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Analysis of precipitation in Belém-PA city (period 1967-2016)

Abstract

The objective of the study was to analyze the precipitation behavior in the city of Belém do Pará (1st 49'S and 48º49'W), between 01/01/1967 and 12/31/2016, the daily data of the National Institute of Meteorology (INMET), are grouped by decades, years and months, to identify the largest and smallest rainfall in the period. Using the percentile technique, events with an upper value of 63mm, considering k-eximo of 0.99, were separated, defining a limit for the study of extreme events and verifying the variation during the period. The results showed a tendency of growth of the amount of average precipitation in the last five decades; however, in the last decade it presents a significant drop, where the precipitation reached 16.9mm. Previous studies indicate that these variations in the precipitation of the city of Belém (PA) are little influenced by the phenomenon of Niño (EN and LN). Concluding that the Intercropical Convergence Zone (ICCIT) and the Instability Line (LS) are the main modulators of precipitation in Belém (PA). The precipitation behavior is similar to the parameters: Southern oscillation index (IOS), quasi-benial oscillation (OQB) and CIIFEN Atlantic Thermal Index (ITA), which refer to global climate change conditions.

Keywords: urban climate, el niño, la niña, ZCIT

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Introduction

The world's climatic conditions are diverse; in addition, populations and economies evolve according to the limits of vegetation distribution, rainfall and temperature. Köppen in 1918 classified the planet in bio-climatic zones, with names: tropical rainy, subtropical, temperate rainy, cold and polar forest (KOTTEK et al., 2006). Thanks to each bio-climatic zone, ecosystems contribute goods and services to mankind, which allow the existence of a very large biodiversity, thus allowing man to satisfy his needs.[1] To this respect, Morris (2012) mentions that, historically, man has preferred to develop his activities near the rivers, because it is where he finds easy access to water for consumption and hygiene, mainly. However, the climatic conditions in the last decades have presented adverse situations for the humanity. In the records available in the international disaster database, Emergency Events Database (EM-DAT) show that events related to climatology, meteorology and hydrology have changed generating concern worldwide, mainly related to human and economic losses. Then, in the relationship between man and water resources, the water resource in the same way as an ally can become a "hazard", a hazard is defined as: "the risk of an uncertain and uncertain relationship that may affect or even affect upsetting a population in their environment, in the routine or way of life, "These hazards are not only natural has a population-environment relationship, observed thus, by the Engineers of the United States of America in 1993, when presenting the construction of dams, irrigation and navigation systems as solutions to flood problems, proposals that still leave important gaps.[2]

Risks have been studied including different perspectives, such as hydrology, climate change, extreme events, and vulnerability. Grosso (2010) mentions that there is a need to articulate a set of actions aimed at reducing risks in urban areas, associated with support and prevention systems, in order to assist municipal management activities, in accordance with the urbanization programs of areas more vulnerable and with low infrastructure. These observations are the basis for generating research actions and directing economic resources, and tackling climate change with increasing population.[3] For management in water management and environmental management are interrelated activities and can affect institutional arrangements inserted in one or other practice, including in management the collection by the use of both waters and soil.[4] Using information from eight South American countries,[5] present sustainable solutions to a problem that generates many losses in society, such as floods. They also indicate that the development of land use (urbanization) is a key factor in impacts on water systems and urban water management. And there are different interactions between the mechanisms of supply, sanitary sewage, urban drainage and river floods and solid waste, in addition to waterborne diseases. In this way, the management of water resources must be conducted in a systemic way, in order to guarantee the supply of water in sufficient quantity and quality to meet the needs of society.[1] Therefore, the interactions between human interventions and the natural environment within river basins must be considered. For water, besides representing an essential resource for life and human society is also a common denominator in any analysis and evaluation of the environment and the natural, terrestrial and aquatic resources of a region.[6] Therefore, these conditions force the evolution of policies and laws to manage these resources, considering also that human actions have consequences. These actions overlap borders, so it is important to build international dialogue that overcomes fragmentation, complex systems, scale disagreement, uncertainty, spaces and climate change.[7]

Climate change is the result of several factors, including anthropogenic actions. In the anthropogenic actions, the man when making use of the natural resources ends up polluting the air, rivers and oceans generates a series of diseases the population. Natural factors are the inclination of the Earth's axis relative to the Sun and its orbit, the distribution of the continents, the availability of sources of moisture, relief, vegetation, and animal species. So it is important to know the relationship between the factors and try to find

proposals that help in the coexistence of Man-Nature, coexistence called "adaptation".[8,9] Adaptation to climate change is approached from different perspectives, both from natural conditions and from population development. However, they present difficulties of understanding and understanding among professionals, scientists, researchers, and especially the population. With different positions the discourse on climate change and the socioeconomic problem.[10,11]

The city of Belém do Pará was selected for the study because of the availability of data and ease of observation of events occurring in the city. The city of Belém was born from a privileged position at the entrance of the Amazon, initially exploited by military strategy and timely trade. The Ver-o-Peso market is an icon because it has prospered the mercantilism and development of the city. The commercialization of rubber in the period 1850-1920 gave rise to several improvements in infrastructure, the most significant of electric light, with the decline of Brazilian rubber to the detriment of Malaysian rubber, the economy declined. Other interventions in the infrastructure of the city of Belém, such as the improvement of the Boulevard da Republic, the implementation of a US naval base in exchange for the levee system to level and mitigate the effects of the tides, basic sanitation and construction of the Belém-Brasília highway was a product of its role in the international context.[12]

Nowadays, the city full of vertical condominium buildings grows both in population and in infrastructure, where new and remodeled buildings intend to harmonize and compete in the local market. The growth and development of the population brought favorable conditions both for the growth of the vehicular fleet and for problems of sanitation, coexistence, security, health, etc., typical of the great cities of the world. The change in the use of soil proves the registration of a reduction of the vegetal cover, caused mainly by the advance of the human occupation, that contributes to intensify the formation of heat islands in the occupied areas this increase of the temperature allied to the stopped water favors the proliferation of vectors of parasitic diseases.[13,14] The infrastructure works thought to be insufficient before the reality, complicating the response of social attention, medical, and work. All this results in an operational chaos, which coexists with natural climatic conditions such as precipitation that constantly threaten the population, with floods and other problems observed by the World Water Assessment Program.[15] For example, Santos,[13] Dos Santos & ROCHA[14] show that the basin of the Quintino Bocaiúva canal has a drainage system incompatible with its current characteristics, 79.26% waterproofed, presenting a very low index according to the classification of Sthraler[16] and that becomes susceptible to floods and floods, also observes the precarious conservation of the canals.[13] The objective of the study was to analyze the precipitation in the city of Belém from 1967 to 2016, identifying the behavior of extreme events, quantity, frequency, and volume of precipitations, with monthly, annual and for decades results.

Material and methods

The city Belém, capital of the state of Pará, Brazil (Figure 1), located on the banks of Guajará Bay (lat.01° 26'06"S; long.48° 26'16"W and at a distance of approximately 100km from the Atlantic Ocean, is bathed by the Guamá River to the south, Guajará Bay and the Pará River to the west. Belém comprises an area of 1,059.00 km² and has a population of 1,526,423 inhabitants according to the 2010 Census. Brazilian Institute of Geography and Statistics (IBGE, 2010). The average temperature is 26°C, prevailing northeast wind

with an average speed of 10km/h, relative humidity of 87%, was founded in 1616 and has an elevation above sea level of 16 meters. The precipitation events were analyzed with data from the National Institute of Meteorology (INMET),[17] (1st 49'S and 48º49'W) Data were grouped by day, month and year, from 01/01/1967 to 31/12/2016. The percentile technique was used to identify the extreme precipitations, using Equation 1 Percentile, as suggested by Xavier et al.,[18] Extreme events of daily rainfall were values greater than or equal to 62mm for Belém and 87mm for the city of Carrillo, corresponding to the ninety-ninth percentile (99%).

$$P_x = \left[F_{i-1} + f_i \frac{X - L_i}{a} \right] \frac{100}{n} = \% \qquad (1)$$

Onde:

P_x =Search Percentile

L_i =Lower limit

$F_{(i-1)}$ =Accumulated absolute frequency above the percentage sought

a=Range width containing percentage

f_i =Simple absolute frequency of the desired percentage range
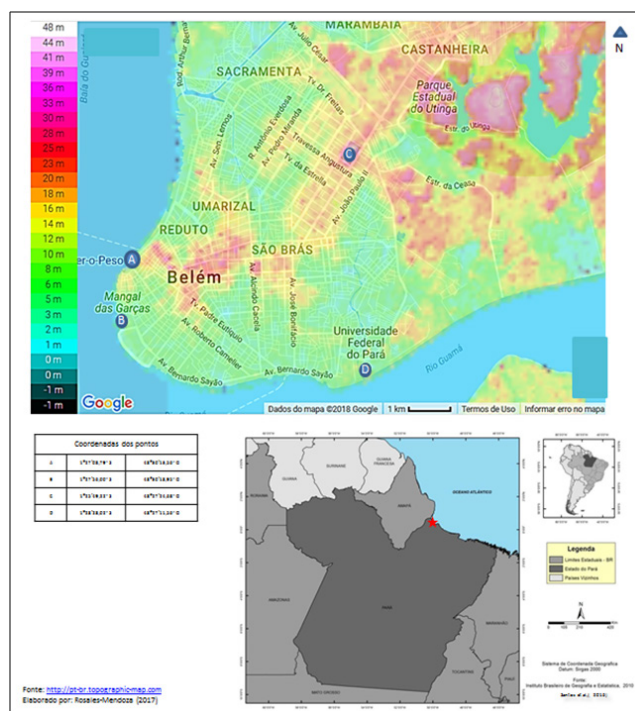
n=Sample size

X=Percentage sought

Figure 1 Representation of the topography of the city of Belém do Pará, Brazil.

Source: Prepared by the Author

Results and discussion

The data reveal the highest and lowest values of precipitation in the period from January 2, 1967 to December 31, 2016, are 200.8 and 0mm respectively (Figure 2). The mean value is 8.4mm; in the period the days that have precipitation equal to zero represent approximately 30%. The analysis centered on the observation of high precipitations, therefore, it used the percentile with a k-eximo value of 0.99 to obtain the boundary line, which is 62mm of precipitation. In the daily precipitation history, some spare points using the boundary line, the data were grouped again in multiples of 62mm, the results in Table 1. The 200 data with a precipitation equal to or greater than 62mm are shown in Figure 3. The five events with the highest precipitation occurred in 1985 (136.9mm), 2000 (133.7mm), 2005 (200.8mm), 2008 (131.4mm) and 2013 (161.20mm), the highest being that of 2005. Identify a 15-year distancing between the first event 136.9 mm in the precipitation and the second most important in the year 2000, after the period of time between 3 and 5 years, the events have a precipitation equal to or greater than 118mm precipitation (Figure 4). The precipitation growth trend of the analyzed events is approximately 0.11%, the annual history and growth (Figure 5). Taking as a limit the year 1967, it observed a tendency to growth until 1974, despite a fall from 3,315.3mm to 1,257.4mm in the year 1975, almost immediately precipitation accumulates returns the trajectory of the growth trend with variations, but always with growth until the year 2016 (Figure 6), where it registers the less accumulated precipitation in the period of the 50 years, bigger than that observed in 1975, cumulative annual precipitation of 904.6mm. The period of intense rains begins in the month of December and extends until the month of April, decreasing in the month of May until the month of November, nevertheless the presence of rains is permanent, always has rain.

Table 1 Grouping by precipitation interval

Rank PRP	Number of events	Reason
186,01 a 240	1	0,000051
124,01 a 186	4	0,000205
62,01 a 124	195	0,010003
1,01 a 62	11607	0,595414
0 a 1	7687	0,394326
Total dados	**19494**	

In the last two decades the highest concentrations of rain occurred in the month of March, draws attention because in previous decades happened in the month of February. The trend and a growth rate of 6.86% in the last five decades (Figure 7). The variation of precipitation in the city of Belém do Pará, Brazil from 2000 to 2016, the annual and average monthly cumulative precipitation, it can be verified that most of the annual precipitations were above 2000(mm), with a tendency to increase. It is observed that the year 2003 presented lower annual precipitation of 2769(mm) and 2013 with the highest rainfall 3776mm. The average of 2003 was 231mm was under the influence of El Niño (EN) and La Niña (LA), while the year 2013, which was influenced by the La Niña phenomenon (LN) had the highest average precipitation of 315mm. The variation of the monthly average rainfall shows two periods:

a. A period of less rain that goes from May to November, with months with less rain (<300mm) and

b. A period with higher rainfall with rainfall>300mm, reaching 50mm in the month of May, it is evident that the month of May is where the highest rainfall occurs.

The precipitations of the city of Belém do Pará evidenced the influence of the ENSO that significantly altered the meteorological variables intensifying or inhibiting the convective activities in the region. Because temperatures were high and precipitation was below average in the year of El Niño, while in the year of La Niña precipitation was above the half of the period. However, annual and interannual scale oscillations appear to determine local precipitation. Rainfall in the metropolitan region of Belém presents spatial and temporal variability. We also observe instability caused by the association to the edge of a High Level Cyclonic vortex (VCAN).[17–24] So, the precipitation of the city of Belém do Pará is influenced by the large-scale Forces of Intertropical Convergence Zone (ITCZ) because the ZCIT is more to the north of the equator, in the months of July to November, when the ITCZ is further south from the equator from December to May, the rains are higher. In addition, ENOS interferes with the amount of rainfall, since in 2003 it was under the influence of El Niño (EN) and 2013 we were influenced by La Niña (LA). The calculation of percentile with k-eximo of 99% allowed separating 46 events with value above 70 mm, it can be identified that on April 24, 2005 had the largest event with 200mm of precipitation. When analyzing extreme precipitation in the city Figure 8, it can be identified that the years 2006 and 2011(8A) had the highest concentration of extreme precipitations, in April it is the one with the highest concentration of extreme events, these high precipitations happen with some frequency between 13,15 and 29(8B). Some dates with higher pluviometric volumes coincided with local newspaper reports,[25] that identified and indicated the neighborhoods of Cremação, Jurunas, Batista Campos, Pedreira, Guama, Marco and Campina such as those most affected by the heavy rains. In the case of April 24, 2005, the G1 news reported the neighborhoods Cremação, São Bras and Marco with flooded streets.[26–32]

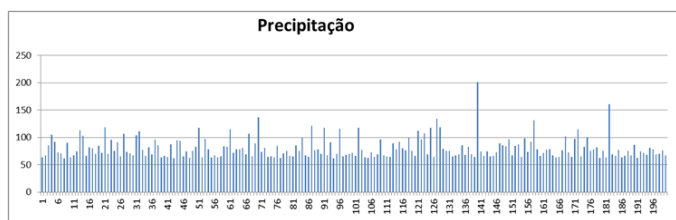**Figure 2** Historical daily precipitation.

Source: Author

Figure 3 Extreme precipitations of the period 1967-2016.
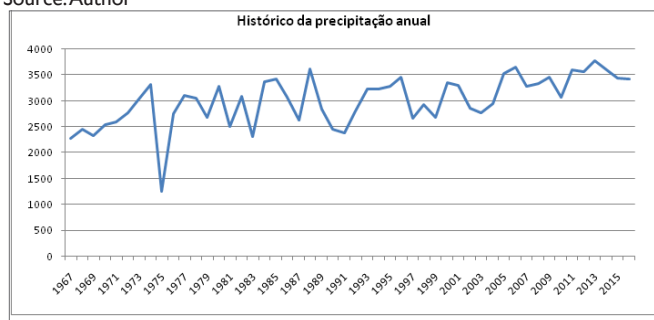
Source: Author

Figure 4 Periocity (A) Growth in millimeters of extreme events. (B) Comportamento das precipitações extremas.
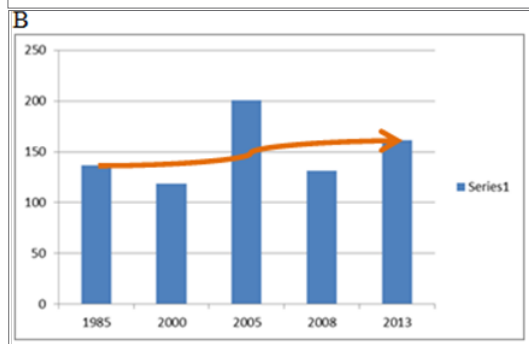

Figure 5 Histogram of precipitation in the period 1967-2016.
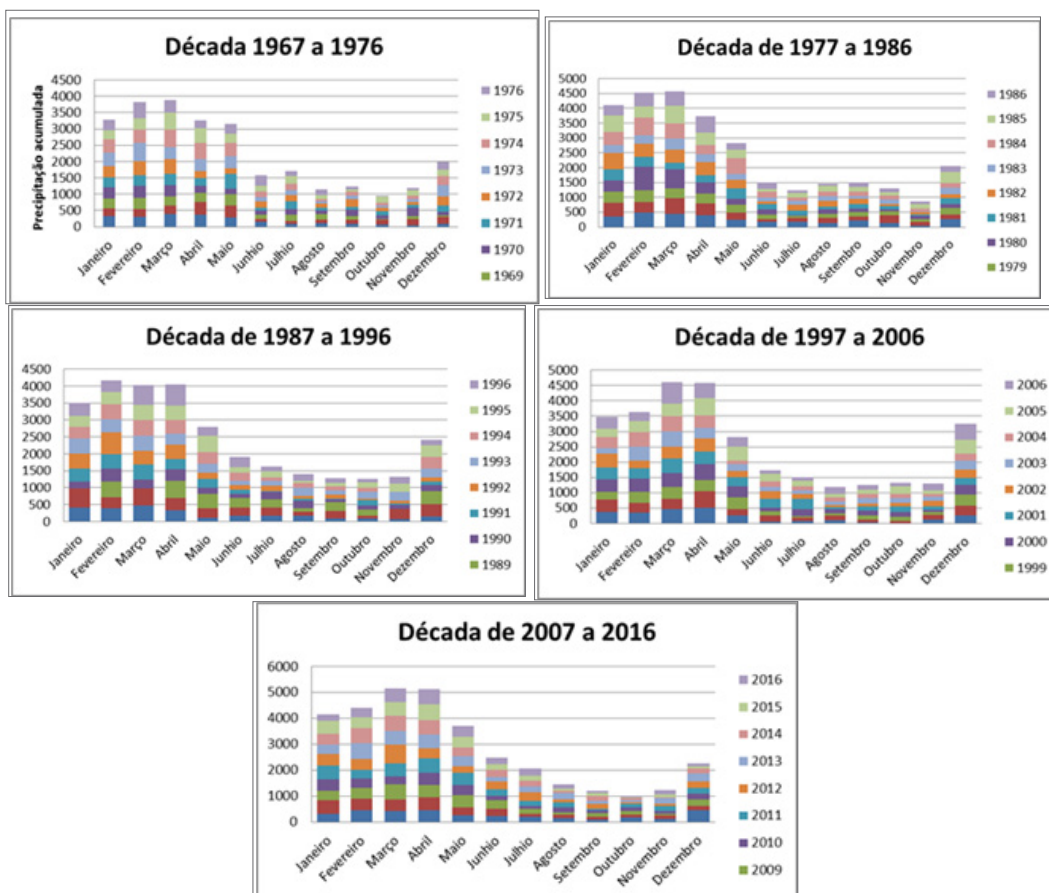
Source: Author

Figure 6 Histogram per decade.

Source: Author

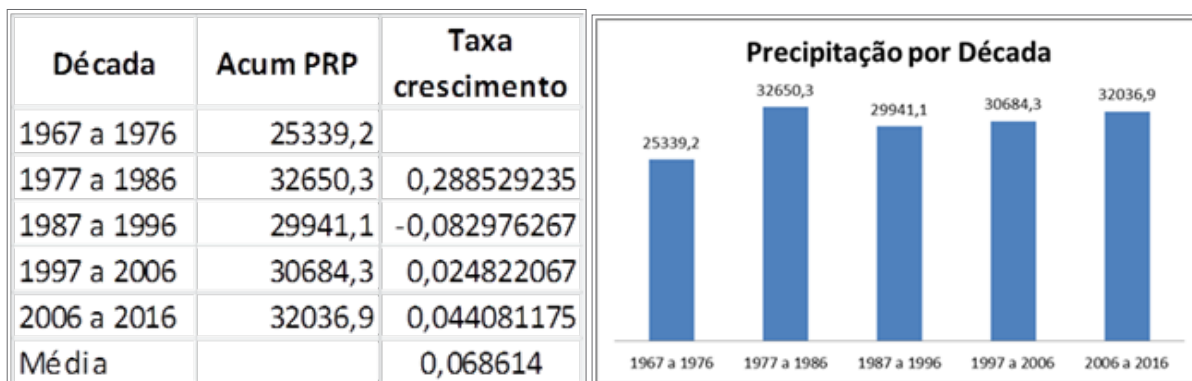| Década	Acum PRP	Taxa crescimento
1967 a 1976	25339,2	
1977 a 1986	32650,3	0,288529235
1987 a 1996	29941,1	-0,082976267
1997 a 2006	30684,3	0,024822067
2006 a 2016	32036,9	0,044081175
Média		0,068614

Figure 7 Representation per decade.
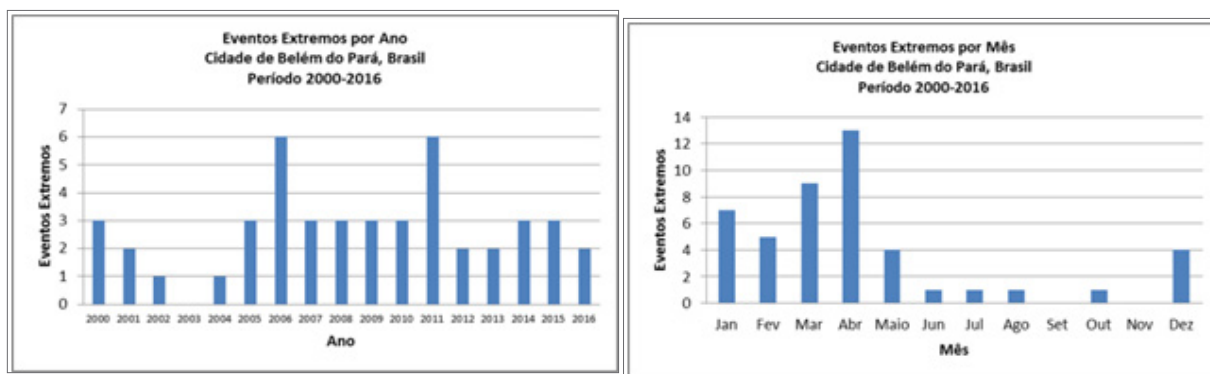
Source: Author

Figure 8 Extreme precipitation in the city of Belém do Pará, Brazil 2000 to 2016, (A) Extreme precipitation per year. (B) Extreme precipitation per month.

Source: Author

Conclusion and recommendations

The very rainy season in the city of Belém begins in December, "very rainy" because the city has rain all year round, without dry periods, influenced, due to its location south of the equator line by the ITCZ, in addition, is also influenced by ENSO, which interferes with the amount of rainfall, as observed in 2003 was influenced by El Niño (EN) and 2013 was influenced by La Niña (LA). In the month of May and the month that presents the greatest amount of extreme events due to heavy rains, due to the fact that the previous month (April) has the highest amount of precipitation, leaving the soil saturated and favoring the conditions for floods. This natural condition that favors the phenomenon of floods and increased by the development of the population, in most cases it was observed the contempt to the urban planning, constructions in or under the protection zones / areas, as a consequence drainage, 'water without cleaning administration, generating stagnant water focus of Leptospirosis. Taking advantage of the knowledge of the precipitation behavior, it is possible to send some corrective or preventive actions in the period of less rain, to minimize the impacts of the floods in the rainy season, actions to avoid the standing waters, mainly avoiding the outbreaks of diseases to the residents. Residents should also assess the suitability of staying within vulnerable areas or areas of high risk exposure, but can only make the decision if they have been informed, in a colloquial language, with certain information like the ones used in this study. In this sense, management can value the convenience of moving settlements and placing them in areas of lesser vulnerability by planning and limiting their use. Planning should also be done for areas that have become available and available for better urban management.[33–35]

Acknowledgements

Conflict of interest

The authors declare there is no conflict of interest.

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