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Temporal analysis of events of drought in the municipalities of Caraúbas and Monteiro - PB

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Abstract
Drought is a prolonged period of water deficit and occurs when a site receives rainfall below normal levels. The aim this study was to identify and analyze the severe and extreme droughts that occurred in the Caraúbas and Monteiro municipalities. The rainfall data were obtained through the Agência Executiva de Gestão das Águas do Estado da Paraíba (AESA). Were used total monthly precipitated data in the period of 1931-2014 for Caraúbas and Monteiro. To monitor the droughts we used the Standardized Precipitation Index. The Caraúbas site presented more droughts than Monteiro this is explained by the fact the Eastern Cariri to be drier than the Western. In total Caraúbas presented 35 (32 severe and 3 extreme) and Monteiro 32 (27 severe and 5 extreme) droughts. It could also be noted that in Caraúbas there was severe and extreme droughts during the decade of 1930 and 2000. Already in Monteiro there was in the decade of 1940 and 1960. Regarding the amounts of droughts that occurred in Caraúbas, the order is as follows: 1950>1970>1980>2010>1990>1940. Already Monteiro, 1980>1930>1950>2010>1990>1970. The most severe droughts in Caraúbas were those of 1952-1955, 2012-2014, 1998-1999 and 1979-1984. Monteiro showed higher severity in 1981-1984, 1998-2000 and 2012-2014. According to these data we conclude that there has not been more droughts in the decade of 2010 than in earlier year, the occurrence of variations are normal for a cyclical phenomenon.

Keywords: Standardized precipitation index, severe droughts, extreme droughts.

1. Introduction

Drought is a natural and cyclical feature of the climate, and occurs in virtually all climatic regimes. Corresponds to a prolonged period of water deficit and occurs when an area receives rainfall below normal levels (Gocic and Trajkovic, 2014). To overhauls complete on concepts and modeling of droughts see Mishra and Singh (2010) and Mishra and Singh (2011).

Because of the need to analyze drought, many indices were developed. Among they are Palmer drought severity index (PDSI) (Palmer, 1965), rainfall anomaly index (RAI) (Rooy, 1965), crop moisture index (CMI) (Palmer, 1968) , standardized precipitation index (SPI) (McKee et al., 1993) and many others. Currently, the PDSI and SPI indices are the best known and used worldwide (Blain and Brunini, 2007).

The SPI was developed by McKee et al. (1993) is the only known tool able to quantify or monitor droughts in different time scales. To these authors, scales such are related to precipitation deficit, become extremely important in the characterization of different types of droughts, for example: meteorological, agricultural, hydrological and socioeconomic. This index is based on precipitation series adjust the gamma distribution incomplete. This distribution is adequate to describe the behavior

of variables having lower limit or greater than zero (Thom, 1966).

Ansari et al. (2010) used the SPI for drought monitoring in Khorasan (northeastern Iran), using 33 years of climate data. They showed that during the period 1968-2000, the occurrence of droughts have been more frequent and with more duration, however, decreased the severity.

Jun et al. (2012) showed a significant reduction in frequency and increased intensity of droughts in the Huaihe River Basin, China, in the 1961-2010 period. Also found that droughts are less intense than elsewhere and that severe droughts rarely occur.

Teixeira et al. (2013) observed that of 1164 months analyzed in Bage - RS, as the SPI values, 6.8% were classified as severe and extreme droughts events. Nandintsetseg and Shinoda (2013) when using the SPI, concluded that there was a higher severity and frequency of droughts in the period of growth of pastures in Mongolia during 2001-2010, and that propelled a reduction in pasture production on site.

Was observed by Gocic and Trajkovic in Serbia in the period from 1948-2013 which occurred 7.9 % of moderate droughts, 5.2% severe and 2.1% extreme. Xu et al. (2014) using the SPI showed that the two most severe drought events in China occurred in the periods of 1962-1963 and 2010-2011, these events affected the northern plains to the Yangtze River decreasing eventually in southwest. Tosic and Unkasevic (2014) using the historical series of the SPI found that the frequency of droughts in southern Serbia was higher than in other parts of the country.

Already Huang et al. (2015) used the SPI and periods of droughts in Inner Mongolia, China. The results show visible spatial patterns with six sub-regions characterized by different climatic variability. Overall, most areas of interior of Mongolia are dominated by trends of dry periods, except for the eastern and western areas.

In the face of what was discussed, it is aimed to identify and analyze the severe and extreme droughts that occurred in the municipalities of Caraúbas and Monteiro during the time series from 1931 to 2014.

2. Materials and methods

The study area comprises the municipalities of Caraúbas and Monteiro. Both are located in Mesoregion of Borborema and at the Microregions of Eastern and Western Cariri, respectively (Figure 1).

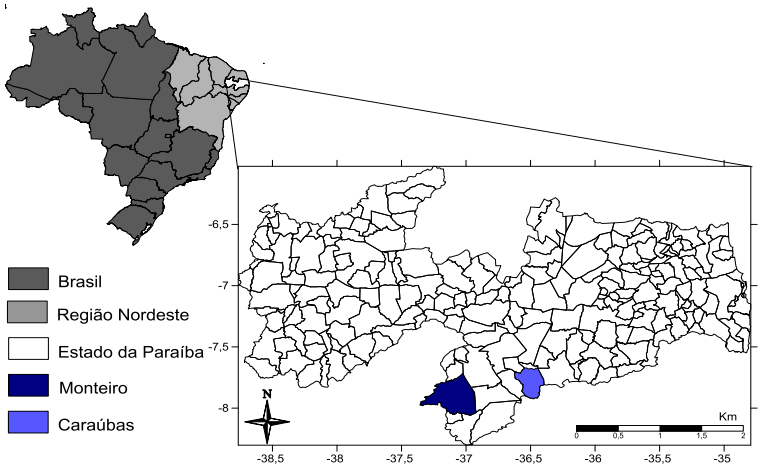

Figure 1 - Geographical location of municipalities of Caraúbas and Monteiro - PB.

The rainfall data were obtained through the Agência Executiva de Gestão das Águas do Estado da Paraíba (AESA). Were used monthly totals precipitates in the 1931-2014 period for municipalities of Caraúbas and Monteiro. The reason for the choice of the municipalities it is that present complete precipitation series for long and the interest here is analyzing which of two is most affected by severe and extreme droughts. The characterization of rainfall regime was

carried out by tuning the empirical series the gamma distribution. The gamma probability distribution function is displayed in Eq. (1).

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad (1)$$

Being:

$\alpha > 0 =$ is a parameter of form for gamma distribution; $\beta > 0 =$ is parameter of scale the gamma distribution; $\chi > 0 =$ total of precipitation; $\Gamma(\alpha)$ = gamma function.

To estimate of parameters α and β, they were used in solutions in likelihood maximum (Eqs. 2, 3 and 4).

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (2)$$

$$\text{in that } A = \ln\left(\bar{x}\right) - \frac{\sum_{i}^{n} x_i}{n} \quad (3)$$

$$\text{and } \hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \quad (4)$$

Being:

$\bar{x}$ = arithmetic mean of rainfall (mm); ln = neperian logarithm; n = number of observations the sample.

After the estimation of g(x) for the series of investigated precipitation, the SPI can be calculated by Eq. (5).

$$H(x) = q + (1-q)G(x) \quad (5)$$

Being:

$H(x) =$ cumulative probability distribution; q = probability of occurrence of null values (zeros); G(x) = theoretical cumulative distribution.

If m is the number of zeros in a series of precipitation, then q = m/n.

Being:

m - number of observations with rain equal zero; n - number of observations with rain more zero.

H(x) was then transformed into a normal variable (final value the SPI) by means of equations developed by Abramowitz and Stegun (1965), the relationship between the distributions the probability gamma and normal it is presented in Eqs. 6, 7, 8 and 9.

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad (6)$$

for $0 < H(x) \leq 0,5$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad (7)$$

for $0,5 < H(x) \leq 1,0$

Being:

$c_0 = 2.515$; $c_1 = 0.803$; $c_2 = 0.010$; $d_1 = 1.433$; $d_2 = 0.189$; $d_3 = 0.001$.

$$\text{wherein } t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \quad (8)$$

for $0 < H(x) \leq 0,5$

$$\text{and } t = \sqrt{\ln\left(\frac{1}{(1-H(x))^2}\right)} \quad (9)$$

for $0,5 < H(x) \leq 1,0$

The values the SPI with your categories are available in Table 1.

Table 1 - Values of SPI and categories of rains and droughts.

Values of SPI	Categories
≥ 2.00	Extreme rain
1.50 a 1.99	Severe rain
1.00 a 1.49	Moderate rain
0 a 0.99	Low rain
0 a - 0.99	Low drought
- 1.00 a - 1.49	Moderate drought
- 1.50 a - 1.99	Severe drought
≤ - 2.00	Extreme drought

Source: (Mckee et al., 1993).

After calculating the SPI on the scales of 3, 6, 9, 12 and 24 months, were selected and analyzed the droughts that presented category severe and/or extreme in the municipalities, for it is these that cause the higher social, economic and environmental impacts.

3. Results and discussion

The average rainfall shows that Caraúbas municipality is constantly hit by droughts. This occur because the drought is a cyclical phenomenon, that is, sooner or later it will occur again. Despite being a well-known and studied phenomenon, the impacts of the droughts are still being serious in the municipality. Table 2 shows the intensity of severe and extreme droughts that happened in Caraúbas for the period of 1931 - 2014.

The series of SPI 3 months has identified seven severe droughts. Those droughts occurred during April 1942, April and August 1953, April and May 1954, March and June 1979, April and June 1982, April and September 1998, and March and June 2013. The durations were of 1, 5, 2, 4, 3, 6 and 4 months and the SPIs of - 1.91, - 1.57, - 1.51, - 1.65, - 1.70, - 1.70 and - 1.78, respectively. The droughts identified in the scale of three months had the lowest durations, for this reflects water conditions on the ground in the short and medium term and provides an estimate of seasonal precipitation. On this scale the impacts were less intense, increasing progressively with increasing duration and of SPI average (Table 2).

The SPI 6 months revealed the occurrence of extreme drought during the months of March and May 1949. In larger quantities, the severe drought hit the municipality between January and August 1958, February and March 1971, March and October 1979, January and February 1983, February and March 1984, April 1998 and February 1999, and April 2012 and August 2013, with durations ranging from 2 to 17 months. It was found that the most number of severe droughts occurred during the decades of 1970 and 1980. The scale of 6 months is associated with water storage abnormalities in dams, rivers and the water table, that why that the impacts were more intense this scale than the previous. The droughts more grave were at 2012-2013, 1998-1999, 1979 and 1958 (Table 2).

The time series of 9 months has identified nine severe droughts. They occurred between April and May 1949, January and December 1953, February and November 1958, May 1959 and February 1960, February and March 1971, April 1979 and January 1980, January and December 1982, May 1998 and March 1999, and May 2012 and November 2013. Some droughts called attention because happened very close each other, are they: 1949, 1953, 1958, 1959-1960, 1979-1980 and 1982, that did with that the impacts if keep acting. Other very serious droughts struck the municipality during 1998-1999, lasting eleven months and SPI average of - 1.74. The last occurred in 2012-2013, lasted 19 months with SPI average of - 1.78 (Table 2).

The SPI 12 months identified droughts in 1952-1954, 1958-1959, 1959-1960, 1979-1980, 1982-1983, 1998-1999 and 2012-2014, with durations that ranged in nine the 26 months. On this scale the impacts were very intense, given the duration of droughts. The 2012-2014 lasted 26 months, already the in 1952-1954 we had duration of 25 months, these were the more intense. Others of impact minor, but serious, occurred in 1982-1983 and 1998-1999. Also contributed to increase the impacts the fact that they have happened near each other and in consecutives years (Table 2).

The scale 24 months identified four droughts, two extreme and two severe. The severe occurred between May 1952 and February 1955, and May 1980 and February 1981. Already the extreme happened of April 1959 to February 1960, and of April 2013 to December 2014. What impresses in these droughts are their durations, 34, 11, 10 and 21 months, respectively. They impacted severely the municipality, principally the severe drought of 1952-1955, and the extreme drought of 2013-2014 (Table 2).

Table 2 - Quantity, period, duration, SPI mean and category of drought obtained by SPIs 3, 6, 9, 12 and 24 months for the municipality of Caraúbas - PB.

Scale of 3 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	Abril 1942	April 1942	1	- 1.91	severe drought
2	April 1953	August 1953	5	- 1.57	severe drought
3	April 1954	May 1954	2	- 1.51	severe drought
4	March 1979	June 1979	4	- 1.65	severe drought
5	April 1982	June 1982	3	- 1.70	severe drought
6	April de 1998	September 1998	6	- 1.70	severe drought
7	March 2013	June 2013	4	- 1.78	severe drought
Scale of 6 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	March 1949	May 1949	3	- 2.00	extreme drought
2	January 1958	August 1958	8	- 1.51	severe drought
3	February 1971	March 1971	2	- 1.65	severe drought
4	March 1979	October 1979	8	- 1.80	severe drought
5	January 1983	February 1983	2	- 1.50	severe drought
6	February 1984	March 1984	2	- 1.50	severe drought
7	April 1998	February 1999	11	- 1.61	severe drought
8	April 2012	August 2013	17	- 1.70	severe drought
Scale of 9 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	April 1949	May 1949	2	- 1.70	severe drought
2	January 1953	December 1953	12	- 1.68	severe drought
3	February 1958	November 1958	10	- 1.54	severe drought
4	May 1959	February 1960	10	- 1.69	severe drought
5	February 1971	March 1971	2	- 1.59	severe drought
6	April 1979	January 1980	10	- 1.90	severe drought
7	January 1982	December 1982	12	- 1.51	severe drought
8	May 1998	March 1999	11	- 1.74	severe drought
9	May 2012	November 2013	19	- 1.78	severe drought
Scale of 12 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	May 1952	May 1954	25	- 1.62	severe drought
2	May 1958	February 1959	10	- 1.61	severe drought
3	April 1959	February 1960	11	- 1.68	severe drought
4	June 1979	February 1980	9	- 1.99	severe drought
5	April de 1982	March 1983	12	- 1.69	severe drought
6	June 1998	May 1999	12	- 1.65	severe drought
7	June 2012	July 2014	26	- 1.69	severe drought
Scale of 24 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	May 1952	February 1955	34	- 1.73	severe drought
2	April 1959	February 1960	11	- 2.04	extreme drought
3	May 1980	February 1981	10	- 1.64	severe drought
4	April 2013	December 2014	21	- 2.16	extreme drought

Already for the municipality of Monteiro, the SPI 3 months identified ten droughts, nine severe and one extreme. The durations of severe varied from one to six months, deserving featured the longest (6 months) and with one of the highest average SPIs (- 1.96) by having happened recently (April-September 2012). The other severe droughts occurred in 1934, 1938, 1953, 1954, 1958, 1977-1978, 1983 and 1998. The extreme drought occurred from March to June 1982, lasted 4 months and reached the average SPI of - 2.07. Again, most of the droughts occurred close to each others. It can be observed, this scale, that the amount of droughts was less during the decades of 1990, 2000 and 2010 (Table 3).

Regarding the period of 6 months, were only identified severe droughts, including, some if repeated in the previous and current SPI, they are: 1934, 1938, 1954, 1958, 1982 and 2012-2013. The another drought occurred in 1936. Among all, the highlight was the 2012-2013, 1934 and 1982 for being the longest and presented the major SPIs. It is important to note the droughts that were identified us previous SPIs and persist in the others, it indicates that they

deserve greater emphasis, because remained acting for more time (Table 3).

On the scale of 9 months the quantity of drought identified was reduced, but there was an increase in duration. This scale have been identified six droughts, four severe and two extreme. The severe occurred from February to May 1938, May 1983 to March 1984, June 1998 to October 1999, and April 2012 to April 2013. Already the extreme droughts occurred from February to December 1934 and from January to December 1982, lasting 11 and 12 months and average SPI of - 2.10 and - 2.12 respectively. All reached the Northeast semiarid in some places lasted longer and caused more impact negative, in others were of less intensity (Table 3).

With the SPI 12 months were identified six droughts, four severe and two extreme. The severe reached the municipality in 1934-1935, 1953-1954, 1983-1984 and 1998-1999, with durations of 12, 14, 11 and 19 months. Extreme droughts occurred of February 1982 to February 1983 and June 2012 to June 2013. Both had duration of 13 months. The longest droughts in the municipality have been identified in the scale of 24 months there were three, all severe, which occurred in 1981-1984, 1998-2000 and 2013-2014, with durations of 34, 23 and 16 months, respectively (Table 3). When it increased the scale, many droughts identified by previous SPIs were grouped into larger scales, for example, droughts with SPIs 3, 6 and 9 months were grouped and formed droughts with SPIs of 12 and 24 months, when it happens, should give larger importance the droughts remaining in the scales higher.

In the analysis it is observed that the severe and extreme droughts in the municipalities had intensities, durations and impacts different. Concretely, the most intense droughts that have been identified are those that literature makes some description. For example, some books and articles highlight those that occurred in the Northeast in the centuries XX and XXI, where occurred droughts of large proportions in 1934, 1938, 1952-1955, 1958, 1966, 1968-1969, 1970-1971, 1979-1984, 1990 -1994, 1998-2000 and 2012-2015. This can be confirmed in Khan and Campos (1992), Duarte (2002), Toni and Holanda Junior (2008), Silva et al. (2013) and Gutierrez et al. (2014).

Although Figure 2 does not show the values of ENSO since 1931, correlation was observed between the most years of droughts and El Niño starting from 1950. Comparing the identified droughts in Caraúbas and Monteiro with El Niño events, Figure 2, it perceives what a majority of droughts occurred in years with positive deviations from the sea surface temperature (SST) in the Pacific. The droughts in the years of 1952, 1953, 1954, 1958, 1959, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1998, 2013, 2014 and 2015 occurred at the same time that the events El Nino. This happened because the El Niño is an important factor affecting the global climate. She and Xia (2013) and Liu et al. (2014) also found many links between El Niño and droughts.

Already others years of droughts occurred during La Niña events, were as follows: 1955, 1971, 1999, 2000 and 2012. Figure 2 shows this relationship. The reason some droughts have occurred during La Niña events is that in the northeastern semiarid the precipitation is also strongly related to SST in the Atlantic Ocean. Moura and Shukla (1981) showed that for some years, the events of droughts in Northeastern (NEB) are associated with a meridional dipole of the Tropical Atlantic SST anomalies, thus the position and intensity of the intertropical convergence zone are affected and, in turn, influences the precipitation in NEB.

Table 3 - Quantity, period, duration, SPI mean and category of drought obtained by SPIs 3, 6, 9, 12 and 24 months for the municipality of Monteiro - PB.

Scale of 3 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	March 1934	July 1934	5	- 1.55	severe drought
2	February 1938	April 1938	3	- 1.52	severe drought
3	April 1953	June 1953	3	- 1.68	severe drought
4	March 1954	April 1954	2	- 1.52	severe drought
5	February 1958	February 1958	1	- 1.53	severe drought
6	November 1977	February 1978	4	- 1.81	severe drought
7	March 1982	June 1982	4	- 2.07	extreme drought
8	May 1983	August 1983	4	- 1.64	severe drought
9	April 1998	August 1998	5	- 1.97	severe drought
10	April 2012	Setember 2012	6	- 1.96	severe drought
Scale of 6 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	February 1934	October 1934	9	- 1.72	severe drought
2	January 1936	January 1936	1	- 1.54	severe drought
3	January 1938	May 1938	5	- 1.87	severe drought
4	April 1954	April 1954	1	- 1.59	severe drought
5	January 1958	March 1958	3	- 1.54	severe drought
6	March 1982	Setember 1982	7	- 1.99	severe drought
7	April 2012	January 2013	10	- 1.90	severe drought
Scale of 9 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	February 1934	December 1934	11	- 2.10	extreme drought
2	February 1938	May 1938	4	- 1.61	severe drought
3	January 1982	December 1982	12	- 2.12	extreme drought
4	May 1983	March 1984	11	- 1.60	severe drought
5	June 1998	October 1999	17	- 1.59	severe drought
6	April 2012	April 2013	13	- 1.92	severe drought
Scale of 12 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	March 1934	February 1935	12	- 1.87	severe drought
2	April 1953	May 1954	14	- 1.54	severe drought
3	February 1982	February 1983	13	- 2.05	extreme drought
4	May 1983	March 1984	11	- 1.70	severe drought
5	June 1998	December 1999	19	- 1.66	severe drought
6	June 2012	June 2013	13	- 2.06	extreme drought
Scale of 24 months					
Quant	Start	End	Duration (months)	SPI mean	Category
1	June 1981	March 1984	34	- 1.79	severe drought
2	May 1998	March 2000	23	- 1.76	severe drought
3	February 2013	May 2014	16	- 1.92	severe drought

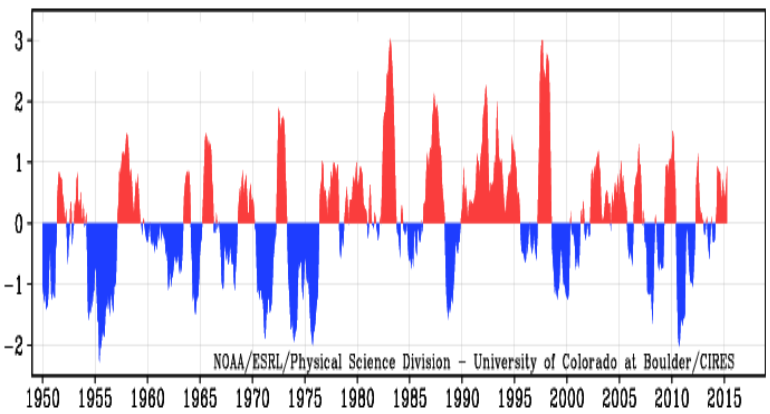

Figure 2 - Multivariate enso index. Source: (NOAA, 2015).

4. Conclusions

The municipality of Caraúbas presented more droughts than Monteiro, this occurred because the Eastern Cariri it is more drier than Western. In total, Caraúbas had 35 (32 severe and 3 extreme) and Monteiro 32 (27 severe and 5 extreme) droughts. It was also possible to observe that the municipality of Caraúbas was not hit by severe and extreme droughts during the decade of 1930 and 2000. Already in Monteiro not occur droughts in the decades of 1940 and 1960.

Regarding the amounts of droughts that occurred in Caraúbas, the order is as follows: 1950>1970>1980>2010>1990>1940. Already Monteiro, 1980>1930>1950>2010>1990> 1970. The most severe droughts in Caraúbas were those of the 1952-1955, 2012-2014, 1998-1999 and 1979-1984. In Monteiro showed higher severity of the 1981-1984, 1998-2000 and 2012-2014. Most of the identified droughts occurred at the same time that the events El Nino. With this information is can be concluded that there has not been more droughts in the decade of 2010 than in earlier, which is occurring are variations normal for a cyclical phenomenon.

The most intense droughts in Caraúbas and Monteiro caused very serious impacts, including reducing the food of the population, conflicts between water users, increasing poverty, population migrations, reduction of agriculture and livestock, death of people, looting, rising unemployment, unavailability of feed for animal, losses to flora, fauna and fish species, and reduction the water amount of dams and rivers.

It's needed separate the droughts into two groups, those that happened before and after 2000. This is because the impacts were larger before of 2000, when the logic of living together with droughts still was not taken into consideration and it did not exist the policies of distribution to income of governments.

It is possible to observe that many impacts that occurred in previous droughts were not repeated in drought of 2012-2014, such as: people dying of hunger and thirst, migration intense and looting. However, the impacts on livestock, agriculture, flora, fauna and availability of water the fountains remain almost identical to the droughts that occurred in the past. How likely solution of the impacts that continued in 2012-2014, may serve as hope the fact that Caraúbas and Monteiro vain receive the waters the Transposição do Rio São Francisco. Thus, it is expected that the impacts that still remained are minimized in future droughts. Importantly what the drought with start in 2012 is not over yet, the year of 2015 is being dried again and only was not identified because the monthly precipitations are not yet available.

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