipality

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Received 28 January 2016; accepted 20 April 2016

Abstract

The Brazilian semi-arid features high climate variability, both spatial and temporal, and it constitutes one of the most vulnerable regions to possible changes in climate. The occurrence of droughts in the region has historically caused economic losses in agriculture and consequently on their local population's well-being. This paper aims to analyze climate variability and extreme events in Petrolina municipality, in the State of Pernambuco and in the low middle São Francisco's development region. We used a Petrolina rainfall station data, selected at 1915 to 2014. Mann-Kendall trend test and the Rainfall Anomaly Index (RAI), respectively, were applied for analysis of climate variability and extreme events. The results point to an increasing trend in precipitation, with statistical significance. This increase has occurred mainly since the 1960s, with the occurrence of the rainiest years from this year on. Meanwhile, the RAI revealed the occurrence of considered 19 years as very dry and two years classified as extremely rainy, highlighting the year 1985, which recorded the highest rainfall in the series (1059 mm).

Keywords: Climatic trend, RAI, semi-arid, rainfall.

1. Introduction

The Brazilian Northeast has high climatic variety, displaying from the semi-arid hinterlands with accumulated rainfall of less than 500 mm / year, to wettest climates, mainly on the East Coast, with annual cumulative rainfall exceeding 1,500 mm. The main rainy season (over 60% of the annual total) in the North of the Region occurs from March to May. The dry season in the semi-arid occurs between August and October, in a northwest / southeast oriented range, from the west

end of the Northeast Region. The most affected area with lack of rain is called the Drought Polygon, a more than one million square kilometers area where 27 million people live, spread in eight Northeastern states (only Maranhão is not included) and the north of Minas Gerais (Marengo, 2008a).

In the Brazilian context, the semi-arid arises as one of the most sensitive regions to climate change. In addition to historically being affected by severe droughts with large agricultural and human losses, climate projections indicate the

region as the country's most affected area in climate change (BRASIL, 2009). The water availability in Brazil largely depends on the weather.

The annual cycle of rains and streamflow in the country varies among basins, and in fact, the interannual climate variability, associated with the phenomena El Niño, La Niña, or with the temperature variability of the Tropical and South Atlantic sea surface can cause climate abnormalities, producing severe droughts, as in 1977, 1983 and 1998 in Northeast Brazil (Marengo, 2008b). Historically, the northeastern semi-arid region is desolated by cyclical droughts, which can be very severe, bringing substantial impacts on agricultural systems, such as loss of livestock and crops (Lindoso et al., 2013). According to predictions, these changes may intensify extreme events occurrence.

Within this context and mainly due to the difficulty of access to many areas, mathematical models and anomaly indexes have been widely used to analyze climate patterns through historical series and predict their future behavior, such as the Mann Kendall test and the Rainfall Anomaly Index (RAI).

The Mann-Kendall test considers that the data needs to be independent and identically distributed random variables. The characteristics of this test are important when applied to the climatological series, such as rainfall, because they do not depend on the temporal series type. Goossens and Berger (1986) assert that the Mann-Kendall test is suitable for analyzing climate change in temporal series because it allows the detection and approximate location of a certain trend starting point (Ferrari et al., 2012).

According to Da Silva (2009), with the use of climate indices, e.g. the RAI, one may develop a monitoring system of the characteristics of the dry or rainy periods, with annual, seasonal or monthly data. Climate indices facilitate deep understanding of the climatology of a region, and verify the impact that global climate causes on local rainfall distribution, that is, the regionalization of precipitation for a given location

(Marcuzzo and Goulart, 2012). Faced with the debate on climate change, one enters into context in how these changes would affect climate on a local scale. Thus, the goal of this work is to analyze climate variability and extreme events in Petrolina-PE municipality.

2. Materials and methods

2.1 Study area location and characterization

The municipality of Petrolina is at the extreme west of the State of Pernambuco and inserted in the Petrolina-Juazeiro Economic Development Integrated Network. Tropical semi-arid is the prevailing climate and it is characterized by short periods of rain with annual rainfall ranging between 300-800 mm, it shows high air temperatures and high evaporation rates which results in reduced water availability in the majority of the year. This harsh climate is the main reason for the predominance of temporary rivers and xerophytic vegetation, characterized by cactaceous and other thorny species (Rocha, 2009).

Three major agricultural areas can be identified in the municipality, namely: rain-fed, irrigation perimeter and riverine, characterized by different forms of access to water. Rain-fed agriculture is the one that counts on hydric resources resulting from rainfall, and their agricultural activities are around streams and temporary waterways (Taura et al., 2011). Therefore, they are more vulnerable to droughts. Irrigated agriculture is represented by the irrigated perimeters Nilo Coelho and Bebedouro. This type of agriculture boosted from the construction of several dams along the São Francisco River, especially Sobradinho dam in the late 1970s (Andrade, 2005). The Senador Nilo Coelho irrigated perimeter has 80% of two lands inserted in Petrolina municipality, having approximately 22,949 hectares total irrigable area. In addition, it also has 2,082 small farmers with family plots (up to 7 ha), 227 small, medium and large companies (over 50 ha), having mango (38.42% of total area), grape (22.6% of total area) and guava (9.8%) as main crops (DNIC, 2014).

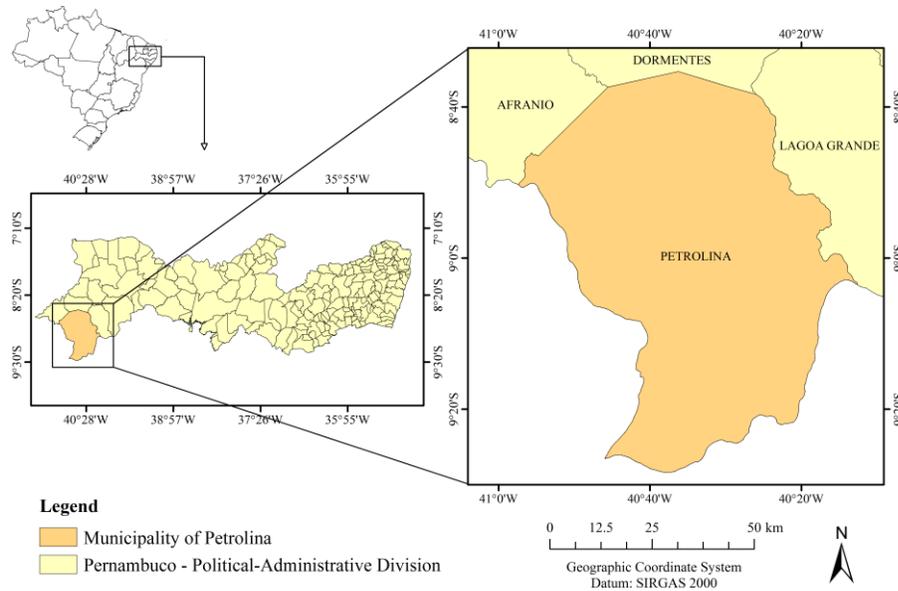


Figure 1- Geographical location of Petrolina municipality, Pernambuco.

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2.2 Methodology

In this study, daily rainfall data were used from the Pernambuco's Water and Climate Agency (APAC) database, referring to the period from 1915 to 2014 of Petrolina rainfall station. In addition, data was collected from Bebedouro station (1985-2014) for gap filling. The data were organized into Excel® spreadsheet and then inserted into CLIMAP software for development of series trends.

- Mann-Kendall trend test

For a data set $x_1, x_2, x_3 \dots, x_n$, with $n > 4$, Mann-Kendall test (Mann, 1945) uses the following equations:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k)$$

Where *sign* function is the variance of *S*, denoted by [Var(*S*)], defined by:

$$\text{Sign}(x_j - x_k) = \begin{cases} 1 & \text{se } x_j - x_k > 0 \\ 0 & \text{se } x_j - x_k = 0 \\ -1 & \text{se } x_j - x_k < 0 \end{cases}$$

$$\text{Var}(S) = \frac{n(n-1)(2n+5)}{18}$$

With iteration, the variance is:

$$\text{Var}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^g tp(tp-1)(2tp+5)]$$

Where *g* is the amount of repeated data groups and *p t* is the amount of data in the *p*-th group. Thus, *S* and *Var(S)* calculate the *Z* statistic, with standard normal distribution:

$$Z = \begin{cases} \frac{S-1}{[\text{Var}(S)]^{\frac{1}{2}}} & \text{se } S > 0 \\ 0 & \text{se } S = 0 \\ \frac{S+1}{(\text{Var}(S))^{\frac{1}{2}}} & \text{se } S < 0 \end{cases}$$

For the trend analysis, it uses value of *Z*. A positive value of *Z* > 0 means an increasing trend, and a negative value *Z* < 0, a *decreasing trend*. The significance level α is adopted $\alpha = 0.05 = 5\%$ for Mann-Kendall test. If the *p* probability of the

Mann-Kendall test is lower than the level α , $p < \alpha$, a statistically significant tendency exists, whereas, a $p > \alpha$ value, confirms an insignificant trend. For samples in which there are no trends, the *Z* value is close to zero (Ferrari et al., 2012). For the results analysis and discussion, the annual averages were used.

- Rainfall Anomaly Index

The rainfall anomaly index serves to sort wet and dry periods. In this study we used the RAI developed and tested by Rooy (1965), however, the monthly averages of the original formula were changed to annual averages. The index can be described by the following equations:

$$RAI = 3 \left[\frac{(N - \bar{N})}{\bar{M} - \bar{N}} \right], \text{ for positive anomalies and}$$

$$RAI = -3 \left[\frac{(N - \bar{N})}{\bar{X} - \bar{N}} \right], \text{ for negative anomalies}$$

Where:

N = Current annual rainfall (mm);

\bar{N} = Average annual rainfall from the time series (mm);

\bar{M} = Average of the ten largest annual rainfall from the historical average (mm);

\bar{X} = Average of the ten lowest annual rainfall from the historical average (mm).

Positive anomalies are represented by above average values, and negative anomalies with values below average and their degree of intensity can be evaluated as shown in Table 1.

Table 1 - Rain Anomaly Index Intensity Classes

	RAI range	Intensity Class
Rain Anomaly Index (RAI)	> 4	Extremely humid
	from 2 to 4	Very humid
	from 0 to 2	Humid
	from 0 to -2	Dry
	from -2 to -4	Very dry
	< 4	Extremely dry

Source: Adapted from Sanches et al. (2014).

3. Results and discussion

Figure 2 shows the monthly and quarterly historical average rainfall variation for 1915-2014 in Petrolina municipality. It is observed then that the rainfall in this municipality is concentrated

between the months of November and April, with the rainiest months being the first three of the year (Figure 2). These three months together correspond to 54.3% of the annual precipitation, especially in the month of March (97.2 mm average rainfall).

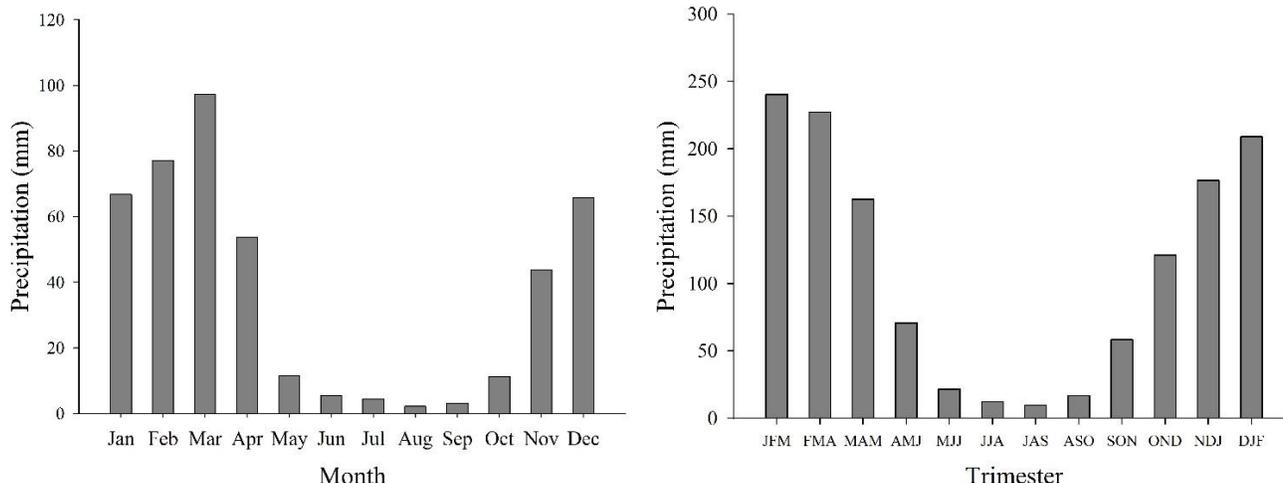


Figure 2- Historical average rainfall (1915-2014) by month and quarter of Petrolina, PE municipality.

The November to April concentrated rainfall occurrence is mainly by the influence of the Inter-Tropical Convergence Zone (ITCZ) and Upper-Tropospheric Cyclonic Vortex (UTCv). The ITCZ is the most important cause of rainfall system in the region, representing the equatorial trough axis and its position and intensity variations that are directly related to positions and intensity changes of the North and South Atlantic subtropical high (Marengo et al., 2011). The ITCZ follows, preferably, the region where the sea surface temperature (SST) is higher, and its performance in the Brazilian Northeast occurs more intensively in the months of February and April.

The lower rainfall time series occurred in the year of 2012, with an annual total of 127.6 mm, while in 1985 the maximum annual value was recorded, being 1059 mm. It is noted by Figure 3, that there was a higher frequency of years with below average annual rainfall in the first half of the historical series (1915-2014).

As previously noted, the second half series showed higher years attendance of above the

historical average. Thus, under the Mann-Kendall test application, a trend of increasing rainfall was noted, especially in the after 1960 period. The trend showed statistical significance ($p < 0.005$) and angular coefficient of 2.05 (Figure 4). For rainfall occurrence of above 1 mm, 10 mm and 20 mm, it was verified a trend of greater than 1 mm increasing in precipitation, with statistical significance. However, there was no statistical significance for the rainfall trend of over 10 mm and 20 mm (Figure 5).

Studies indicate precipitation reduction trend in the Northeastern semi-arid region, as in the case of Lacerda et al., (2009) that identified a reduction in rainfall in eight rainfall stations in the watershed area of the Pajeú-PE River using 1965 to 2004 data. However, Marengo et al. (2011) points out that the trend in rainfall will depend on the analyzed period and that there is no consensus on the existence of systematic reductions in rainfall in the semi-arid region of the Northeast in the last 60-70 years, but what really exists are decadal variations possibly associated with the Pacific

Decadal Oscillation.

Application of Rainfall Anomaly Index (RAI) enabled the rainfall classification scale of extreme periods of drought and rain. In the 1915 to 2014 period, it was not verified an extremely dry year ($RAI < -4$), being the minimum RAI value recorded in 2012 (-3.71). On the other hand, 19

years were classified as very dry ($-4 < RAI < -2$), namely, 1915, 1917, 1918, 1919, 1928, 1931, 1932, 1933, 1943, 1950, 1951, 1952, 1958, 1959, 1961, 1962, 1993, 2008 and 2012 (Figure 6). In the class of years classified as dry there are 37 years, among which are highlighted 1982, 2007 and 2011, with RAI closest to -2

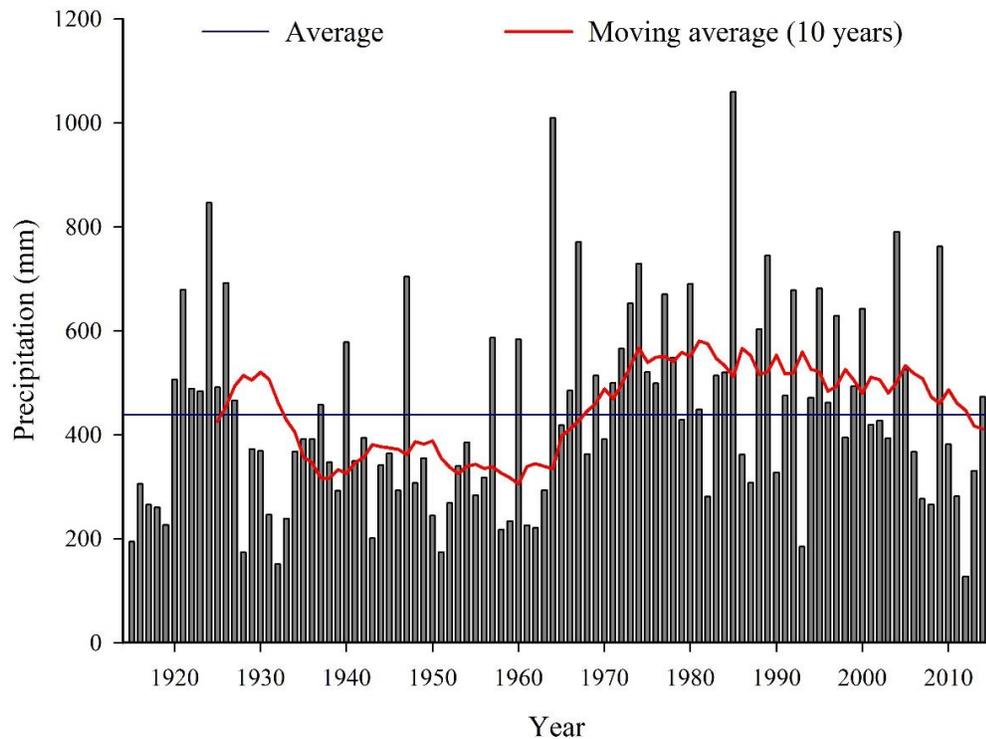


Figure 3- Annual precipitation from Petrolina’s rain station, for the 1915 to 2014 period, and its respective average and moving average (10 years).

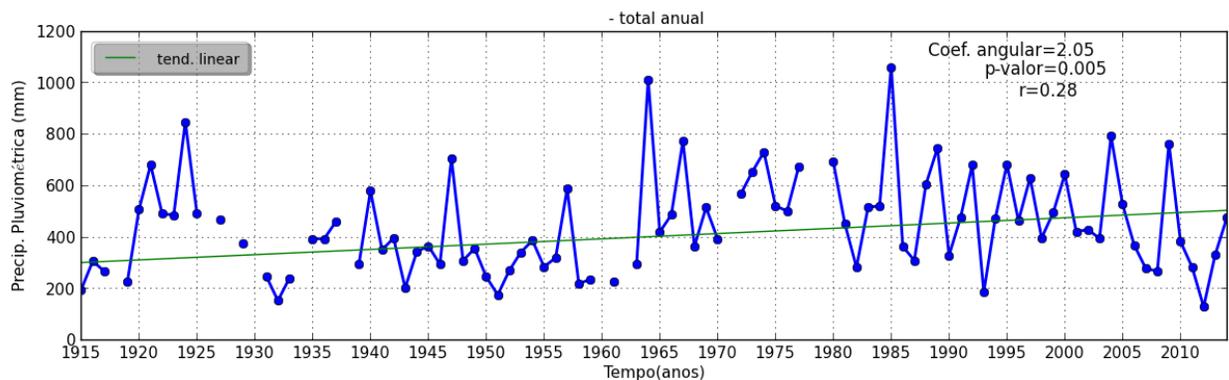


Figure 4- Rainfall trend of Petrolina rainfall station for the 1915-2014 period, according to the Mann-Kendall test.

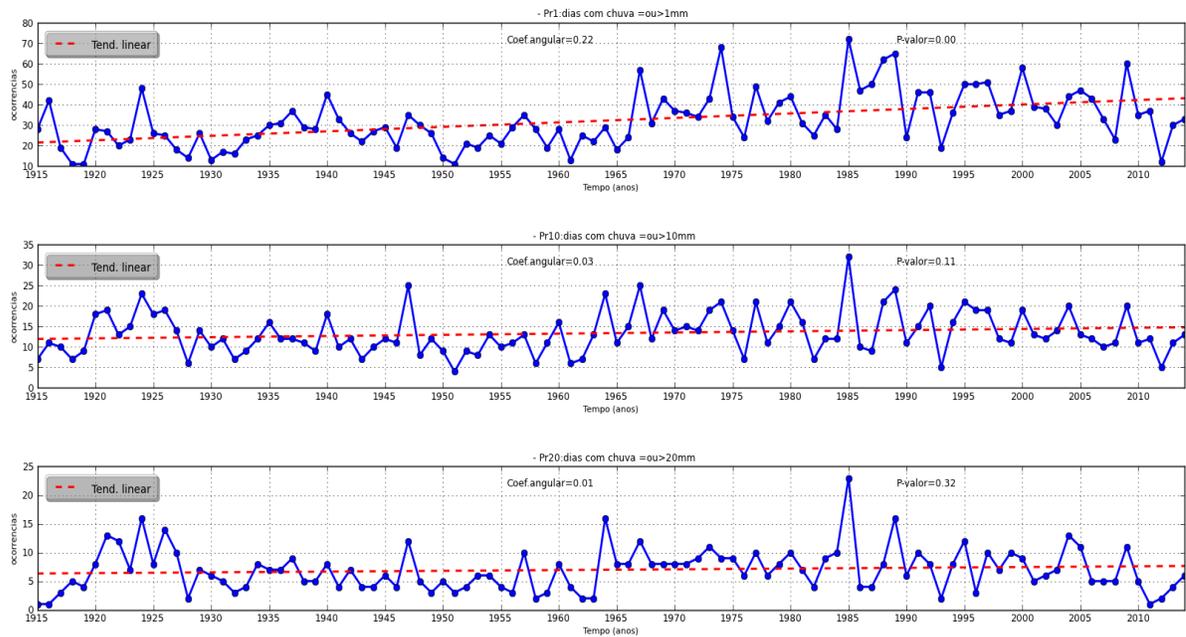


Figure 5- Trend of the precipitation above 1 mm, equal to the Petrolina rainfall station, for the 1915-2014 period, in accordance with the Mann-Kendall test.

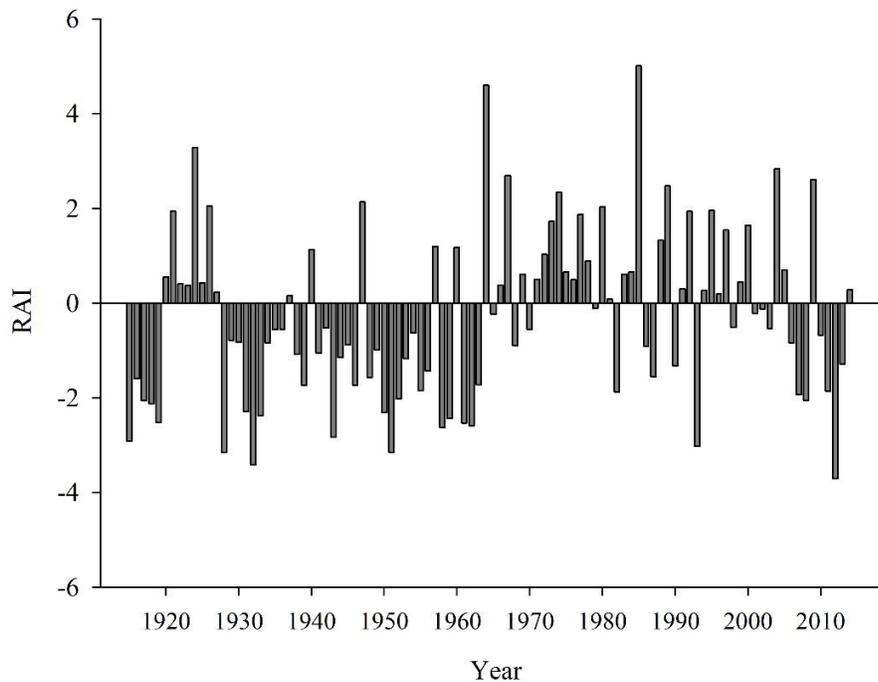


Figure 6- Rainfall Anomaly Index (RAI) for the Petrolina municipality, in the 1915-2014 period.

Regarding the years with positive RAI, the years of 1964 and 1985 were classified as extremely rainy (RAI > 4), while the other nine years were classified as very rainy years (1924, 1926, 1947, 1967, 1974, 1980, 1989, 2004, 2009).

In addition, 33 years of the analyzed period were classified as dry, especially the years 1921, 1973, 1977, 1992, 1995, 1997 and 2000, which showed RAI between 1.5 and 1.9.

Table 2- Years of El Niño occurrence and its intensity.

Period of occurrence	Intensity	Period of occurrence	Intensity
1913-1914	Moderate	1972-1973	Strong
1918-1919	Strong	1976-1977	Weak
1923	Moderate	1977-1978	Weak
1925-1926	Strong	1979-1980	Weak
1932	Moderate	1982-1983	Strong
1939-1941	Strong	1986-1988	Moderate
1946-1947	Moderate	1990-1993	Strong
1951	Weak	1994-1995	Moderate
1953	Weak	1997-1998	Strong
1957-1959	Strong	2002-2003	Moderate
1963	Weak	2004-2005	Weak
1965-1966	Weak	2006-2007	Weak
1968-1970	Moderate	2009-2010	Weak

Source: CPTEC/INPE (2015).

El Niño influences the interannual variability of rainfall in Northeastern Brazil, causing reduction in annual rainfall. However, ENSO events do not necessarily imply the occurrence of droughts, as can be seen in the results of this study. From the 19 years classified as very dry, only eight are associated with occurrence of ENSO, of which five of them correspond to years of strong El Niño.

The variability of precipitation in Northeast Brazil is also related to SST anomalies in the Atlantic Ocean, in addition to anomalies in the Pacific Ocean. The anomalous SST gradient between the Tropical North Atlantic (TNA) and the Tropical South Atlantic (TSA) is considered the main influence on rainfall anomalies in the region because it acts on the position of the ITCZ, which conditions the rainy season in the Northeast (LIVRO TEMPO E CLIMA)

4. Final considerations

Trend analysis using Mann-Kendall test showed a clear tendency towards an increase in rainfall in Petrolina municipality, using a data series that covers the 1915-2014 period. However, some studies have shown a reduction trend in rainfall in semi-arid areas of Pernambuco and even in Petrolina itself. Thus, it should be noted that the

data periods used in such studies differ from those used in the present paper, and rainfall in the semi-arid region exhibit large temporal and spatial variability. Regardless, it was noted that after the 1960s there was an increase in the number of years that had annual rainfall above the historical average, contributing to a positive trend.

As regards the Rainfall Anomaly Index, it was observed as whole more years with negative RAI, i.e., years considered dry, being 19 of those years classified as very dry. However, this higher incidence of dry years was not enough to leave the trend negative, since the rainfall events were more intense. Nevertheless, half of those considered very dry years do not coincide with the occurrence of El Niño, revealing thus the importance that the oscillations of the Atlantic Ocean temperature has on rainfall in the Northeast semi-arid. In years when the South Atlantic is warmer, the ITCZ tends to move more south of the equator, causing abundance of rainfall in the region.

Lastly, understanding climate variability in the region is extremely important for planning agricultural activities and actions for the population to cope with droughts. Over the past four years, the semi-arid region has been undergoing a drought, and alternatives to the water capture and storage should be put into practice. In addition, the already existing actions should be

expanded (e.g. construction of cisterns, underground dams, among others) in order to benefit the entire population. These actions are essential, especially in the context of climate change, as they allow for the adaptation and mitigation of the effects of climate change.

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