

Temporal variability of rainfall and environmental vulnerability of the northern part of the zona da mata and metropolitan region of Pernambuco

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Abstract

Climate variabilities cause significant interference on human activities, hence the relevance of studies that relate the climate variability and environmental vulnerability. This paper aimed at analyzing the climatology of precipitation in the cities of Itambé and Recife (Pernambuco), identifying extreme events of precipitation and occurrences that impacted the socioeconomic conditions. As methodological procedures, sought daily rainfall data for the period between 1963 and 2014 for the cities of Itambé and Recife and then used the CLIMAP Version 1.1 application for processing. It was found that for the city of Itambé the highest recorded rainfall was 182 mm in 2011, 173 mm in 1978 and 168.2 mm in 1970 for the period of study. In Recife, the year of 1970 presented the biggest rainfall event, which was of 335.8 mm, followed by the year of 1986 with 235 mm and 185.9 mm accumulated in 2000. In the analysis of rainfall data of both municipalities, it was noticed the lack of trend, statistically significant, of modification in the historical series, with no decrease or increase trend. Recife, where population density is higher and there is a large number of people living in areas of elevated environmental vulnerability, must be taken up for study in order to find alternatives to minimize the problems experienced by the population during extreme precipitation events. Those relating to Itambé works should be maximized, given the scarcity of results, in order to have a greater input of scientific information about it.

Keywords: Extreme events, rainfall, climate trends.

1. Introduction

Climate variabilities cause significant interference on human activities, and there may be fluctuations in terms of temperature, precipitation

and frequency of extreme events such as heavy rains and in contrast, drought. These facts result in impacts on water resources, health, agriculture and the environment as a whole, they can bring forth effects in local or regional scale. A detailed analysis about the long-term climate data is

fundamentally important to modern societies, since from this it is possible to acquire a foundation for the understanding of climate trends and their causes, once climate oscillations are correlated with extreme precipitation events (Souza et al., 2012).

According to Souza and Azevedo (2012), studies on variability and climate change point out the variations in precipitation as being an index able to detect climate change due to long processes of observational records. The global average surface temperature is taken in several studies to designate the degree and significance of changes in climate over the last century, due to the association that the global average temperature should answer the radiative forcing that is linked to the growth of greenhouse gases (GHG) emissions.

For Confalonieri (2003), the concept of climate variability would be something intrinsic Earth's climate system, responsible for natural fluctuations in weather patterns observed in the global, regional and local. Which should not be mistaken for the concept of global climate change, which is the increase in global temperature that has caused the anthropogenic emissions of greenhouse gases.

Local climate changes have been studied through the analysis of historical data taking into account the meteorological variables, such as precipitation of rainfall and air temperature. Observation of these trends of the variables for a particular location is that it will demonstrate whether climate changes have been occurring (Souza and Azevedo, 2012).

According to Souza et al. (2012), rainfall is one of the meteorological variables most relevant when it comes to climate studies, due to many impacts they cause in many segments of society. Its excessively occurrence leads to landslide barriers and flooding, when absent it causes siltation of rivers, droughts, affecting different productive sectors in the scales: economic, environmental and social of a region.

For Silva et al. (2010) the Brazilian northeast can be characterized in temporal and spatial irregularity of precipitation. According to

Alcântara et al. (2010), the changes taking place in the climate of the northeast, could have the following impacts in the future: An increase of 3°C or more on average temperature; the agricultural subsistence production of large areas could become unviable; decrease of water lakes, ponds and reservoirs; vulnerability to torrential rains and concentrated in a short period, resulting in floods and severe social and environmental impacts.

Climate variability related studies are developed by several researchers in Brazil (Confalonieri, 2003; Silva et al., 2010; Souza et al., 2011; Souza and Azevedo, 2012; Salvador, 2014; Santos et al., 2014; Silva et al., 2014; Nóbrega et al., 2015) and they enable contributions to urban planning through results that allow the development of strategies to amortization of extreme events of dry and wet periods.

In the context of climate change, it is important to emphasize the concept of population vulnerability as points out Barbieri (2013), who claims that it relates to the ability of social groups to predict exposure situations to environmental hazards and respond to impacts caused by them. Moreover, this concept brings together social and economic determinants that predispose individuals or groups to a greater or lesser susceptibility to danger is a real physical fact (Hogan, 2005). The environmental vulnerability concept will only be understood entirely itself if it reflects the relationship between man and the environment. In the course of time and events that have occurred caused by climate change, people have realized the close relationship between man and the climate due to the influence that those changes have on social welfare (Melo et al., 2011).

In order to reduce vulnerability about climate variability is needed to establish warning and forecasting systems, to be determined where and when each population will be affected, as well as the definition of priority groups and a set of interventions already defined. To treat solely current vulnerabilities is not enough when it is a protection for the future, especially when they

come from more intense climatic or environmental changes (Silva, 2014).

Threatening conditions still can be extended due to the pressures of the different forms of production of geographical space on the natural space that primarily occur without considering the vulnerability of social groups and natural systems (Zanella et al., 2013). And to respond to climate change, it is important to conduct a risk management process, involving actions to identify and analyze the risks, aiming to achieve the effectiveness of the measures needed (Ocampo, 2011).

Carmo and Silva (2009) pinpoint that discussions on urban infrastructure and risk areas of employment are important in the context of climate change, as it has the potential to result in growth of the vulnerability of certain social groups, taking into account these new risks.

Given the above, this study aims to analyze the climatology of rainfall precipitation in the cities of Itambé and Recife (Pernambuco), identifying the extreme precipitation and major events that affected the socioeconomic conditions of the regions.

2. Materials and methods

As an initial procedure, there was the collection of secondary data through literature and desk research, journal articles, technical articles, dissertations, theses, research reports and websites news with known confidence level. According to Gil (2008), the literature has the advantage of providing to investigators the phenomena covering in a broader manner. In this way, aiming to carry out a proper survey to the subject, keywords have been selected in the pursuit of related work, namely: climate variability, environmental vulnerability, climate and rainfall.

After the literature review, it sought daily data monitoring rainfall through the Agência Pernambucana de Águas e Climas database (APAC), from January 1963 to December 2014, totaling 51 years of daily data. For this study, were selected municipalities in the region of development (RD) of the Northern part of the Zona da Mata and the Metropolitan Region of Recife (RMR), based on the work of Salvador (2014) were not used very short series or excessive number of data missing. Thus, the chosen municipalities were Itambé and Recife (Figure 1), which allowed further analysis of the time series. The rain gauges were: Itambé, belonging to the Instituto de Pesquisas Agronômicas de Pernambuco (IPA) (-7 latitude, longitude and 41 - 35, 18), and the climatological station of Recife (-8.05° latitude and longitude -34.95°) belonging to the Instituto Nacional de Meteorologia (INMET).

The RD of the Northern Zona da Mata has 19 municipalities, including: Aliança, Buenos Aires, Camutanga, Carpina, Chã de Alegria, Condado, Ferreiros, Glória do Goitá, Goiana, Itambé, Itaquitinga, Lagoa de Itaenga, Lagoa do Carro, Macaparana, Nazaré da Mata, Paudalho, Timbaúba, Tracunhaém and Vicência, totaling an area of 3,242.9 square kilometers. 16 of those municipalities have rain gauges, but the existing flaws are more than 1 year of measurements. In the metropolitan RD the scenario is similar, all 16 municipalities in the region, among Abreu e Lima, Araçoiaba, Cabo de Santo Agostinho, Camaragibe, Fernando de Noronha, Igarassu, Ipojuca, Itamaracá, Itapissuma, Jaboatão dos Guararapes, Moreno, Olinda, Paulista, Recife and São Lourenço da Mata, have rain gauges, but it turns out that the time series for the selected period of study was not complete.

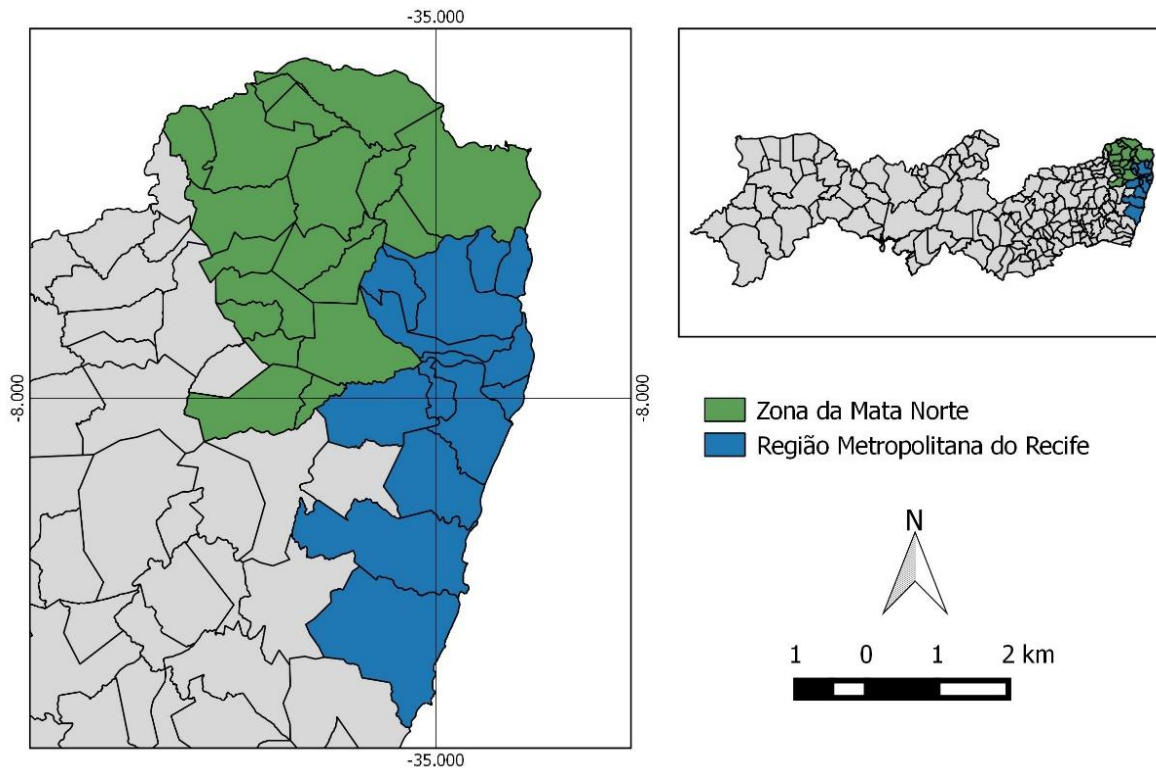


Figure 1 - Location of the study area highlighting the cities of Itambé (RD of the Northern Zona da Mata) and Recife (Metropolitan RD).

For the existing inconsistent data in the selected municipalities, the gaps were filled up with the series data of rain gauges located at a distance up to 25km, filling up to 20% of all data series as Salvador (2014) recommends in order to not compromise the results.

Based on the rainfall data, it was taken up the application for climatic data analysis - CLIMAP Version 1.1, which is a free-use tool (Salvador, 2014). Through the application, were studied averages monthly rainfall, as well as the highest cumulative rainfall in a day, total rainfall and standard deviation (DPP), linear regression and sequential Mann-Kendall test (MK) and trend analysis in the precipitation series.

3. Results and discussion

By reading off the graphs (Figure 2), it was found that the municipalities of Itambé and Recife have dry and wet periods well defined and similar of each other, having higher average rainfall in May, June and July, these being considered the quarterly maximum. This behavior is consistent with the results obtained by Nóbrega et al. (2015) where in the RMR, Zona da Mata and Agreste rains have the greatest volume of rainfall between autumn and winter.

However, it is noteworthy that for the Recife pluviometric precipitations (mm) are superior to Itambé throughout the year, reaching averages around 400 mm in June, while Itambé has average rainfall around 240 mm. For Nóbrega et al. (2015) the highest average precipitation, in terms of volume, occurs in the RMR and Zona da Mata.

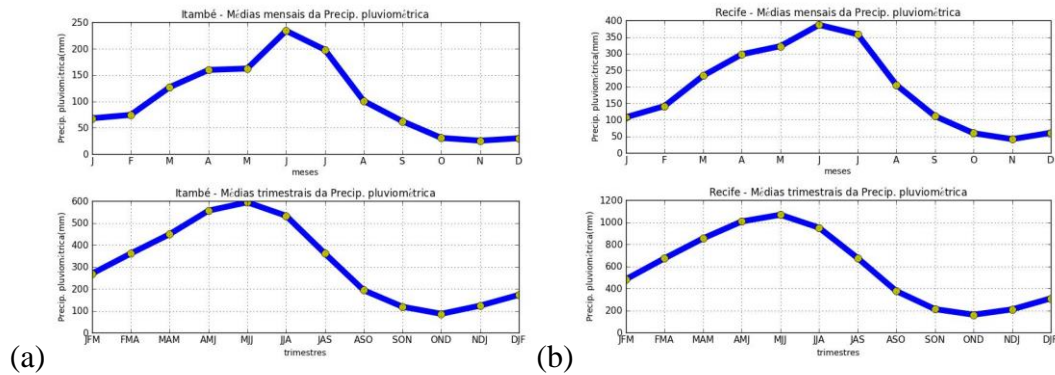


Figure 2 - Monthly averages of rainfall in the municipalities of (a) Itambé and (b) Recife.

According to Galvão (2014), the rainiest months of the RMR are caused by the advance of the Atlantic Polar Front and the instabilities that come from the easterly waves, generating moderate to heavy rainfall that usually last two to three days. These rains are usually the cause of the landslides of hills that occur in the city of Recife.

The months that present more rainfall events are in the middle of the calendar year and the large volume of rainfall leads to countless damages.

The months regarded as the driest ones are October, November and December, but it is pertinent to note that in both regions precipitation occurs during this period, although lower. This driest period creates problems for the whole RMR.

The rainfall has dissimilar importance for both municipalities. In the municipality of Itambé there are several perennial rivers, nonetheless with small flow and the groundwater potential is short (CPRM, 2005), with a current population of 35,398 (IBGE, 2010) and not relying on water supply provided by the Companhia Pernambucana de Saneamento (Compesa) (CNPQ, 2015), governmental institutions should have strategies to provide water. In the city of Recife, population density is 1,537,704 (IBGE, 2010), representing a high demand for water resources. The metropolitan region of Recife has perennial streams and high levels of runoff during the rainy season (March to August), however, the driest months (October-January) the flow rates are reduced and may dry in northwest, when in

prolonged droughts (Pfaltzgraff, 2003). In these periods of drought, due to the permanent water demand, there may be water rationing with reduced supply by the supply service.

The historical average monthly rainfall presents results that allow inferences as the sourcing strategies of the entire population. However, although it has possession of these results, extreme events can occur and compromise the dynamics of locations and accentuate vulnerabilities of local people. The driest periods create inconvenience to the socioeconomic activities, but the periods of heavy rains also significantly affect these locations.

It is perceived that the graph shown previously (Figure 2) the average precipitation refers to the total reached during the month; however, by the highest cumulative rainfall chart in a day (Figure 3), it is observed that the existence of events that isolated include values close to climatology of a single month. Such data must be observed as extreme precipitation events, and temperature, are aspects of climate that can be altered by climate change and the results of these events can affect not only the people directly, but also infrastructure, systems and sectors (Lopez-Diaz et al., 2013).

For the city of Itambé, the highest recorded rainfall was 182 mm in 2011, 173 mm in 1978 and 168.2 mm in 1970. The series of annual record of precipitation in one day shows a downward trend, with a rate of 0.01 mm/year, with no statistical significance (Figure 3). Among the study period,

the year of 1970 was the one that the greatest rainfall, which was 335.8 mm, followed by the year of 1986 with 235 mm and 185.9 mm accumulated in 2000. For Recife, the series also shows a downward trend, with a rate of 0.15 mm/year, but it does not show statistical significance. According to Souza (2011), it is important to note that these three events occurred not necessarily in the rainy season, this fact only occurred in 1986, showing that extreme events can occur in any season. Nóbrega et al. (2015), analyzing indices of climate extremes have found that there is upward trend in the occurrence of extreme events in the state of Pernambuco, but in the Zona da Mata region there is a downward trend. The authors also obtained results in their study that showed that the middle region of RMR is the one with greater regularity in the occurrence of extreme events both dry and rainy.

With regard to extreme precipitation, after the 1970 rains in the city of Recife after inaugurated the dam of Tapacurá believed to be the solution to the flooding, there was the occurrence of a new critical event in 1975 (Andrade, 2006). Between the 17th and 18th of July, 80% of Recife's population went through another flood, when 25 municipalities in the Capibaribe River basin were affected, 107 people died and thousands were homeless. Structural

damages, include: destroyed railways, collapsed bridges, and houses were swept away by the waters, the city of Recife was isolated by land for two days from the rest of the country (Andrade, 2006; NE10, 2015). According to Alcoforado and Cirilo (2001), floods are one of the most ruthless natural phenomena. They cause damage in several ways: destruction, loss of life and numerous varieties damage. This problem intensifies when the affected areas are densely populated. The lack of city planning, real estate speculation product and the occupation of the floodplains of rivers stand out as key factors for the occurrence of floods.

Another event was recorded on May 23rd, 2005, at 9 o'clock, it rained 35% from the expected for the entire month of May in Recife. In time analysis, extreme events usually occur in the rainy season, which happens differently to the accumulated rainfall in 24 hours, which may be registered in any season (Souza, 2011). For the author, this fact takes place, possibly, by the action of eastern waves, which is the most active weather system in the wettest quarter.

For the city of Itambé there are few records of large impactful events, even through the time series check, the existence of rainfall changes over the years. This may be related to lack of studies focused on climate variability in this locality.

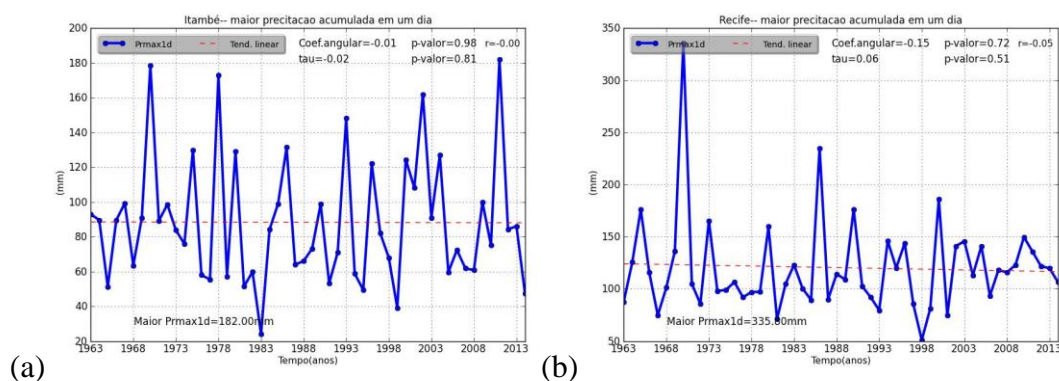


Figure 3 - Increased cumulative rainfall in a day in the municipalities of (a) Itambé and (b) Recife.

These precipitations can cause landslides, floods, and also temporary flooding incidents in small proportion. There may also be a collapse in

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infrastructure and deaths in the population due to accidents or contamination by waterborne diseases. Damage can also be psychological, due

to the "stress" that occurs with coping with floods (Souza et al., 2012).

Some extreme precipitation events when they occur in urban areas, can cause disasters and catastrophes, and these negative impacts on the socio-economic system (Souza et al., 2012). According to Souza (2011), the community may be unable to transform its structures, its rhythms and reset the direction of its processes as an agile and flexible response to the environment is now changing.

Even with all the technological innovation to aid in the detection of extreme events, some appear quickly drastically affecting the logic of the affected locations. In addition, as Thomalla et al. (2006) mentioned, many companies are still not prepared to deal with extreme events and climate change emerge as threats to local development in terms of poverty reduction and disaster risk management.

Souza (2011) shows that in the state of Pernambuco are displayed two phenomena in the opposite direction: in general the RMR and the Zona da Mata, as it passes by high rainfall often occur landslides of slopes, flooding and flooding. As for the regions of the Sertão and Agreste are usually affected by dry spells, which makes the water supplies of these regions adversely affected, and damage agriculture and livestock, thus affecting the economy and the social.

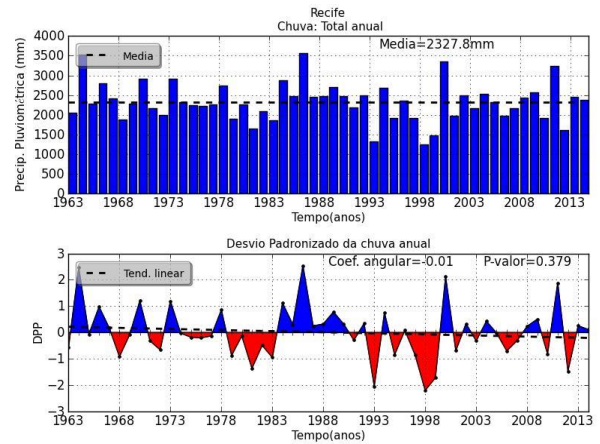
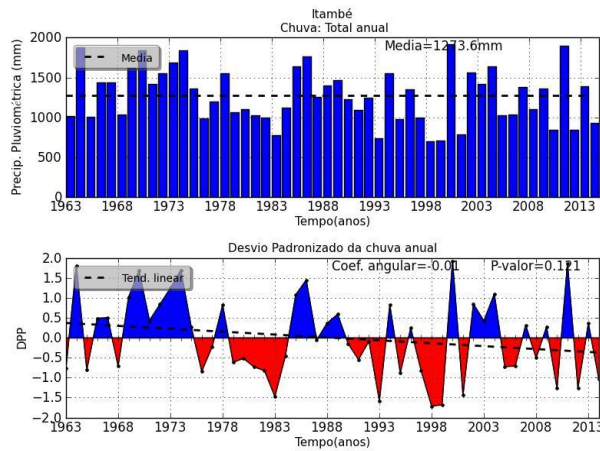
Regarding the annual variability of total precipitation, Itambé municipality historically has a volume lower than in Recife, with an average of 1054.2 mm lower (Figure 4). There is a downward trend of the annual volume in both municipalities; for Itambé, a declining rate of 0.01 mm/year, with no statistical significance. In the study of Santos et

al. (2014) for some municipalities in the southern part of the Zona da Mata, pointed out that during the study period from 1963 to 2012 there is also a downward trend in annual rainfall in the municipalities of Palmares, Gameleira, Barreiros and Quipapá. For Recife, the declining rate was 0.01 mm/year with no statistical significance for the level of 5% (p value > 0.05).

The rainfall of a city has economic and social functions and therefore the analysis of the increasing or decreasing trend of these rains must be observed. Moreover, according to Nóbrega et al. (2015) in the localities of greater urban concentration in RMR and eastern part of the Zona da Mata there is a decrease of rainy days in a row, resulting in an increase of dry consecutive days as well, and in a decreasing of annual rainfall.

Yet as explained by Nóbrega et al. (2015), negative climate trends for consecutive days of rainfall have influence on agricultural production, resulting in dry season of long, compelling the labor force, which in the Zona da Mata is mainly local, to seek other employment activities. This idea corroborates socioeconomic impacts already mentioned. Silva et al. (2011) noted in their study that the Zona da Mata region presents low water deficit, as a result of rains in this region. The period 1983-1988 was predominantly wettest, and the occurrence of precipitation extremes in both locations. However, they occurred mainly dry periods as it appears in the standard deviation charts (Figure 4) between the years between 1993 and 2003, with rainfall less than the annual average.

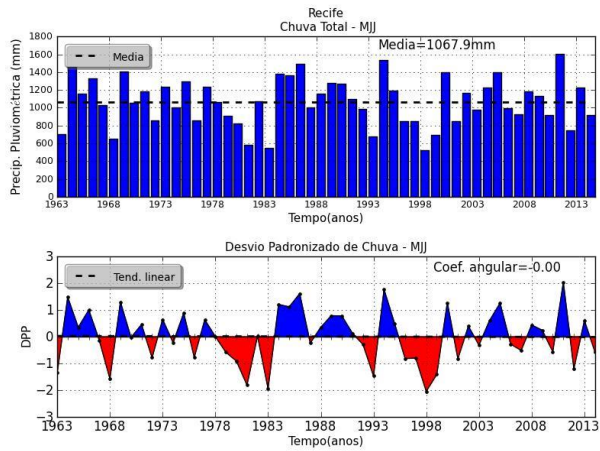
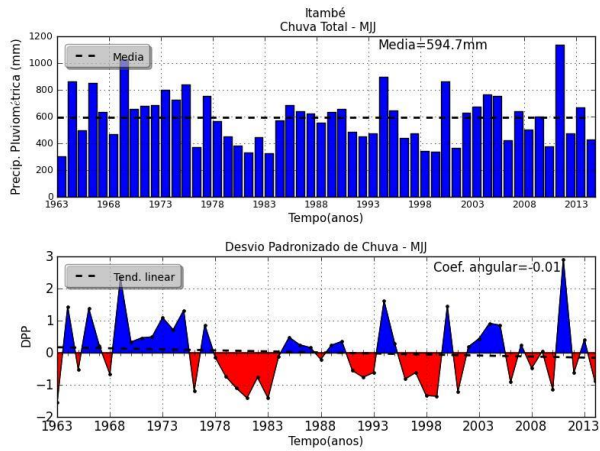
As per Santos et al. (2014), the years of 1993 and 1998 represent a season of extreme drought in northeastern Brazil.



(a) (b)
 Figure 4 - Total annual rainfall and DPP in the towns of (a) Itambé and (b) Recife.

In order to better analyze the time series, the wettest quarter (May-June-July) was observed (Figure 5). It is noticed that only this quarter accounts for over 45% of the volume of annual precipitation of both municipalities. Between 1983 and 1988, the MJJ quarter, there was a higher

frequency of rainfall above the average in both locations. For Itambé, the period 1968 to 1975 had a significant impact from rainfall events over the recent years; the year 2011 is the one with the highest precipitation in the quarter for both cities.



(a) (b)
 Figure 5 - Total rainfall and quarter of DPP MJJ in the towns of (a) Itambé and (b) Recife.

News from the local newspapers describe how the high rainfall events of May 2011 affected the population in the state of Pernambuco. According to the G1 (2011), 18 municipalities were affected by the rains, especially nine cities in the Southern Zona da Mata and three in the Northern Zona da Mata. In addition, according to the source, in Recife about 630 families were

homeless or displaced due to falling barriers and flooding. In total, the amount of stricken people by the heavy rainfall was about 144,532. Despite the high rainfall events in Itambé, they were not recorded major incidents in the city compared to the impacts in other locations.

Although the year 2011 has been significant in relation to the rains in 2010 even

with rainfall below average, also showed high precipitation event for both Recife and for the city of Itambé. As described by Souza (2011), who showed that these rains caused great tragedies, where 49 cities between the Zona da Mata and the coast of Pernambuco were affected. According to G1 (2010), more than 10,500 people left their homes due to the rains in the state. In this scenario incidence of heavy rainfall and modification of river flows, the population has an environmental vulnerability, seeking to adapt to extreme events that may affect them, culminating in the construction of wooden houses on stilts. This happens also, in the view of the author, because river levels, food production, seasonality of rain, transport, fisheries are elements that affect the regional economy and influence on life in the cities.

According to Souza (2011) the conception of vulnerability it is vital to decrease the negative effects of disasters on society. As described, the vulnerability is an fundamentally human characteristic, which is directly connected with the

production of spaces and environmental conditions are the direct answers from disaster. Capitalist relations are the main causes of vulnerabilities and risks, by the exploitation of labor, capital accumulation and concentration of wealth by a small group and others factors.

According to Alcoforado and Cirilo (2001), if a longer period of drought takes place, with high urbanization, people neglect the floods and will live in the floodplains, thus forgetting of the past flood levels. The flow grows as the surfaces are waterproofed, as urbanization and reduction of vegetation hinders the process of water infiltration into the soil.

According to the graphs of linear regression (LR) (Figure 6), it is noticed that there was a decrease in the number of days with precipitation greater than or equal to the 95th percentile of significant rainfall over the time series. There was a reduction for Itambé with average rates of 0.03 mm/year and 0.04 mm/year for Recife, with no statistical trend for both municipalities.

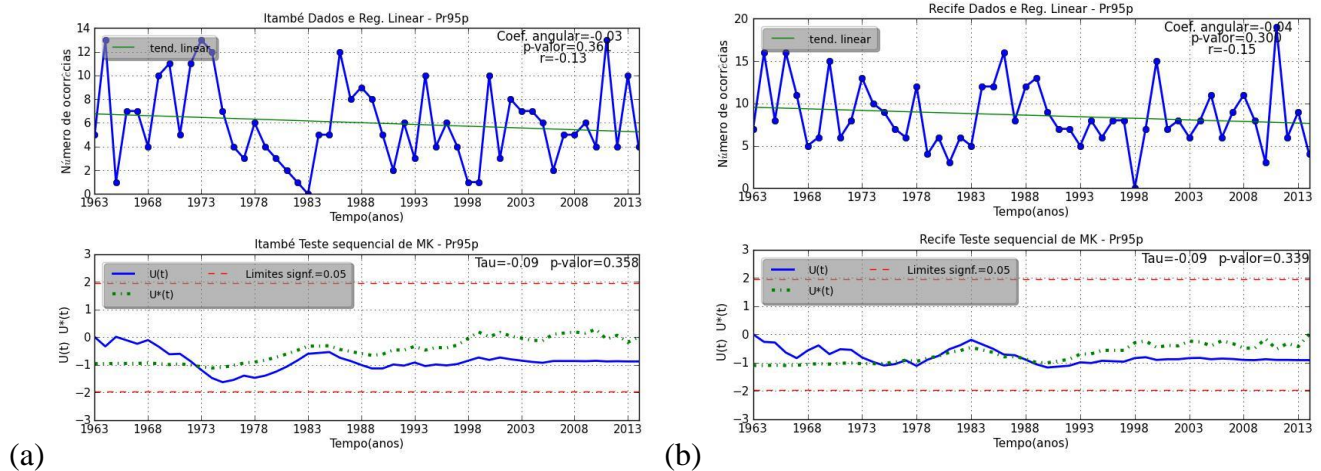


Figure 6 - Linear Regression Graph and Sequential Test MK Test Pr95p in the towns of (a) Itambé and (b) Recife.

Observing the annual precipitation (Figure 7), it was noticed that there is a downward trend in annual precipitation in both time series, but the trend is not significant, with p-value greater than

0.05. The reduction in average rates obtained were respectively 4.89 mm/year and 4.05 mm/year for Itambé and Recife.

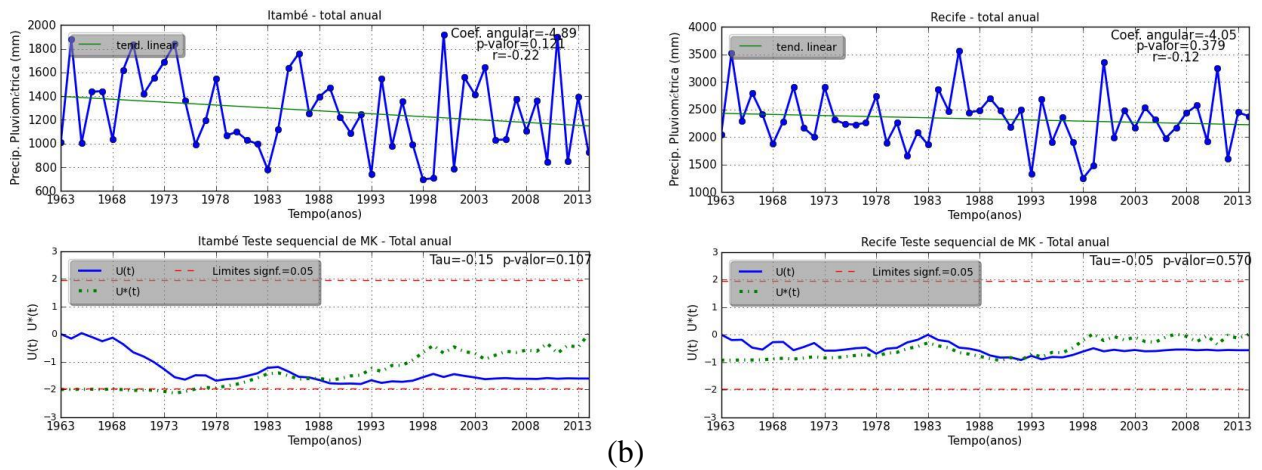


Figure 7 - Linear Regression Graph and Sequential Test total annual MK for (a) Itambé and (b) Recife.

Analyzing the months of the rainy season MJJ by LR and MK test (Figure 8), it was found that in both locations there is a trend

of decrease in rainfall with average rates of 1.21 mm/year in Itambé and 0.20 mm/year for Recife, without any statistical significance.

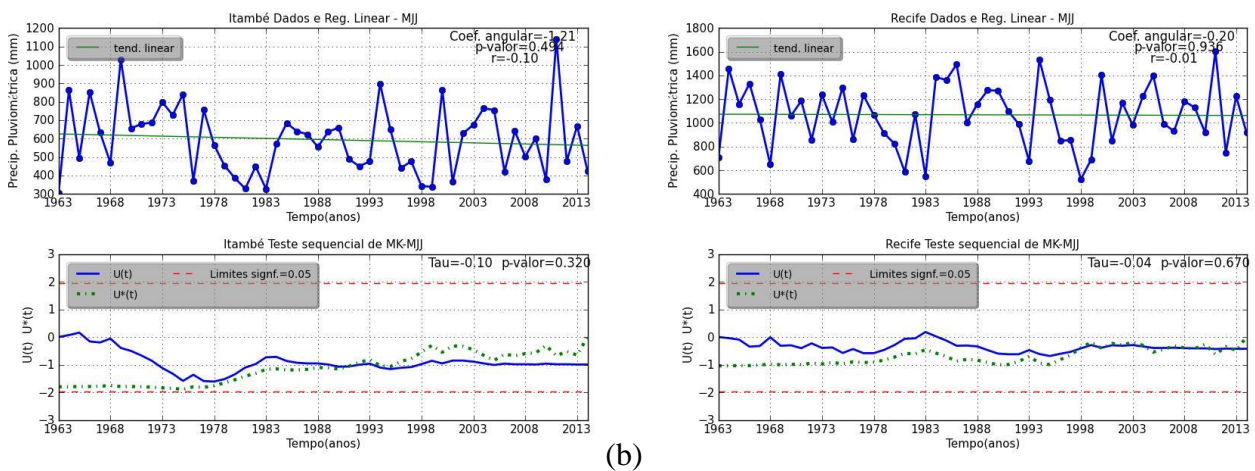


Figure 8 - Linear Regression Graph and Sequential Test MK for the rainy season MJJ for (a) Itambé and (b) Recife.

It is essential that the monitoring of rainfall series is continuous, since as pointed out by Silva et al. (2010) it is important for planning agricultural activities and water resources, in addition to that, changes in climate have influence in everyday life of society, which can cause impacts on social, economic and even cultural activities (Nóbrega et al., 2015). For Santos et al. (2014), climate variability and the frequency of

dry and wet extreme events affect on different scales agriculture, water, health and environment.

When observing the months individually (Figure 9) for the rainy season MJJ, all of them represent rainfall downward trend, except for the month of June in Recife, which presents an increase, however it is clear that none of the cases have statistical significance.

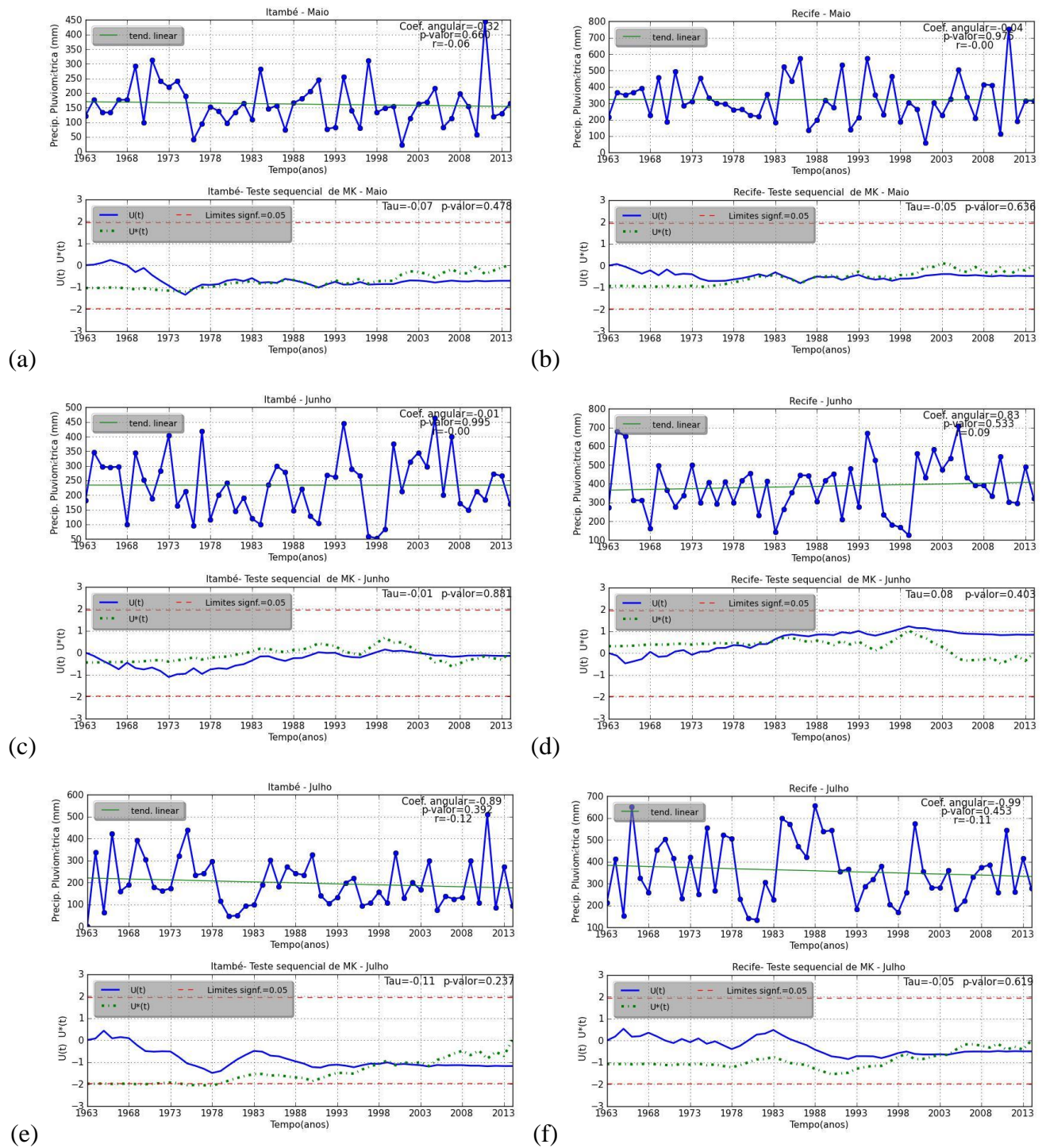


Figure 9 - Linear Regression Graph and MK Sequential Test for the months of May, June and July for Itambé (a), (c) and (e), and Recife (b), (d) and (f).

4. Conclusions

In the seasonal scale, the driest period for both studied locations occurs in the months of October, November and December. In addition, the rainy season occurs during the months of May, June and July.

Although it has been observed that the driest periods occur between October and December, the locations do not have significant water deficit, since according to the climatology, precipitation can also be seen in these months. However, there may be years with lower rainfall than the climatological average, as in the period between 1993 and 2003.

Precipitation extremes related studies are critical in the state of Pernambuco, as the recorded occurrences caused numerous socio-economic impacts for different locations. The city of Recife, which population density is higher and there are large numbers of people living in areas of high environmental vulnerability, must be studied in order to find alternatives to minimize the problems experienced by the population during extreme precipitation events. However, despite Itambé experienced just a few problems records related to extreme events, this city should also be studied in order to have a greater input of information about it.

Reconciling climate studies with environmental vulnerability of the population are important for the planning of cities and minimization of risks associated with climate change.

In the analysis of rainfall data from both municipalities, it is perceived the lack of trend, statistically significant, with modification in the time series, with no downward trend or increment related to the highest cumulative rainfall in a day, total annual rainfall and in the rainy season MJJ, and precipitation greater than or equal to the 95th percentile of significant rainfall.

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