

## **Monitoring of droughts in municipalities of the Sertão Paraibano**

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### **Abstract**

Drought is a natural phenomenon that affects all regions. There is great difficulty in getting a consensus to define the real meaning of the theme; this occurs mainly there are differences in hydrometeorological variables and socioeconomic factors as well as the random nature of the demand for water. Despite the large number of researchers working with dried in the world, there is an information gap, especially in duration, water deficit, intensity and return period of droughts in Northeast Brazil. The objective this research is to analyze the duration, water deficit, intensity and return period of droughts in the municipalities of the Sertão Paraibano. Were used data of precipitates monthly totals in the period of 1994-2014 the municipalities of Cajazeiras, Catolé do Rocha, Patos, Pombal, São Bento and Sousa. The execution method was used in order to identify periods of droughts and assess their statistical properties. The municipality of Sousa had the highest number of droughts, eight in total, followed by Cajazeiras, Catolé do Rocha, São Bento (seven droughts), Patos and Pombal (six droughts). The longest drought occurred in Patos, started in 1997 and ended in 2001, lasting five years. The more severe droughts in these municipalities occurred between 1997-1999, 2001-2003 and 2012-2014, that is, those who had longer duration, bigger water deficit and bigger intensity. The analysis of period of return of droughts most severe in the municipalities show very different values, with the longest occurring in Patos, during the drought of 1997-2001, where the probability of occurrence of another drought of the same duration is of one to every 89 years. Droughts with durations equal or superior can occur in 67 years. Already the water deficit can be overcome in 33 years.

Keywords: Droughts, water deficit, execution method.

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### **1. Introduction**

Drought is a natural phenomenon present in all regions of the world. Of all natural disasters, drought accounts for 22% of spending, 33% of the number of people affected and 3% of the number of dead.

Drought is the most complex of all natural phenomena, affecting a larger number of people than any other (Wilhite et al., 2007). Differences in hydrometeorological variables and socioeconomic factors as well as the

stochastic nature of the demand for water in different regions around the world, have become an obstacle to have a precise definition of drought. Still, the World Meteorological Organization (WMO, 1986) defines drought as a deficiency in precipitation. Already the United Nations Convention to Combat Desertification and Drought (UNCCD, 1994) defines as a naturally occurring phenomenon when precipitation has been significantly below normal levels registered, causing serious hydrological imbalances that adversely affect urban and rural areas.

Depending on the duration, water deficit and intensity, the droughts can be classified into four categories: low, moderate, severe and extreme. Although the primary cause of the droughts lies in irregular rainfall, there is a sequence of causes and effects that take place due to the intensity of the events and of types of droughts, which can be meteorological, agricultural, hydrological and socioeconomic.

Droughts are natural phenomena that differ sharply from other phenomena, such as hurricanes, earthquakes, tsunamis and volcanic eruptions; which starts and end suddenly, in addition to restrict, normally, to a small region, while the phenomenon the drought has, often, a slow start, a long duration and disperse, in most of times, by an extensive area (Freitas, 2005).

A drought can be characterized both by the low level of annual precipitation from the average of a year of normal precipitation, and by their irregular distribution during the rainy season, which usually lasts 4-6 months in the semiarid northeast. When there is a drought, the level of annual rainfall and the distribution pattern during the rainy season are different of the years considered with normal rainfall, or as is said in northeastern: year of "winter". It may also happen that half of the annual precipitation from one location has occurred in a single month and in a single day rain.

Alves (2003) says that during the drought of 1723-1729, the chief captain of the captaincy of Paraíba notified the king of Portugal on the local situation of hunger and disorders that was going on because of the drought. The Charter of 25 of may of 1725, in response to the chief captain, the king of

Portugal, D. João wrote: "Ye recommend seek when you it possible tilt the inhabitants the culture the land and that apply the use some office in order to avoid idleness that comes his ruin". The Charter also determined the culture of cassava and inspection with fines for those who refuse to work for the production of flour.

In 1776-1778 the drought was intensified by the large outbreak of variola, causing a high rate of human mortality, also happening massive loss of livestock. The flagella were gathered in towns on river banks, in determining the Portuguese Court (Silva et al., 2013). In this drought, which became known as the drought of three seven (1777), is estimated to have been decimated seven-eighths of flock of State of Ceará (Alves, 2003).

Reads in memory of priest Joaquim José Pereira, vicar the Rio Grande do Norte, what at drought the 1792 appeared in the region an immense amount of bats (*Diphylla ecaudata*), what even of day attacked people and animals. It appears, thus, that these animals commonly to nightlife, excited by hunger, passed to stir during the day, attacking the man himself, which usually they fear. The snakes, what emerge ordinarily after the major droughts, also reflect the change in behavior of these animals what, the courts of plenty, living mostly in their dens and that as a result of hunger in drought begin to stir so alarming (Castro, 2008).

In 1824-1825, drought and variola together they spread, sterilizing the hinterland, hunger reached including mills of sugar cane (*Saccharum officinarum* L.). In 1831 the Regency Triune, against the prolonged drought, authorizes the opening of deep artesian sources. It is the first government reaction signal before the phenomenon (Canuto et al., 2013).

Campos (2014) says that the last drought recorded before the 1877 tragedy occurred in 1845. It passed 32 years of good "winters" in which there was growth of herds and populations not accompanied by the strengthening of infrastructure of açudagem and roads. It is created a highly vulnerable population, what like this developed by ignorance of physical geography and regional

climate variability, this fact resulted in the tragedy of drought from 1877-1879.

The Ceará, at that time, with a population of 800.000 inhabitants was heavily hit. Of these, 120.000 (15%) migrated to the Amazon and 68.000 people went to other states. It is said that much of the population of Fortaleza has been eliminated. The economy was devastated, disease and hunger decimated the herds (Canuto et al., 2013). Villa (2002) reported: "the drought of 1877-1879 was one of the most terrible, it would have wiped out about 4% of the Northeastern population".

Castro (2008) says that after the drought of 1877-1879 in Rio Grande do Norte, was developed in the province a terrible evil. The rattlesnake (*crotalos hórridos*) devastated the hinterlands of fearfully. These reptiles appeared so often that 500 people died in a short time. The life of the backcountry and cattle that escaped the drought was likely to end up in the teeth of the animal venomous.

The drought of 1979-1984 was one of the longest in the history of the Northeast. Reached the entire region, leaving a trail of misery and hunger in all states. A UNESCO survey showed that 62% of northeastern children, of 0-5 years, in the countryside, living in a state of acute malnutrition (Silva et al., 2013). On NEB, analyzing the effects of drought in the 1979-1984 period, Khan and Campos (1992) estimated that total losses for the period reached the impressive numbers of 1.6 million tons of cotton (*Gossypium hirsutum* L.), 1 million ton of cassava (*Manihot esculenta* Crantz), 3 million tons of maize (*Zea mays*) and 952.000 tons of beans (*Phaseolus vulgaris*), as well as losses of several other products.

Another major drought occurred in the years 1998-2000, being caused by El Niño, this was considered the strongest of the century, that drought caused, in the NEB, great social, economic and environmental impacts. Among they are included the considerable loss of herds, the general decline of the harvest, in addition to disorders in water supply in urban and rural areas. Still are alive in the population

mind, scenes that the national press disclosed: farmers baking cactus (*Opuntia ficus indica*) to feed the family; cattle (*Bos indicus*), goats (*Capra hircus*) and sheep (*Ovis áries*) dying daily for lack of food and water; children hunting birds and reptiles for if feed; women and children walking kilometers to transport, in the head, poor quality water cans. To these heartbreaking and humiliating scenes, they amounted to others, revealing the desperate hungry people groups looting fairs and trucks.

To date, the literature on the drought of 2012-2015 for the NEB is still very scarce, most information that are on the internet and in newspapers refer to local situations, and there are no studies that add a number of regional or even national information. The existing concrete is that the region was burdened by severe impacts on agriculture. The lack of rain affects the lives of millions of Brazilians in the Northeast have left deep marks in economic activity. And not just in agriculture and livestock, drought caused unavailability of water in approximately 95% of the reservoirs, the collapse in supply has led to an unprecedented crisis in the municipalities.

Knowledge about duration, water deficit and intensity of droughts that occurred and the forecast for when future droughts may occur, are of great importance, especially in rural areas, due to the amount of people who work and live in the countryside, which are the most affected. It is also important for allowing the man from the country who can perform a plan to reduce the impacts to which animals and plants are submitted against a drought.

Given the above, aimed to analyze duration, water deficit, intensity and return period of droughts in the municipalities of Sertão Paraibano.

## 2. Materials and methods

The study area comprises the municipalities of Cajazeiras, Catolé do Rocha, Patos, Pombal, São Bento and Sousa. All located in the Mesoregion of Sertão paraibano (Figure 1).

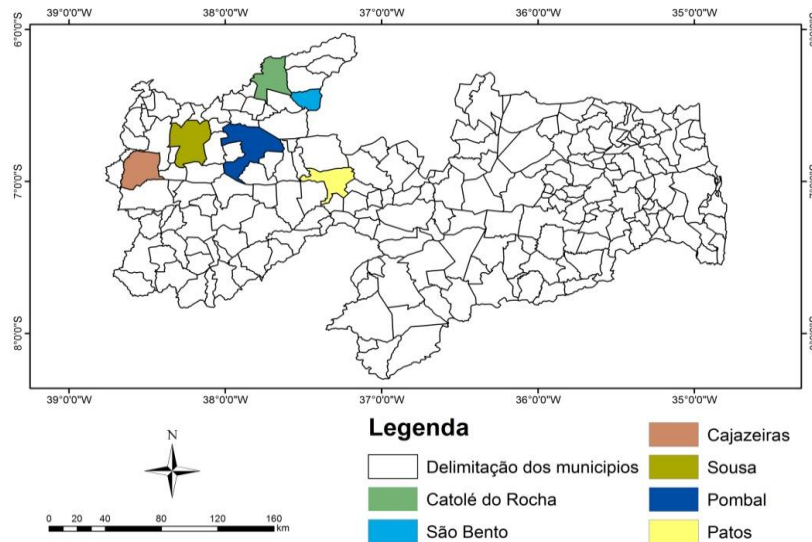


Figure 1 - Geographical location of the municipalities of Cajazeiras, Catolé do Rocha, Patos, Pombal, São Bento and Sousa-PB.

The precipitation data were obtained through the Agência Executiva de Gestão das Águas do Estado da Paraíba (AESAs). Were used monthly totals precipitates in the 1994-2014 period for municipalities of Cajazeiras, Catolé do Rocha, Patos, Pombal, São Bento and Sousa. The choice of municipalities was to be constantly hit by droughts that cause social, economic and environmental impacts serious, and have shocked a large number of people.

The execution method was used in order to identify periods of drought and assess their statistical properties. According to this method, a drought period coincides with a rainfall of value, defined as a consecutive series of intervals where the hydrological variable remains below an average value (Yevjevich, 1967). The advantage of using the method is the ability to identify the characteristics of the drought, such as duration, water deficit, intensity and return period (Cancelliere et al., 1998).

Given a distinct time series  $h(i)$ ,  $i = 1, 2, \dots, n$  and a level of truncation  $h_0$ , it is possible to identify the positive and negative deviations according to the difference between the values observed for the variable and the fixed threshold.

By analyzing a drought, it's possible identify the following characteristics:

- Duration  $L(s)$ , defined as the number of consecutive intervals in which the variable remained below the threshold;

- Water deficit  $D(s)$ , defined as the sum of the negative deviations, extended to the entire period of drought;
- Intensity  $ID(s)$ , defined as the ratio of the deficit and duration.

More precisely,  $d(i)$  being the deficit in the break  $i$  (Eq. 1):

$$d(i) = [h_0 - h(i)] \cdot I[h(i)] \quad \text{Eq. (1)}$$

what  $I[h(i)] = 1$ , if  $h(i) < h_0$   
 $I[h(i)] = 0$ , if  $h(i) \geq h_0$

The duration of the drought was obtained by Eq. 2:

$$L(s) = i_f - i_i + 1 \quad \text{Eq. (2)}$$

where  $i_f$  and  $i_i$  are such that:  $d(i) > 0$  for  $i_i \leq i \leq i_f$  and  $d(i_i - 1) = 0$ ,  $d(i_f + 1) = 0$ ;

The deficit was obtained by Eq. 3:

$$D(s) = \sum_{i=i_i}^{i_f} d(i) \quad \text{Eq. (3)}$$

The Eq. 4 allowed calculate the intensity:

$$ID(s) = D(s)/L(s) \quad \text{Eq. (4)}$$

The return period was calculated from equations 5, 6, 7 and 8:

$$\text{return period}_{\text{duration}} = \frac{E(L)}{1 - F_L(L)} \quad \text{Eq. (5)}$$

$$\text{return period}_{\text{deficit}} = \frac{E(L)}{1 - F_d(d)} \quad \text{Eq. (6)}$$

Where  $L$  is the period between the events of drought;  $E(L)$  is the average time of occurrence and  $F_L(L)$  and  $F_d(d)$  are the function the cumulative probability distribution the

duration and deficit the drought, respectively. The return period was divided into probability of exceedance of the duration and deficit ( $L>l$  and  $D>d$ ) and to overcome the duration or the deficit ( $L>l$  or  $D>d$ ). For each condition, the equations 7 and 8 follow below.

$$\text{return period } L>l \text{ and } D>d = \frac{E(L)}{P(L > l \text{ or } D > d)} = \frac{E(L)}{1 - FL(l) - FD(d) + C[FL(l), FD(d)]}$$

Eq. (7)

$$\text{return period } L>l \text{ or } D>d = \frac{E(L)}{P(L > l \text{ or } D > d)} = \frac{E(L)}{1 - C[FL(l), FD(d)]}$$

Eq. (8)

After calculating the above variables, it was possible to compare the entire series through the maximum and minimum values for each variable. The main advantages of this method are the ease in identification and analysis of droughts, since the limit is set.

To calculate the execution method was used Regional Drought Identification Module (REDIM). The REDIM package is software which lets you droughts analysis in different historical series, in one or more regions. The software is executed on windows platform and is structured with a series of dialogs that guide the user through the entire analysis.

The main characteristics of REDIM are the following:

- Data files are in Microsoft access format, which allows flexibility and compatibility with databases and windows based programs;
- The import data allow automatically create the Microsoft access database files from existing ASCII text files, avoiding process of database creation tedious;
- Can be used on different time scales;
- The reports of texts are produced in Microsoft word format that facilitates the integration of outputs with other existing documents.

### 3. Results and discussion

Drought is a different phenomenon from other natural phenomena. By having slow start, its consequences accumulate slowly over time, this causes various social, economic and environmental impacts. Among them are health problems on the low flow, unequal distribution of resources during the drought, mental wear, reductions in food of the population, conflicts between water users, increasing poverty, population migrations, reduction of agriculture, rising unemployment, higher costs for transporting water, unavailability of feed animal, disruption of reproductive cycles, reduction of recreation and tourism, damage to fauna, flora and fish species; and decreased water quality. Monitor droughts events is an important aspect to reduce these impacts. To reduce them is necessary, among many things, know their characteristics, such as duration, water deficit, intensity and return period.

All municipalities this analysis have in agriculture an important source of food and income, activities such as exploration cultures of corn, bean and coconut; and creation of cattle, goats and sheep help the population get better living conditions. While, in dry years, most of these activities are paralyzed and the losses accumulates slowly, mainly in rural areas.

The municipality of Cajazeiras presented great temporal variability of precipitation during 1994-2014, that is observed through consecutive years with rainfall above and below the average. Years with above average rainfall hit the municipality in 1996, 1997, 2000, 2004, 2006, 2008, 2009 and 2011. Droughts occurred in the years 1994-1995, 1998-1999, 2001-2003, 2005, 2007, 2010 and 2012-2014 (Figure 2). These caused very serious impacts in the municipality, mainly the longest. Shorter periods result in droughts meteorological, the longest in agricultural and hydrological droughts; with influence on agriculture and the supply of rivers and dams.

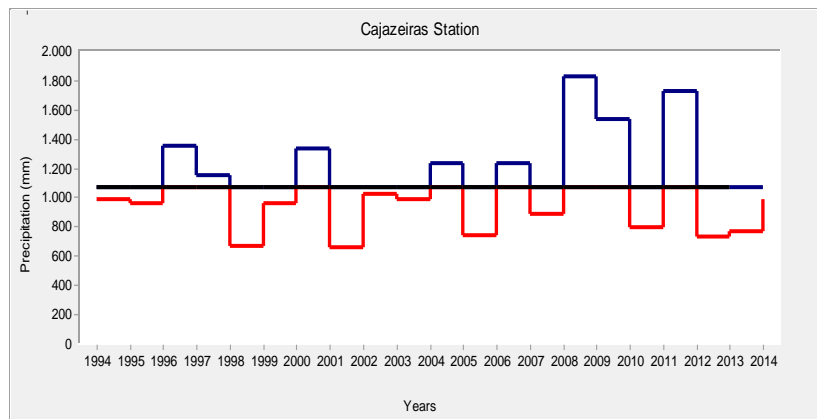


Figure 2 - Annual precipitation between the period 1994-2014 for the municipality of Cajazeiras-PB.

The most serious droughts of municipality occurred in the following sequence: 2012-2014, 2001-2003, 1998-1999, 2005, 2010, 1994-1995 and 2007. The three most serious droughts lasted 3, 3 and 2 years; water deficit of 729, 547 and 525 mm; and intensity of 243, 182 and 262 mm/year, respectively (Table 1). It is important observe that the three most serious droughts occurred in different decades and followed, 2010, 2000 and 1990. And there enters the return period of droughts, very important information to reduce impacts and live with a drought. The analysis shows that each of the three most serious droughts occurred in decade followed and different, in this case, it is to be expected, at least, to the same happens in the future. With this information, the government can start

planning the future of populations living in rural areas.

Leaving aside the coincidence of the former case, using the execution method, the probability of occur droughts with the same duration of the three most serious is every 29, 29 and 17 years. Droughts with durations greater than or equal to the three most serious can occur at 17, 17 and 11 years. With regard to water deficit, values greater than 729, 547 and 525 mm may occur again at 15, 10 and 10 years. Crossing the duration and deficit data, is small the probability the duration be equal and the water deficit superior to those observed in the three most serious droughts. This can occur every 89, 46 and 65 years. Already the possibility of the duration is equal or superior to deficit is superior to 17, 13 and 10 years, respectively (Table 1).

Table 1 - Number, duration, water deficit, intensity and return period of droughts in the municipality of Cajazeiras-PB.

Nº	Start	End	Duration (years)	Water deficit (mm)	Intensity (mm/year)	Rp(L=l) (years)	Rp(L=>l) (years)	Rp(D>d) (years)	Rp(L=l,D>d) (years)	Rp(L=>l,D>d) (years)
1	2012	2014	3	729	243	29	17	15	89	17
2	2001	2003	3	547	182	29	17	10	46	13
3	1998	1999	2	525	262	17	11	10	65	10
4	2005	2005	1	332	332	11	6	7	64	7
5	2010	2010	1	279	279	11	6	6	42	6
6	1994	1995	2	200	100	17	11	5	19	7
7	2007	2007	1	187	187	11	6	5	22	5

In Catolé do Rocha were identified 7 droughts during 1994-2014, that occurred in 1997-1999, 2001, 2003, 2005, 2007, 2010 and 2012. Important observe that 14.3% of them occurred in the decade of 1990, 28.6% in 2010

and 57.1% in 2000. Years with above average rains hit the municipality in 1994, 1995, 1996, 2000, 2002, 2004, 2006, 2008, 2009, 2011, 2013 and 2014. Unlike Cajazeiras, the municipality had no precipitation below

average in 2013 and 2014 (Figure 3). Even with the above average precipitation in 2013 and 2014, the municipality suffered major impacts, because the year 2012 was very dry and It did not allow the dams accumulate water. With most of the reservoirs to collapse, there was the need to supply the homes through tank trucks. The corn and bean crops

were also impacted, around 90% of them were lost. With regard to cattle, most of the cattle died of hunger and thirst, others were sold for prices far below market. Already the impacts on goats and sheep were lower, because these animals are fed a larger quantity of plant species, are resistant to phenomenon and easier to sell.

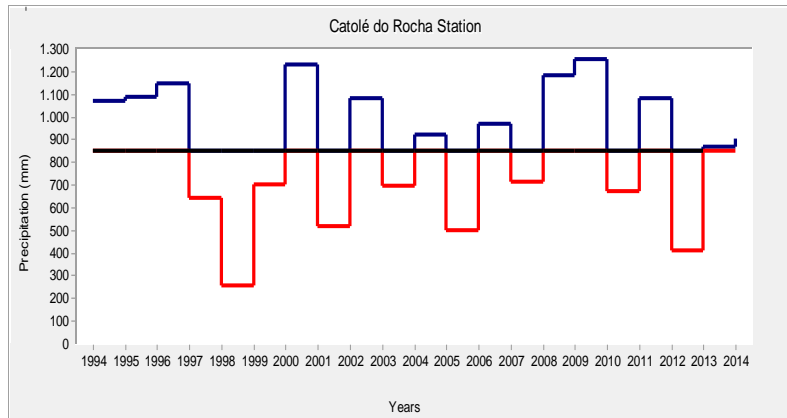


Figure 3 - Annual precipitation between the period 1994-2014 for the municipality of Catolé do Rocha-PB.

The more serious droughts were the 1997-1999, 2012 and 2005. These had durations of 3, 1 and 1 year (s); water deficit of 956, 441 and 353 mm; and intensity of 318, 441 and 353 mm/year, respectively. The analysis of return period the droughts shows that the probability to another drought occur with the same duration of 1997-1999 is every 38 years. Drought with equal or superior duration the 1997-1999 can happen in 51 years. Water deficit greater than 956 mm may occur every 34 years. Regarding the duration and deficit data, is very low the probability the

to be duration equal and the water deficit superior the observed in 1997-1999. The opposite was found for duração equal or superior and deficit superior (Table 2).

The other droughts have extremely low return period, ie, high probability of occurrence. The of the 2012, 2005, 2001, 2010, 2003 and 2007 obtained the following values:  $R_p(L=1)$ : 7;  $R_p(L=>1)$ : 9;  $R_p(D>d)$ : 8, 7, 6, 5, 4 and 4;  $R_p(L=1,D>d)$ : 47, 25, 22, 10, 9 and 8; and  $R_p(L=>1,D>d)$ : 9, 7, 7, 4, 4 and 4 years, respectively (Table 2).

Table 2 - Number, duration, water deficit, intensity and return period of droughts in the municipality of Catolé do Rocha-PB.

Nº	Start	End	Duration (years)	Water deficit (mm)	Intensity (mm/year)	$R_p(L=1)$ (years)	$R_p(L=>1)$ (years)	$R_p(D>d)$ (years)	$R_p(L=1,D>d)$ (years)	$R_p(L=>1,D>d)$ (years)
1	1997	1999	3	956	318	38	51	34	120	4
2	2012	2012	1	441	441	7	9	8	47	9
3	2005	2005	1	353	353	7	9	7	25	7
4	2001	2001	1	335	335	7	9	6	22	7
5	2010	2010	1	182	182	7	9	5	10	4
6	2003	2003	1	155	155	7	9	4	9	4
7	2007	2007	1	140	140	7	9	4	8	4

The municipality of Patos presented one of the lowest numbers of droughts of this

analysis. Were six in total, which occurred in 1995, 1997-2001, 2003-2004, 2007, 2010 and

2012-2013. On the other hand, had a longer duration, start in 1997 and end in 2001, lasting five years. For having been too long, strongly impacted all sectors, in addition, the poorest sections of the local population were left with few or no means of livelihood, making it dependent on aid from governments to survive. Water distribution through water

trucks, basic food donation and emergency fronts were some measures taken by the government to help people during the long drought. But such measures have proved inefficient, not solving the problem definitely. Rains above the average were observed only in the years 1994, 1996, 2002, 2005, 2006, 2008, 2009, 2011 and 2014 (Figure 4).

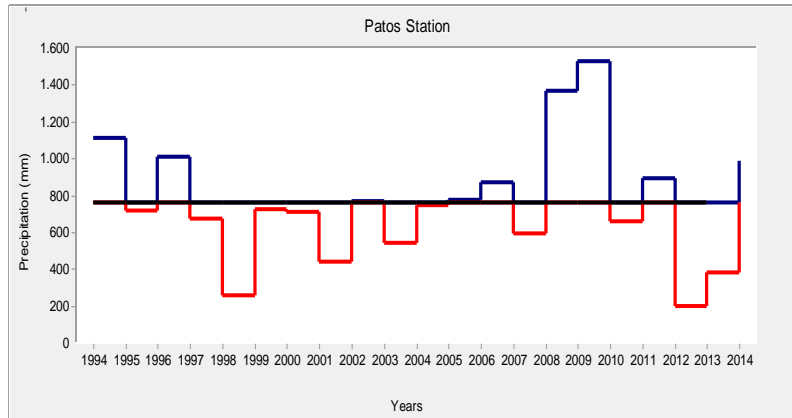


Figure 4 - Annual precipitation between the period 1994-2014 for the municipality of Patos-PB.

The three most serious droughts occurred in 1997-2001, 2012-2013 and 2003-2004. With durations of 5, 2 and 2 years; water deficit of 1.000, 939 and 228 mm; and intensity of 200, 469 and 114 mm/year, respectively (Table 3). The water deficit the droughts of 1997-2001 and 2012-2013 it was very high, with values of 1.000 and 939 mm, numbers above the average rainfall which is 759.12 mm.

The probability of occur droughts with durations of the three most serious are each 89, 16 and 16 years, respectively. Due to the long drought period of 1997-2001, is very low the

likelihood of another drought occurs with this duration. Droughts with durations greater than or equal the three most serious can occur at 67, 12 and 12 years. With regard to water deficit, values greater than 1.000, 939 and 228 mm may occur again at 33, 29 and 6 years. Relating the duration and deficit data, is small probability the duration be equal and the water deficit superior to those observed in the three most serious droughts. It can happen every 188, 342 and 23 years. Already the possibility that the duration is equal to or superior and the deficit superior can occur at 58, 30 and 8 years, respectively (Table 3).

Table 3 - Number, duration, water deficit, intensity and return period of droughts in the municipality of Patos-PB.

Nº	Start	End	Duration (years)	Water deficit (mm)	Intensity (mm/year)	Rp(L=l) (years)	Rp(L=>l) (years)	Rp(D>d) (years)	Rp(L=l,D>d) (years)	Rp(L=>l,D>d) (years)
1	1997	2001	5	1.000	200	89	67	33	188	58
2	2012	2013	2	939	469	16	12	29	342	30
3	2003	2004	2	228	114	16	12	6	23	8
4	2007	2007	1	164	164	9	7	5	20	5
5	2010	2010	1	97	97	9	7	4	14	4
6	1995	1995	1	39	39	9	7	4	1	4

The analysis identified periods with above average rainfall in Pombal in 1994, 1995, 1996, 2000, 2002, 2004, 2006, 2008, 2009, 2010 and 2011. Already droughts occurred in 1997, 1998, 1999, 2001, 2003, 2005, 2007, 2012, 2013 and 2014. In all six droughts, the same amount of municipality of

Patos. The droughts more serious (1997-1999 and 2012-2014) in Pombal also occurred in other municipalities. Is possible observe that 16.6% of droughts occurred in the decade of 1990, 16.6% in 2010 and 66.8% in 2000 (Figure 5).

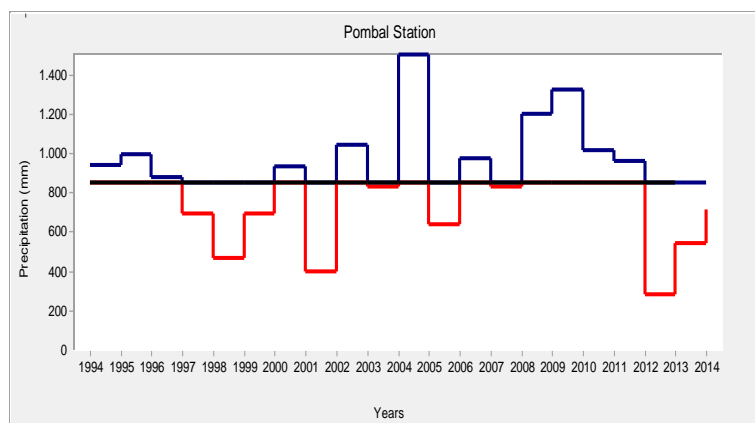


Figure 5 - Annual precipitation between the period 1994-2014 for the municipality of Pombal-PB.

The most serious droughts in Pombal occurred in 2012-2014, 1997-1999 and 2001. The duration of these was 3, 3 and 1 year (s). The water deficit has reached 1.015, 692 and 453 mm during the years of drought. And the intensity was 338, 230 and 453 mm/year, respectively (Table 4). Some values the duration, deficit, intensity and return period the droughts were approximate to those obtained for Patos.

The analysis shows that the probability of occur other droughts with the same duration of 2012-2014, 1997-1999 and 2001 is the each 33, 33 and 7 years. Droughts with duration equal or greater than these may occur at 37, 37

and 8 years. It is estimated that water deficit bigger than 1.015, 692 and 453 mm can occur every 41, 18 and 10 years. Is very low the probability of duration be equal and water deficit superior that observed in 2012-2014, 1997-1999 and 2001. Regarding the duration equal or superior and deficit superior, is likely to occur at 48, 26 and 10 years (Table 4).

The other three droughts have return period extremely low, ie, there is high probability of occurring again. The of 2005, 2007 and 2003 reached the following values:  $Rp(L=1)$ : 7;  $Rp(L=>1)$ : 8;  $Rp(D>d)$ : 5, 4 and 4;  $Rp(L=1,D>d)$ : 16, 7 and 7; and  $Rp(L=>1,D>d)$ : 5, 4 and 4, respectively (Table 4).

Table 4 - Number, duration, water deficit, intensity and return period of droughts in the municipality of Pombal-PB.

Nº	Start	End	Duration (years)	Water deficit (mm)	Intensity (mm/year)	$Rp(L=1)$ (years)	$Rp(L=>1)$ (years)	$Rp(D>d)$ (years)	$Rp(L=1,D>d)$ (years)	$Rp(L=>1,D>d)$ (years)
1	2012	2014	3	1.015	338	33	37	41	198	48
2	1997	1999	3	692	230	33	37	18	69	26
3	2001	2001	1	453	453	7	8	10	62	10
4	2005	2005	1	211	211	7	8	5	16	5
5	2007	2007	1	23	23	7	8	4	7	4
6	2003	2003	1	22	22	7	8	4	7	4

In the municipality of São Bento were identified 7 droughts that occurred in 1995,

1997-1999, 2001, 2003, 2005, 2007 and 2012-2014. Both caused very serious impacts,

mainly in agriculture. Another activity impacted was to production the net, main economic activity of the city, also known as "the world capital of the net." Important be noted that most of droughts occurred in the

decade of 2000, followed by the 1990 and 2010. Years with above average rainfall occurred in 1994, 1996, 2000, 2002, 2004, 2006, 2008, 2009, 2010 and 2011 (Figure 6).

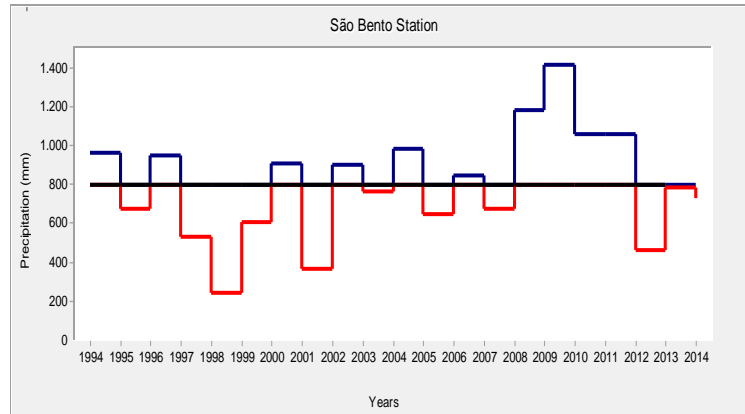


Figure 6- Annual precipitation between the period 1994-2014 for the municipality of São Bento-PB.

The three most serious droughts in the municipality occurred in 1997-1999, 2001 and 2012-2014. These have durations of 3, 1 and 3 years; water deficit of 1.007, 428 and 418 mm; and intensity of 335, 428 and 139 mm/year, respectively. The analysis of return period the droughts shows that other droughts may occur with the same durations of the three most severe at 30, 8 and 30 years. Droughts with durations equal or superior than these may occur at 27, 7 and 27 years. With regard to water deficit, values greater than 1.007, 428 and 418 mm may occur again at 44, 10 and 10 years. Regarding the duration and deficit, is little the probability of equal duration and

superior water deficit to those observed in the three most serious droughts. This can happen every 290, 80 and 41 years. Already the possibility that the duration is equal to or superior and water deficit superior may occur at 49, 10 and 17 years, respectively (Table 5).

The other droughts had low return period, this means that there is a high probability of occurring again. The of 2005, 2007, 1995 and 2003 obtained the following values:  $R_p(L=l)$ : 8;  $R_p(L=>l)$ : 7;  $R_p(D>d)$ : 5, 5, 5 and 4;  $R_p(L=l,D>d)$ : 15, 13, 13 and 9; and  $R_p(L=>l,D>d)$ : 5, 4, 4 and 4 years, respectively (Table 5).

Table 5 - Number, duration, water deficit, intensity and return period of droughts in the municipality of São Bento-PB.

Nº	Start	End	Duration (years)	Water deficit (mm)	Intensity (mm/year)	$R_p(L=l)$ (years)	$R_p(L=>l)$ (years)	$R_p(D>d)$ (years)	$R_p(L=l,D>d)$ (years)	$R_p(L=>l,D>d)$ (years)
1	1997	1999	3	1007	335	30	27	44	290	49
2	2001	2001	1	428	428	8	7	10	80	10
3	2012	2014	3	418	139	30	27	10	41	17
4	2005	2005	1	147	147	8	7	5	15	5
5	2007	2007	1	122	122	8	7	5	13	4
6	1995	1995	1	121	121	8	7	5	13	4
7	2003	2003	1	36	36	8	7	4	9	4

The municipality of Sousa was the one with the highest number of droughts, eight in total, which occurred in 1995, 1997-1999,

2001-2003, 2005, 2007, 2010, 2012 and 2014 (Figure 7). These caused many impacts, mainly to man of the field. In addition to the

losses in corn and beans (subsistence), there was significant reduction in the production of coconut, as this is one of the main commercial activities of the municipality. Including currently the dam that supplies the municipality this with less than 10% capacity. Since 2012 the reservoir has had its small volume, due to erratic rainfall. Thus, the state's

largest coconut production was impaired. An area of 2.400 hectares practically is not producing. The pumps of the irrigation system have been disabled. According to the candy industry union and state food preserves, in all space the irrigation perimeter of São Gonçalo, 80% of coconut trees are dead.

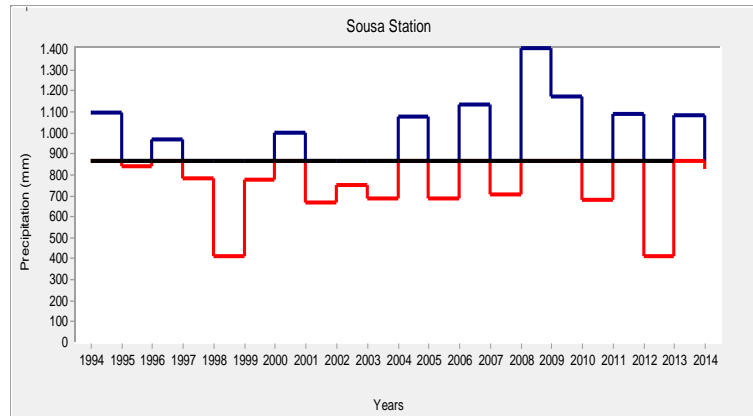


Figure 7 - Annual precipitation between the period 1994-2014 for the municipality of Sousa-PB.

The sequence of more serious droughts in the municipality was as follows: 1997-1999, 2001-2003, 2012, 2010, 2005, 2007, 2014 and 1995, with durations of 3, 3, 1, 1, 1, 1, 1 and 1 year (s); deficit the 631, 502, 459, 188, 182, 163, 42 and 29 mm; and intensity of 210, 167, 459, 188, 182, 163, 42 and 29 mm/year, respectively (Table 6). It is found that the three most severe droughts occurred in different decades, 1990, 2000 and 2010, thus, based on information like this, it's possible accomplish proper planning knowing that occur, at least, a more serious every decade, making possible risk reduction.

Can occur droughts with the same duration the three most severe in 29, 29 and 9 years. Droughts with durations equal or superior to 21, 21 and 7 years. With regard to water deficit, values greater than 631, 502 and 459 mm may occur again in 18, 12 and 11 years. Crossing the duration and deficit data is small the likelihood of duration equal and water deficit superior to those observed in the three most serious droughts. This can happen every 90, 55 and 191 years. Already the probability the duration be equal or superior and the deficit superior may occur at 21, 17 and 11, respectively (Table 6).

Table 6 - Number, duration, water deficit, intensity and return period of droughts in the municipality of Sousa-PB.

Nº	Start	End	Duration (years)	Water deficit (mm)	Intensity (mm/year)	Rp(L=1) (years)	Rp(L=>1) (years)	Rp(D>d) (years)	Rp(L=1,D>d) (years)	Rp(L=>1,D>d) (years)
1	1997	1999	3	631	210	29	21	18	90	21
2	2001	2003	3	502	167	29	21	12	55	17
3	2012	2012	1	459	459	9	7	11	191	11
4	2010	2010	1	188	188	9	7	5	24	5
5	2005	2005	1	182	182	9	7	5	23	5
6	2007	2007	1	163	163	9	7	5	20	5
7	2014	2014	1	42	42	9	7	4	10	4
8	1995	1995	1	29	29	9	7	4	10	4

#### 4. Conclusions

The municipality of Sousa had the biggest number of droughts, eight in total, followed by Cajazeiras, Catolé do Rocha, São Bento (seven droughts), Patos and Pombal (six droughts). The longest drought occurred in Patos, starting in 1997 and ending in 2001, lasting five years.

The three most serious droughts of the municipalities were as follows:

- Cajazeiras: 2012-2014, 2001-2003 and 1998-1999. Lasting 3, 3 and 2 years; water deficit of 729, 547 and 525 mm; and intensity of 243, 182 and 262 mm/year.
- Catolé do Rocha: 1997-1999, 2012 and 2005. These had durations of 3, 1 and 1 year (s); water deficit of 956, 441 and 353 mm; and intensity of 318, 441 and 353 mm/year.
- Patos: 1997-2001, 2012-2013 and 2003-2004. Durations of 5, 2 and 2 years; water deficit of 1.000, 939 and 228 mm; and intensity of 200, 469 and 114 mm/year.
- Pombal: 2012-2014, 1997-1999 and 2001. The duration of these was 3, 3 and 1 year (s). The water deficit has reached 1.015, 692 and 453 mm during the years of droughts. And the intensity was 338, 230 and 453 mm/year.
- São Bento: 1997-1999, 2001 and 2012-2014. These have durations of 3, 1 and 3 years; water deficit of 1.007, 428 and 418 mm; and intensity of 335, 428 and 139 mm/year.
- Sousa: 1997-1999, 2001-2003 and 2012. Durations of 3, 3 and 1 year (s); water deficit of 631, 502 and 459 mm; and intensity of 210, 167, 459 mm/year.

All these droughts caused very serious impacts on municipalities, including reducing the feed of the population, conflicts between water users, increasing poverty, population migrations, reduction of agriculture, rising unemployment, unavailability of animal feed, disruption of reproductive cycles, reduction of recreation and tourism, damage to fauna, flora and fish species; and decreased water quality.

Is important observe that the three most

serious droughts of all municipalities occurred in decades different and followed, 1990, 2000 and 2010. In this case, it is to be expected, at least, what in the future from happening the same. With this information, the government can start plan the future of people living in urban and rural areas.

Analysis of the return period the most serious droughts of the municipalities shows widely varying values, with the longest occurring in Patos, during the drought of 1997-2001, where the likelihood of another drought of the same duration occur is every 89 years. Droughts with equal or superior duration may occur at 67 years. Already the water deficit can be overcome in 33 years.

For the other municipalities, the return period of the droughts ranged from 6 to 44 years. The least serious droughts have return period ranging from 4 to 17 years. Regarding the duration and deficit data, is very low the probability of duration being equal and water deficit superior to periods of droughts in the municipalities. The opposite was found for duration equal to or superior and superior deficit. The droughts return analysis system can be very useful for the public agencies responsible for the management of these events, to predict and assess drought impacts within its administrative limits, and respond rationally during the period.

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