

Trend analysis in rainfall time series in some Brazilian semiarid cities

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Abstract

Nowadays, the climate changes are a frequent issue of the scientific community, and although it occurs on a global scale, its impacts often vary from region to region. The objective of this research was to identify the climatic change trends from rainfall in some Brazilian semiarid cities of the Pernambuco state. The Mann-Kendall and Sen-slope trend tests were applied to detect possible trends in the rainfall time series. In addition, the Pettitt test was also applied to identify abrupt changes in precipitation records represented by break points in the time series. The results showed trends of climatic changes in rainfall in fifteen cities, being observed in some localities the decrease of the tendencies in the rainy season, representing a serious problem that compromises the water supply, suppresses agricultural activities, thus making life difficult for the population, because it's in this short rainy season that the water reservoirs of the region are replenished.

Keywords: Climate variables. Rainfall patterns. Non-parametric tests. Mann Kendall. Sen's slope.

1. Introduction

The necessity for a better understanding of the consequences of climate change on water resources has been the greatest challenge in water planning and management, especially in arid and semiarid regions, dependent on climate variability, mainly rainfall distribution (Zhao et al., 2013).

However, there are many uncertainties associated with climate change, whether due to natural climate variability or anthropogenic action, which determines increases in the concentration of greenhouse gases in the atmosphere (Marengo, 2008).

Although they occur on a global scale, climate change and its impacts often vary from region to region (Trajkovic and Kolakovic, 2009).

Therefore, the analysis of statistical variations in the meteorological variables of rainfall, as well as of temperature, represent important tasks in detection of climate changes on regional scale (Gocic and Trajkovic, 2013).

With a fragile water system, the semiarid coexists with high temperature records, and projections on a global scale. According to the IPCC (2007) planetary temperature will increase by about 1 °C by 2100, with projections of up to 4,5 °C in the

worst scenario, one of the expected consequences of global warming is that increasing surface temperature would lead to increased evaporation (Su et al., 2015).

Expected that the Climate change alter the average values of temperature and precipitation and increase the variability of extreme events in the form of even more intense and frequent floods and droughts (IPCC, 2001c).

In this context, the semiarid region of Brazilian northeastern presents fluvial systems characterized by long periods without runoff, with the exception of some perennial rivers, in addition, the hydrological behavior of the semiarid region is characterized by a distinct and intense pattern, rainfall over a short period of time, as well as a large variation of rainfall recurrence, irregular spatial and temporal occurrence of rainfall, generating surface and subsurface runoff that often occur in the form of extreme, rapid and simple peak events with great annual and interannual variability (Cantalice et al., 2013).

Rainfall variability is an important feature of semiarid climates, and climate change is likely to increase this variability in many of these regions around the world (Batisani and Yarnal, 2010).

Many of the arid and semiarid areas will suffer a decrease in the availability of water resources

due to climate change, evidenced in the form of runoff river reductions and recharge of the aquifers, specifically in Brazilian Northeast (Döll and Flörke, 2005). In this sense, the IPCC (2001c and 2007) reported rainfall reduction, river flow and water availability for dry regions in middle latitudes and the tropical semiarid between 10 and 30%, and a reduction of aquifer recharge by 70%.

These changes in the hydrological regime imply severe impacts, especially in agriculture, which is the most sensitive sector to the risks related to hydrological changes, because climate change affects two of the most important direct inputs of agricultural production that are rainfall and the temperature (Philip et al., 2014; Addisu et al., 2015). In addition to reducing water supply and consequently irrigation, making arable areas in idle areas, thus increasing the soil erosion severity of these vulnerable areas at the time of extreme precipitation events (IPCC, 2001a, b).

The evaluation effects of climate change on river basin outflow is crucial for the future management of water supply, as well as the generation of hydroelectric power, use of water in agriculture and other activities dependent on water resources. However, conducting these evaluations on a regional scale is a challenge; this approach allows

better management of available water and mitigates the future impacts of extreme hydrological events and their consequences for water resources (Silberstein, et al., 2012).

Therefore, to consolidate knowledge about how the Brazilian semiarid environment will behave face of climate change and the repercussions on hydrological patterns, in this research, the patterns of precipitation in the semiarid were verified in cities of the Sertão region of Pernambuco State for identification the presence or not of positive or negative trends in rainfall time series.

2. Material and methods

Study area

In this research we used data from time series of monthly rainfall of cities in the Sertão of the State of Pernambuco, a semiarid climate region of the Brazilian Northeast (Figure 1), which is characterized by an irregular (space/ time) rainfall regime, low rainfall index, with average annual rainfall of 800 mm or less, average annual temperatures ranging from 23 to 30 C°, average insolation of 2,800 h year⁻¹, the predominant climate of the semiarid region of Pernambuco is classified as being of the hot dry type or BSh of Köppen (Alvares, 2014).

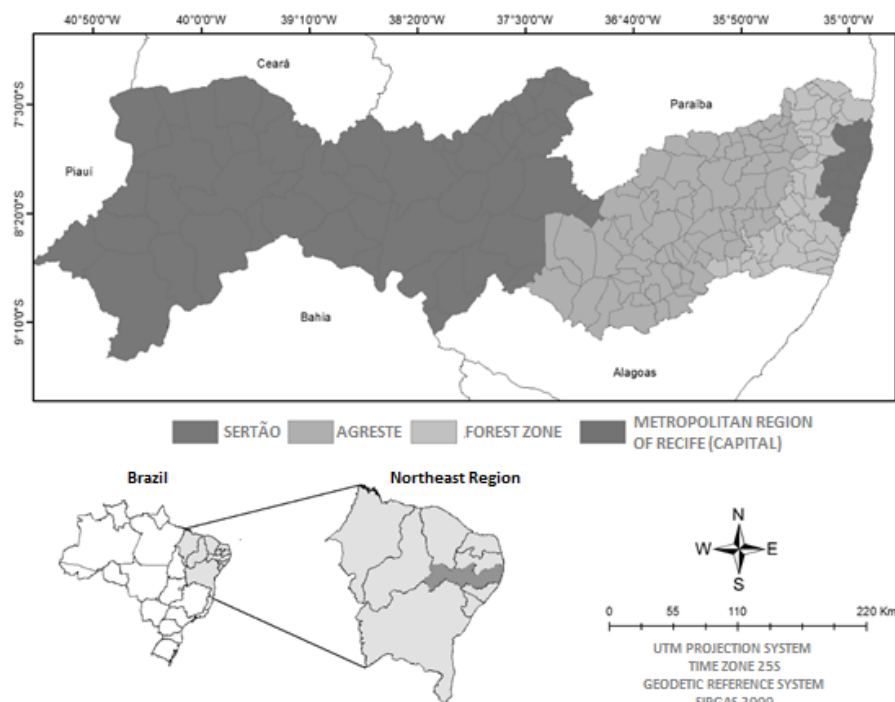


Figure 1 - Geographic location of Pernambuco State.

Climatic data

The historical series of rainfall data used are part of the SUDENE (1990) database, originating from stations under the responsibility of the Pernambuco State Agency for Water and Climate

(APAC); National Water Agency (ANA); Agronomic Institute of Pernambuco (IPA); National Department of Works Against Drought (DNOCS); Company of Technical Assistance and Rural Extension of the State of Pernambuco (EMATER-PE); Mineral

Resources Research Company (CPRM) and San Francisco Hydroelectric Company (CHESF), compiled and made available from the Hidroweb portal of the National Water Agency (ANA) website.

The time series of rainfall analyzed have different periods, where the criterion of selection was a minimum of 30 years of records, as shown in Table 1, which is the standard for the statistical description in terms of average and variability of climatic elements, as recommended by the World Meteorological Organization (WMO), specialized agency of the United Nations for meteorology.

Trend tests

Were applied tests to rainfall data for

detection of significant trends in time series, the trend tests can be classified as parametric and non-parametric methods, parametric trend tests require that data be independent and normally distributed, while non-parametric trend tests require only that the data be independent, without restrictions on data distribution (Gocic and Trajkovic, 2013).

In this research, the Mann-Kendall test (Mann, 1945; Kendall, 1975) and the Sen's slope (Sen, 1968) were used to detect the trends of the meteorological variables in all-time series and in function of seasonality with monthly evaluations. The software's used for the analysis was the XLSTAT Software for Windows version 2016 and Software R version 3.3.1 (2016).

Table 1 - Geographic characteristics of stations sites analyzed (Rainfall).

Station Code		Station	Latitude (S)	Longitude (W)	Altitude (m)	Period (Nº of years)
00737023	1	Afogados da Ingazeira-PE	07°44'	37°38'	525	1914-2016 (103)
00841015	2	Afrânio-PE	08°29'	41°00'	530	1934-2016 (83)
00740014	3	Araripina-PE	07°33'	40°34'	620	1934-2016 (83)
00837005	4	Arcoverde-PE	08°26'	37°04'	663	1913-2016 (104)
00838004	5	Belém de São Francisco-PE	08°45'	38°57'	305	1935-2016 (82)
00838005	6	Betânia-PE	08°17'	38°02'	431	1936-2016 (81)
00739021	7	Bodocó-PE	07°48'	39°56'	440	1934-2016 (83)
00839002	8	Cabrobó-PE	08°30'	39°19'	350	1911-2016 (106)
00837011	9	Custódia -PE	08°06'	37°39'	542	1933-2016 (84)
00739023	10	Exu-PE	07°31'	39°43'	510	1934-2016 (83)
00737027	11	Flores-PE	07°52'	37°58'	460	1911-2016 (106)
00838000	12	Floresta-PE	08°32'	38°11'	361	1926-2016 (91)
00837025	13	Ibimirim-PE	08°23'	37°38'	445	1934-2016 (83)
00737030	14	Iguaraci-PE	07°55'	37°31'	585	1962-2016 (55)
00837038	15	Inajá-PE	08°55'	37°49'	355	1937-2016 (80)
00740018	16	Ipubi-PE	07°39'	40°08'	560	1962-2016 (55)
00737031	17	Itapetim-PE	07°22'	37°11'	630	1962-2016 (55)
00740021	18	Ouricuri-PE	07°53'	40°04'	432	1912-2016 (105)
00839013	19	Parnamirim-PE	08°05'	39°34'	379	1911-2016 (106)
00938000	20	Petrolândia-PE	09°04'	38°18'	282	1935-2016 (82)
00940006	21	Petrolina-PE	09°23'	40°30'	376	1911-2016 (106)
00839016	22	Salgueiro-PE	08°04'	39°07'	415	1911-2016 (106)
00839018	23	Santa Maria da Boa Vista-PE	08°48'	39°50'	452	1911-2016 (106)
00738029	24	São José do Belmonte-PE	07°52'	38°47'	460	1911-2016 (106)
00737036	25	São José do Egito-PE	07°28'	37°17'	575	1914-2016 (103)
00738030	26	Serra Talhada-PE	07°59'	38°18'	435	1911-2016 (106)
00739026	27	Serrita-PE	07°49'	39°29'	440	1934-2016 (83)
00837033	28	Sertânia-PE	08°05'	37°16'	605	1911-2016 (106)
00738032	29	Triunfo-PE	07°50'	38°07'	1010	1911-2016 (106)
00738036	30	Verdejante-PE	07°55'	38°59'	455	1962-2016 (55)

Source of data described in topic 2.2.

Mann-Kendall test

This is a non-parametric test for the evaluation of time series trends without specifying if the trend is linear or non-linear, in which, in the hypothesis of the stability of a time series, the values must be independent, being, therefore, a robust test for influence of extremes, and insensitive to the lack

of values in incomplete series. The statistic, which has mean zero and the variance (S) calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(X_j - X_k)$$

$$\text{sgn}(x) = \begin{cases} 1, & \text{if } x > 0 \\ 0, & \text{if } x = 0 \\ -1, & \text{if } x < 0 \end{cases}$$

$$\text{Var}(S) = [n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)] / 18$$

Where:

X_j and X_k = sequence values;

n = sample size;

t = the extension of the data (period).

The normal pattern of z variables is computed as:

$$Z = \begin{cases} \frac{s-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{s+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases}$$

The null hypothesis (H_0) of no trend in the series is accepted $|Z| \leq \alpha/2$ if at the $\alpha/2$ significance level of the test on both sides of the trend. Positive values of Z indicate increasing trends while negative values of Z show decreasing trends. Statistical test values were calculated, and when values were within the range of -1.96 to 1.96, the null hypothesis wasn't rejected at the significance level of 1% and 5% probability using a two-tailed test.

Sen's Slope

Although the Mann-Kendall test allows the detection of statistically significant trends, it does not provide estimates of the magnitudes of these trends. For this reason, its application was complemented by a statistical trend estimator, namely the Sen's Slope, initially proposed by Sen (1968).

The Sen's slope determines the magnitude of a trend in a time series, that is, if a linear trend is present in a time series, then the slope is true and can be estimated by this method. This technique is a classification method aligned with procedures that first remove the effect of the seasonality of each data, then add the pairs of points in a dataset of the time series and finally produce a statistic from these sums. The slope estimates of N data pairs are calculated by the following equation:

$$Q_{Med} = \frac{X_j - X_k}{j - k} \quad \text{sendo, } i = 1, \dots, N$$

In which:

X_j and X_k are the time data values j and k ($j > k$), respectively. The median of these N values of Q_{Med} is the slope estimator of Sen.

If there is only one data in each time period, the $N = \frac{n(n-1)}{2}$, where n is the number of time periods. If there are multiple observations in one or more periods, then $N < \frac{n(n-1)}{2}$, where n is the total number of observations.

The N values of Q_{Med} are classified as being smaller than the highest and the median slope or Sen's Slope is calculated as:

$$Q_{Med} = Q_{\frac{[N+1]}{2}}, \text{ If } N \text{ is odd.}$$

$$Q_{Med} = Q_{\frac{N/2}{2}} + Q_{\frac{[N+2]}{2}}, \text{ If } N \text{ is even.}$$

The Q_{Med} signal indicates the trend (increasing or decreasing) of the data, while its value shows the slope (magnitude) of the trend.

Pettitt test

In order to investigate if the hydrological time series that were studied presented ruptures, the Pettitt test (1979) described in Back (2001), using a version of the Mann-Whitney test, was used in which two samples $X_1, \dots, X_t$ and $X_{t+1}, \dots, X_T$ are from the same population.

The statistic U_t, T counts the number of times a member of the first sample is greater than the member of the second, and can be written:

$$U_{t,T} = U_{t-1,T} + \sum_{j=1}^T \text{sgn}(X_i - X_j) \quad \text{para } t = 2, \dots, T$$

Where $\text{sgn}(x) = 1$ for $x > 0$; $\text{sgn}(x) = 0$ for $x = 0$; $\text{sgn}(x) = -1$ for $x < 0$.

The statistic U_t, T is then calculated for the values of $1 < t < T$, and the Pettitt test statistic $k(t)$ is written:

$$k(t) = \text{MAX}_{1 \leq t \leq T} |U_{t,T}|$$

This statistic locates the point where there was an abrupt change in the mean of a time series, and its significance can be approximately calculated by the equation:

$$P \cong 2 \exp \{-6k(t^2) / (T^3 + T^2)\}$$

The abrupt change point is t where the maximum of $k(t)$ occurs. The critical values of K can be calculated by the equation:

$$K_{crit} = \pm \sqrt{\frac{-\ln\left(\frac{P}{2}\right)(T^3 + T^2)}{6}}$$

3. Results and discussion

Behavior of the rainfall regime in the semiarid Brazilian cities

In the table 2 we can see the monthly and annual average rainfall of the Historical series of the cities under study. From the monthly precipitation averages, for all the evaluated cities an irregular distribution of the same ones was evident during the year, where the rains are concentrated in periods of 3 to 5 months of the year, beginning eventually in December, but with greater expression between January and April, and decreasing in May, different of the exceptions occurring in Arcoverde-PE and Triunfo-PE.

These cities presented a distribution that differs from the others analyzed, both are influenced by altitude and orographic factor, mainly in Triunfo-PE (1010 m), in the case of Arcoverde-PE (663 m) besides altitude, the fact of being in a climatic transition zone between the Agreste region and the Sertão region of the State of Pernambuco, which interferes in a different distribution of the monthly rainfall presented for the other cities.

The critical drought period observed for the analyzed cities was between June and November, with August, September and October registering the lowest average monthly precipitation, however, some cities, such as: Afrânio-PE; Belém de São Francisco-PE; Cabrobó-PE; Floresta-PE; Parnamirim-PE; Petrolândia-PE; Petrolina-PE; Salgueiro-PE e Santa

Maria da Boa Vista-PE, presented as historical average of rainfall, already in the month of May, rains below 30 mm, these cities are concentrated in the mesoregion of the Sertão do São Francisco, with the exception of Parnamirim-PE and Salgueiro-PE that are located in the mesoregion called Alto Sertão, but both border the Sertão do São Francisco.

Table 2 - Monthly and Annual Rainfall Average (mm) and Standard Deviation (σ) of the Time Series of Analyzed cities.

Station	January	February	March	April	May	June	July	August	September	October	November	December	ANNUAL
1 Afogados da Ingazeira-PE	68,0 ± 75,5	101,7 ± 74,1	150,0 ± 105,1	121,7 ± 84,7	66,4 ± 63,5	36,1 ± 33,6	26,0 ± 28,0	9,8 ± 18,9	4,6 ± 10,5	10,2 ± 21,6	13,0 ± 22,5	30,4 ± 42,4	638,0 ± 262,0
2 Afrânio-PE	90,2 ± 95,5	84,5 ± 53,5	110,3 ± 71,6	75,2 ± 61,7	22,2 ± 17,0	10,5 ± 7,0	6,1 ± 4,7	4,8 ± 2,9	15,0 ± 9,8	35,5 ± 24,1	52,3 ± 42,9	66,0 ± 52,0	572,5 ± 174,4
3 Araripina-PE	116,3 ± 56,4	120,2 ± 51,4	170,2 ± 73,3	88,0 ± 63,8	37,4 ± 62,4	17,8 ± 47,9	12,0 ± 51,3	7,2 ± 29,7	9,9 ± 15,1	20,2 ± 20,6	47,9 ± 26,1	77,8 ± 39,7	724,8 ± 218,6
4 Arcoverde-PE	50,4 ± 56,4	61,5 ± 51,4	95,9 ± 73,3	86,8 ± 63,8	86,2 ± 62,4	72,2 ± 47,9	71,4 ± 51,6	37,9 ± 29,7	18,4 ± 15,0	24,2 ± 20,6	28,2 ± 26,1	38,4 ± 39,7	671,4 ± 207,4
5 Belém de São Francisco-PE	76,4 ± 98,6	65,4 ± 66,5	104,6 ± 91,0	58,5 ± 59,5	25,6 ± 36,1	11,6 ± 12,5	9,4 ± 9,1	3,5 ± 7,2	3,2 ± 6,9	7,1 ± 13,6	37,6 ± 56,1	47,7 ± 53,4	450,4 ± 204,8
6 Betânia-PE	67,8 ± 64,4	74,3 ± 59,9	122,9 ± 85,6	79,3 ± 60,2	40,2 ± 37,7	23,1 ± 24,6	17,9 ± 20,4	5,4 ± 7,5	7,1 ± 11,0	10,4 ± 16,6	23,1 ± 31,3	43,1 ± 44,4	514,6 ± 180,6
7 Bodocó-PE	115,4 ± 114,6	117,8 ± 109,9	146,4 ± 89,5	115,7 ± 112,6	46,2 ± 55,5	13,3 ± 11,5	12,6 ± 13,9	3,7 ± 6,6	4,8 ± 10,0	21,0 ± 27,2	48,3 ± 58,6	80,6 ± 84,2	725,8 ± 317,9
8 Cabrobó-PE	69,9 ± 64,1	82,2 ± 75,1	112,6 ± 82,3	72,2 ± 64,0	28,1 ± 31,6	14,1 ± 14,9	9,0 ± 10,9	3,1 ± 4,3	4,1 ± 11,2	10,4 ± 15,8	39,2 ± 40,7	55,8 ± 67,2	500,6 ± 202,8
9 Custódia -PE	73,7 ± 72,8	105,9 ± 74,7	168,2 ± 138,2	132,0 ± 87,4	85,7 ± 69,8	58,0 ± 46,0	39,9 ± 38,5	16,6 ± 17,7	13,8 ± 19,1	13,9 ± 21,8	27,4 ± 33,0	34,6 ± 34,0	769,6 ± 275,9
10 Exu-PE	104,5 ± 82,1	122,0 ± 91,6	159,9 ± 88,4	106,0 ± 90,5	74,0 ± 71,5	33,3 ± 31,5	25,3 ± 34,0	12,0 ± 20,1	7,3 ± 15,3	21,5 ± 38,3	40,6 ± 49,4	61,1 ± 55,6	767,7 ± 310,3
11 Flores-PE	82,7 ± 75,1	115,4 ± 82,2	163,2 ± 105,4	126,9 ± 82,7	69,0 ± 56,0	35,3 ± 37,7	25,6 ± 27,7	9,7 ± 14,4	8,2 ± 14,5	14,4 ± 25,6	26,4 ± 36,4	37,6 ± 43,8	714,4 ± 265,7
12 Floresta-PE	67,5 ± 74,8	83,9 ± 76,6	120,0 ± 94,5	67,0 ± 61,0	25,9 ± 23,9	17,8 ± 21,2	12,5 ± 13,2	3,9 ± 4,8	5,4 ± 10,9	9,2 ± 17,6	21,4 ± 28,7	51,5 ± 60,1	486,0 ± 208,8
13 Ibimirim-PE	54,2 ± 64,5	76,8 ± 66,7	128,7 ± 109,5	100,8 ± 103,8	61,2 ± 58,4	37,9 ± 44,6	27,9 ± 34,5	11,4 ± 21,7	5,7 ± 11,8	11,3 ± 21,0	21,7 ± 27,6	38,8 ± 42,7	576,5 ± 270,3
14 Igaraci-PE	78,6 ± 79,0	100,9 ± 73,4	164,7 ± 116,7	139,4 ± 107,1	75,5 ± 59,4	46,9 ± 32,3	32,2 ± 31,0	15,7 ± 24,8	11,2 ± 14,6	13,5 ± 20,6	22,5 ± 25,1	41,9 ± 48,3	743,1 ± 310,5
15 Inajá-PE	52,6 ± 55,6	49,9 ± 50,5	82,7 ± 75,8	50,0 ± 49,0	35,0 ± 33,5	31,7 ± 24,4	32,5 ± 23,0	15,1 ± 14,1	8,7 ± 12,4	9,1 ± 14,4	22,2 ± 25,6	37,9 ± 51,1	427,4 ± 172,2
16 Ipubi-PE	128,7 ± 106,2	135,0 ± 109,7	194,2 ± 142,7	116,8 ± 124,7	54,1 ± 55,8	30,6 ± 36,5	21,6 ± 26,0	6,5 ± 9,6	11,7 ± 19,6	17,2 ± 19,1	49,6 ± 43,5	79,7 ± 66,7	845,8 ± 362,3
17 Itapetim-PE	81,8 ± 70,9	114,8 ± 148,1	143,7 ± 95,2	137,0 ± 125,4	68,4 ± 68,8	41,1 ± 36,5	29,7 ± 24,9	12,9 ± 19,8	5,9 ± 9,6	16,8 ± 29,1	12,2 ± 17,0	34,8 ± 39,2	698,9 ± 363,1
18 Ouricuri-PE	91,9 ± 80,9	99,0 ± 84,1	137,3 ± 112,0	90,4 ± 79,1	36,2 ± 57,6	12,8 ± 19,4	8,8 ± 10,9	3,4 ± 7,3	5,6 ± 15,4	20,3 ± 31,0	38,4 ± 49,5	63,2 ± 57,8	607,2 ± 261,8
19 Parnamirim-PE	87,9 ± 78,7	104,1 ± 69,1	132,5 ± 89,6	78,8 ± 71,1	29,2 ± 33,1	11,7 ± 14,5	9,5 ± 12,8	3,1 ± 5,2	4,7 ± 11,0	13,5 ± 25,3	32,6 ± 44,9	59,3 ± 59,9	566,7 ± 200,6
20 Petrolândia-PE	54,4 ± 55,5	50,4 ± 50,3	82,4 ± 82,8	45,3 ± 51,9	28,9 ± 27,0	25,6 ± 23,2	21,1 ± 21,6	7,7 ± 7,2	8,9 ± 20,9	7,2 ± 11,1	28,6 ± 28,9	39,7 ± 44,2	400,2 ± 178,3
21 Petrolina-PE	71,6 ± 77,1	81,3 ± 81,2	97,4 ± 90,3	53,1 ± 58,6	8,7 ± 16,2	6,0 ± 14,3	3,4 ± 6,1	2,0 ± 4,2	3,8 ± 9,3	11,6 ± 22,3	42,6 ± 45,7	57,4 ± 56,5	438,8 ± 198,2
22 Salgueiro-PE	92,0 ± 71,9	103,3 ± 72,3	147,5 ± 96,7	83,8 ± 65,5	29,2 ± 35,1	10,6 ± 13,9	9,2 ± 12,2	3,6 ± 6,5	6,1 ± 12,0	14,5 ± 22,6	31,8 ± 37,1	56,2 ± 53,1	587,8 ± 191,2
23 Santa Maria da Boa Vista-PE	73,0 ± 86,7	78,8 ± 64,6	110,5 ± 103,1	62,1 ± 66,7	22,6 ± 27,8	8,2 ± 10,2	6,3 ± 11,6	2,0 ± 5,1	2,5 ± 6,3	13,4 ± 24,8	31,3 ± 40,0	52,0 ± 50,6	463,6 ± 231,3
24 São José do Belmonte-PE	95,4 ± 83,3	114,8 ± 82,5	163,3 ± 117,5	105,0 ± 80,7	36,2 ± 36,9	19,8 ± 19,9	12,6 ± 16,1	3,0 ± 5,7	4,4 ± 9,1	10,6 ± 18,1	31,0 ± 41,0	46,5 ± 49,2	642,6 ± 256,6
25 São José do Egito-PE	57,8 ± 62,6	82,1 ± 75,6	119,5 ± 95,3	109,7 ± 87,2	59,6 ± 59,2	33,5 ± 36,4	20,1 ± 24,1	6,6 ± 14,6	3,4 ± 9,1	6,4 ± 16,3	8,1 ± 15,6	24,8 ± 37,6	531,5 ± 287,4
26 Serra Talhada-PE	83,3 ± 82,4	106,1 ± 77,9	146,6 ± 96,5	101,8 ± 68,8	48,9 ± 45,8	27,5 ± 28,9	16,7 ± 18,3	7,4 ± 16,4	5,1 ± 11,3	12,7 ± 22,4	28,0 ± 38,6	50,1 ± 50,7	634,3 ± 240,3
27 Serrita-PE	91,1 ± 72,1	100,4 ± 70,3	141,5 ± 115,3	96,9 ± 78,7	40,4 ± 49,8	12,5 ± 12,7	9,9 ± 13,9	3,0 ± 5,5	3,5 ± 6,6	13,3 ± 18,5	37,9 ± 51,5	65,0 ± 61,0	615,4 ± 240,0
28 Sertânia-PE	53,6 ± 59,1	74,9 ± 59,3	121,1 ± 94,2	97,8 ± 73,7	55,7 ± 49,4	32,2 ± 30,4	22,2 ± 26,3	9,8 ± 13,1	7,4 ± 13,1	16,6 ± 22,7	17,7 ± 26,2	29,3 ± 41,1	538,3 ± 215,1
29 Triunfo-PE	110,7 ± 86,4	153,8 ± 108,9	209,5 ± 124,8	184,8 ± 117,3	146,0 ± 115,4	120,9 ± 82,8	97,0 ± 59,1	46,8 ± 44,3	22,1 ± 24,8	30,4 ± 34,4	37,7 ± 39,9	57,6 ± 51,1	1217,2 ± 377,7
30 Verdejante-PE	84,6 ± 75,0	111,2 ± 114,5	127,3 ± 76,5	98,1 ± 100,9	27,7 ± 34,0	14,3 ± 25,7	8,9 ± 16,0	3,9 ± 11,7	5,2 ± 12,7	8,7 ± 12,4	18,5 ± 24,9	43,0 ± 48,5	551,5 ± 297,3

Source of data described in topic 2.2.

The annual historical averages were also observed, where we can highlight the stations of Ipubi-PE with an average of 845.8 mm in a period of 55 years, this register is opposed to the general average for the semiarid region according to Rocha (2009) and Moura, et al. (2007) which is between 200 and 800 mm per year, on the other hand, the station located in the city of Petrolândia-PE registered in an 82-year period an annual average of 400.2 mm, obviously the spatio-temporal variability that is characteristic of the climate in the semiarid region is evidenced through the monthly and annual historical records, in addition another factor that we must take into account is the size of the series that influences in these historical average values.

The inter-annual (seasonal) variability characteristic of precipitation in the Northeastern semiarid region is associated with variations of the Sea Surface Temperature patterns over the tropical

oceans, affecting the position and intensity of the Intertropical Convergence Zone on the Atlantic Ocean, which contributes to the occurrence or not of rainfall in the region (Hastenrath and Heller, 1977; Moura and Shukla, 1981; Hastenrath, 1984), thus, the occurrence of low total annual rainfall values during the rainy season (December-May) is closely related to interannual variability in rainfall records.

In specific studies on climate in the northeastern semiarid developed by NAE (2005), Kayano and Andreoli (2009), and Marengo et al. (2011) discussed important aspects of the water regime and the vulnerability of this region to extremes of climatic variability, where the authors reiterate that the occurrence of periods like a “small summer” in the rainy season, depending on intensity and duration, can cause serious damage to agriculture local.

The historical average records confirmed this interannual variability of the rainfall; in addition, a high intraseasonal variability in the rainfall regime can be observed through the standard deviation (σ) in the previous table, where we find values higher than the historical average for some months, whether in rainy season or the dry season. According to Kayano and Andreoli (2009), the semiarid region of Brazil is the one with the highest intra-seasonal variability in South America.

Trend analysis of rainfall time series

Trend tests were carried out in order to detect the presence or not of significant changes in the rainfall regime in cities of Sertão region of Pernambuco State. In this research, two non-parametric methods (Mann-Kendall and Sen's Slope) were used to detect trends in time series of rainfall data.

According to the results of the trend analysis (Table 3) through the Mann-Kendall and Sen's Slope tests at the 1 and 5% probability level, it was observed that some cities such as Afranio-PE, Arcoverde-PE, Belém de São Francisco-PE, Betânia-PE, Bodocó-PE, Custódia-PE, Exu-PE, Floresta-PE, Ibimirim-PE, Inajá-PE, Parnamirim-PE, Salgueiro-PE, Santa Maria da Boa Vista-PE, Serra Talhada-PE and Triunfo-PE, didn't show any type of trend, either positive or negative, that is, increase or decrease in the prediction of rainfall volume, according to the tests carried out monthly in time series of precipitation.

As the region presents a rainfall regime, which despite its temporal and spatial variability, is well defined in rainy season (December - May) and dry season (June - November), the trend tests predict with a higher degree of reliability the rainy season, in the period of low rainfall the averages of precipitation are very low and any precipitation, no matter how small, but larger than the historical average, end up causing the trend test to overestimate an increase in precipitation, when in fact this increase is negligible, knowing that the statistical test considers the average observations, so for this analysis, our object of interest became only the rainy season.

The results of the trend analysis showed an increase in monthly precipitation at the 1% probability level, according to the Mann-Kendall test and Sen's slope in the following cities: Itapetim-PE (December), Petrolina-PE (April), São José do Belmonte-PE (May) and São José do Egito-PE (December, January and May). The cities of Afogados da Ingazeira-PE (December), Cabrobó-PE (April), Itapetim-PE (January), Ouricuri-PE (May), Petrolândia-PE (February), Petrolina-PE (January and April), Serrita-

PE (January and May) and Sertânia-PE (January) at the 5% probability level.

The analyzes also showed a negative trend, that is, a decrease in the monthly precipitation in the cities analyzed, at the 1% probability level, the cities that presented a negative trend were: Araripina-PE (February), Flores-PE (February and March), Igaraci-PE (March) and Itapetim-PE (April) -PE (April), Ipubi-PE (March) and Verdejante-PE (March).

In a regional study developed by Salviano et al. (2016), the Northeast region presented a negative trend only for the month of March, in contrast to the results of the present study, where negative trends were observed not only in March, but also in February and April, being these three months of extreme importance in the contribution of rainfall volume in the rainy season in the Sertão of the State of Pernambuco, as well as other States that are located in the semi-arid region. The result is an alert because below average rainfall in the period in which they are expected, represent severe water difficulties for the region, thus committing the supply of water and making unviable the local agriculture and livestock.

On the other hand, positive trends with increased precipitation were also reported in studies developed in the Brazilian Northeast by Hastenrath (2000) and Santos et al. (2010). The displacement of the Intertropical Convergence Zone, as well as the Hadley-Walker cells may be an explanation for the positive rainfall trends for the semiarid region of the Northeast.

Another relevant factor in studies of trend analysis is the size of the historical series, such as a study by Moncunill (2006), who observed a reduction of annual precipitation of 6% per decade in the interval between 1961 and 2003 for the State of Ceará, excepting in regions where precipitation is dependent on topography, also observing a decrease in precipitation Salati et al. (2007) estimated a decrease of 11.6% in precipitation during the period from 1961 to 2004.

Decreases in rainfall were also observed in China, Zhangweinan River Basin, through studies by Yang et al. (2012) using the Mann-Kendall test in a historical series of 53 years of rainfall data, where the author states that precipitation series show strong continuity in the Zhangweinan River Basin, indicating that the future trend will be consistent with that of the past. In addition, the author reiterates that these research results will not only help to provide evidence for climate change in the Zhangweinan River Basin, but also indicate the basis for future studies on the evaluation of water security under climate change conditions.

Using hydrological data for trend analysis, the time series are assumed stationary, ie, there is no abrupt variation or change in their characteristics over time (TUCCI, 2005). Since reliable measurements of climate data are the essential basis for quantitative analyzes of climate variables, but several factors inherent in measuring equipment that affect the quality of climate data and these factors need to be understood and considered for the

analyzes climate, although exist universally accepted standards and recommendations for the installation and observation of instruments, practices and measuring instruments may differ from station to station in a particular country and also there may be changes in an individual station from time to time. As a result, these factors cause variations in the time series of the station (Sahin and Cigizoglu, 2010).

Table 3 - Mann-Kendall and Sen's Slope trend tests for rainfall time series of the cities under study

Stations	Tests	Rainy Season						Dry Season					
		Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1 Afogados da Ingazeira-PE	Z _{MK}	-0,2	2,4 *	0,6	0,3	0,7	1,9	1,9	3,4 **	0,1	1,1	0,7	-0,8
	Q _{Méd}	0	0,389 *	0,13	0,094	0,179	0,3	0,171	0,239 **	0	0	0	0
2 Afrânio-PE	Z _{MK}	1,0	0,8	0,0	1,8	1,4	0,7	-1,5	-2,0 *	-1,0	-2,0 *	1,2	-0,4
	Q _{Méd}	0,148	0,152	0	0,5	0,222	0	0	0 *	0	0 *	0	-0,005
3 Araripina-PE	Z _{MK}	-1,3	-0,2	-2,1 *	-0,6	1,0	-0,7	-3,5 **	-3,5 **	-4,1 **	-2,0 *	-1,6	-2,8 **
	Q _{Méd}	-0,2	-0,046	-0,730 *	-0,227	0,203	0	-0,132 **	-0,054 **	0 **	0 *	0	-0,297 **
4 Arcoverde-PE	Z _{MK}	-1,1	-0,5	-0,1	0,1	0,0	0,2	1,1	1,7	2,4 *	0,6	-1,9	-1,7
	Q _{Méd}	0	-0,009	0	0	0	0,013	0,124	0,194	0,184 *	0	0	0
5 Belém de São Francisco-PE	Z _{MK}	-0,8	0,3	0,0	0,3	-0,8	0,7	0,5	1,7	2,0	0,0	0,4	-1,9
	Q _{Méd}	-0,085	0,038	0	0,094	-0,115	0,015	0,013	0,039	0,013	0	0	-0,144
6 Betânia-PE	Z _{MK}	0,1	0,1	0,5	-0,9	0,8	0,5	-1	0,8	1,1	2,0 *	1,8	1,6
	Q _{Méd}	0	0,01	0,11	-0,31	0,145	0,042	-0,067	0,017	0,0	0 *	0	0,075
7 Bodocó-PE	Z _{MK}	0,0	0,2	-1,0	-1,0	-1,2	1,2	1,5	2,1 *	2,8 **	4,2 **	2,5 *	1,7
	Q _{Méd}	0,0	0,015	-0,392	-0,428	-0,455	0,083	0,035	0,042 *	0 **	0 **	0,100 *	0,127
8 Cabrobó-PE	Z _{MK}	0,4	0,5	-0,1	0,4	2,1 *	1,9	0,7	0,9	1,5	4,3 **	2,0 *	1,3
	Q _{Méd}	0	0,034	0	0,044	0,314 *	0,094	0	0,003	0	0 **	0 *	0,037
9 Custódia -PE	Z _{MK}	1,3	1,2	1,1	-1,0	-1,5	-1,3	-2,4 *	-0,2	-0,3	2,2 *	1,8 *	0,8
	Q _{Méd}	0,128	0,211	0,293	-0,448	-0,458	-0,339	-0,412 *	-0,004	-0,00002	0,036 *	0,001 *	0,0004
10 Exu-PE	Z _{MK}	-0,2	1,6	-0,9	-1,3	-0,6	-0,3	-1,5	-0,1	0,2	1,2	0,0	-0,9
	Q _{Méd}	0	0,468	-0,307	-0,575	-0,193	-0,027	-0,145	0	0	0	0	0
11 Flores-PE	Z _{MK}	-0,3	0,7	-2,0 *	-2,1 *	-0,6	-0,1	1,0	1,9	2,0 *	0,3	0,6	-1,0
	Q _{Méd}	0	0,118	-0,556 *	-0,660 *	-0,136	-0,003	0,061	0,099	0 *	0	0	0
12 Floresta-PE	Z _{MK}	0,5	1,9	-0,1	0,9	0,7	0,2	1,7	2,7 **	0,8	0,6	-0,1	-0,8
	Q _{Méd}	0,043	0,311	-0,036	0,262	0,12	0,007	0,057	0,098 **	0	0	0	0
13 Ibimirim-PE	Z _{MK}	0,1	-0,2	0,9	-0,5	-0,8	0,3	0,0	1,5	1,4	1,1	1,1	0,5
	Q _{Méd}	0	0	0,2	-0,207	-0,238	0,035	0	0,1	0	0	0	0
14 Igaraci-PE	Z _{MK}	0,2	-0,2	-1,6	-3,4 **	-2,4 *	-0,7	-1,6	0,1	2,4 *	0,6	1,7	1,7
	Q _{Méd}	0	-0,088	-0,925	-2,9 **	-1,764 *	-0,289	-0,481	0	0,071 *	0	0,004	0,069
15 Inajá-PE	Z _{MK}	-0,8	0,0	0,9	0,8	0,5	-0,5	2,0	2,7 **	1,4	1,6	1,0	-0,6
	Q _{Méd}	-0,071	0	0,138	0,234	0,072	-0,039	0,197	0,288 **	0,077	0,025	0	-0,01
16 Ipubi-PE	Z _{MK}	0,2	0,3	-1,7	-2,1 *	-1,1	0,9	-0,7	1,1	4,0 **	4,1 **	2,5 *	0,0
	Q _{Méd}	0,063	0,195	-1,556	-1,664 *	-0,622	0,273	-0,093	0,067	0,138 **	0,075 **	0,15 *	0
17 Itapetim-PE	Z _{MK}	2,5 **	2,0 *	-1,4	-0,7	-2,7 **	-0,5	0,0	0,7	2,1 *	2,6 **	4,0 **	2,9 **
	Q _{Méd}	0,25 **	1,012 *	-0,773	-0,575	-1,702 **	-0,113	0	0,079	0,059 *	0,0001 **	0,253 **	0,021 **
18 Ouricuri-PE	Z _{MK}	0,2	0,6	-1,0	0,6	0,5	2,3 *	2,2 *	2,4 *	2,2 *	4,4 **	1,2	0,8
	Q _{Méd}	0,008	0,122	-0,199	0,176	0,064	0,119 *	0,022 *	0,01 *	0 *	0 **	0	0,004
19 Parnamirim-PE	Z _{MK}	0,6	-0,1	-1,2	-0,5	0,3	0,0	0,1	-1,1	0,6	-1,4	-0,4	-0,4
	Q _{Méd}	0,096	-0,009	-0,277	-0,15	0,028	0	0	0	0	0	0	0
20 Petrolândia-PE	Z _{MK}	0,6	1,3	2,0 *	0,5	1,8	-0,4	1,0	0,1	0,2	2,1 *	3,5 **	1,4
	Q _{Méd}	0,061	0,166	0,336 *	0,111	0,196	-0,029	0,07	0,002	0	0,029 *	0,072 **	0,1
21 Petrolina-PE	Z _{MK}	-0,5	1,1	0,4	0,2	2,6 **	2,4 *	4,0 **	3,9 **	**	2,0 *	0,9	0,5
	Q _{Méd}	-0,049	0,167	0,053	0,024	0,229 **	0 *	0,01 **	0 **	**	0 *	0	0
22 Salgueiro-PE	Z _{MK}	0,1	1,2	-0,1	-0,9	1,7	1,7	1,2	1,1	0,1	2,7 **	1,2	-0,2
	Q _{Méd}	0,008	0,236	-0,031	-0,252	0,357	0,088	0,022	0,009	0	0 **	0	0
23 Santa Maria da Boa Vista-PE	Z _{MK}	-0,3	0,1	-1,5	0,5	0,2	0,0	-0,8	2,8 **	1,6	0,2	-1,6	-0,4
	Q _{Méd}	-0,024	0	-0,236	0,108	0,006	0	0	0,027 **	0	0	0	0
24 São José do Belmonte-PE	Z _{MK}	2,4 *	2,6 *	0,8	1,3	2,1 *	2,9 **	1,5	3,1 **	3,7 **	4,1 **	3,2 **	2,4 *
	Q _{Méd}	0,207 *	0,519 *	0,157	0,389	0,438 *	0,215 **	0,04	0,07 **	0 **	0 **	0 **	0,118 *
25 São José do Egito-PE	Z _{MK}	3,4 **	4,1 **	1,8	1,2	1,5	2,8 **	3,6 **	2,9 **	3,4 **	4,2 **	3,9 **	3,7 **
	Q _{Méd}	0,09 **	0,613 **	0,333	0,313	0,344	0,418 **	0,27 **	0,104 **	0,019 **	0 **	0 **	0 **
26 Serra Talhada-PE	Z _{MK}	-0,5	1,5	-0,2	0,2	0,5	0,9	0,4	2,6 *	0,0	0,1	-1,0	-0,1
	Q _{Méd}	-0,05	0,226	-0,033	0,066	0,097	0,104	0,021	0,093 *	0	0	0	0
27 Serrita-PE	Z _{MK}	0,7	2,2 *	1,1	-0,3	0,4	2,2 *	1,6	3,0 **	3,6 **	3,6 **	1,9	0,6
	Q _{Méd}	0,148	0,6 *	0,358	-0,151	0,112	0,271 *	0,063	0,044 **	0 **	0 **	0	0,025
28 Sertânia-PE	Z _{MK}	1,3	2,5 *	-0,1	-0,4	0	0	0	1	1,9	1,8	3,0 **	1,3
	Q _{Méd}	0,021	0,281 *	-0,006	-0,1	0,01	0	0	0,039	0,02	0	0,078 **	0
29 Triunfo-PE	Z _{MK}	0,4	1,3	-0,3	-1,3	0,3	0,1	-0,1	0,4	1,7	1,7	2,7 **	2,1 *
	Q _{Méd}	0,0001	0,243	-0,006	-0,335	0,055	0,0001	-0,00001	0,048	0,133	0,050	0,142 **	0,096 *
30 Verdejante-PE	Z _{MK}	0,8	-0,2	0,0	-2,0 *	-1,0	1,5	1,4	2,7 *	2,8 *	3,4 **	2,8 *	2,8 *
	Q _{Méd}	0	0	0	-1,3 *	-0,412	0,152	0,0002	0 *	0 *	0,00004 **	0,0005 *	0,21 *

ZMK: Mann-Kendall Test, Q_{Méd}: Sen's Slope; (*) Significant Trend Statistically at the 5% probability level; (**) Significant Trend Statistically at the 1% probability level. Source of data described in topic 3.2.

Homogeneity test of rainfall data in time series of the cities that presented a significant trend

The time series trends of rainfall indicated one variation, mainly in the average during the period

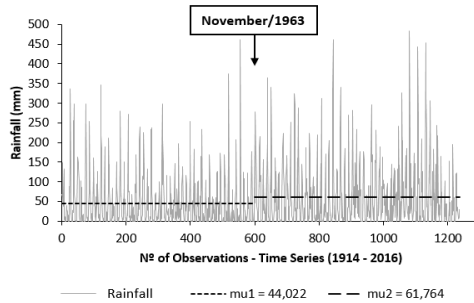
analyzed in this research, this variation can be discrete or abrupt, and the real reasons for this discontinuity become object of study, was to verify if they are natural variations, imposed by the

circulations of the climatic systems or attributed to climatic changes intensified by the anthropic action, mainly through the emission of greenhouse gases, as well as in man's actions modifying natural ecosystems modifying them in agricultural fields or degraded areas.

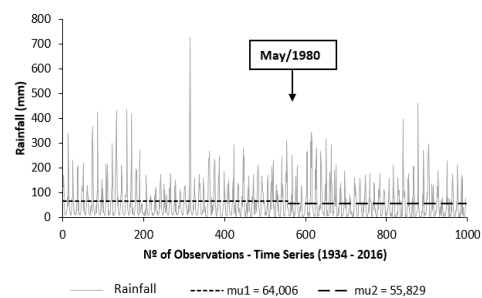
Thus, the Pettitt homogeneity test (Pettitt, 1979) was applied in rainfall data only from the cities in Sertão region of Pernambuco State (Figure 2), which showed some trend (positive or negative) with

a significance level of 5%, assuming that cities with no significant trend have a homogeneous data series. Thus, the data are homogeneous if the calculated p-value was greater than the significance level $\alpha = 0.05$. However, if the calculated p-value was lower than the significance level $\alpha = 0.05$, we rejected the null hypothesis in which the data are homogeneous, in favor of the alternative hypothesis, in which there was a change in the data.

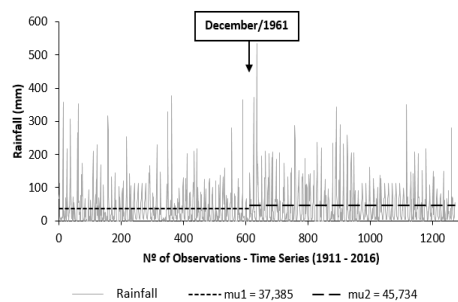
1 - Afogados da Ingazeira - PE



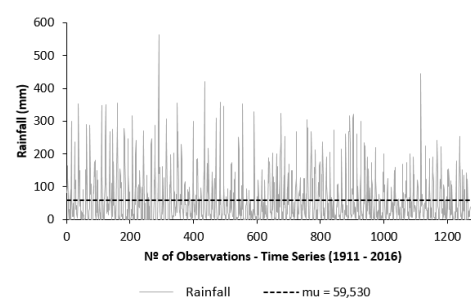
3 - Araripina - PE



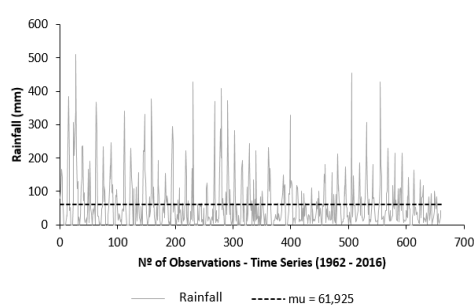
8 - Cabrobó - PE



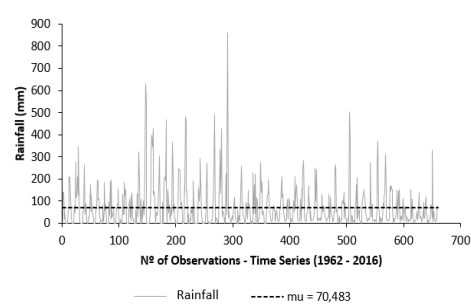
11 - Flores - PE



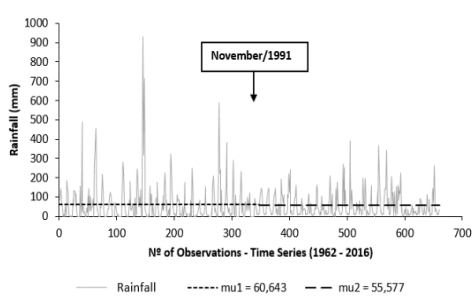
14 - Igaraci - PE



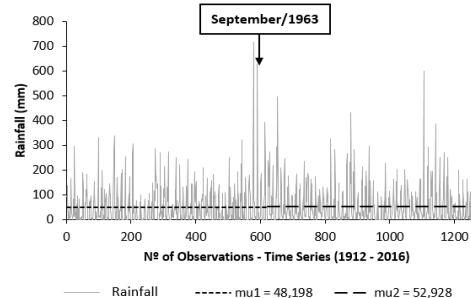
16 - Ipubi - PE



17 - Itapetim - PE



18 - Ouricuri - PE



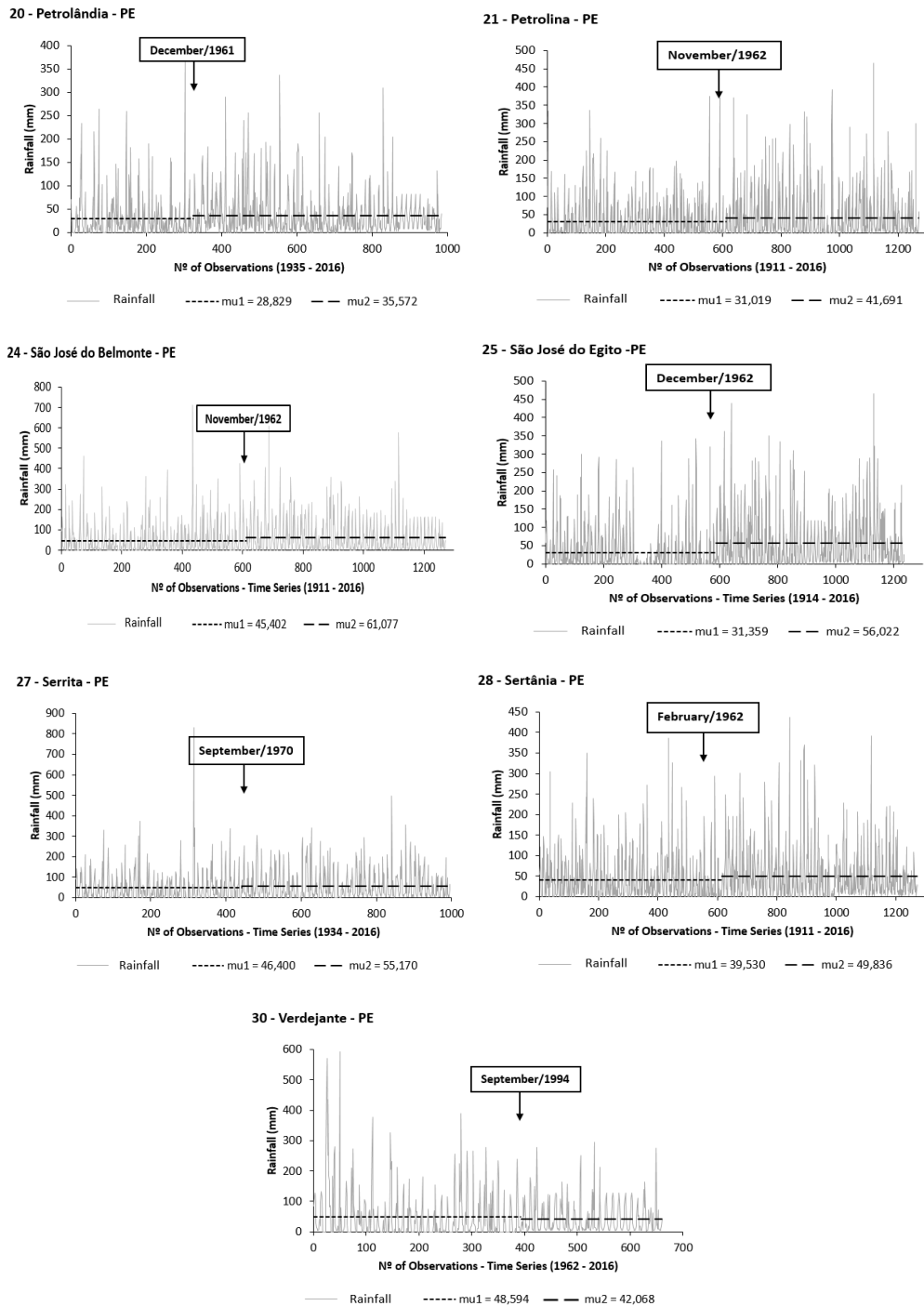


Figure 2 - Pettitt homogeneity test in rainfall data of cities that showed a tendency (positive or negative).

The homogeneity test applied to the analyzed cities that presented trends showed that not necessarily the variation of the average monthly precipitation is accompanied by an abrupt change, this change can occur in a discrete way over the analyzed period, as seen in the cities of Flores-PE, Igaraci-PE, Ipubi-PE, being the historical series of rainfall data homogeneous according to the Pettitt test at the 5% probability level, and although these cities show a tendency for a decrease in precipitation, this variation did not occur abruptly, that is, it is possible that this trend started earlier than in the start the period of analyzed historical series.

The cities of Araripina-PE, Itapetim-PE and Verdejante-PE that presented a tendency of decrease in rainfall, an abrupt change in the mean precipitation (mm) in the time series of approximately 8 mm, 5 mm and 6.5 mm respectively was observed, characterizing the heterogeneity of the precipitation data set, this variations were detected in the historical series according to the Pettitt homogeneity test at the 5% probability level in the following moments: Araripina-PE (May / 1980), Itapetim-PE (November / 1991) and Verdejante-PE (September 1994), one of the factors that we can highlight is the influence of

rainfall events related to ENSO (El-Niño - Southern Oscillation) (CPTEC / INPE 2016).

On the other hand, the cities of Afogados da Ingazeira-PE, Cabrobó-PE, Ouricuri-PE, Petrolina-PE, Petrolândia-PE, São José do Belmonte-PE, São José do Egito-PE, Serrita-PE and Sertânia-PE, which showed a tendency to increase precipitation according to the Mann-Kendall trend analysis and the Sen's slope, and showed that the rainfall data aren't homogeneous according to the Pettitt test at the 5% probability level, had the moment of detection of the abrupt change in the following months / years: Afogados da Ingazeira-PE (November/1963), Cabrobó-PE (December/1961), Ouricuri-PE (September/1963), Petrolina-PE (November/1962), Petrolândia-PE (December/1961), São José do Belmonte-PE (November/1962), São José do Egito-PE (December/1962), Serrita-PE (September/1970) e Sertânia-PE (February/1962), period after strong El Niño and before a period of moderate La Niña (CPTEC / INPE 2016).

According to the homogeneity test applied in rainfall data from 232 stations in Turkey in the period 1974-2002 by Sahin and Cigizoglu (2010), where 30 of the 232 stations presented heterogeneous data, however, only a few stations detected abrupt changes in the series, thus, most statistical discontinuities, the authors argued, this fact would be related to long term fluctuations and significant trends, both accepted within other no-random characteristics of the series of climatological observations.

Some of the cities that were submitted the Pettitt test, evidenced a similar period of the occurrence of the detected change, we can highlight the years 1961, 1962 and 1963, mainly the year 1962, where it was observed that the cities of Petrolina-PE (November), São José do Egito-PE (December) and São José do Belmonte-PE (November) presented an increase in precipitation.

In a study conducted in Madhya Pradesh in India by Kundu et al. (2015), evaluating spatial distribution and temporal variation of seasonal and annual precipitation in 45 seasons during the period 1901-2011 (111 years), there was variation in the spatial distribution of annual rains and monsoon rains, which showed a decreasing trend in most of the 45 stations where the probable break point in the series was in the year 1978 and the extreme negative event of rain became frequent in the years after the break point from 1979 to 2011, the authors observed an annual decrease of -6.75% of the precipitation observed in the period from 1901 to 2011.

Changes in the rainfall pattern have a considerable impact on the agricultural and water supply sector and any fluctuations in the hydrological cycle will have a considerable effect on the availability of fresh water according to Cruz et al.

(2007). Thus, changes in precipitation, land cover and land use are also observed to have a significant effect on sediment production and surface runoff (Wei et al., 2015).

The cities of Sertão region of the Pernambuco State, as well as the others located in the semiarid region of the Brazilian Northeast, presented serious problems of water supply for years, due to the evident variability of the water regime observed in the results, but mainly the periods of drought, evidenced in years with reduced precipitation in the rainy season aggravate the situation, exposing serious economic and social problems in the region, studies about the behavior of the hydrological cycle are extremely important in planning actions that minimize the impacts caused by the lack or excess of rainfall in people's lives, as well as in the conservation of the environment and the sustainability of ecosystems.

4 - Conclusions

The results found in the rainfall trend analysis showed that climate change has the potential to interfere with hydrological patterns. On a regional scale, it was observed that some cities in the Sertão region of Pernambuco State showed a tendency to reduce rainfall in the rainy season.

Thus, the need for a better planning of the water resources in the region is evident, since the future climate scenarios, according to the results of the Mann-Kendall and Sen's Slope tests applied in the rainfall time series, the water situation in climate change on a regional scale tends to get worse, following trends in climate change on a global scale.

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