
Analysis of rainfall variability and its contribution to the study of urban climate in the city of Feira de Santana-BA

Análisis de la variabilidad de las precipitaciones y su contribución al estudio del clima urbano en la ciudad de Feira de Santana-BA

Análise da variabilidade pluvial e sua contribuição para o estudo do clima urbano do município de Feira de Santana-BA

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Abstract

The article proposes to identify the rainfall pattern for the municipality of Feira de Santana-BA. For this purpose, two statistical techniques were applied to propose the ordering of the indexes, both monthly and annual, namely, Sturges formula and the quartile technique. The treatment of the data took place through the tabulation, elaboration of graphs and tables, which were executed in the Excel and Qtiplot software. As a synthesis of the results generated, the technique of representation by the box plot graphs and the summary table is used. It was found that the greatest variability occurs in the summer, highlighted by the occurrence of variability and high rainfall that trigger hydrometeorologic impacts. Less variability in spring, seasonality with greater predictability of reduced rainfall volumes.

Keywords: Variability; urban climate; hydrometeorologic impacts.

Resumen

El artículo se propone identificar el patrón de lluvia para el municipio de Feira de Santana-BA, para lo cual se aplicaron dos técnicas estadísticas para proponer el ordenamiento de los índices, tanto mensuales como anuales, a saber, la fórmula de Sturges y la técnica del cuartil. El tratamiento de los datos se dio a través de la tabulación, elaboración de gráficos y tablas, los cuales fueron

ejecutados en el software Excel y Qtiplot. Como síntesis de los resultados generados se utiliza la técnica de representación mediante los gráficos box plot y la tabla resumen, se encontró que la mayor variabilidad se presenta en el verano, destacándose por la ocurrencia de variabilidad y altas precipitaciones que desencadenan impactos hidrometeorológicos. Menos variabilidad en primavera, estacionalidad con mayor previsibilidad de volúmenes de lluvia reducidos.

Palabras clave: Variabilidad; clima urbano; impactos, hidrometeorológicos

Resumo

O artigo propõe-se identificar o padrão da pluviosidade para o município de Feira de Santana-BA.. Para tal finalidade, foram aplicadas duas técnicas estatísticas para propor o ordenamento dos índices, tanto mensais quanto anuais, a saber, fórmula de Sturges e a técnica dos quartis. O tratamento dos dados se deu por meio da tabulação, elaboração de gráficos e tabelas, as quais foram executados no software Excel e Qtiplot. Utiliza-se como síntese dos resultados gerados a técnica de representação pelos gráficos *box plot* e do quadro síntese. Verificou-se que a maior variabilidade acontece no verão, destacado pela ocorrência de variabilidades e de chuvas elevadas chuvas que deflagram impactos hidrometeorológicos. A menor variabilidade na primavera, sazonalidade com maior previsibilidade de volumes de chuvas reduzidas.

Palavras-chave: Variabilidade; Clima urbano; impactos hidrometeorológicos.

Introduction

Understanding rainfall variability is usual for risk management. In geographic climatology, the behavior of climatic conditions is essential, through actions that can cause in spaces. Although it is conceived how much the climate is dynamic, depending on the different interferences that occur in the atmosphere. However, when considering risks and vulnerability in space, the prediction and understanding of the climate rhythm become essential, to point out the usual pattern and atypical situations, which compromise nature and society.

It is known that climate conditions interfere in the socio-environmental dynamics in its biophysical, economic aspects, in the daily events of society, etc. In this context, Climatology in Geography tends to offer and understand structural information of the climate at the interface of geographic attributes on the surface. According to Schneider and Silva (2014, p. 132) "The understanding of the rhythmic

variation of climatic elements is fundamental for understanding the essence of climate, thus contributing to geographic analysis, specifically, to Geographic Climatology”.

Carlos Augusto Figueiredo Monteiro (1991) when addressing the rhythm in Geographical Climatology pointed out the importance of samples by standard years when relating the concept to the succession of atmospheric states, giving a more dynamic analysis to the study of climate. This criterion has been one of the most used methodologies in scientific studies related to variability, with the aim to present representative years of climatic conditions. Authors such as Zavattini and Boni (2013) and Schneider and Silva (2014), Pinto (1999) used the procedure to point out patterns and classify them from the usual to events that are far from the averages and/or medians.

The importance of surpassing analyzes of only the averages is highlighted, since they omit the details and generalize the information. Barros and Zavattini (2009) consider that the understanding of the climatic rhythm will only be possible with the decentralization of the average values, so that the extremes are visualized and considered integral part of the climatic reality of a place. In this regard, the methodologies applied to identify the standard years statistically consider the measures of dispersion of the variables through deviation, amplitude, variance, among others, which point out the variability of the analyzed data, including extreme values.

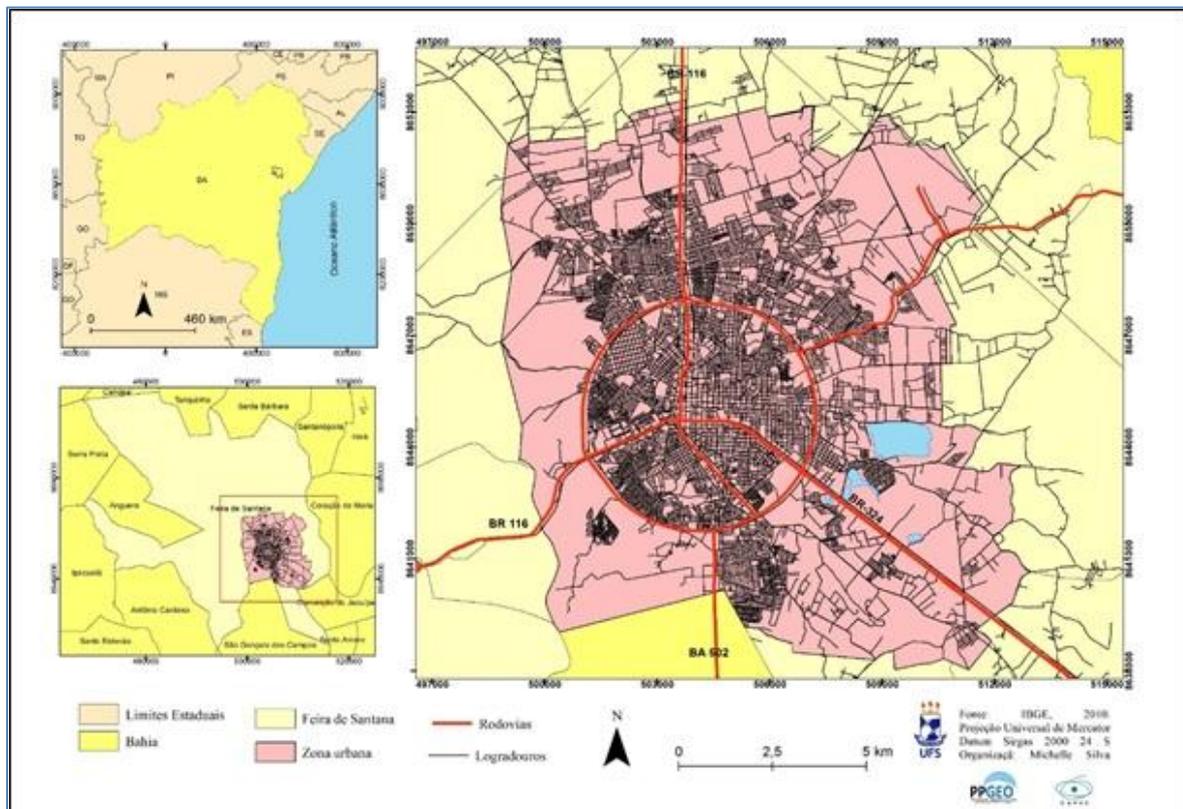
The statistical threshold of rainfall is important to classify them, however the value alone does not represent the level of impact that the phenomenon may or may not have on society. According to Armond and Sant’Anna Neto (2017) extreme events and exceptionalities in Geography are now analyzed not only in quantitative terms or in terms of thresholds, but in terms of the relationship between rainfall and the triggered impacts. This perspective moves towards an epistemological approach to Climate Geography (SANT’ANNA NETO, 2001).

This work aims to understand the variability of rainfall in the municipality of Feira de Santana, in order to identify and classify the pluviometric conditions of the locality. For that, two statistical techniques were applied to define ranges and classes, namely, the Sturges rule and the quartile rule. The temporal series of pluviosity (rainfall) consists of the period 1937 to 2019, totaling 78 years. The classes follow the recommendations of both authors Zavatinni and Boni (2013) and Scheneider and Silva (2014) with the identification of dry, rainy and usual standard years.

Area of study

The municipality of Feira de Santana-Bahia, located approximately 107 km from the capital Salvador (Map 1). It is the second largest city in the state, it is part of the Portal do Sertão Identity Territory with an estimated 614,872 people (IBGE, 2019). Also known as Princesa do Sertão, this last nomination has an association with its climatic aspect, although it is located in a transition zone of morphoclimatic domains, but penetrating in the zone of the forest and caatingas.

Map 1- Map of the location of the municipality of Feira de Santana-BA



Source: Silva (2020)

Materials and methodological procedures

The first procedural step was to obtain the pluviometric (rainfall) variables, which were collected in the database of the National Institute of Meteorology (INMET) and in the HidroWeb portal of the National Water Agency (ANA). These public bodies have and make available on their websites, historical series of monitoring stations in the municipality. Subsequently, the tabulation of rainfall data was organized, establishing the period from 1937 to 1988; 1988 to 1994; 1994 to 2019. It is noteworthy that the temporal cuts were necessary due to the flaws found and, therefore, some years had to be discarded. The monthly and annual rainfall indexes were tabulated in a spreadsheet in *Excel* and *Qtiplot software*, version 0.9.8.6.

To verify the pluvial behavior, considering their limits in the seventy-eight years, statistical methods were applied, which consist of analyzing the frequency and determination of range in the data sample. Data treatment follows the recommendations suggested by Zavattini and Boin (2013) when approaching methodologies and practices to work with rainfall data on a monthly and annual scale with dispersion measures. The authors point out means of classification for standard years when considering the most frequent and sporadic occurrences.

Sturges' formula was applied, whose function is to point out the number of classes for the sample in question. By applying the formula $k=1+3.3 \log n$, where k: number of classes, n is the total number of years and the logarithm to base 10, the number seven was obtained as a result. Next, the range of classes is established, whose value is the result of the total amplitude of variation divided by the number of classes. Then, the naming of the classes is made based on the climatic context of the study area.

The second technique consists of quartile, used for both annual and monthly accumulated totals. In this technique the data are separated into four parts, 50% values equal to and higher than the median and 50% less than or equal to the median.

The graphic representation of the quartile technique is the box diagram, elaborated in the *Qtplot software*. According to Silva et. al (2017, p. 27) “the *Box Plot* technique allows the exploration and analysis of rainfall data, providing information on its distribution and dispersion”. The grouping highlights the interquartile shift. The upper and lower bound, which is the length of the box, is given by the following calculations: Lim. Lower = $Q1 - 1.5 \cdot AIQ$ and Upper Lim = $Q3 + 1.5 \cdot AI$. The differing values are those that exceed the upper and lower limits, called outliers.

The four classes presented characterize the following classifications: dry, usual, rainy and super-dry and super-rainy. The ranges established statistically, namely,

- ✓ the 25% of the data that are between the minimum value and the threshold of the first quartile, fit the classification of dry months (yellow color);
- ✓ 50% are between the first quartile and the threshold of the third quartile, which concentrate the usual months (green color);
- ✓ the remaining 25% of the data correspond to the rainiest months (blue color), which are between the third quartile to the maximum value of rainfall;
- ✓ the values that are lower than the lower limit are the driest (red color);
- ✓ those that exceed the upper limit correspond to the super rainy.

The results are presented through representative classes and their respective colors, which are explained in tables, summary table, frequency histogram and graphics.

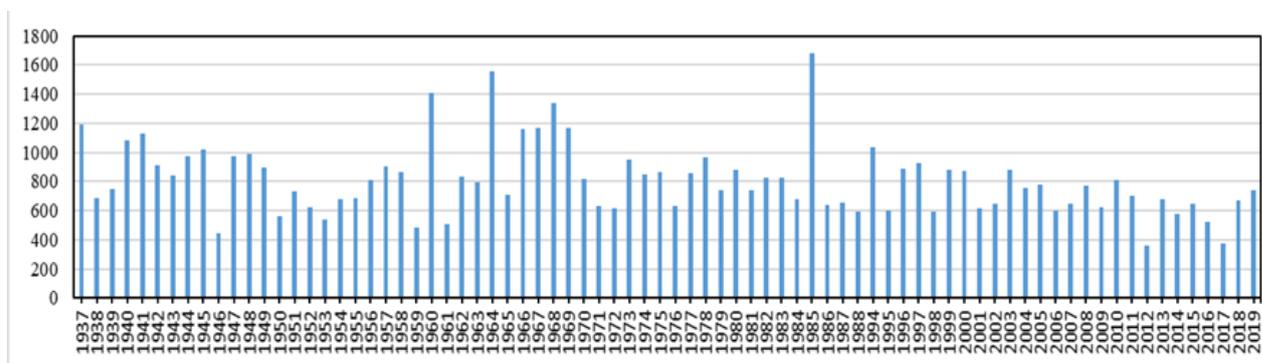
Annual variability of rainfall

In terms of the climate transition of the municipality under analysis, the spatial and temporal behavior in the regional context must be understood. The Brazilian semiarid is marked by the occurrence of rains that happen irregularly and scarcely in time and space. It is in the semiarid region that the morphoclimatic conditions of the Caatingas are recorded.

This variability condition occurs on different time scales, with annual, monthly and/or seasonal oscillations. Zavattini and Fontão (2019) consider the variability of annual precipitations based on the identification of usual and extreme standard years, dry and rainy, thus the authors use statistical techniques to support the empirical and qualitative classification.

The climate diagram presents the annual totals of pluvial precipitation during 1937 - 2019 in the municipality of Feira de Santana, it can be seen in this first exploratory observation that the temporal distribution varies in the amount of rainfall over the highlighted years (Graph 1).

Graph 1- Graph of annual rainfall in the municipality of Feira de Santana (1937-2019)



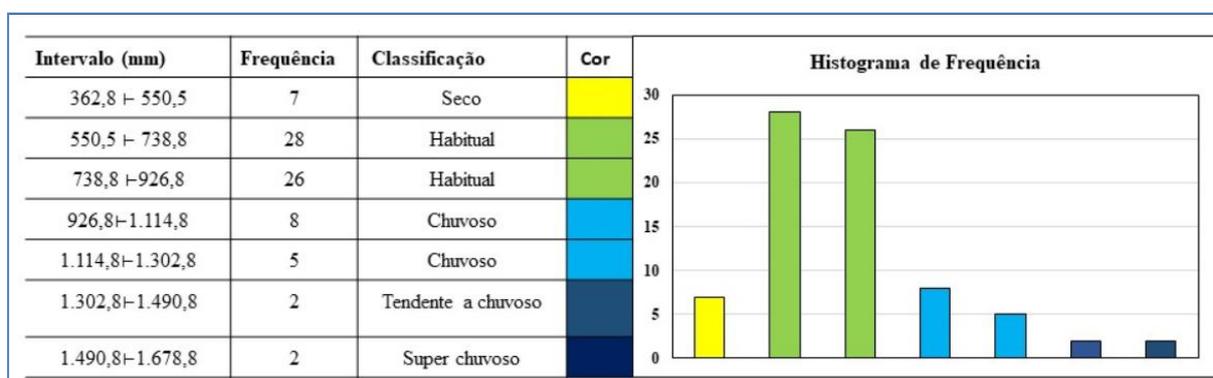
Source: ANA/Hidroweb; INMET Org. Silva(2020)

In the scope of this article, it was initially sought to verify the characteristics of the variability of annual rainfall from the frequency in the data series. The table summarizes the information, which demonstrates the classification of rainfall into seven classes as indicated by the application of Sturges' rule (table 1). The classifications refer to the dry, usual, rainy, tending to rainy and super rainy patterns.

The most frequent precipitations are concentrated in the ranges of 550 to 738.8 mm and 738.8 to 926.8 mm as shown in the table and in the histogram (Table 1). Thus, it is interpreted that the total annual rainfall from 550 to 926.8 mm represents the usual pluviometric behavior due to the succession verified in the time series.

In this technique, it was not possible to identify extreme values associated with drought, for the lowest rainfall index were grouped into a single class called dry pattern. Thus, seven years with the lowest rainfall index, less than and equal to 550.5 mm were in the first interval, referring to the following years: 1946, 1953, 1959, 2012, 2016 and 2017.

Table 1- Interval of classes and frequencies of annual rainfall (mm)

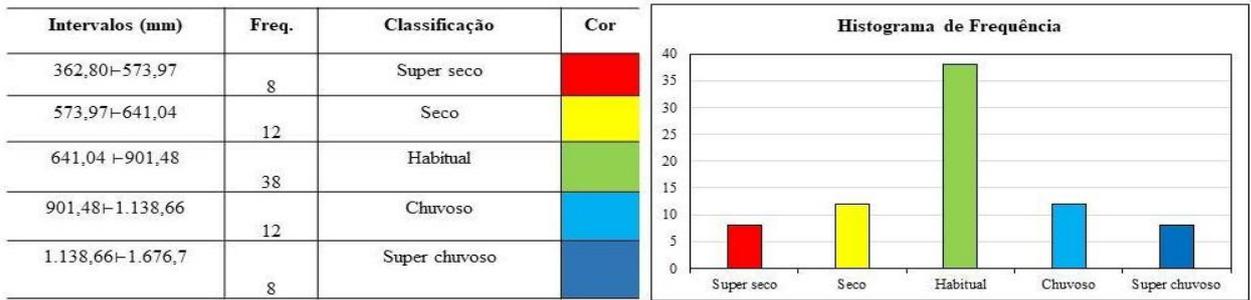


Source: ANA; INMT. Org. Silva (2020)

The analysis of interannual variability is complemented with the application of the statistical technique of quartiles, which consists of organizing the sample into four parts. The groupings are related to the classes: rainy, dry, usual, super rainy and super dry (table 2). In this procedure, the median value is 777.6 mm.

The classification of the usual rainfall for the municipality is concentrated in the annual totals from 641.03 to 901.48 mm, representing 50% of the data. The standard rainy years comprise the precipitation in the range of 901.48 to 1,138.66 mm, the super rainy ones are from 1,138.66 to 1,676.7 mm. On the other hand, the years with rainfall below 641.03 to 573.96 mm represent dry years, and below 573.96 the super dry ones.

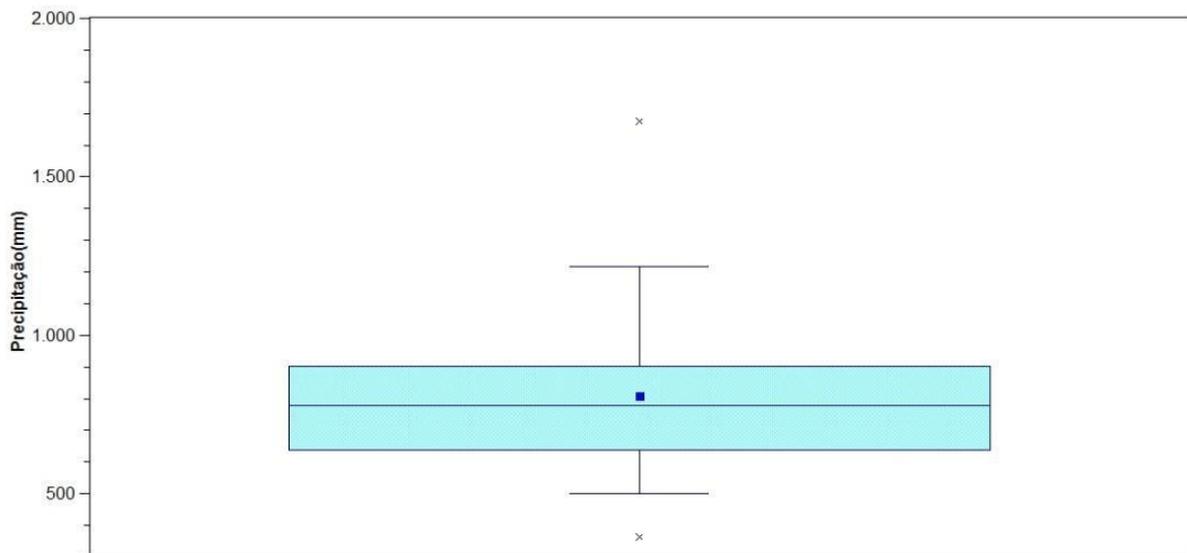
Table 2- Ranges, frequency and classification of rains



Source: ANA; INMT. Org. Silva (2020).

Regarding the exceptional conditions, the quartile methodology allowed both the classification for extreme values and for the super rainy and super dry, both representing atypical years. The *box plot* graphic shows the distribution of annual pluviometric totals based on the range of quartiles and *outliers* (graph 2). The asterisks correspond to the extreme values, that is, those that are very far from the median with rainfall over 1411.9 mm to 1676.7 mm. The symmetry of the box diagram demonstrates that there is low variability as pointed out in the first technique used.

Graphic 2- *Box plot* of the annual precipitations from 1937 to 2019



Source: ANA; INMT. Org. Silva (2020)

Therefore, in the summary table, it is set out the identification of the standard years according to the quartile technique, which helped in the determination of the standard years (Figure 1).

Figure 1- Summary table of the pattern years

1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019

Legenda		Habitual	
Super seco		Chuvoso	
Seco			

Source: ANA; INMT. Org. Silva (2020)

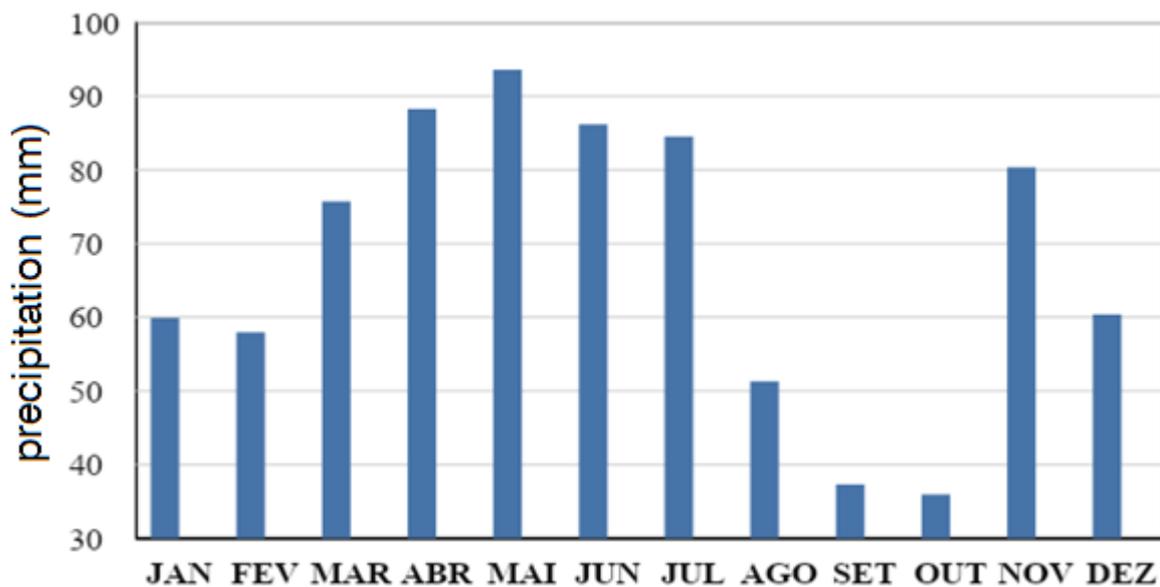
The two techniques applied for analysis are effective in establishing the ranges and classifying them according to the reality of the study site. The small differences between the results found as in the dry and super dry pattern are due to the number of defined classes, so it is understood that the results depend on the research techniques employed (ZAVATTINI, BOIN, 2013). It is up to the researcher to have a theoretical basis associated with critical thinking so that the technique presented is a positive attribute.

Regarding the distribution of rainfall throughout the year, there are two periods marked by the pluviometric behavior, namely, one moderately rainy and the other drier (Graph 3). The incidence of the most concentrated and constant rainfall comprises autumn and early winter (March-April, May, June and July). In later months, it is observed that there is a reduction in rainfall, from the end of winter to spring and beginning of summer.

The summer season presents high rainfall due to the thunderstorms that usually occur during this period and at the end of spring. The rains happen in a short

space of time, in an intense and fast way, making the monthly amount accumulated stand out in the year. This condition is due to the action of the East Wave Disturbances (DOL), which occurs in the coastal area and takes moisture to Feira de Santana.

Graphic 3- The average precipitation of rainfall from 1937-2019



Source: INMET; ANA. Org. Silva (2020)

The summer season presents high rainfall due to the thunderstorms that usually occur during this period and at the end of spring. The rains happen in a short space of time, in an intense and fast way, making the monthly accumulated stand out in the year. This condition is due to the action of the East Wave Disturbances (DOL), which occur in the coastal strip and take moisture to Feira de Santana.

The DOLs that form in the South Atlantic Ocean region move westward and intensify on the east and north coast of Northeast Brazil (ALVES; CAVALCANTI; NÓBREGA p.179, 2013). When encountering opposite conditions in the municipality, the mass of hot and dry air collides, promoting the formation of cumulonimbus clouds and, consequently, thunderstorms. It is observed in November, rainy months with precipitation above 120.6 mm and exceptional precipitation above 170.36 mm. However, there are dry months with rainfall below 20 mm, and the usual rainfall in the range of 20 to 120.6 mm.

The table shows the intervals of monthly rainfall and the respective variability through the statistical technique of quartiles (Table 3)

Table 1. Monthly rainfall ranges from 1937 to 2019 in the municipality of Feira de Santana-BA

	Jan.	Fev.	Mar.	Abr.	Mai.	Jun.	Jul.	Ago.	Set.	Out.	Nov.	Dez.
Lim. Sup.	184,7	137	195	158,5	158,41	130,0	141,4	85,7	70,6	76,6	170,3	136,5
Máx.	259,7	267,2	352,8	288,8	225,8	433,1	267,2	151,2	157,	121,9	402,7	270,5
Quartil 3	69,1	84,3	85,9	121,1	123,8	99,9	110,1	64,9	52,6	50,7	120,6	86,6
Mediana	40,6	40,3	37,2	80,7	95,4	72,7	74,6	46,3	32,7	26,5	55,7	43,1
Quartil 1	10,3	11,2	18,8	42,2	53,0	55,5	49,5	33,3	18,8	11,1	20,8	19,1
Lim. Inf.	4,4	4,3	8,2	23,6	34,7	47,4	40,8	22,7	5,2	3,80	3,3	8,4
Mín.	0	0	0	1,5	7,5	17,1	8,7	13	0		0	0

Source: INMET; Org. Silva(2020)

The representation of the *boxplot* chart of each month demonstrates the variability (chart 4). January presents itself as a median rainfall of 40.65 mm. The precipitation considered as usual is in the range of 10.38 to 69.10 mm. The months considered rainy are part of the pluviometric range from 69.10 to 184.76 mm. In relation to the super dry and super rainy period class, they have a lower and maximum equal to 4.44 and 184.76 mm respectively.

In February, it is expected rains of 11.25 to 84.33 mm, classified as usual. The rainy class is in the range of 84.33 to 137.07 mm. On the other hand, there are dry years with scarce rainfall, below 11.25 mm and super dry years below 4.30 and with some years without recorded precipitation.

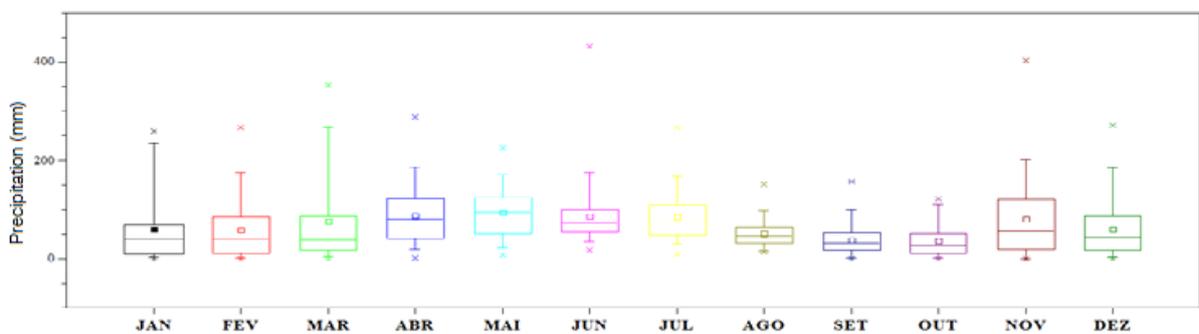
In March, the usual pluviometric index is in the range of 18.85 to 85.98 mm. Abundant rainfall exceeds 85.95, reaching 195.65 mm. In addition, the atypical events register rains superior to 195.64 to 352.8 mm and the super dry ones in the interval of 18.85 to 0. With the end of the summer and the arrival of the autumn, in the month of March, it begins a more humid period in the municipality with more constant rainfall during the following months.

In the month of April, it is expected precipitation of 42.28 to 121.15 mm. In May the usual class has the range from 95.45 to 123.88 mm, rainy from 123.88 to

158.41 mm. Therefore, the usual rainfall in the autumn ranges from 18.85 to 123.88 mm.

In winter, the pluviometric precipitation occurs in the range of 33.30 to 110.10 mm. The end of the season is marked by the reduction of rainfall in August, with rainfall from 33.30 to 64.92 and a median of 46.35 mm.

Graphic 4- Monthly Variability in Feira de Santana-BA from 1937-2019



Source: INMET; ANA. Org. Silva (2020)

The analysis using the quartile technique and the *box plot* made it possible to observe the amplitude, data asymmetry and dispersion for each month. Therefore, it is concluded that the months with the highest variability occur in early summer and autumn, with emphasis on the months of December, January, February and March. In the same period, they present high precipitations, which increase the amplitude and consequently the variability. On the other hand, the end of winter in August has low variability, moving on to spring, which remains with higher predictability of rain behavior in this period.

Urban hydrometeorologic impacts in Feira de Santana-Ba

The temporal investigation and the determination of rainfall patterns are procedures that allow relating the events that affect society. This fact helps to overcome the statistical description in climatology, since it makes it possible to correlate rain with possible risks.

In the urban area, the summer rains that occur in an intense way, for a short period of time, cause disorders in the urban zone. The atmospheric systems that act

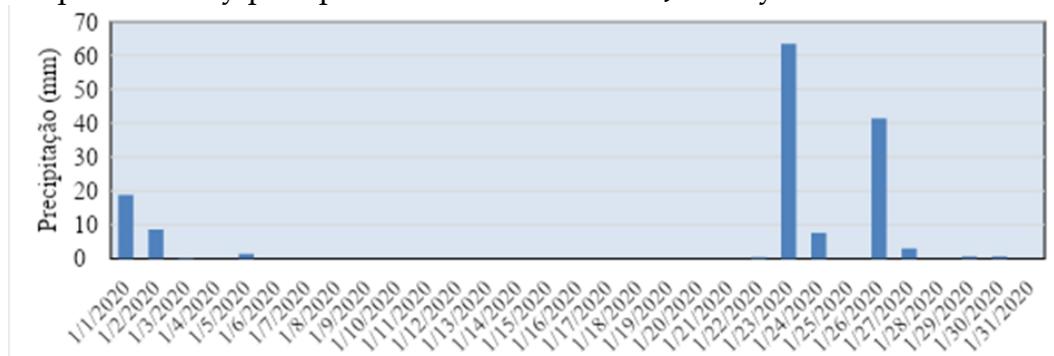
on different spatial and temporal scales contribute to extreme episodes of weather and climate that might result in intense rains, prolonged droughts, strong winds or cold and heat waves (OLIVA, 2019).

In 2020, January was marked by several hydrometeorologic impacts in Brazil, resulting from the accumulation of rainfall in a short period of time, mainly in the Southeast, Northeast and especially in Bahia. According to the INMET Bulletin (2020) the Humidity Convergence Zone (ZCAS) caused instability and in the Northeast the performance of the Intertropical Convergence Zone (ITCZ).

In Feira de Santana, the consequences in the urban area were related to material losses and human life, inconvenience caused by flooding in the streets and overflowing channels. This scenario is part of its urban climate, since the geographic conditions of socio-environmental vulnerability contribute to the intensification of these episodes.

According to the quartile technique, the median for the month of January is 40.65 mm and the usual rainfall in the pluviometric rainfall range is from 10.38 to 69.10 mm. In January 2020, the accumulated monthly rainfall was 146 mm, classified as a rainy month. The distribution of daily precipitation is observed and rain peaks are noted between the 23rd and 27th (graph 5). The episode on the 23rd had a total of 63.4mm, a rainfall rate within the range expected for the entire month. On the 26th, rainfall accounted for 41.4mm, daily volume within the usual class range.

Graphic 5- Daily precipitation in the month of January 2020

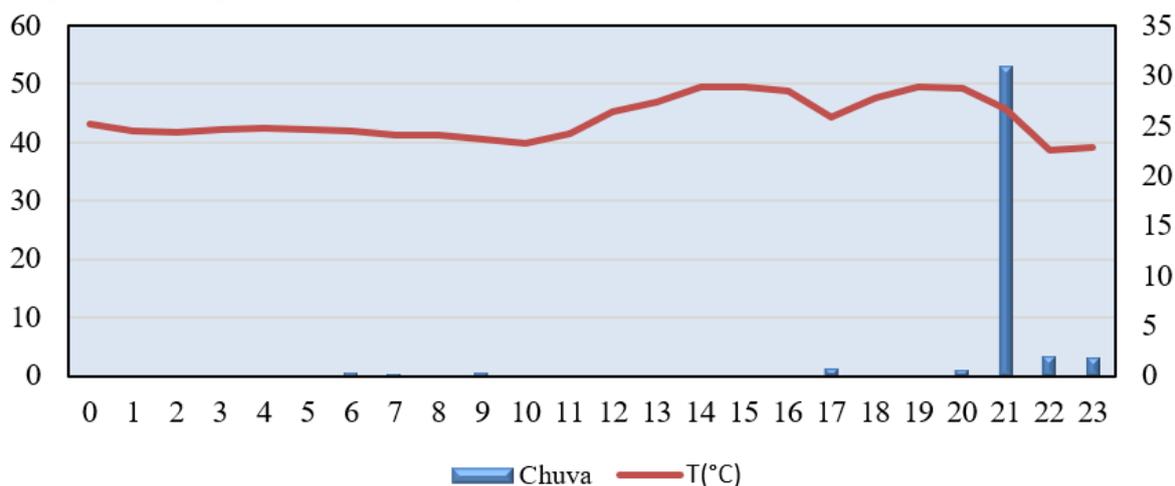


Source: INMET (2020)

In the month of January, there is also a record of rainfall in a single hour of 52.8 mm, at 9 pm, an episode that triggered impacts due to the socio-environmental

vulnerability of the location (Graph 6). The collection of information for January 2020 shows that the impacts are associated with flooding, overflowing streams, flash floods, flooded houses, material losses and human life. According to local media news, the most affected neighborhoods in the episodes of heavy rains, the most cited neighborhoods are Campo Limpo, George Américo, Rua Nova and Conjunto Feira X.

Graphic 6- Precipitation and hourly temperature - January 23, 2020



Source: INMET; Org. Silva (2020)

The precarious infrastructure for the drainage of rainwater favors the emergence of flooding, in addition to environmental interventions that produce a waterproofed urban land cover, favorable to the negative effects of water infiltration.

The streams that overflow and form floods have affected the population of Conjunto Feira X for some years. Residents near the canal often suffer from episodes of rain-triggered damage (photo 1). It is a sector of the city that has many streams, but that was channeled and buried with the process of occupation and urbanization.

The episodes of high rainfall in the summer configure a risk scenario in the urban areas of Feira de Santana resulted from the urban climate. Since the danger is recognized, for example, for the community of the Conjunto do Feira X. Mendonça (2021) when addressing hydrometeorological risks in the Environmental risk category, they are understood as hybrid risks, since they result from the association between natural risks and those aggravated by human activity and the use and occupation of land.

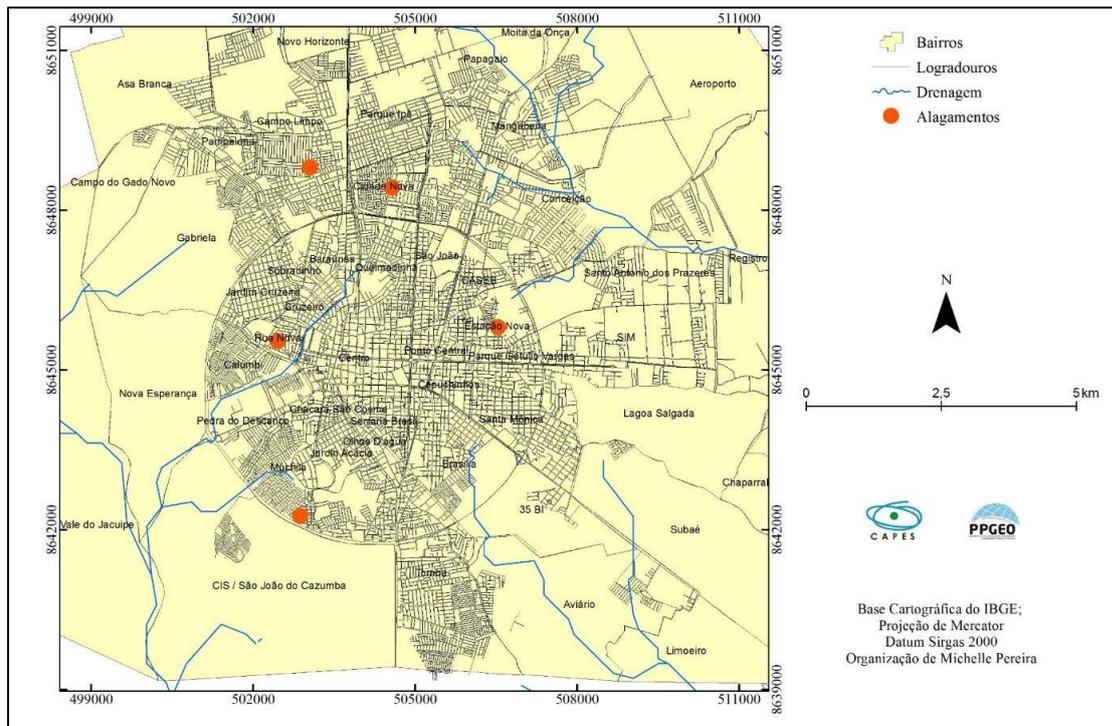
Photo 1- Residences next to the stream in Conjunto Feira X



Source: Ed Santos/Acorda Cidade, 2020.

The following map shows the spatialization of the flooding outbreaks that occurred in January 2020 (Map 2) in residential neighborhoods, identified through the news published in the local media. The proximity to the headwaters of rivers and neighborhoods with intense occupation of fragile socio-environmental contexts can be observed.

Mapa 2- Flooding in the urban area of Feira de Santana



Source: Silva (2020)

Final considerations

The volume of rainfall in space-time for Climate Geography is relevant as it is observed how the pluviometric phenomenon happens and interferes in the produced space. It is within the scope of Geography to relate biophysical conditions with society's reaction, especially in the face of unusual events that require adaptations and mitigating actions on the part of society. It is convenient to emphasize the meaning of the analyzed quantitative.

For the study area of this work, the quartile technique presented a more detailed classification regarding the temporal variation of pluviosity (rainfall) to determine the standard years. At this point, it was analyzed with data grouping and ordering using quartile techniques.

Thus, understanding the distribution of rainfall is a fundamental characteristic of studies, with the purpose of adding to other knowledge and planning infrastructure, economic activities, daily life of society, etc. Such measures are essential, especially for the population that is exposed to risk scenarios and socio-environmental vulnerability.

It was found that at the end of spring and the arrival of summer, intense rains occur in Feira de Santana. The scenario of this condition configures a socio-environmental problem in the urban space, as there are scenarios aggravated by human activity and by use and occupation.

Regarding to variability and space - time of rainfall are important characteristics in the study of geographic climatology, since it allows observing the rainfall indices that can cause disorders. However, this observation is peculiar to each space because it depends on the environmental conditions and the situation of exposure to meteorological phenomena.

The characteristics of the urban climate of Feira de Santana, becomes the stage for occurrences of impacts in more vulnerable spaces. In this way, we observed that the geo-urban characteristics in certain neighborhoods, which are susceptible to

flooding and/or inundation, were not given conditions to prevent this situation from being softened with planned actions.

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Author 1: Elaboration, proposal of results and bibliographic research.

Author 2: Supervision, final analysis of results and text review.

Author 3: Supervision and final analysis of results.