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SPATIOTEMPORAL RAINFALL VARIABILITY IN THE PAJEÚ RIVER BASIN, PERNAMBUCO, BRAZIL

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The northeastern region of Brazil (NEB) presents great climate diversity due to the various weather systems responsible for rainfall distribution. Thus, the monitoring of rainy and dry periods and spatiotemporal rainfall variability is essential for the management of water resources in semiarid regions such as the NEB. So, the aim of the present study was to evaluate the spatiotemporal rainfall variability in the Pajeú river basin through the Rain Anomaly Index (RAI). RAI is a technique used to characterize and monitor the spatiotemporal rainfall variability of a region, which allows comparing current precipitation conditions to historical values and serves to evaluate the spatial distribution of an event and its intensity. Therefore, monthly precipitation data from 1912 to 2013 of 32 weather stations were used in this study. The results showed peculiarities throughout this historical series such as alternating between negative and positive values up to the 1950s and later changes in the average rainfall pattern, with succession of dry and rainy periods. The temporal variation revealed that there is predominance of negative RAI for all months of the year, but the spatial variation showed that in the entire river basin, RAI is between dry and very dry, with the exception of the municipality of Triunfo, considered too rainy for being a swamp area. The analysis of the historical series of rainfall in the Pajeú river basin through RAI allowed detecting the interannual variability with predominance of dry years with more extreme inflection points in rainy years. It was also found that this variability has strong association with the occurrence of El Niño and La Niña phenomena and with their intensities in extreme drought and rainfall events, respectively; however, no evidence of climate change was found.

INTRODUCTION

The northeastern region of Brazil (NEB) presents great climate diversity due to various weather systems responsible for the rainfall distribution in the region, as well as to the interannual and intraseasonal variability. Excessive rains and severe droughts have been linked to dynamical systems of global atmospheric circulation, among them the *El Niño* Southern Oscillation (ENSO), as the cause of such fluctuations.

The ENSO is an almost stationary wave in the Sea Level Pressure (SLP) of global scale, followed by warming (*El Niño*) or cooling (*La Niña*), anomalous of surface waters of the central and eastern equatorial Pacific, causing droughts and intense rains, respectively (KAYANO; ANDREOLI, 2009). "This ENSO component dynamically binds to the Southern Oscillation, which manifests as a barometric seesaw with action centers in Indonesia and Southeastern Pacific" (ANDREOLI *et al*., 2004, p. 178).

This component of the earth's climate system promotes interaction between the ocean surface and the lower atmosphere adjacent to it. The processes of energy and moisture exchange between them determine the climate behavior, and changes in these processes may affect the global and regional climate (OLIVEIRA, 2001).

So, the monitoring of rainy and dry periods and spatiotemporal rainfall variability is essential for the management of water resources in semi-arid regions such as the NEB. Thus, "it is of paramount importance to have a practical instrumental to aid in decision-making, especially in periods of drought" (FREITAS, 2005). Studying the rainfall behavior is critical because it allows detecting trends or climate changes in different scales (local, regional, national and continental) as well as the comparison between them (MARCUZZO; GOULARTE, 2012). "The relative amounts of rainfall (volume), its seasonal or daily regimen (temporal distribution) and intensities of individual rainfalls (volume / duration) are some of the features that directly or indirectly affect the population, economy and environment" (BRITTO; BARLETTA; MENDONÇA, 2006).

The rainfall variability and irregularity, as well as exceptionalities and climatic hazards (such as Indian summers in NEB, among other meteorological phenomena) are events that heavily interfere in agricultural activities, minimizing production efficiency and compromising agricultural calendars, in addition to exercising strong influence on landscape transformation, since they escape from the protection capacity of contemporary society (SANT'ANNA NETO, 1998).

Therefore, the use of climate indexes is essential for the monitoring of the characteristics of dry or wet periods, as well as the different measures to be implemented in accordance with values reached by these parameters. Yearly, seasonal or monthly precipitation information can substantially reveal the weather of a region and verify the impact of the global climate on the local rainfall distribution (ARAÚJO; MORAES NETO; SOUSA, 2009a).

Thus, the present study used the Rain Anomaly Index (RAI) developed by Rooy (1965), for being a simple and effective index for monitoring rainfall spatiotemporal variability of the Pajeú river basin.

Several studies have been conducted in the NEB using RAI such as Freitas (2004; 2005) for some areas of the State of Ceará, Araújo *et al*. (2008) for the Cariri region of Paraíba, Araújo; Moraes Neto; Souza (2009b) for the Paraíba river basin, Da Silva (2009) and Da Silva; Sousa; Kayano (2010) for the

Mundaú river basin (PE/AL), and in the São Francisco river, Da Silva; Galvíncio; Nobrega (2011) sought to understand the influence of climate variability and associations of climate phenomena, among many other studies.

In all studies, RAI has proved to be suitable for the study of drought in the NEB due to its consistency in providing information about occurrence, severity and impact. It is noteworthy that the drought phenomenon can be diagnosed through indexes such as RAI, based on a historical series of climatological data.

Therefore, this research is relevant because this index was never applied to the Pajeú river basin, which faces the problem of water scarcity. Thus, this study will be useful for the management of local water resources, promoting regional development as it makes it possible to understand local problems, while seeking alternatives to minimize them or resolve them through strategic planning of actions in social, economic and environmental sectors.

Therefore, given the importance of climate changes, the increased frequency of extreme drought events in the hinterland and the need to better understand the scales of rainfall variability, the objective of this study was to assess the spatiotemporal rainfall variability in the Pajeú river basin using the Rain Anomaly Index (RAI).

DESCRIPTION OF STUDY AREA, DATA COLLECTION AND METHODS

Thus, this study used the monthly precipitation data in the historical series from 1912 to 2013 of 32 weather stations in the Pajeú river basin (Figure 1). The weather stations were selected for the availability of municipalities within the river basin area and amount of rainfall data. This information

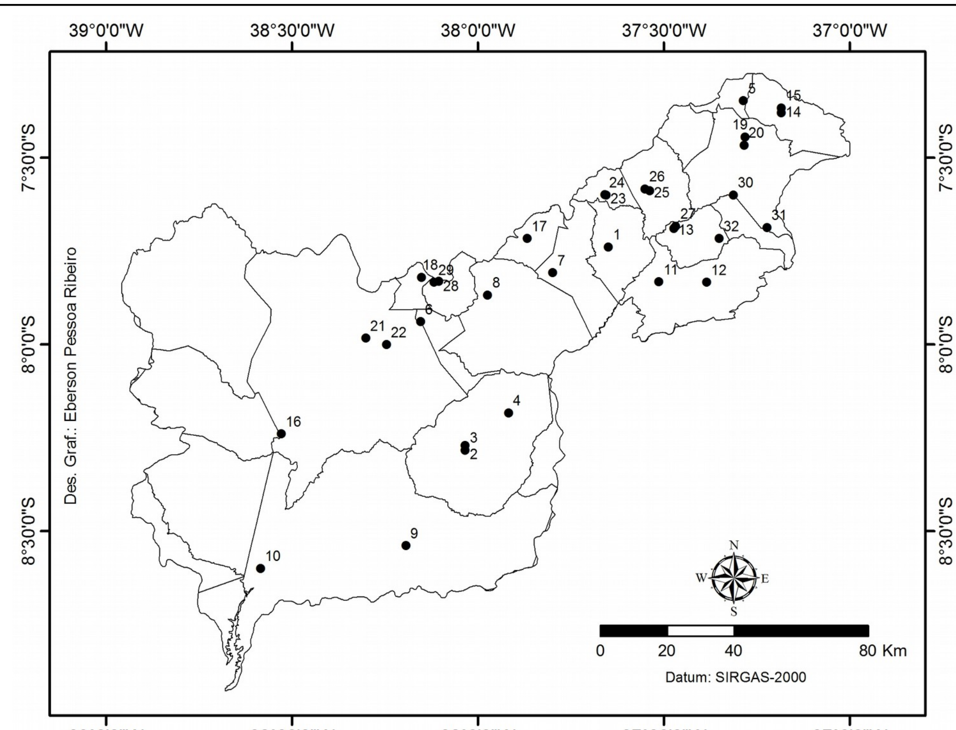

Figure 1. Spatial configuration of the rainfall network in the Pajeú river basin.

was obtained through the National Water Agency (ANA) and the Pernambuco Water and Climate Agency (APAC) through websites www.ana.gov.br/hidroweb and www.apac.pe.gov.br/meteorologia/monitoring-pluvio respectively.

These data were essential to characterize excessively dry and wet periods that occurred in the area, as well as the historical comparison in the search for trends and change patterns in this climatic element.

Rain Anomaly Index (RAI)

Rainfall is one of the susceptibility indicators for locations under the process of desertification. In northeastern Brazil, this climatic element has considerable seasonal and interannual variability.

The Rain Anomaly Index is a technique used to characterize and monitor the spatiotemporal rainfall variability of a region, being effective for semi-arid regions such as the NEB and allows the "comparison of current precipitation conditions to historical values and serves to evaluate the spatial distribution of the event and its intensity" (DA SILVA; GALVÍNCIO; NÓBREGA, 2011, p 49), as well as the multidecadal variation. Therefore, the series of monthly precipitation were used to detect wet and dry periods considered extreme.

RAI was chosen because, in addition to the aforementioned features, it shows easy computational procedure and has no significant differences from more complicated indexes such as Palmer and Bhalme & Mooley (OLADIPO, 1985). The Palmer Drought Severity Index (PDSI) measures the loss and moisture supply demand of land for homogeneous regions; while the Bhalme & Mooley Drought Index seeks to assess the drought intensity by using only rainfall data without regarding regional climatic conditions (FERNANDES, 2009), making it a poor indicator for NEB.

According to Rooy (1965), the base for the calculation of the Rainfall Anomaly Index (RAI) is relatively simple and effective and allows comparing the precipitation deviation in relation to the normal condition of different regions by means of equations 1 and 2:

$$\mathrm{RAI} = 3\left[\frac{\mathrm{N} - \bar{\mathrm{N}}}{\bar{\mathrm{M}} - \bar{\mathrm{N}}}\right] \text{ for positive anomalies} \quad (1)$$

$$\mathrm{RAI} = -3\left[\frac{\mathrm{N} - \bar{\mathrm{N}}}{\bar{\mathrm{X}} - \bar{\mathrm{N}}}\right] \text{ for negative anomalies} \quad (2)$$

where N = current annual rainfall (mm), $\overline{N}$ = average annual rainfall of the historical series (mm), $\overline{M}$ = average of the ten largest annual rainfalls in the historical series (mm) $\overline{X}$ = average of the ten lowest annual rainfalls the historical series (mm), and positive anomalies were values above the average and the negative anomalies were those below the average.

The RAI values were ordered according to the classification of dry and wet years proposed by Rooy (1965) and adapted by Freitas (2005) for the NEB (Table 1).

It is noteworthy that the RAI "does not present standard for inclusion in a category that qualifies a meteorological event" (ALVES *et al*., 2010, p. 6), i.e., if a value is above or below zero, this means that the result was compared with the historical average rainfall of the area under study, classified as a wet or dry period, respectively. The phenomenon becomes more intense as the intensity class value increases or decreases as can be seen in Table 1.

Table 1. Intensity Classes of the Rain Anomaly Index.

	RAI range	Intensity class
Rain Anomaly Index (RAI)	Above 4	Extremely Wet
	2 to 4	Very Wet
	0 to 2	Wet
	0 to -2	Dry
	-2 to -4	Very Dry
	Below -4	Extremely Dry

Source: Araújo; Moraes Neto; Souza (2009b, p.96).

The results obtained with the RAI calculations were analyzed and compared with the years of occurrence and the intensity of *El Niño* and *La Niña* phenomena (Table 2) in order to investigate the degree of influence of these phenomena on rain anomaly.

Table 2. Occurrence and intensity of *El Niño* and *La Niña.*

Occurrences of El Niño		Occurrences of La Niña
1877 - 1878	1888 - 1889	1886
1896 - 1897	1899	1903 - 1904
1902 - 1903	1905 - 1906	1906 - 1908
1911 - 1912	1913 - 1914	1909 - 1910
1918 - 1919	1923	1916 - 1918
1925 - 1926	1932	1924 - 1925
1939 - 1941	1946 - 1947	1928 - 1929
1951	1953	1938 - 1939
1957 - 1959	1963	1949 - 1951
1965 - 1966	1968 - 1970	1954 - 1956
1972 - 1973	1976 - 1977	1964 - 1965
1977 - 1978	1979 - 1980	1970 - 1971
1982 - 1983	1986 - 1988	1973 - 1976
1990 - 1993	1994 - 1995	1983 - 1984
1997 - 1998	2002 - 2003	1984 - 1985
2004 - 2005	2006 - 2007	1988 - 1989
2009 - 2010		1995 - 1996
		1998 - 2001
		2007 - 2008
		2011 - 2012

LEGEND

Strong	Moderate	Weak

Source: Adapted from Rasmusson and Carpenter 1983 Monthly Weather Review, Ropelewski and Halpert 1987 Monthly Weather Review. Cold episode sources Ropelewski and Halpert 1989 Journal of Climate. Climate Diagnostics Bulletin. In: INPE / CPTEC (2014ab).

In view of the Rain Anomaly Index (RAI) analyses for the 102 years and the comparison with the years of occurrence and intensity of *El Niño* and *La Niña* phenomena, it was possible to develop the results and discussions to this study.

RESULTS AND DISCUSSION

The analysis of the Rain Anomaly Index based on historical series from 1912 to 2013 helped identifying patterns in the rainfall behavior in the study area and assessing the degree of influence of *El Niño* and *La Niña* on years of extreme events. Through the RAI of the Pajeú river basin (Figure 2), great variability between dry and wet years was observed. Of the 102 years surveyed, 53 were dry years (negative RAI), whose classification revealed dry (0 to -2) or very dry years (-2 to -4) and 49 were rainy years (positive RAI), whose classification revealed rainy (0 to 2), very rainy (2 to 4) or extremely rainy years (above 4).

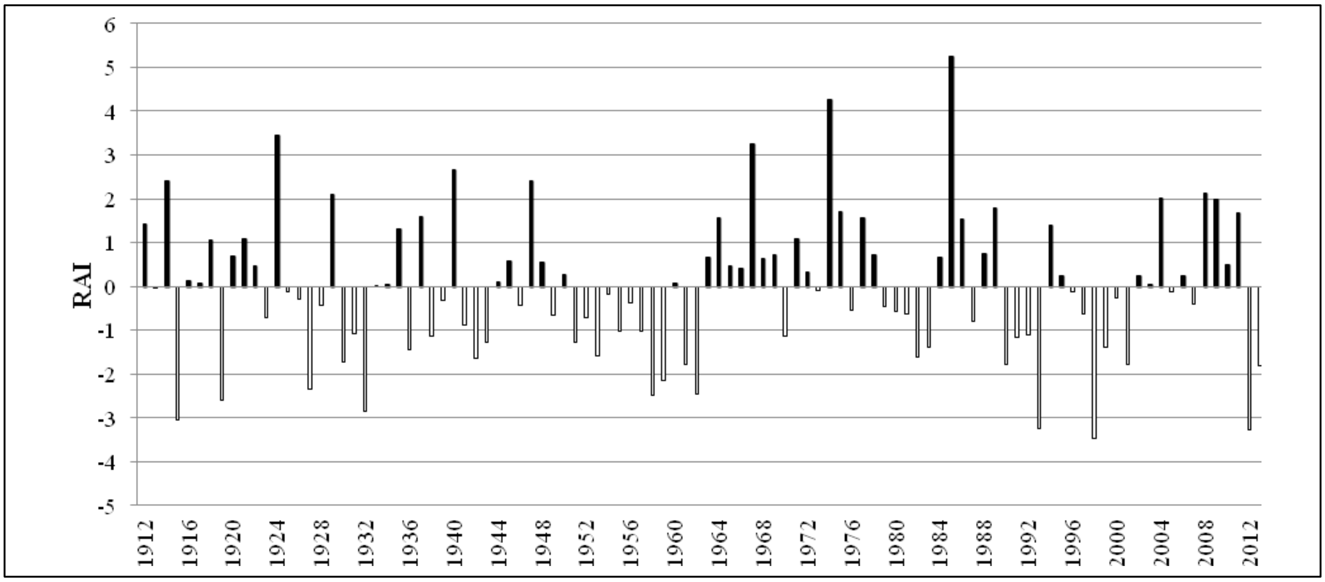

Figure 2 - Rainfall anomaly index of the Pajeú river basin from 1912 to 2013Data Source: ANA (2014) and APAC (2014).

The RAI the Pajeú river basin showed some peculiarities throughout the historical series, since until the 1950s, this index alternated between positive and negative values, the latter being more frequent. However, from the beginning of the 1950s to the early 1960s, there was a change in the rainfall variation because there is a predominance of drier years, succeeding an “inflection point”, which reveals a probable climate change in the rainfall pattern. This period coincided with the occurrence of *El Niño* of weak (1951, 1953, 1963) and strong intensities (1957 - 1959).

From the beginning of the 1960s (1963), the rainfall pattern in that river basin was reversed, since the positive RAI values become more frequent, with the intensity class ranging from rainy to very rainy and only the year 1974 as extremely rainy, which obtained the annual rainfall of 1.252 mm, the second highest rainfall in the historical series, reaching positive RAI of 4.28. This period was marked by alternation of *La Niña* (1964 - 1965 and 1970 - 1971; 1973 - 1976, with weak and strong intensities, respectively) and *El Niño* (1963 and 1977 - 1978, 1966 and 1968 - 1970; 1972 of weak, moderate and strong categories, respectively).

This same events of “inflection points” of driest years alternating with more rainy years were also observed by Araújo; Moraes Neto; Souza (2009b) for the Paraíba river basin.

Subsequently to these climatic variation successions in the Pajeú river basin, RAI revealed two short distinct periods, one dry (1979 - 1983) and another very rainy (1984 - 1989). The first period is related to the occurrence of *El Niño* (1979 - 1980; 1982 - 1983, of moderate to strong intensity, respectively) and the second with the occurrence of *La Niña* (1983 - 1985 and 1988 - 1989, of weak to strong intensity, respectively) and moderate *El Niño* (1986 - 1988), which coincides with the dry year 1987 that rained only 531 mm. In this rainy season, the highest rainfall in the historical series was observed, with 1.390 mm in 1985, which reached the highest positive RAI of 5.24 (extremely wet).

Then, there was quite a long dry period (1990 - 2001) interposed by wet years (1994 - 1995) associated to a moderate-intensity *El Niño* (1994 - 1995) followed by a weak-intensity *La Niña* (1995 - 1996). In this dry period, the intensity class ranged from dry (0 to -2) to very dry (-2 to -4), represented by years 1993, which was the third driest in the series with 210 mm/year, reaching RAI of -3.24; and 1998, with the hoghest negative RAI (-3.46) and lowest precipitation, with 181,2 mm/year among the 102 years analyzed.

Finally, there was a rainy interval (2002 - 2011) with interruptions of dry years (2005 and 2007 with annual rainfall of 620.2 and 584,3 mm, respectively), marked by moderate (2002 - 2003) and weak (2004 - 2005, 2006 - 2007 and 2009 - 2010) *El Niño* and strong (2007 - 2008) and weak *La Niña* (2011 - 2012) phenomena. The years 2012 and 2013 were very dry (-3.26) and dry (-1.81) with average annual rainfall of 207.7 and 399,3 mm, respectively. The year 2012 was the second driest of the historical series from 1912 to 2013, possibly starting another period of negative anomalies, according to the rainfall variations analyzed. Importantly, there have been considerable inversions in the average rainfall pattern of the Pajeú river basin, alternating, after the 1950s, periods of dry years more frequent than rainy years.

From the highest and lowest annual RAI values of 1974 and 1985 (rainy years) and 1998 and 2012 (dry years), respectively, it was possible to demonstrate the spatial distribution of these inflection points in Figure 3.

The rainy year 1974 presents a variation of positive categories. Rainy intensity class (0 to 2) is located in the mid-western portion (municipalities of Mirandiba, Serra Talhada, Floresta and Carnaubeira da Penha, the rainy season (2 to 4) is predominant in the river basin and the extremely rainy season (over 4) is located in the northern and northeastern portion. Municipalities of Triunfo (north), which obtained annual rainfall of 2.052,4 mm and achieved RAI of 9.8 and Itapetim (northeast), showing total precipitation in that year of 2.408,1 mm stood out, resulting in RAI of 12.3. In both municipalities, the rainiest months occurred in the first half, following the rainy season, but in the second half, rains were below average for the year 1974. Despite being the second rainiest year of the historical series, this year showed the highest rainfall peaks.

The wettest year 1985 reveals a great RAI variation from dry to extremely rainy. The period of heavy rainfall stands out in the northern portion, highlighting the municipality of Triunfo, with RAI of 11.8 (2.331,6 mm/year). Areas of low rainfall such as the municipalities of Afogados da Ingazeira and Betânia also stood out. The first had negative RAI (-0.4) with approximate annual rainfall of 580 mm and the second had RAI of 0,7, with total rainfall of 747,2 mm/year.

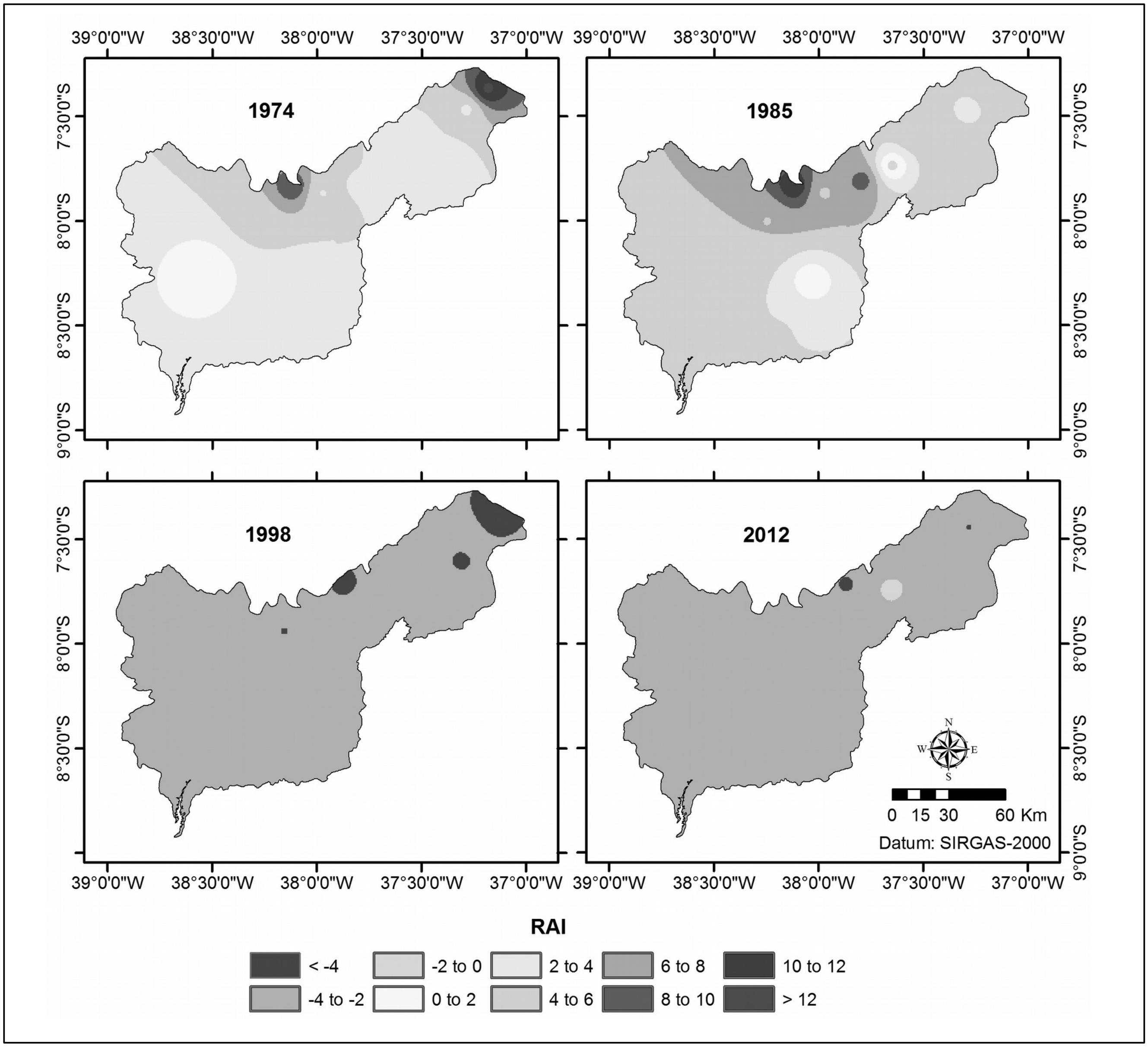

Figure 3 - Spatial distribution of RAI values for years 1974, 1985, 1998 and 2012 Data Source: ANA (2014) and APAC (2014).

The RAI spatialization of the Pajeú river basin for the dry years 1998 and 2012 was characterized by very dry intensity (-2 to -4). The year 1998 represents the lowest value (-3.46) in the historical series and the largest amount of negative RAI. Some localities at northeastern river basin (high Pajeú) reached the extremely dry class (less than -4). In this year, the drought severity was influenced by intense *El Niño* occurrence.

The year 2012, the second driest year in the series, showed the smallest extreme dry areas at high Pajeú, reaching RAI of -1.47 (dry category) in the municipality of Afogados and Ingazeira. The poor performance of *La Niña* (2011 - 2012), which also ends in the first half of that year, may have interfered in the low total, monthly and annual rainfall levels of municipalities.

Great interannual variability was found, as well as spatiotemporal and climate variation in the rainfall element; however, no evidence of climate change was found. The average annual rainfall of the Pajeú river basin from 1912 to 2013 (Figure 4) confirms this fact, since the slope of the linear trend straight line was almost zero and showed an inexpressible rainfall growth in the Pajeú river basin of 0,02.

However, two large trend cycles could be observed, both of 51 years, one from 1912 to 1962 with a decrease in the amount of rainfall and the other from 1963 to 2013, with increased amount of rainfall. The average annual rainfall of 638 mm of the Pajeú river basin in the above historical series can be compared with the average of the two periods above, as well as the rainy and dry years, above or below the linear trend line, respectively. The first had average rainfall of 603,3 mm/year, consisting of 21 years and above 30 years below the trend line, while the average rainfall in the second period was 678,8 mm/year, in which 28 years were above and 23 years were below the linear trend line.

Thus, the climatological seasonal variability of the Pajeú river basin was determined through the monthly total rainfalls for the time series evaluated. Figure 5 shows that the monthly average rainfall in the region is 56 mm and that the rainy season extends from January to April (black columns), with maximum precipitation values of 148 mm for the month of March and the driest interval occurs from August to November, with the month of September being the driest of the year, with an average of 8 mm.

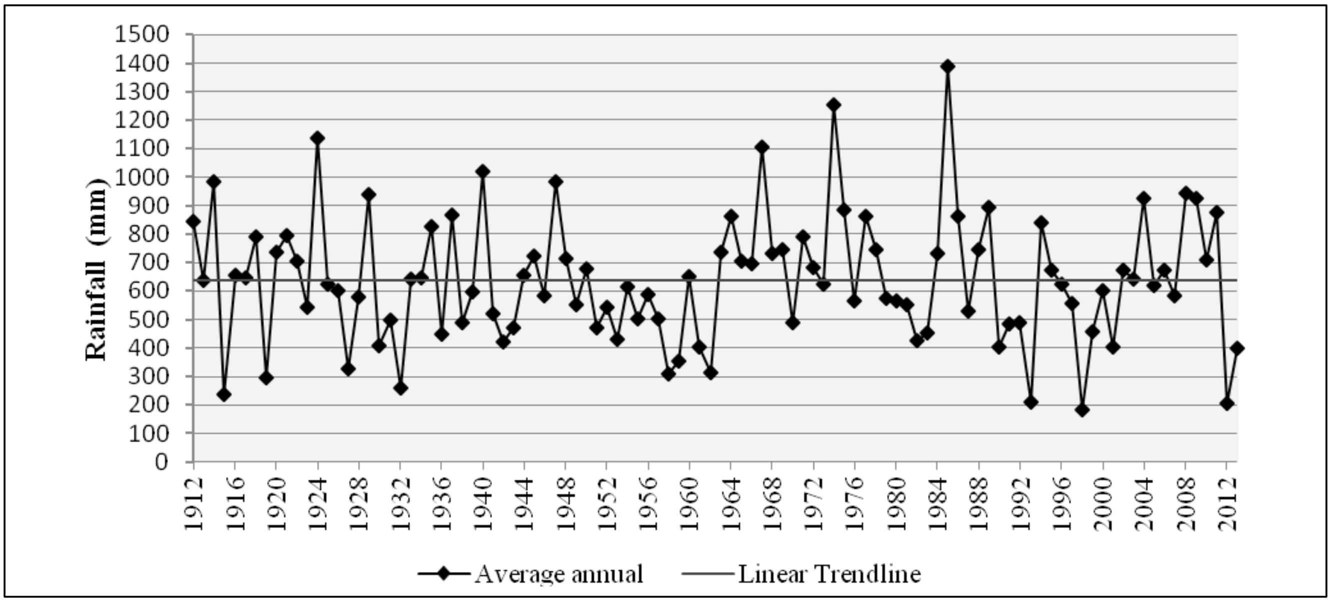

Figure 4 - Average annual rainfall of the Pajeú river basin from 1912 to 2013. Data Source: ANA (2014) and APAC (2014).

The rainy season occurs during these months due to the approach of the Intertropical Convergence Zone (ITCZ), considered the most important rainfall generating weather system, and to the high energy availability in northeastern Brazil (NEB). Months with lower rainfall values occur because the ITCZ seasonally migrates from its south position to its north position in late April and early May in years considered normal, returning only from late September to early October, causing a gradual increase of rainfall in NEB as it migrates to south (MELO; CAVALCANTI; SOUZA, 2009).

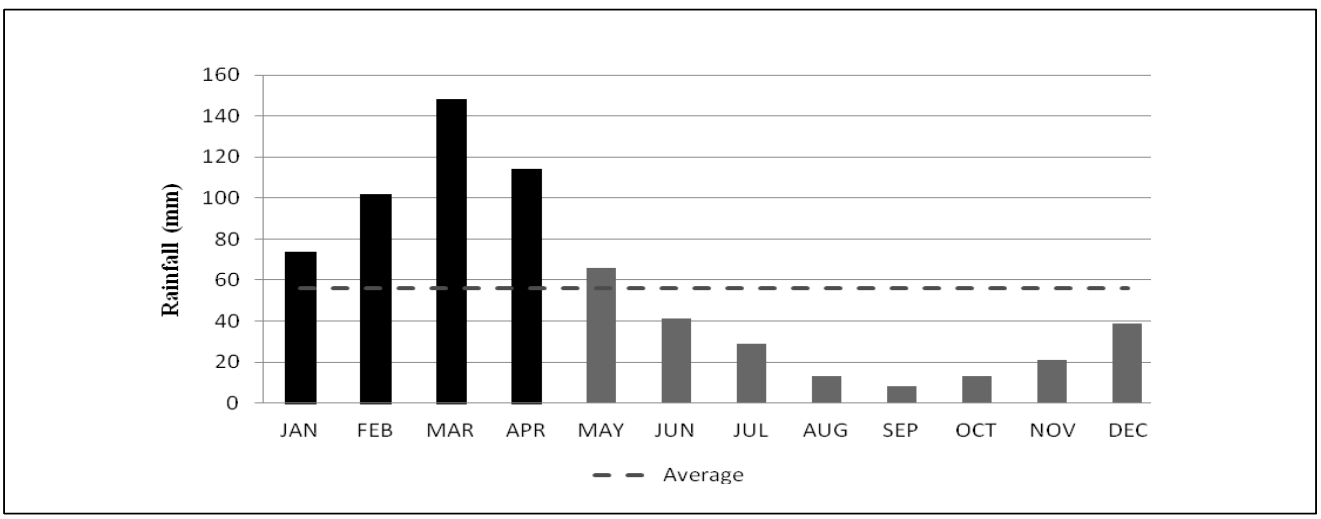

Figure 5 - Rainfall chart showing the total monthly rainfall of the Pajeú river basin from 1912 to 2013. Data Source: ANA (2014) and APAC (2014).

To assess the degree of severity of wet and dry events during the rainy season, the RAI was used due to seasonal rainfall variability of the Pajeú river basin. So, Figure 6 shows the RAI of the rainy season (January, February, March and April) from 1912 to 2013, where a predominance of negative

RAI was observed, whose classification of dry (0 to -2) and very dry years (-2 to -4) stood out especially for the "inflection points" in March 1915 (-3.38), March 1919 (-3.53), April 1932 (-3.43) and April 2012 (-3.33). The positive RAI alternated among rainy (0 to 2), very rainy (2 to 4) or extremely rainy classes (above 4), especially for the "inflection points" in January 1914 (4.69), March 1947 (4.97), January 1985 (4.84) and January 2004 (7.03), which showed the highest precipitation of the rainy season.

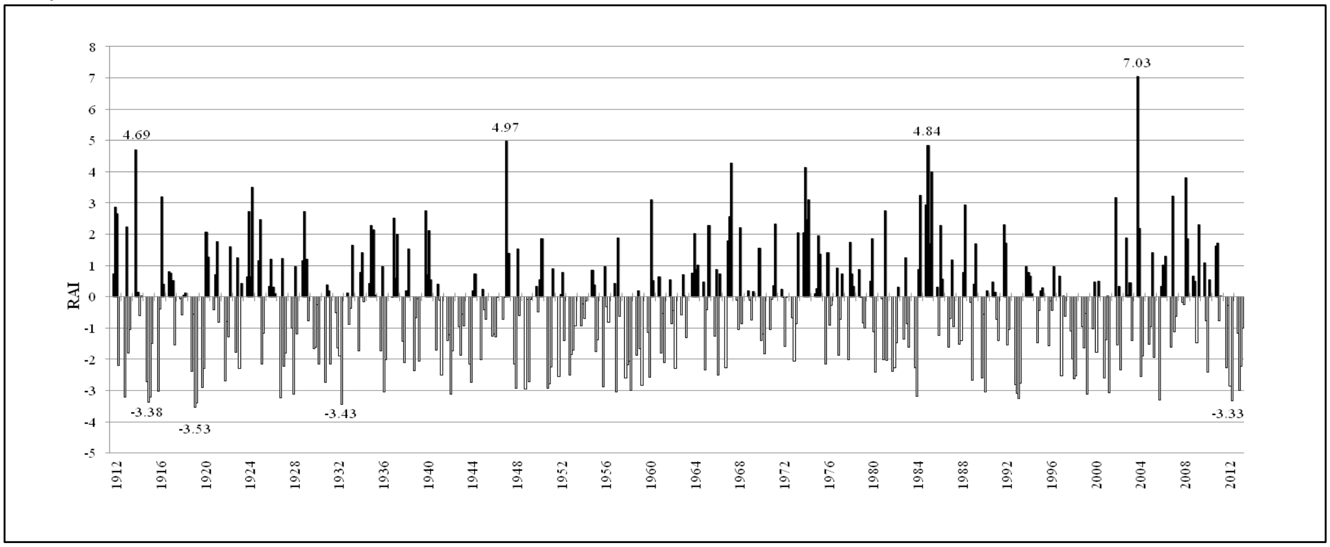

Figure 6 - Rainfall anomaly index of the rainy season from 1912 to 2013, Data Source: ANA (2014) and APAC (2014).

Although most rainy seasons showed negative RAI, positive ones showed the highest RAI intensities. Thus, we sought to assess the RAI for each month of the year (Figures 7a to 7d). For the month of January 65 years were dry: 37 were dry (0 to -2) and 28 were very dry (-2 to -4), with the lowest inflection points for the years 1927 (-3.24) and 2006 (-3.29), with weak *El Niño*; and 37 years were rainy: 30 years were rainy (0 to 2), 5 were very rainy (2 to 4) and 2 were extremely rainy (above 4), years 1914 (4.69) and 2004 (7.03), with the occurrence of moderate and weak *El Niño*, respectively.

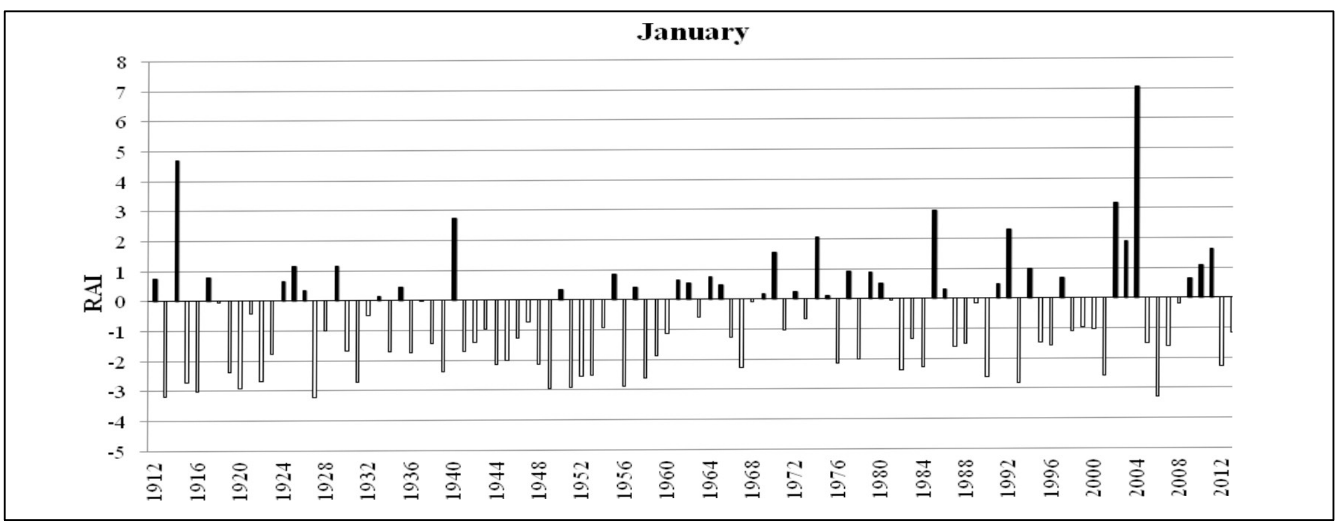

Figure 7. Rainfall anomaly index of the Pajeú river basin for the month of January. Data Source: ANA (2014) and APAC (2014).

February shows 58 years with negative RAI, ranging from dry to very dry classes, with lower inflection points for years 1915 (-3.38) and 1984 (-3.18) and weak *La Niña*; and 44 years of positive RAI, with 32 rainy, 10 very rainy and 2 extremely rainy years, 1974 (4.12) and 1985 (4.84), both with the occurrence of strong and weak *La Niña*, respectively.

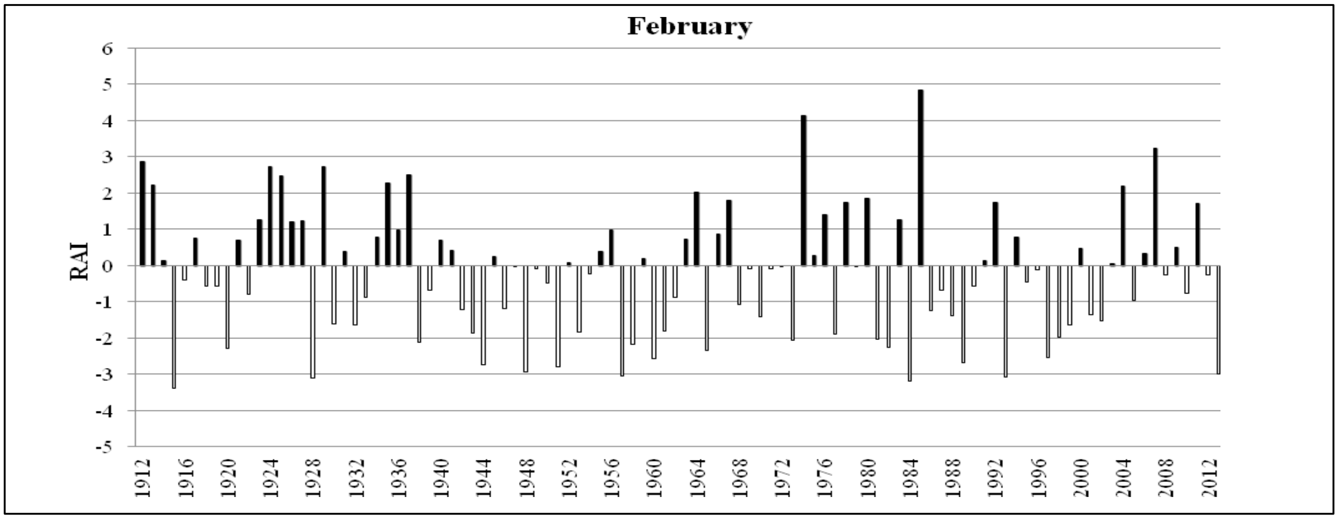

Figure 8. Rainfall anomaly index of the Pajeú river basin for the month of February. Data Source: ANA (2014) and APAC (2014).

In the March time series, 55 years were dry, alternating between dry (37 years) and very dry (18 years); negative years were 1919 (-3.53) and 1993 (- 3.26); and both years showed strong *El Niño* events; and 47 years were rainy: 34 rainy, 12 very rainy and 1 extremely rainy, with the greatest inflection point in the year 1947, with precipitation of 416,3 mm and a positive RAI of 4.97 in a year of occurrence of moderate *El Niño*.

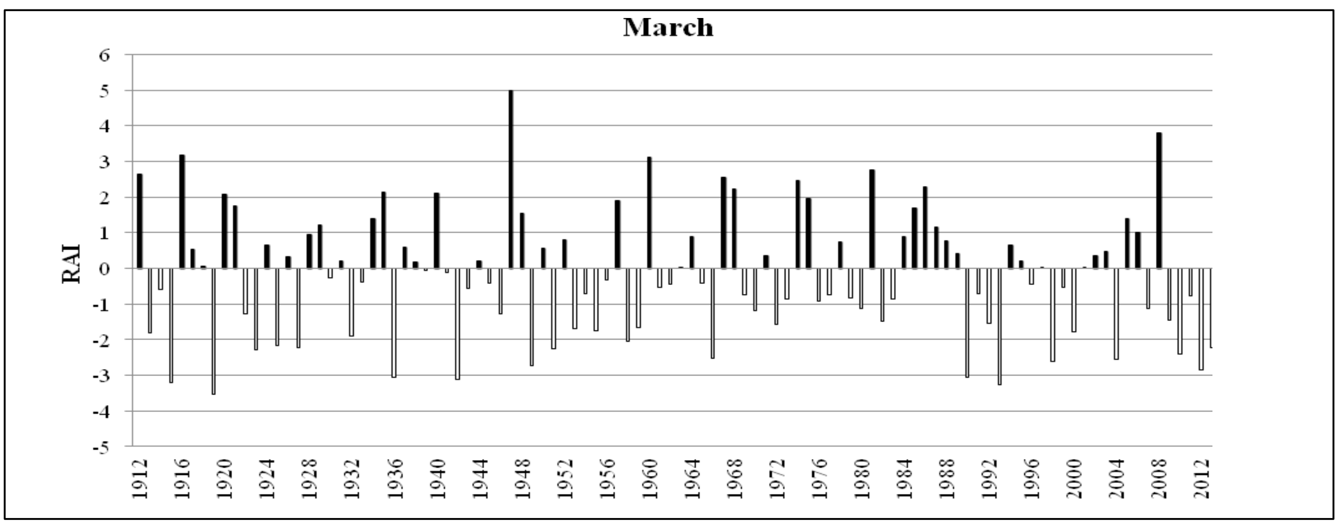

Figure 9. Rainfall anomaly index of the Pajeú river basin for the month of March. Data Source: ANA (2014) and APAC (2014).

During the month of April, between 1912 and 2013, 57 years were dry and 45 were rainy, with the major inflection points occurring in 1967 with RAI of 4.26 (no episodes of temperature anomaly in the equatorial waters of the Pacific ocean) and 1985 with RAI of 3.99 (weak *La Niña*). The lowest inflection points of the dry years are represented by years 1919 and 1932, with negative anomalies of -3.39 and -3.43 under strong and moderate *El Niño* events, respectively.

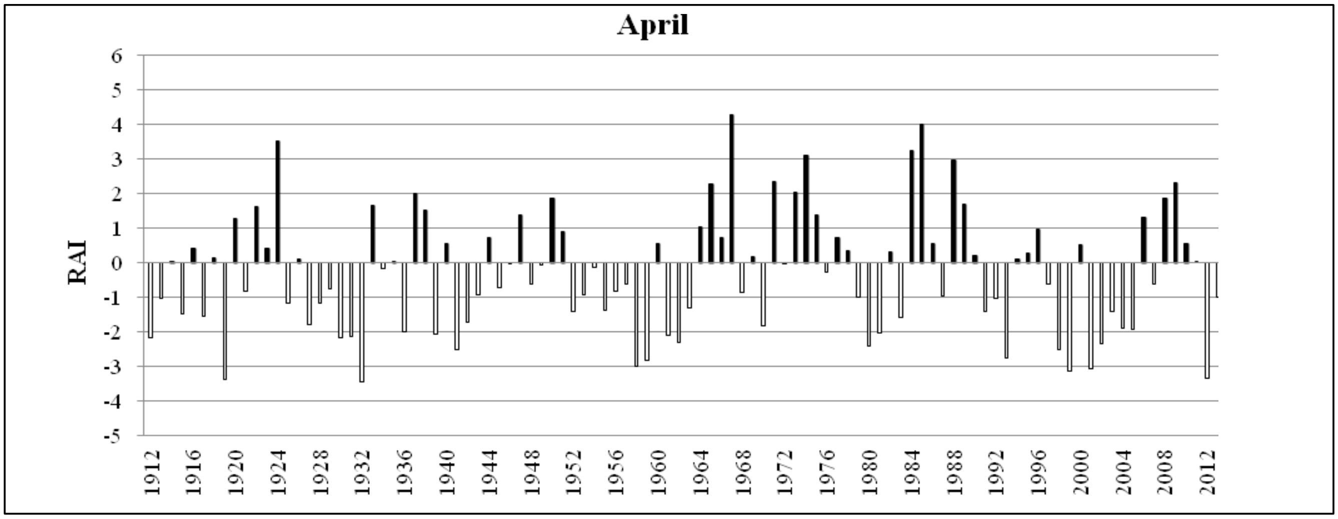

Figure 10. Rainfall anomaly index of the Pajeú river basin for the month of April. Data Source: ANA (2014) and APAC (2014).

The RAI for the month of May (Figure 11) was dry (37 years) and very dry (19 years) with the largest negative values represented by 1919 (-3.22) and 1998 (-3.21); two years with strong *El Niño* events; and 35 rainy, 9 very rainy and 2 extremely rainy years. The highest inflection points were observed for years 1924 (4.12) and 2009 (4.33), with occurrence of moderate *La Niña* and weak *El Niño*, respectively.

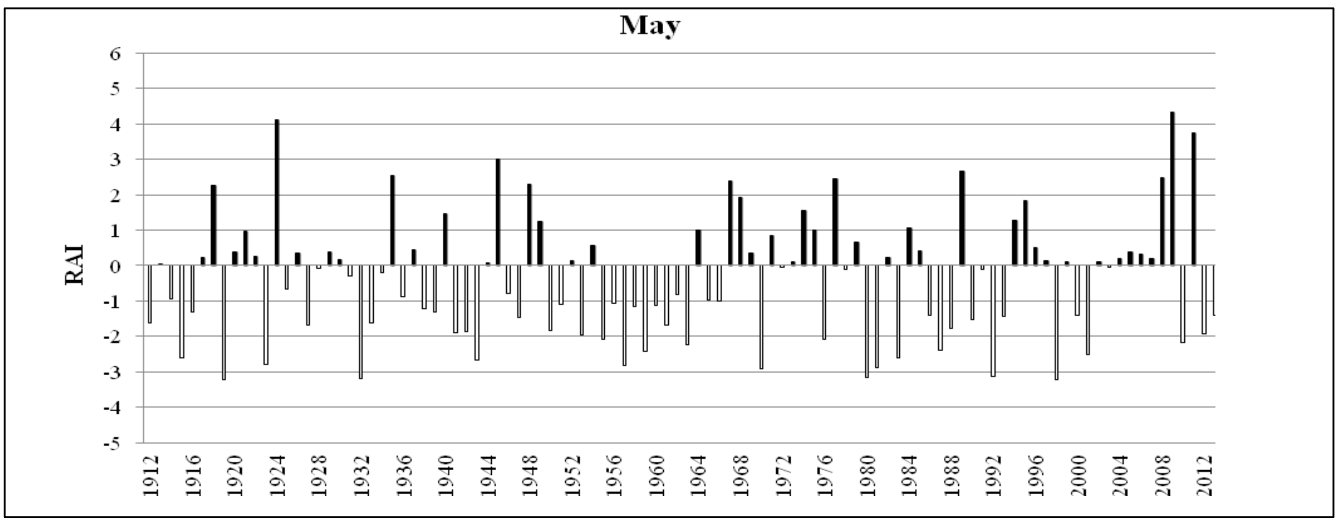

Figure 11. Rainfall anomaly index of the Pajeú river basin for the month of May. Data Source: ANA (2014) and APAC (2014).

It can be seen in Figure 12 that the RAI of June obtained 66 negative years, ranging from dry intensity (0 to 2) with 40 years to very dry (-2 to -4) with 26 years, with the smallest inflection points for years 1976 (-3.32) and 1999 (-3.34), without the occurrence of *El Niño* and *La Niña*, while that of low-intensity *El Niño*; and 36 years of positive RAI, with 26 rainy, 9 very rainy and 1extremely rainy years (1914 with RAI of 4.10), a year with occurrence of moderate *El Niño*.

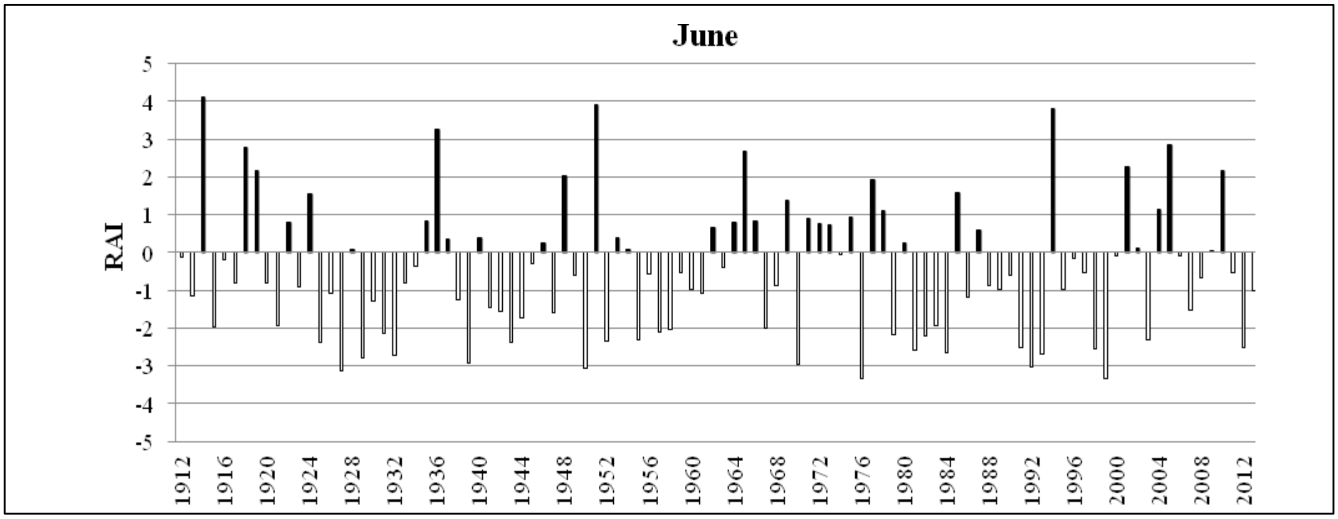

Figure 12. Rainfall anomaly index of the Pajeú river basin for the month of June. Data Source: ANA (2014) and APAC (2014).

The RAI of July (Figure 13) showed a predominance of dry (38 years) and very dry years (23 years), and major droughts were observed in 1930 (-3.23) without episode of *El Niño* and *La Niña*, and 1991 (- 3.47), with the occurrence of strong *El Niño*; and 35 rainy, 5 very rainy and I extremely rainy years, with precipitation of 129 mm in 1969, providing an RAI of 6.21, year of moderate *El Niño*.

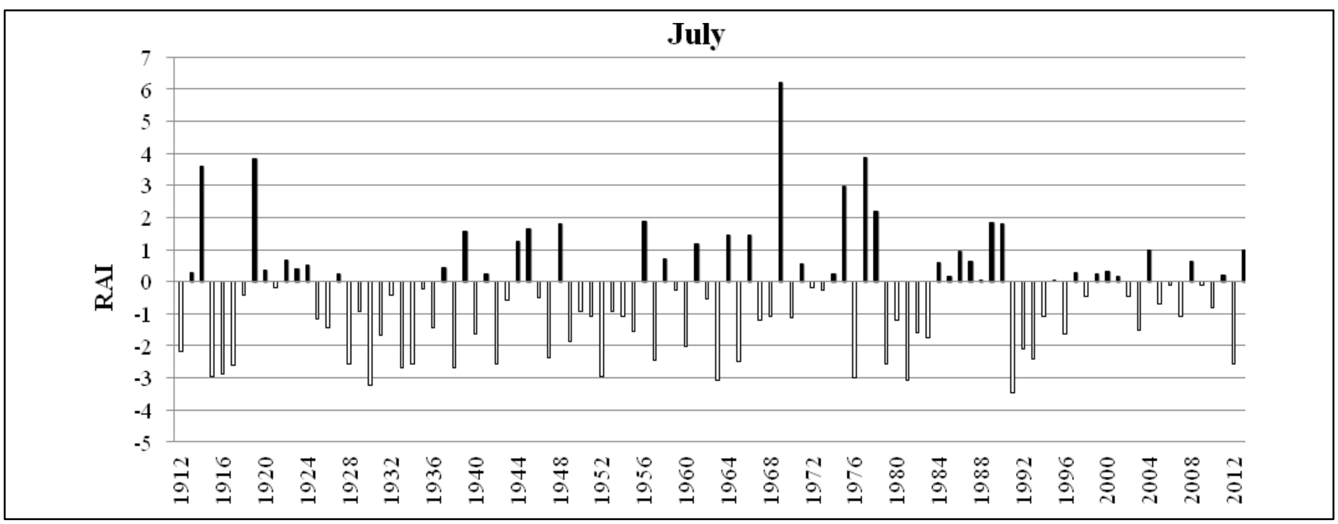

Figure 13. Rainfall anomaly index of the Pajeú river basin for the month of July. Data Source: ANA (2014) and APAC (2014).

For the month of August (Figure 14), 68 years were dried, being the only month with equivalence between intensity classes of dry (0 to -2) and very dry years (-2 to -4), with year 1925 (-3.16) and 1932 (-3.19) showing the lowest rainfall due to the influence of *El Niño* of strong and moderate intensitie, respectively; and 34 rainy years, 29 rainy, 4 very rainy and 1 extremely rainy, the year 1914 (6.40) being under the influence of moderate *El Niño*.

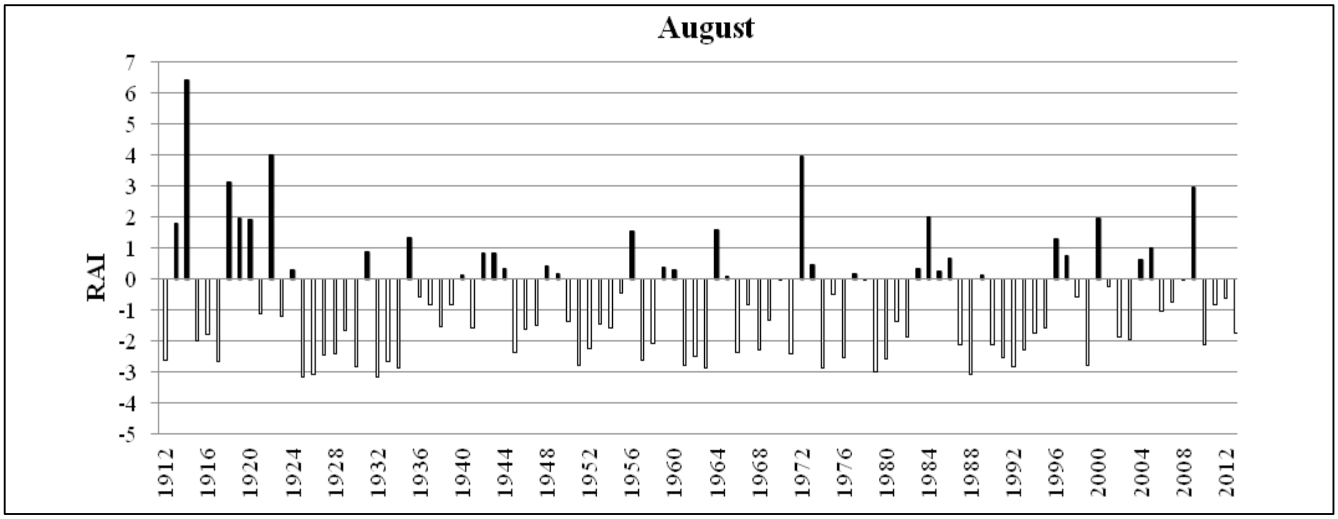

Figure 14. Rainfall anomaly index of the Pajeú river basin for the month of August. Data Source: ANA (2014) and APAC (2014).

The month of September (Figure 15) was the driest of the historical series. It was characterized by an average rainfall of 8 mm with predominantly dry years (64) in relation to rainy years (38 years). The lowest inflection points obtained RAI of -3 in years 1923, 1924, 1930, 1956, 1959, 1983.1987, 1991, 1997 and 1998. Positive RAI values alternated among rainy (30 years), very rainy (7 years) and extremely rainy (1 year), which in 1912 reached RAI of, 5.98, occurrence of strong *El Niño*.

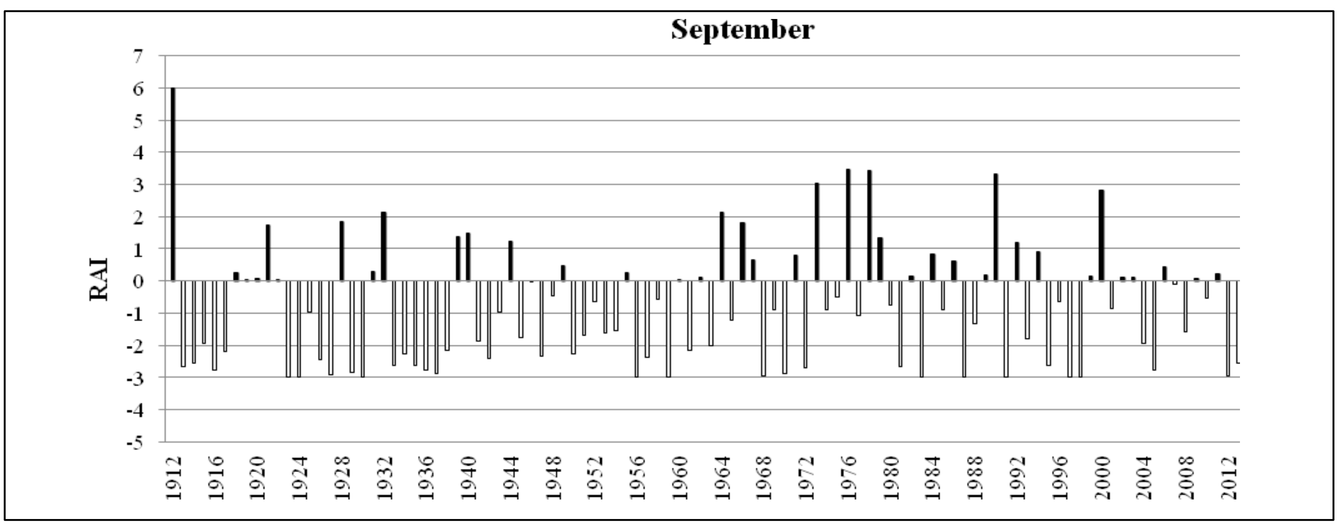

Figure 15. Rainfall anomaly index of the Pajeú river basin for the month of September. Data

Source: ANA (2014) and APAC (2014).

In Figure 16, the RAI of October emerged as the month with the highest number of dry years, with a total of 74 years and with predominance of very dry years (-2 to -4), totaling 41 years, while dry years (0 to -2) were only 33. Years 1915, 1926, 1935, 1991, 1992, 2004 and 2008 reached the same negative RAI of -3.01. Rainy years were 28 distributed into rainy (34 years), very rainy (7 years) and extremely rainy years (2 years), with the highest inflection point of all months in the year 2010, with total rainfall of 109 mm, in which the month of October had average rainfall of 13 mm, reaching positive RAI of 7.24 on a year of occurrence of weak *El Niño*.

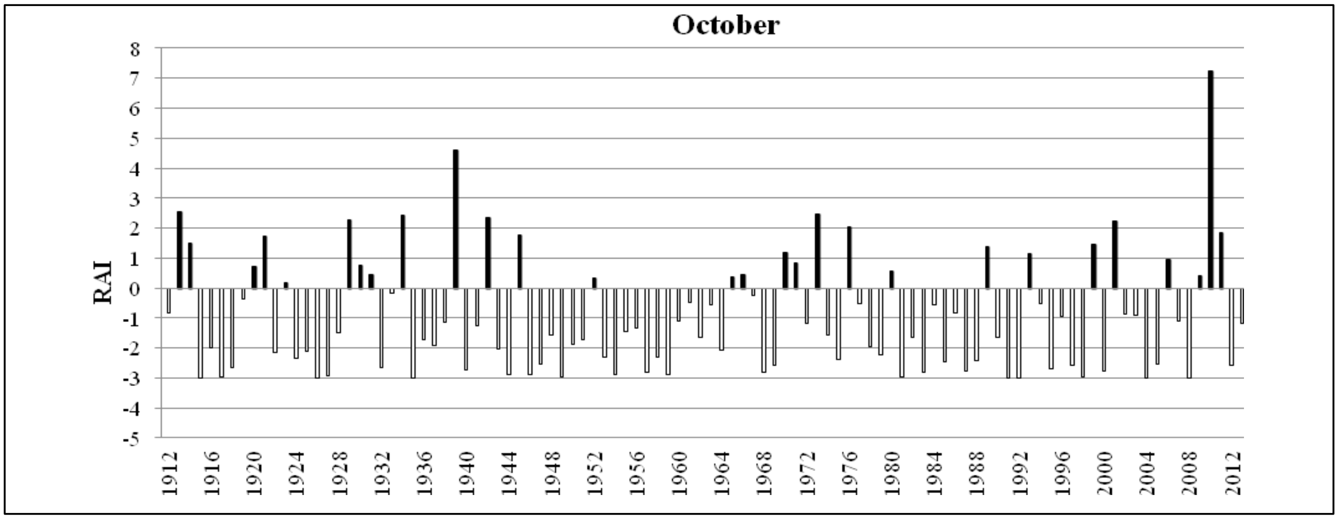

Figure 16. Rainfall anomaly index of the Pajeú river basin for the month of October. Data Source: ANA (2014) and APAC (2014).

It could be inferred that the RAI for the month of November (Figure 17) obtained 65 years of negative RAI, ranging from dry (27 years) to very dry categories (38 years), with the lowest inflection point for the year 1982 (-3.79), which is a year of occurrence of strong *El Niño*; and 37 years of positive RAI, with 29 rainy, 6 very rainy and 2 extremely rainy years, with inflection points in years 1947 (4.66) and 1949 (4.86), with occurrence moderate *El Niño* and strong *La Niña*, respectively.

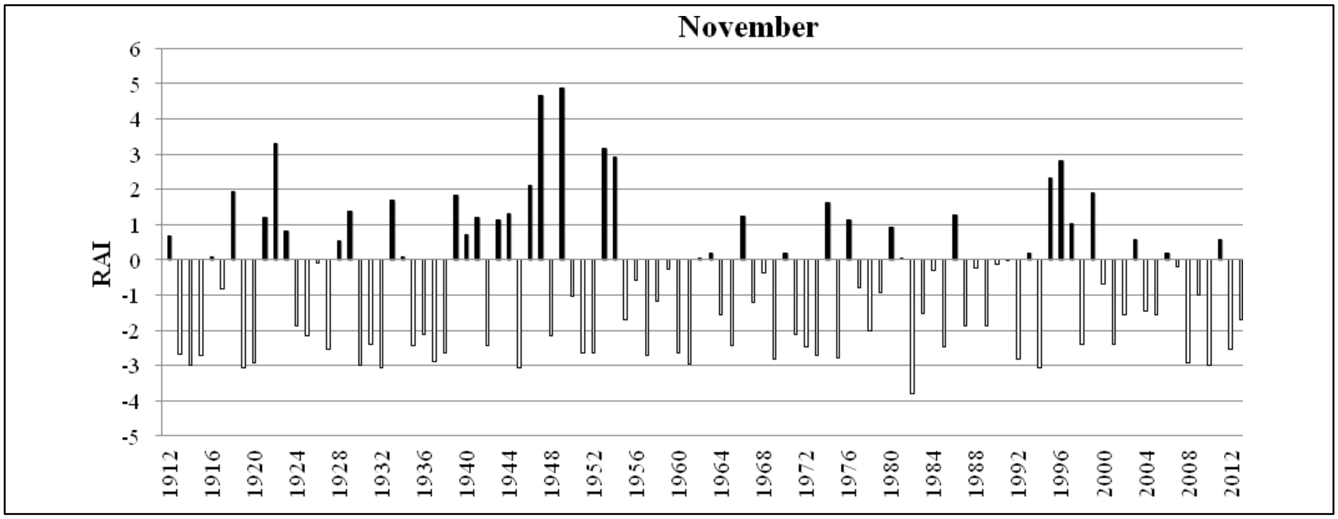

Figure 17. Rainfall anomaly index of the Pajeú river basin for the month of November. Data Source: ANA (2014) and APAC (2014).

In RAI of December (Figure 18), as in all other months, showed a predominance of dry years with 63 years, alternating between dry (35 years) and very dry categories (28 years), with the major droughts in the years 1912 (-3.11) and 2006 (-3.10), with occurrence of strong and weak *El Niño*; and 39 rainy years (30 rainy, 8 very rainy and 1 extremely rainy years), with the highest rainfall in 1963 with a total of 223,3 mm, which provided RAI of 7.19 in *El Niño* year of weak intensity.

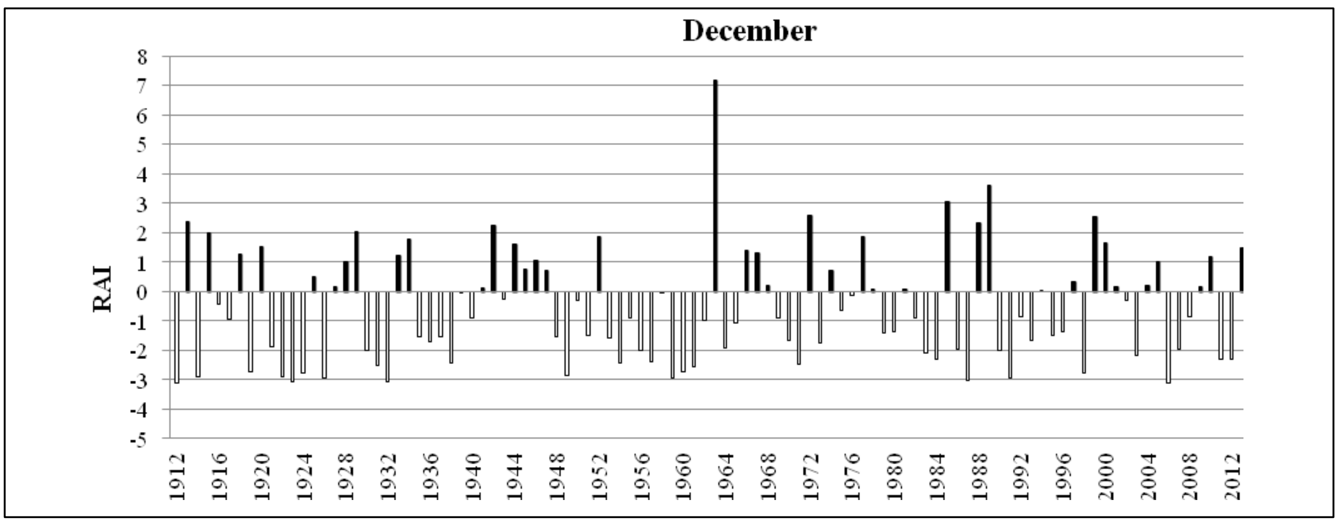

Figure 18. Rainfall anomaly index of the Pajeú river basin for the month of December. Data Source: ANA (2014) and APAC (2014).

Over the period analyzed, seasonal rainfall variability was observed, as well as the occurrence of *El Niño* and *La Niña* and their intensities in extreme drought and rainfall events. However, it is necessary to compare these data with other weather systems such as the occurrence of Atlantic Dipole.

CONCLUSIONS AND RECOMMENDATIONS

Analyzing rainfall in the historical series (1912 - 2013) of the Pajeú river basin through RAI, large interannual variability between dry and wet years was observed, with predominance of dry years and inflection points more extreme in rainy years.

Based on the calculation of the annual RAI, some peculiarities throughout the series were observed, since until the 1950s, this index alternated between negative and positive values, with changes in the average rainfall pattern of the Pajeú river basin, alternating periods of dry (1951 - 1962, 1979 - 1983, 1990 - 2001 and 2012 - 2013) and rainy years (1963 - 1978, 1984 - 1989 and 2002 - 2011).

Thus, climate variation in the rainfall element was found; however, no evidence of climate changes was observed, as the average annual rainfall of the Pajeú river basin showed inexpressible rainfall growth. It was also inferred that the interannual rainfall variability, with alternation of years with negative and positive RAI during the study series, confirmed the existence of strong influence of the occurrence of *El Niño* and *La Niña* phenomena and their intensities in extreme drought and rainfall events, respectively.

The temporal variation of RAI revealed that the rainy season (January, February, March and April), as well as the other months of the year, has predominance of negative RAI, in addition to irregular rainfall distribution. The spatial variation demonstrated that for the entire Pajeú river basin, RAI is between dry and very dry, except for the municipality of Triunfo, considered very rainy with positive RAI of 3.5 because it is a swamp area, which influenced precipitation.

It was shown that the RAI is a useful tool to evaluate the rainfall variability in the semiarid region of northeastern Brazil and assists in the strategic planning of a location (city, state, river basin, etc.) through climate monitoring. Further studies should be carried out with RAI for comparison purposes including other weather systems such as occurrences of the Atlantic Dipole, Upper Tropospheric Cyclonic Vortex (UTCV), instability lines, Mesoscale Convective Complexes.

Due to the results of this study, it is extremely important to monitor precipitation, the active weather systems and their effects on the Pajeú river basin necessary for the management of water resources used in the various socioeconomic activities.

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