

Extreme rain events associated with the risks of floods in Aracaju, Sergipe

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Abstract: Chaotic urban growth has led to the existence of risk scenarios caused, among other things, by climatic factors. In Aracaju, the capital of the state of Sergipe, in northeastern Brazil, this reality seems to be no different from other medium and large-sized Brazilian municipalities affected by extreme rainfall events. Thus, this article aimed to analyze the occurrence of rainfall events and their relationship with floods and inundations in the urban area of Aracaju. By processing historical data collected from the official meteorological station of the National Institute of Meteorology (INMET), data from the Municipal Civil Defense, and journalistic records from the local press, it was possible to observe, from a systemic perspective, how the dynamics of urban space production in the city have been reflected in socio-environmental consequences by disregarding the seasonality of rainfall events.

Key words: extreme rainfall; flooding; inundations; risks; Aracaju

1 Introduction

Geographic climatology is a field of knowledge and research associated with the environment, integrating the atmosphere with geographic space. The role of this science in urban space is particularly noteworthy, particularly in the field of study known as urban climate, a fundamental source of research on the interaction between atmospheric systems and the city. The city is conceived as a complex transformation of primitive nature imposed by social agents, and is related to the capitalist logic of space production.

Urban climate, therefore, allows for the study of climate from the interaction between the city/urban phenomenon and atmospheric/climatic variables, integrating anomalies that may arise from urban planning projects that are inadequate to the environment in which the city is located, as Cardoso and Amorim (2016) point out. Such anomalies tend to be accentuated in environments lacking public services where individuals are deprived of rights related to the city, causing harm to the way of life of the populations. For Pinto (2003, p. 5),

(...) the city is an excellent laboratory in which one can experiment, in a relatively simple way, with the complex mechanisms triggered by human action on the climate, the modifications that occur as a consequence of these actions, and the influences that such modifications can have on humankind.

The impacts stemming from urbanization have caused environmental imbalances directly proportional to the level of urban density in the locality. Buildings, the large amount of infrastructure, population growth, soil sealing, the channeling of waterways, and the removal of original vegetation cover modify the local climate and are capable of disrupting social life.

According to Feltrin and Raia Júnior (2012), Brazilian cities, in conjunction with other geographical factors, trigger climatic risk events. Specifically addressing hydrometeorological impacts, their manifestations can be observed through the occurrence of intense rainfall and flooding. The tropical climate, coupled with disordered land occupation, the devastation of green areas, the lack of rainwater drainage, and the lack of environmental education regarding waste disposal are some of its main risk factors (PINTO; BRAZIL, 2016).

In the last two decades (2000-2020), in the municipality of Aracaju/SE, the intensification of urban development projects, coupled with an insufficient drainage network to handle accumulated rainfall, has contributed to the occurrence of flooding and inundation scenarios throughout the urban area.

Currently, the problem is recurring due to a lack of protective equipment, monitoring, warning systems, and rain prevention measures, compromising the safety of Aracaju citizens in the face of climatic risks, highlighting the absence of better public management in the urban environment regarding the prevention of risks faced by society.

Given the above, the objective of this article is to analyze extreme rainfall events in the capital of the state of Sergipe (located in the Brazilian Northeast), considering the historical series of meteorological data and analyzing how these events, associated with the production of unequal urban space, have triggered risks of flooding.

2 Methodological procedures of the research

This study employed a mixed-methods approach (qualitative and quantitative), combined with a systemic perspective on the urban climate, specifically on extreme rainfall events and the risks associated with them.

In order to gather information specific to the systematization of this article, it was necessary to use the comparative method as described by Coelho (2001): the use of evolutionary memory based on the record of areas affected by floods and inundations in the past, identified with the aid of resources such as newspaper records from the local press, statistical data (historical series from 2000 to 2019, acquired from the INMET platform - National Institute of Meteorology), use of Excel (Microsoft Office) and R computer software for data tabulation and graph creation, in addition to gathering information available on the virtual platform of competent public bodies.

The database of daily precipitation data for the period 2000 to 2019 was obtained from the INMET portal, based on data collected at the meteorological station located at the Aracaju/SE airport. This data was organized using Excel software to generate detailed information about rainfall characteristics. Data on flooding and inundations in the capital of Sergipe were extracted from the virtual platform of the Aracaju Municipal Civil Defense.

Regarding data processing in the R software, this tool was chosen due to its precision in calculations, delimitation, and results of what is requested through the R language offered by this resource. With the aid of Excel, a table can be created discriminating the dates of the events, as well as the variation between minimum and maximum temperatures, and the precipitation levels in the period delimited for the work (2000-2019). When reconciling the spreadsheet with the R program, it was essential to assign the correct commands, choosing which steps would be essential for creating the graphs.

Emphasizing the qualitative analysis, this was carried out through a literature review of scientific publications, as well as a survey of news published by the local press and on newspaper websites regarding flood and inundation events and their repercussions, in order to understand the causes of these impacts, based on an analysis of the interaction between the atmosphere and the urban environment.

Lima and Amorim (2014, p. 197) emphasize that "the joint analysis of news published in newspapers and the corresponding climate data can identify potential risk situations and areas potentially subject to impacts."

Thus, news articles were consulted using the terms "rains, floods, flash floods, inundations, and flooding" on the Google search engine, and subsequently organized by dates, locations, and photographs in spreadsheets. As a

methodological procedure, the use of news in the media for qualitative climate analysis is a relevant point for the development of this type of research; the same procedure was successful in the works of Brandão (2001), Vicente (2004), Teodoro (2008), Mendonça (2011), among others.

3 The incidence of extreme rainfall as an analytical bias in urban climate

The analysis of rainfall and its repercussions in the urban area of Aracaju will be based on the approach presented in the doctoral thesis of Carlos Augusto Figueiredo Monteiro, published in 1976 and entitled *Urban Climate System*. This work, conceived as an academic landmark in Brazilian climatology, contributes to the evaluation of the performance of the natural climatic framework and its reflections in the urban space. Monteiro and Mendonça (2003, p. 10) cite cities as "the places where environmental results are configured as a joint work of nature reworked and perfected for the purposes of human life".

Urban climate is a line of research in the field of Geography that focuses on the analysis of urban geographic space and its relationship with the local climate (COLTRI, 2006; MONTEIRO, 1976). In the socially constructed environment of the city, the intensification of urbanization is immediately reflected in the formation of what is called the urban climate. It is in this space where the operation of atmospheric agents becomes more evident, given the risks of vulnerability to which the population is subjected.

The urban climate system seeks to "treat the city from a systemic point of view, even if considering only one of its constituent elements – the atmosphere/climate – but understanding it as part of a larger system, the city" (MENDONÇA, 2004). This theory explains the phenomenon of urban climate through the integration of the different elements that compose it, implying the performance and functional organization of the system as perceived by human perception.

Within the Urban Climate System, the hydrometeorological subsystem groups together water forms (rain, snow, hail), as well as the influence these phenomena exert on urban planning. It also concerns the impacts caused by hydrological events. Pinto and Brazil (2016, p. 113) consider "rain to be preponderant over temperature and pressure in the face of atmospheric weather-producing systems." Excessive rainfall, for example, can alter surface water runoff, causing flooding and other potential associated disasters.

Under tropical climates, extreme rainfall events commonly occur, concentrated in the rainiest season. However, these events are characterized by their irregularity, especially in terms of frequency and intensity; and they are also distinguished by their perverse effects on cities, which produce unequal outcomes due to tensions between social classes that occupy the urban space. Therefore, associated with human land use, extreme rainfall events can cause socio-environmental problems. Monteiro (2009, p. 13) emphasizes:

Rainfall, when it occurs with great intensity and especially when associated with flash floods (...) in artificial rivers and streams, can completely paralyze a city. These rapid movements of water and mass can reach high speeds (> 6 m/s) and sweep away people and property. When it is scarce, the water also causes negative impacts of great magnitude in urban areas, such as soil compaction leading to ruptures in buildings and infrastructure, water supply and sanitation, public health, etc.

In Brazilian cities, problems stemming from extreme rainfall are constant. Gonçalves (2003) describes these precipitations as being driven by historical political-structural issues and a lack of planning adequate to Brazil's climatic reality, whose impacts affect populations with lower purchasing power, making society susceptible to this phenomenon, a vulnerability represented by the number of extreme events that cause economic and social disruptions.

Conti (2011) emphasizes that rainfall can only be considered critical in urban areas when it exceeds 50 mm/24h. However, the literature presents a wide variety of initial limits for rainfall extremes. Thus, Vicente (2004) set a limit of 50

mm/24h for the metropolitan region of Campinas. Santos and Galvani (2014) consider daily events above 40 mm in Caraguatatuba (SP) to be extreme. Pinto and Brazil (2016) defined 60 mm/24h for Aracaju/SE. Monteiro and Zanella (2017) stipulated a threshold of 50 mm/24h for the cities of Crato, Fortaleza, and Sobral in Ceará; Wanderley et al. (2018) set a limit starting at 25.1 mm/24h for the city of Recife.

Wanderley et al (2018, p. 149) corroborate what was previously stated when they quote: "(...) this disharmony between the climate and the cultural features of the space can be attributed to the non-application, in territorial planning, of the notion of cyclicity of strong rainfall episodes". For this reason, urban environments are affected by climatic events, with floods and inundations being the most common impacts caused by intense rainfall, that is, rainfall of short duration and high accumulation.

Given the context presented, an extreme event is understood as one in which the accumulated rainfall is outside the climatological pattern (historical series) for a given area, presenting magnitudes that exceed the resilience capacity of that location, consequently causing impacts in different parts of the municipality. These losses reflect the intensification of urban occupation with high soil impermeability and the difficulty in draining rainwater due to the unequal distribution of space. Flooding is the result of heavy rainfall in the urban environment. It arises as a consequence of the absence of a drainage network and the high impermeability of the soil, hindering surface runoff. Inundations, on the other hand, occur during the river's high water period, when water overflows its banks and floods the surrounding area.

Oliver-Smith (2004) suggests that intense urbanization processes are the potentiators of disasters, catastrophes, risks, and vulnerabilities. Zamparoni (2012) situates natural disasters as resulting from the conflictual relationship established between society and nature, stemming from the combination of the physical characteristics of the place, which reflect the susceptibility, fragility, and vulnerability of society. In this light, one of the great challenges for cities is to promote urban growth and development that provides social and environmental comfort for their inhabitants, as these problems take on greater proportions in peripheral countries.

Mendonça and Leitão (2008) cite the vulnerability of the city as a set of factors that make human groups susceptible to the impacts arising from risks formed in urban contexts. In Brazilian cities, the least favored social communities are forced to occupy environmentally fragile areas irregularly and illegally, a reality aggravated by the model of appropriation of space, which is based on unequal access to goods and services, affecting the quality and conditions of human life.

Thus, a portion of the population is excluded from being part of the urban network of safe housing, from having access to basic sanitation, education, and other essential citizen rights, and ends up residing on the city's periphery, reproducing houses in places lacking basic services whose infrastructure presents various risks to life in the face of natural processes; when associated with social vulnerabilities, these risks generate concern and demand greater scientific-technological and political involvement to guarantee and manage their treatment. Jacobi (2004) views urban environmental risks as conditions that cause direct damage to health, comfort, and the property of individuals, in addition to compromising the exercise of urban functions, including harm to land mobility.

Pinto and Brazil (2016, p. 126) point out that greater urban investments are being made in areas considered upscale at the expense of peripheral areas, leading to risks for impoverished populations due to their (in)ability to cope with disasters. The following quote reflects an example of what happens in the city of Aracaju.

Thus, the articulated relationship between the State and the private sector, especially real estate corporations, drives the valuation of areas of intense speculation, providing structural development in these spaces to add value to developments, at the expense of the periphery, which receives little investment in urban infrastructure, thus leaving the population of these areas more vulnerable to the risks associated with extreme

rainfall events (PINTO; BRAZIL, 2016, p. 126).

In the context of addressing urban socio-environmental risks, Mendonça et al. (2016) state that a given risk can trigger others. Even so, environmental or social problems are capable of self-regulation. In this process, it becomes possible to detect imbalances and, through the power of decision-making, attribute to human beings the intervention and adaptation to the functioning of the system. However, Pinto and Brazil (2016, p. 126) point out the interference of the lack of state planning in addressing hydrometeorologic impacts, since it is known that "preventive work is superficial; only in moments of risk do they remove residents from their homes, unclog sewers, and collect garbage, without, however, eliminating the problems that recur routinely."

Dubois-Maury and Chaline (2004) identify prevention, public oversight of urban insecurity, and state intervention as risk management tools. Regulatory strategies rely on adaptability, flexibility, and responsiveness to external environmental demands; they must encompass the entire urban community, with the aim of improving environmental quality through the prevention and remediation of risk sources.

Pinto and Brazil (2016) clarify the need for an integrated approach between urbanization and its environmental impacts, grounded in planning interventions and interactions related to the diverse uses of urban land. This approach is framed by legislation and guided by the sustainability of actions aimed at preventing and controlling the quantity and quality of meteoric water. Accordingly, it will be possible to achieve a dynamic balance of the urban climate through the power of social action, via feedback mechanisms for actions that disrupt the system.

Úgeda Júnior and Amorim (2016), however, view the social and economic interests of the cultural organization of Brazilian societies in the production of urban space as taking precedence over social and environmental quality of life. According to this premise, solutions to climate problems become increasingly difficult and costly. Nevertheless, change is possible, provided there are technical solutions, debate about economic interests, and effective social participation.

4 Discussion of results

Aracaju is a coastal city and the largest urbanized municipal unit in the state of Sergipe (Figure 1). It is the urban space in Sergipe with the most research on urban climate undertaken to date, with emphasis on the thermal field, although research on rainfall in the city has also been carried out, as exemplified by Brazil (2016).

The city's relationship with water is intense, given that Aracaju is bordered by the Sergipe River and its tributaries to the north, the Vaza-Barris River to the south, and touched by the Atlantic Ocean to the east. Rainfall events frequently reveal a problem whose impacts are reflected in the disruption of urban functions and significantly affect the population's quality of life. Under the influence of a humid tropical climate (As, according to the Köppen-Geiger climate classification), the capital has a dry season between September and December, with significant rainfall in January and February, as well as substantial rainfall between March and July/August, reaching an accumulated annual rainfall of 1,300 mm.

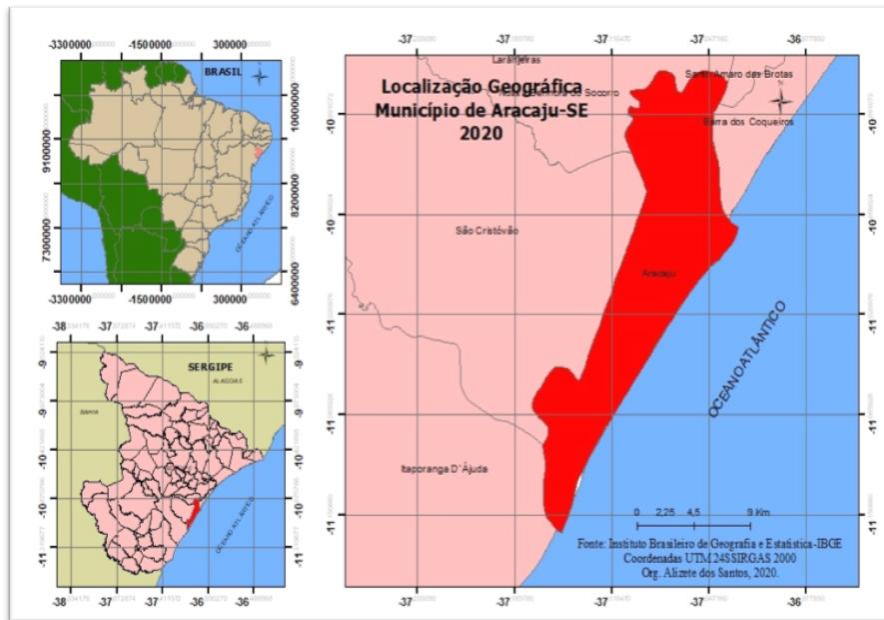


Figure 1. Location of the study area

Source: IBGE (2000). Edited by: Alizete dos Santos (2020).

To support this study, a historical series (covering the years 2000 to 2019) of meteorological data on precipitation, maximum and minimum temperature was collected in order to investigate the interannual variable behavior of these indicators.

Figure 2 shows the accumulated annual rainfall throughout the analyzed data series and indicates that the rainiest years reached, on average, levels exceeding 1,000 mm, with particular emphasis on 2000, 2001, 2006, 2008, 2009, 2010, 2011, 2017, and 2019. As the year 2020 had not yet concluded at the time of writing, the indicators for this period were not included.

In turn, the average temperature variation of 24°C to 28°C occurs in the milder months (July and August), while an average of 27°C to 29°C is recorded in January, February and March, which are the hottest months, and can easily exceed a perceived temperature of 30°C.

Temperature data are complementary in this study. Figures 3a and 3b show the behavior of the annual average of maximum and minimum temperatures as a result of the dynamics of urban space production, where the intensification of infrastructure works, the expansion of the road network, the construction of high-rise buildings, and the increase in the flow of motor vehicles have contributed to the increase in maximum temperatures, which have oscillated between 29°C and 32°C since the beginning of the historical series and have been reaching peaks of 34°C to 35°C since the 2010s, when urban development projects intensified, corroborating the increased thermal discomfort felt by city dwellers.

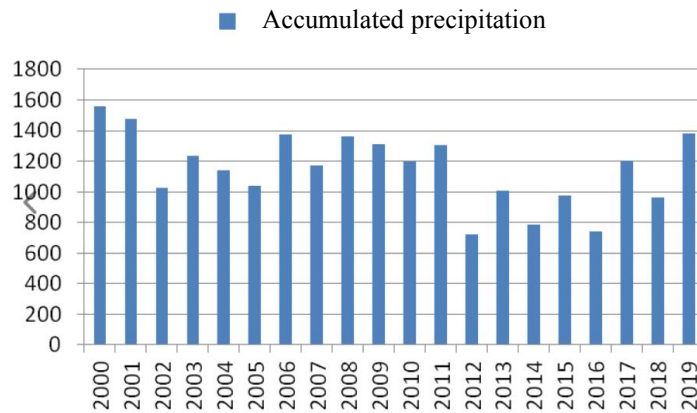


Figure 2. Accumulated precipitation in Aracaju during the period 2000-2019.

Source: INMET. Edited by: Duarte and Santos (2020).

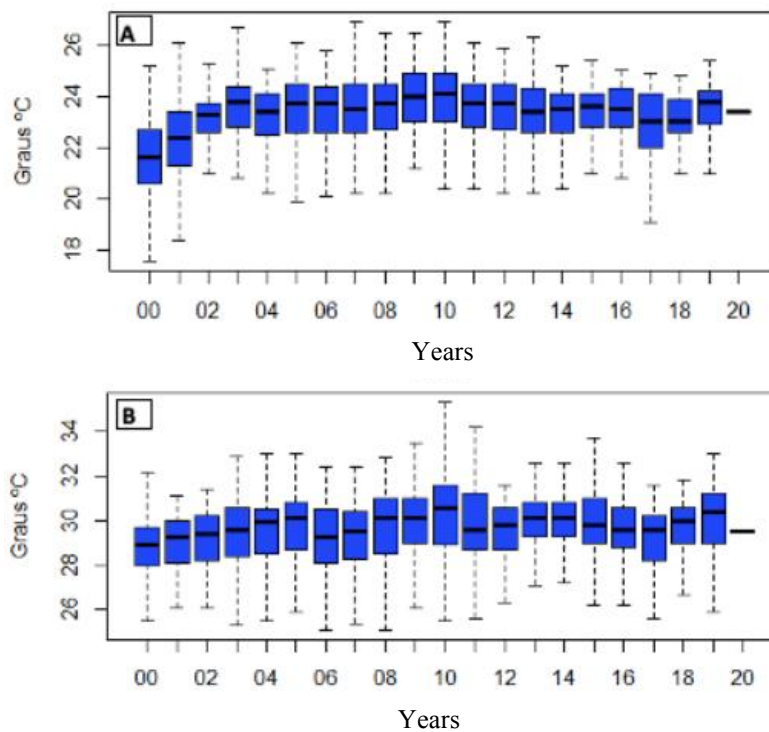


Figure 3 – a). Boxplot of the interannual mean minimum temperature in Aracaju/SE.; b). Boxplot of the interannual mean maximum temperature in Aracaju/SE.

Source: INMET. Edited by: Duarte; Santos (2020)

A scatter plot of the climatic variables was also created (Figure 4), given the need to verify the cause-and-effect relationship. The case study made it possible to correlate the variables (maximum temperature, minimum temperature, and precipitation) with the distribution of extreme rainfall events. When comparing the minimum temperature and rainfall index variables, it can be inferred that the relationship between them is minimal. The rainfall events recorded on the ordinate axis are concentrated within a temperature range on the abscissa axis. In turn, when checking the maximum temperature and precipitation values, a slight correlation is observed: as the temperature increases, the rainfall values decrease.

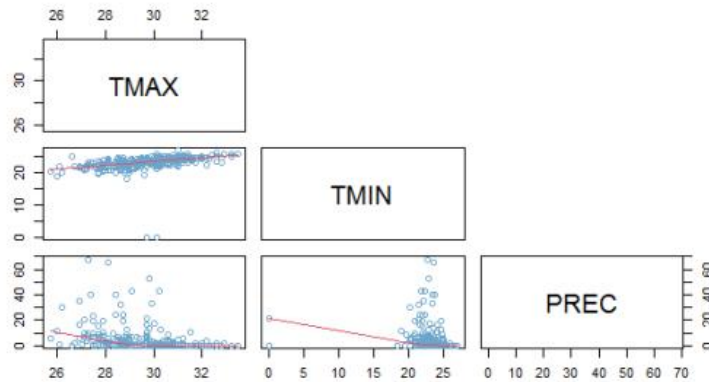


Figure 4. Scatter plot of the variables analyzed in this study.

Source: INMET. Edited by: Duarte; Santos (2020).

For the municipality of Aracaju, extreme rainfall events are considered to occur when the volume of rain statistically reaches an index equal to or greater than 30 mm/24h, based on the 95th percentile. In other words, considering the city's dynamics, an extreme rainfall event can be defined as one that falls within the top 5% of values in the historical series studied. Considering the 99th percentile, it is understood that there are very extreme rainfall events with an index reaching 57.2 mm/24h, approaching the value established by Pinto and Brazil (2016) for extreme events, which is 60 mm/24h. These values can be observed in Figure 5; the percentile corresponds to the fragmentation of the sample into equal portions given as percentages.

Based on the data sample in Table 1, it can be observed that one hundred and forty-nine extreme rainfall events were cataloged throughout the studied period, using a threshold value of 57.2 mm. The rainiest period, susceptible to flooding in the city, occurs in the months of April and May (between the end of autumn and the beginning of winter). It can be noted that rainfall events decrease around the end of winter and reappear at the beginning of summer, with convective rainfall. The years 2000, 2001, 2006, 2009, 2019, and 2020 stand out as the years that recorded the highest number of events.

In the historical series, the municipality of Aracaju presented a variable behavior of interannual rainfall. Through the analysis of the distribution of monthly rainfall accumulation and the number of extreme rainfall events collected, the occurrence of a rainy or very rainy period is observed, resulting in a considerable increase in the frequency of these events, as shown in Table 1.

Table 1. Relationship of extreme rainfall events in Aracaju by month (2000-2020)

Year	Months												TOTAL
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	1	2	0	5	0	1	0	0	0	0	0	1	10
2001	0	1	0	1	0	3	2	1	1	2	0	0	11
2002	1	0	0	0	2	1	0	0	0	0	0	0	4
2003	0	0	0	0	2	1	1	0	0	2	1	1	8
2004	2	0	0	0	2	0	1	1	0	0	0	0	6
2005	1	1	0	2	0	0	0	1	0	0	0	1	6
2006	0	0	0	3	3	2	0	0	1	2	0	0	11
2007	0	1	1	1	2	2	1	0	0	0	0	0	8
2008	0	1	3	0	3	1	0	0	0	0	0	0	8
2009	0	0	0	1	7	1	0	2	0	0	0	0	11
2010	0	0	0	4	1	2	0	0	0	0	0	0	7
2011	0	0	0	2	4	0	0	1	0	1	0	0	8

Year	Months												
	1	2	3	4	5	6	7	8	9	10	11	12	Total
2012	0	1	0	0	1	0	1	0	1	0	0	0	4
2013	0	0	0	3	0	1	1	0	0	0	1	1	7
2014	0	0	0	1	0	0	2	0	0	0	0	0	3
2015	0	0	0	1	3	0	1	0	0	0	0	0	5
2016	0	1	0	0	1	3	0	0	0	0	0	0	5
2017	0	0	0	1	3	0	1	0	2	1	0	0	8
2018	0	1	2	2	1	2	0	0	0	0	0	0	8
2019	0	0	1	2	2	2	3	0	0	1	0	0	11
2020	1	2	0	5	0	1	0	0	0	0	0	1	10
Total Events	19	10	11	23	34	14	6	3	1	3	1	0	149

Source: Inmet (2021). Org.: Duarte; Castelhana (2021).

The various forms of production of geographic space exert strong pressure on natural space, being carried out without considering the vulnerability of populations and the environment itself, as pointed out by Pinto and Brazil (2016). Thus, the impacts of floods and inundations reveal a segregating process in the occupation of Aracaju's urban space. Although rainfall is a natural event, the severity of the phenomenon will be related to society's capacity to respond to the impacts produced. In this context, the city is exposed to environmental risks, with the climate system being the main agent causing the damage.

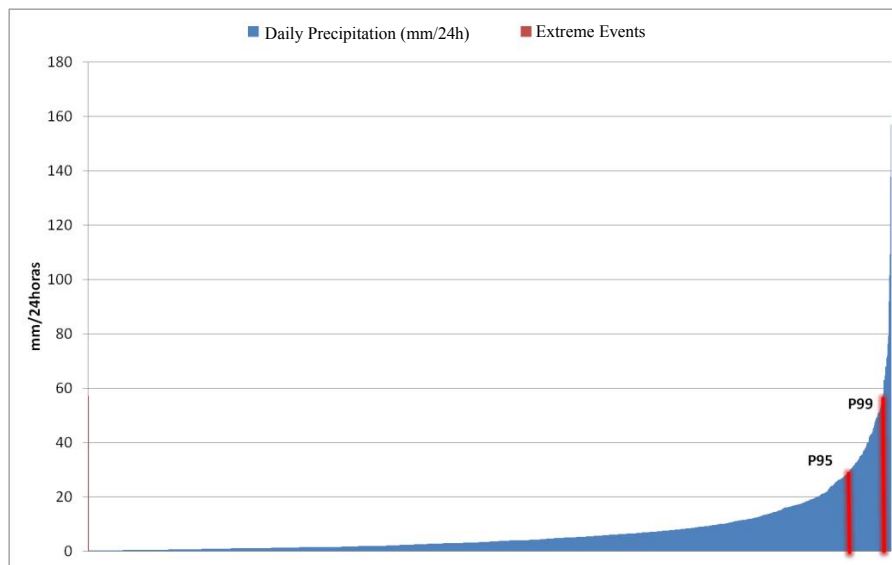


Figure 5. Extreme rainfall event indices for the municipality of Aracaju/SE.

Source: INMET. Org.: Castelhana (2020).

Searches conducted in online newspapers of the local press between 2000 and 2020 made it possible to catalog the main flood and inundation events in the city. It is important to highlight the fact that the sources used in this study come from private institutions.

Through the analysis of Figures 6a, 6b, and 6c, the occurrence of extreme rainfall events was observed in different areas of the capital city during the period adopted in the historical data series, ranging from upscale neighborhoods (such as Jardins, Grageru, and 13 de Julho, all mentioned in the headline shown in Figure 6a) to peripheral neighborhoods (such as Getúlio Vargas, Santos Dumont, and 18 do Forte, mentioned in the news report shown in Figure 6c). However, the events are largely distributed in the northern zone, where the most severe occurrences are in high-risk areas, where the population

is more impoverished and therefore more vulnerable.

According to press reports, extreme rainfall events are common between May and June, during the rainy season, between the end of autumn and the beginning of winter. Pinto and Brazil (2016) highlight that "[...] rainfall events are a consequence of the lack of management and planning of land use and occupation in the city of Aracaju" and "[...] the lack of rainwater drainage is a problem identified in the locality, thus generating disruptions to the population, resulting in floods and consequently risk to the population". Figure 7 shows the flood risk areas by neighborhood in Aracaju classified into four classes; the neighborhoods in the northern zone, the expansion zone, and the Santa Maria neighborhood (in red) are the locations with the highest risks.

The map in Figure 7 was extracted from Pinto; Brazil (2016). It was produced from quantitative data on extreme rainfall events combined with an integrated analysis of geomorphological maps of slope, drainage, and municipal land use.

According to the map that considered extreme rainfall events between 2004 and 2014, the Porto Dantas neighborhood, located in the northern zone, presents the highest risk of flooding due to accelerated, disorganized occupation and the absence of urban planning; during the analyzed period, this was one of the neighborhoods with the highest number of occurrences, where significant material damage was recorded. In turn, in the southern zone of the city, the Santa Maria neighborhood, in addition to presenting the same causes as the Porto Dantas neighborhood, also suffers from a precarious drainage network and clogged drains caused by garbage thrown by the population. Regarding the expansion zone, the location is considered high-risk, given that the lacustrine morphology of the area was buried from 2009 onwards with the occupation of upper-middle-class families in high-standard residential condominiums, impacting the macro-drainage of the locality, which did not happen previously.



Figure 6 a). Headline from the Infonet portal, published on May 21, 2008; b). Article published on the G1 Sergipe portal on May 24, 2011; c) News article published on the G1 Sergipe portal on May 25, 2016.

Source: a) <http://g1.globo.com/vc-no-g1/noticia/2011/05/chuva-transformou-cidade-em-um-caos-diz-leitor-em-aracaju.html>; b) <https://infonet.com.br/noticias/cidade/alagamentos-causam-transtornos-em-aracaju/>; c) <http://g1.globo.com/se/sergipe/noticia/2016/05/ruas-enchem-e-canais-transbordam-com-chuva-intensa-em-aracaju.html>

It can be inferred that the lack of land use planning, as well as land occupation associated with inadequate stormwater drainage and disordered urban development in housing complexes that still lack infrastructure in urban planning projects, most commonly cause the population to face the risks of flooding caused by rainfall. Although extreme rainfall events affect the capital as a whole in all the years studied, subjecting the city to impacts, the upscale neighborhoods showed less intense socio-environmental vulnerability when compared to the neighborhoods located in the northern zone of Aracaju.

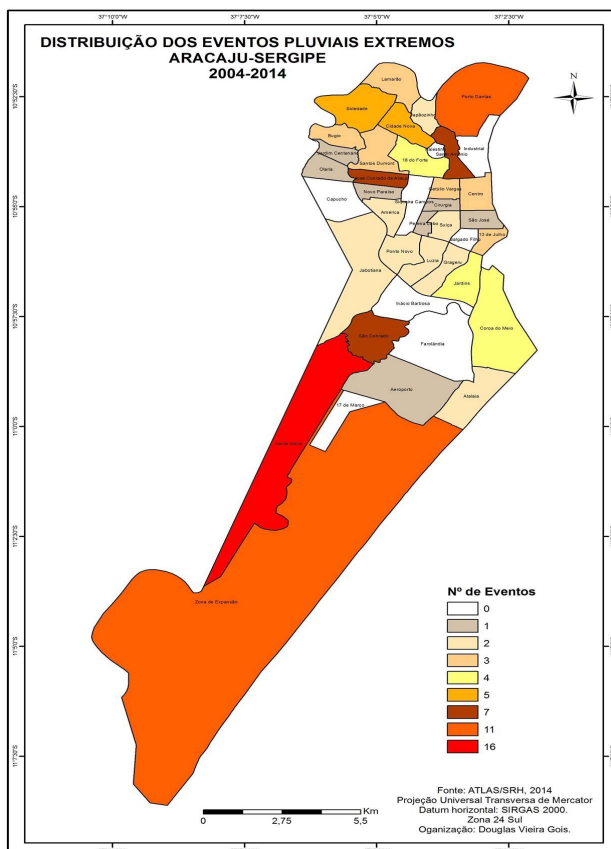


Figure 7. Flood risk map for the city of Aracaju/SE

Source: Atlas SRH, 2014. Edited by: Douglas Vieira

The reality presented reveals the production of an irregular urban space, resulting from the unequal and contradictory model of the capitalist system, in which the majority of the city's population finds itself on the margins of the benefits provided by infrastructure and basic sanitation services when disasters occur during periods of meteorological rainfall events. Furthermore, the articulated relationship between the State and the real estate sector drives the valuation of prime areas, subject to intense speculation, to the detriment of areas considered peripheral, where investments in urban infrastructure are insignificant, making the population more vulnerable to the risks associated with extreme rainfall events.

5 Final considerations and perspectives

Data extracted from INMET and processed using the R software confirm the seasonality of extreme rainfall events in the capital of Sergipe, while information obtained from the Aracaju Municipal Civil Defense and journalistic records points to the disruptions caused by excessive rainfall. The urban socio-environmental impacts, ranging from various material losses to traffic mobility issues, overflowing sewage systems, loss of movable and immovable property, and even

the risk of death, are treated with negligence by the authorities, who generally intervene in a palliative manner but do not strive to effectively resolve the problems arising from the rains.

Analysis of records of extreme events allows us to establish a temporal delimitation for the months of April and May as the periods of greatest concentration of these events, accounting for approximately 40% of occurrences, and therefore, the months in which municipal authorities should be on alert. Figure 8 reveals a relationship: the seasonality of extreme events in conjunction with monthly rainfall totals, confirming this fact.

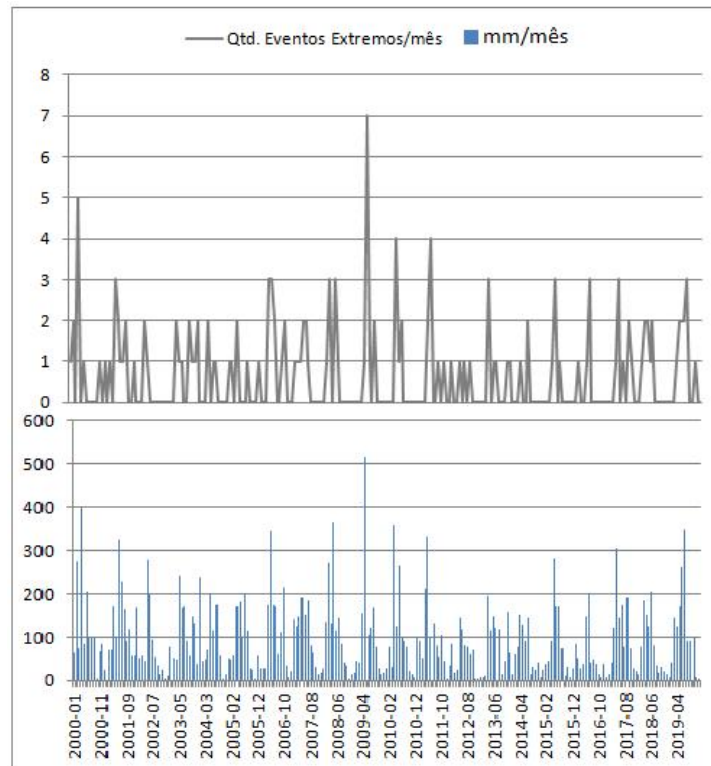


Figure 8. Occurrence of extreme precipitation events and accumulated monthly precipitation in Aracaju/SE – 2000-2019

Source: INMET, 2002 Org.: Castelhana, 2021

The variability in the annual frequency of extreme events also responds directly to rainfall volumes (Figure 9). It is observed that the years with the fewest events were those with rainfall volumes below 1,000 mm annually, such as 2012, 2014, 2015, and 2016. Conversely, the years with the most events were those with the highest annual rainfall values, such as 2004, 2005, and 2006. The value of 1,300 mm of annual rainfall proved to be a threshold. Every year with volumes exceeding this amount had more than 10 records of extreme events. A simple linear regression, with a 95% confidence level, revealed that approximately 71% of the occurrence of extreme rainfall events is explained by the natural oscillation of rainfall. Thus, it is highlighted that the apparent decrease in the occurrence of extreme events and, consequently, their repercussions are directly linked to the recent decrease in rainfall volume.

This reinforces the need for studies focused on understanding the genesis of rainfall and its intensity in the Aracaju region, analyzing, above all, the effect of teleconnections and convective precipitation on the occurrence of extreme events over the capital of Sergipe.

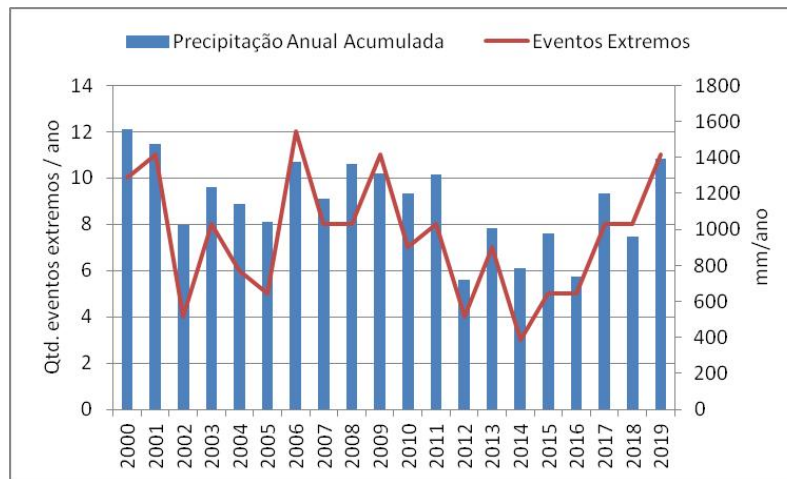


Figure 9. Occurrence of extreme precipitation events and accumulated annual precipitation in Aracaju/SE – 2000-2019

Source: INMET, 2002. Edited by: Castelhana, 2021.

Through research, it was observed that extreme rainfall events occur periodically in Aracaju, in the autumn and winter, in all years of the historical series; and cause exposure to risks for the city's resident population. Although the temporal distribution of the event shows a strong correlation with the natural oscillation of rainfall, the spatial distribution of the occurrences, indicated by Figure 7, reveals how socioeconomic differences interfere with the capacity to respond to risk events. The most vulnerable segment of the population, that of the northern zone and the expansion zone of Aracaju, suffers the consequences of such events with greater intensity due to their lower capacity to cope with disasters when compared to the less vulnerable middle-upper and upper-class population, since they live in the safer part of the city, a location less exposed to risks.

Based on these facts, the gravity of the socio-environmental problems stemming from the ineffectiveness of public administration regarding the planning of land use and the disorderly occupation becomes clear. Therefore, it is hoped that both the understanding of the occurrence of extreme rainfall events and the disorder caused by their impacts will allow for the prediction and prevention of risks. Within this framework, it is necessary for sectors of society, as well as state managers, to seek to implement alternative proposals for urban socio-environmental security and social justice, such as expanding basic infrastructure services to the most vulnerable population, removing them from risk areas and relocating them to safe housing areas in the city, prioritizing the implementation of technological equipment for monitoring, protection, alerting, and preventing rainfall. All knowledge is useless if it is not applied to solve problems.

The relationships between climate and society depend on the characteristics of the atmosphere, as well as the social structure and the urban environment itself. Studies of urban climate make it possible to verify the socio-environmental problems in the city resulting from atmospheric dynamics and the dynamics of human actions, including the occurrence of extreme weather events.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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