Journal of Geoscience and Environment Protection, 2023, 11, 1-16
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Drainage and Preliminary Risk of Flooding in an Urban Zone of Eastern Amazon

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How to cite this paper: Sousa, T. S., Viegas, C. J. T., Cunha, H. F. A., & da Cunha, A. C. (2023). Drainage and Preliminary Risk of Flooding in an Urban Zone of Eastern Amazon. *Journal of Geoscience and Environment Protection, 11,* 1-16.
https://doi.org/10.4236/gep.2023.115001

Received: April 4, 2023
Accepted: May 16, 2023
Published: May 19, 2023

Abstract

Drainage system is a poorly investigated basic sanitation and urban planning issue in the Amazon, which is often related to flooding processes and public health. The aim of the present research is to correlate Preliminary Risk of Flooding (PRF) to independent variables, based on the following methodology: 1) identifying and classifying risk areas by using the Geographic Information System (GIS) and 2) statistically correlating risk to sanitary and environmental variables. Results have shown that preliminary risk is correlated to, at least, seven sanitary and environmental variables, depending on flood influence area; and there are significant correlations observed in the rainy season interval [probability or significance (p) < 0.05]. In conclusion, PRF is higher in the rainy season, but it is spatially influenced by the elevation of terrain, number of flooding points, drainage typology and Environmental Salubrity Index (ESI) of neighborhoods, which directly affect the water quality in nearby groundwater wells (Total Coliforms, nitrate (NO_3) and ammonia (NH_3)). However, this influence can eventually significantly change in the dry season.

Keywords

Drainage System, Environmental Salubrity Index, Groundwater, GIS

1. Introduction

Urban drainage and rainwater management depend on a set of services, infrastructure and sanitation facilities developed to "transport, detain or retain flood flow damping and to treat the final disposal of drained rainwater, including cleaning and preventing network inspections" (Brasil, 2007a, 2020).

The importance of drainage systems in developed countries is acknowledged and valorized, because their design is integrated to different urban equipment that, altogether, becomes social well-fare and environment ecological health factors. Therefore, the option made for environmentally sustainable and efficient drainage systems also improves cities' economic attractiveness and competitiveness (Piacentini & Rosseto, 2020; Ferrans et al., 2022).

Despite its importance, urban drainage systems have been neglected as essential basic sanitation attribute, mainly at urban planning scope in the Amazonian region. Such a statement reflects on deficits that have contextual and structural consequences expressed through flooding issues (Tamm et al., 2023).

Drainage and rainwater management in Brazil is an integral part of the National Basic Sanitation Policy—Bill 11.445/07, which was updated by the new legal sanitation framework—Bill 14.026/20 (Brasil, 2007a, 2020). Nevertheless, although it is addressed in the referred Bill, basic sanitation in Brazilian cities remains under chaotic condition—it has poorly advanced towards both the strategic use of this structural factor and environmental sustainability. According to the National Sanitation Information System-SNIS, approximately 45% of Brazilian municipalities do not have exclusive drainage systems. In other words, most of them use unitary systems (drainage/sewage network) or do not have any drainage system type, at all. This scenario becomes even more worrisome in the Northern region, which presents the highest rate of municipalities with no drainage services—approximately 45.8% (Snis, 2019).

Macapá City is a clear example of such a scenario. It is located in Northern Brazil, in Amapá State and has a poor drainage system, which was built over 30 years ago—it did not receive adequate preventive maintenance overtime. This drainage system was originally conceived to be of the absolute type (system to separate rainwater from sewage), but due to recurrent clandestine connections to domestic sewage networks, it became a unitary system (PMSB, 2016; de Abreu et al., 2020; Sousa et al., 2021).

The micro-drainage infrastructure in Macapá covers approximately 58,884 meters of culverts, gullies, small rectified canals, among others—it only represents 11.9% of the total urban area (PMSB, 2016). Accordingly, it is possible observing that most of Macapá's population does not have access to a drainage system, and this finding likely explains why the city suffers from frequent flooding events.

The aforementioned scenario highlights managers and researchers' growing concern, with the impact of this structural deficiency on sanitation indicators, as well as on the environment and on urban public health. The relatively low Environmental Salubrity Index (ESI) and the negative impact on the quality of groundwater in Macapá can be also observed in the present research (Santos, 2012; Grott et al., 2018).

Accordingly, the current research is pioneer in contributing to studies on rainwater drainage relation to preliminary risks of floods in Macapá-Amapá. The present research will subsidize the relevance of urban planning in face of basic sanitation challenges posed to Amazonian cities. Moreover, it can be useful given the lack of information necessary to feed monitoring, management and contingency systems for civil defense actions (de Oliveira et al., 2019).

Therefore, the aims of the present research were to describe the current preliminary risk of flooding in Macapá and to analyze the consequences of such a risk through its correlation to sanitary variables (Environmental Salubrity Index, number of flooding points, water quality in wells in the surrounding areas of flooded sites) and environmental variables (mean elevation in the risk area, drainage typology).

2. Methodology

2.1. Study Site

The research was carried out in the urban zone of Macapá City, Eastern Amazon (Northern Brazil); it is the capital of Amapá State (**Figure 1**). It had estimated population of 522,357 inhabitants, in 2021; its urban zone counts on approximately 381,214 inhabitants—this number corresponds to 73% of the total population in the state (IBGE, 2023).

Macapá is located in Southeastern Amapá State; its territory covers 6563.849 Km^2. This region belongs to the estuarine-coastal area and is subjected to constant anthropic pressure in land, water resources and climate, due to its closeness to the two biggest cities in Amapá State: Macapá and Santana (da Cunha et al., 2021).

The urban zone in Macapá is mainly drained by Fortaleza Igarapé basin (**Figure 1**); it presents dendritic geometry (Northern, Southern and Western zones) and it is influenced by hydrodynamic processes typical of estuaries; It is bathed by the Amazon River, which is connected to channels that penetrate the city's urban zone (Western zone) (Santos, 2016).

Macapá presents warm and humid climate with temperatures ranging from 26˚C to 38˚C; it presents two clear seasonal periods: dry (September/November) and rainy (December/August). Approximately 80% annual rainfall (2300 mm/year) is observed in the rainy season, and it requires closer monitoring regarding flooding cases at this time of the year.

2.2. Data Collection and Gathering

2.2.1. Identifying and Classifying Flooding Sites

Coordenadoria Estadual de Defesa Civil (CEDEC) is the institution in Amapá State in charge of collecting and outspreading data related to flooding events (Cedec, 2015, 2018). It aims at providing support to crisis-management actions, but it has also helped important research about this topic.

Information about flooding sites recorded up to 2015 (last CEDEC record) was collected. This procedure was based on identifying areas that constantly get flooded in the city. A geographic coordinate was delimited within each of these areas to indicate that the entire area around this point was floodable. This coordinate was defined by a "point or flooding site". This procedure was based

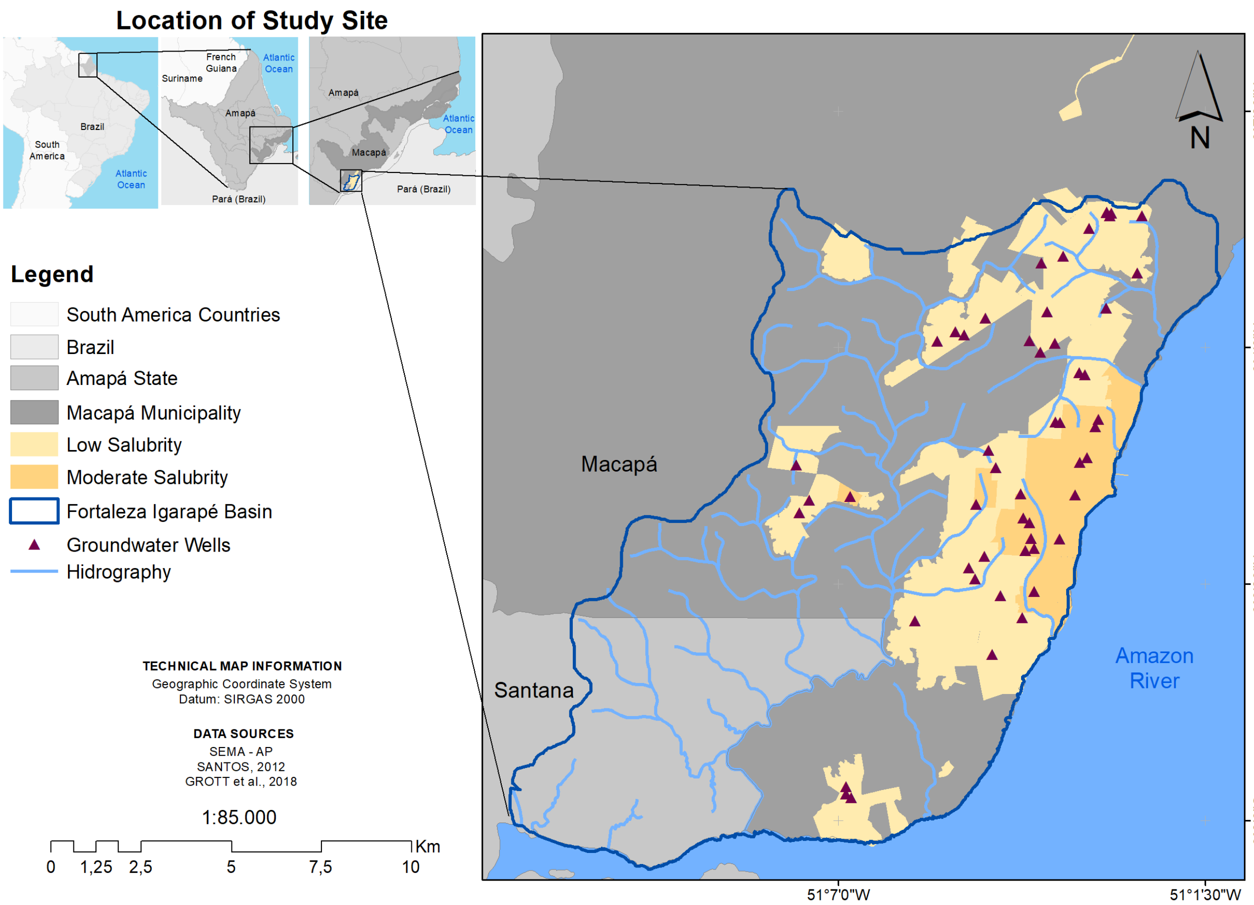

Figure 1. The study area. Dark yellow and light yellow areas represent the moderate and low salubrity zones (ESIs), respectively. Triangles in red represent groundwater in wells monitored by Grott et al., 2018.

on satellite images and on the fieldwork performed by CEDEC agents. This protocol also helped developing site descriptions and suggesting remediation or prevention measures.

The flooding points' analyses and classification were carried out in Qgis software, version 3.8.1 (Qgis, 2022). It was done by taking into account the: location, terrain-elevation, closeness to the natural drainage network, and insertion in lowered areas criteria.

Orthophotos taken in 2015, at resolution of 0.20 meters—taken by *Projeto Base Cartográfica Digital Contínua do Amapá* (BCDCA, 2015)—were used to set the location criterion. Level curves (at 1-meters spacing) and the Digital Terrain Model (DTM with 2.5 meters resolution) by the BCDCA project were adopted to define the terrain-elevation criteria of each flooding point.

The most recent and available drainage database was launched in 2003 by the State Environment Secretariat (SEMA), and was used to set the closeness to the natural drainage network and insertion in the lowered areas criteria.

All classification criteria were interpreted and, subsequently, turned into thematic maps plotted in Qgis software. It is important highlighting that sites without flooding were taken into consideration in the analyses as firm ground areas.

2.2.2. Risk Areas

Flood risk areas refer to the area likely to be flooded, such as marginal land and watercourses occupied by low-income populations that form precarious housing settlements prone to suffer with flooding (Brasil, 2007b).

The flood risk areas in Macapá were mapped by CEDEC. The latest survey dates from 2018 (Cedec, 2018). Geographic analyses of these areas were carried out in Qgis platform based on criteria set by the Cities Ministry and by the Institute of Technological Research (Brasil, 2007b). This methodology aims at supporting risk analyses of Brazilian cities; it is widespread and applied in several studies, being to the country's official methodology (Rodrigues & Listo, 2016; da Silva et al., 2017; Sousa et al., 2021).

This methodology counts on two risk types: the preliminary and the final risks. The used criteria are precisely the difference between them. On the one hand, the preliminary one uses hydrological scenarios (C) and vulnerability (V); On the other hand, to quantify the final risk the hazardousness criterion (P), should be included, in addition to scenarios (C) and vulnerability (V). Only the preliminary risk was herein determined, since there was not enough drainage data available to find the final risk level. Therefore, the importance of preliminary risk stood out, especially in areas lacking database, such as Macapá.

2.2.3. Criteria to Classify Risk Areas

Two criteria were adopted to assess the degree of preliminary risk: a) hydrological process (C1, C2, C3) and b) housing vulnerability (V1, V2). Type C1 hydrological processes refer to watersheds whose flooding has slow water flow and results from normal processes that take place in river plains, as well as whose destruction potential is lower. Type C2 is identified as susceptibility to flooding events presenting greater kinetic energy than process C1. Type C3 is characteristic of watersheds where flooding happens at high-energy flow and can transport solid materials—it has greater destruction potential (Brasil, 2007b).

The physiographic indices of a given watershed can influence its hydrological behavior (Bastos, 2010). Hydrological processes in Fortaleza Igarapé Basin, for instance, were defined based on compactness coefficient (Kc) and shape factor (Kf), important indices to measure the susceptibility of the basin to flooding (**Table 1**).

Based on information in **Table 1**, Kc (1.34) and Kf (0.046) point out that Fortaleza Igarapé Basin is overall hydrologically little subjected to flooding—in this case, Type C1 is the estimated hydrological process. However, due to tide effects, they can suffer significant influence from floods because of the greater kinetic energy observed when some areas in the watershed are more specifically analyzed (da Cunha & Sternberg, 2018; de Abreu et al., 2020). Thus, these specific areas in the watershed were considered prone to the type C2 hydrological process. None of the areas fitted Type C3.

Table 1. Physiographic indices recorded for Fortaleza Igarapé Basin (adapted from Bastos, 2010).

Index	Value/Equation	Description of variables
Compactness coefficient (*Kc*)	$Kc = 0.28 \times \frac{P}{\sqrt{A}} = 0.28 \times \frac{66.053}{\sqrt{190.823}} = 1.34$	Compactness coefficient (*Kc*) is the association between the perimeter (*P*) of the basin and the circumference of a circle presenting area equal to the basin ($\sqrt{A}$).
Shape factor (*Kf*)	$Kf = \frac{A}{L^2} = \frac{190.823}{64^2} = 0.046$	The shape factor (*Kf*) is the association between the mean width (*A*) and the axial length of the basin (L^2).

Urban occupation vulnerability can be categorized as high (V1) or low (V2), depending on housing standard, based on the second criterion adopted to assess the degree of preliminary risk. Indicator V1 was adopted for locations that mostly have wooden and MDF houses, or houses made of other materials, that have low potential to resist impacts caused by hydrological processes. Indicator V2 concerns areas where most of the houses are made of masonry and have good potential to resist the impacts caused by these processes (Brasil, 2007b). These physical aspects were taken into account in the analysis based on BCDCA's orthophotos.

After both the analysis and the definition of each criterion, the degree of preliminary risk of flooding was determined based on the arrangement of variables related to hydrological processes and vulnerability, as shown in **Table 2**. This degree of risk classification is shown in the results through thematic maps plotted in Qgis. The referred map's correspondence is highlighted by a specific color in order to make the analysis easier. Low risk is highlighted on green on the map, moderate risk is shown in pink and high risk is depicted in red.

Table 2. Preliminary degree of risk based on the arrangement between hydrological scenarios (C) and housing vulnerability (V) (Adapted from Brasil, 2007b).

	C_1	C_2
V_1	Moderate Risk (M)	High Risk (H)
V_2	Low Risk (L)	Moderate Risk (M)

2.3. Sanitary and Environmental Variables

2.3.1. Using the Environmental Salubrity Index (ESI)

Environmental Salubrity Index (ESI) quantifies the salubrity of an area through the analysis of environmental and sanitary indicators. In Macapá, the Environmental Salubrity Index (ESI-MCP) used the means of four basic sanitation sub-indicators to determine the quality of the environment. The most relevant ones were 1) water supply (weight of 40%); 2) sanitary sewage (weigh of 30%); 3) solid waste (weigh of 10%); and 4) urban drainage (weigh of 20%) (Santos, 2012). Sub-indicators' weight is subjective and may be different depending on the study site, since it also depends on the author's view. In other words, the sub-indicators that are considered the most important for the area (in the author's view) they will account for the greatest weight. The opposite applies to those with lower weights; in this case, Santos (2012) adapted the weights based on his conception of and knowledge on the local reality in Macapá.

To the best of our knowledge, ESI-MCP was firstly assessed in Macapá by Santos (2012); it is the only local record available in the literature on this topic in the country. The present research used the same classification in different neighborhoods; it adopted neighborhoods' shapefiles provided by SEMA. The analysis focused on the officially launched neighborhoods—remaining neighborhoods were classified as "other sectors". All analyses were carried out in Qgis software, and it allowed spatializing these data and making it easier to understand Macapá's urban area based on its salubrity.

2.3.2. Quality of Groundwater

Data on the quality of groundwater were collected during the investigation in groundwater wells in Macapá, conducted by Grott et al. (2018). It is the only study conducted in Macapá focused on relating seasonally given water-quality data to environmental parameters recorded for the urban zone. These authors randomly assessed 52 domestic wells that were geographically distributed in the urban zone (**Figure 1**) in order to monitor water quality throughout two seasonal periods: Amazonian lesser-rainy (November 2014) and rainy (May 2015) seasons. They analysed parameters such as pH, turbidity, color, iron (Fe), nitrate (NO_3), manganese (Mn), chlorine (Cl), ammonia (NH_3), aluminum ions (Al), total coliforms, and Escherichia coli (*E. coli*) in the water of the wells.

The database about the residential wells monitored by Grott et al. (2018) and the flooding points observed by CEDEC (2015) it was done in order to assess the significance of the cause-effect link between the presence/absence of critical flooding points and effects in environmental quality. Although only one fraction of these wells was close to flooding points, it was possible associating the water quality parameters, as well as with sanitary and environmental parameters set for the surrounding areas (Buffer zones).

2.3.3. Definition of Buffer (Or Influence Area)

Buffers are circles representative of areas whose core meets a certain flooding point. Thus, two categories of Buffers were defined to test what was the best scale (radius of influence) to explain the flooding; in other words, buffers with radius equal to 500 meters and the ones with radius equal to 750 meters. All information found within this circle may, or may not, have data representative of sanitary and environmental variables that were made available by Grott et al. (2018), Santos (2012) and CEDEC (2015).

Therefore, the Buffers represent the "area of influence" in flooding points depending on the sanitary and environmental conditions observed in the surrounding areas, if have consequences on the quality of groundwater presented by Grott et al. (2018).

2.4. Statistical Analysis

Data were organized in tables and statistically processed as matrix of categorical and continuous data. Data in the matrix were subdivided into two basic groups: a) sanitary variables (preliminary risk; number of flooding points, quality of groundwater, environmental salubrity index), and b) environmental variables (terrain-elevation, drainage typology). The whole database was adjusted and processed in R-Project Software (2022).

Important premises on the distribution of frequencies and variances in all variables were assessed to test the responses of degree of preliminary risk of flooding (Risk area 500-RA500 for those within the 500 meters buffer; and Risk area 750-RA750, for those within the 750 meters buffer)—by indicating the response variables Y1 (rainy) or Y2 (dry)) (**Table 4**).

There was no normal distribution in most data distribution (Shapiro-Wilk). Thus, paired Wilcoxon non-parametric statistical test and Friedman test were used to compare Risk area 500 meters to Risk area 750 meters in the two seasonal periods—rainy and dry seasons (Crawley, 2007). The analysis of the two periods was important to help better understanding water quality variations. However, the choice for different buffers to test Risk area was also useful to test the "ideal scale of influence" that would better represent the Risk area responses explained by independent variables.

The Wilcoxon method was adopted to test the hypotheses with only two simultaneous comparisons (rainy/dry). Thus, all statistical correlations were assessed at significance level $\alpha < 0.05$ (Crawley, 2007).

Therefore, these statistical analyses were adopted to test correlations among preliminary risk of flooding and sanitary and environmental variables, to allow the conduction of a holistic analysis of the current drainage scenario in Macapá.

3. Results and Discussion

3.1. Flooding Points

In 2015, 29 flooding points were detected in Macapá (Cedec, 2015) and classified into 5 typologies: 1) lowered area, 2) flooded area, 3) embankment area, 4) area close to the channel and 5) Amazon Riverbank (**Table 3**; **Figure 2**). Each typology was analyzed and accounted the frequency observed (**Table 3**).

Category "lowered area" (**Figure 2**, spots in purple) encompassed 41.37% of identified flooding points. Such a higher rate suggests faster growth in urban center zones with subnormal agglomerates and flaws in the drainage system.

Table 3. Flood typology and frequency.

flooding points typology	Frequency in 2015	percentage of points identified (%)
Lowered area	12	41.37
Flooded area	8	27.58
Embankment area	4	13.79
Close to the channel	3	10.34
Amazon Riverbank	2	6.92
Total	29	100.00

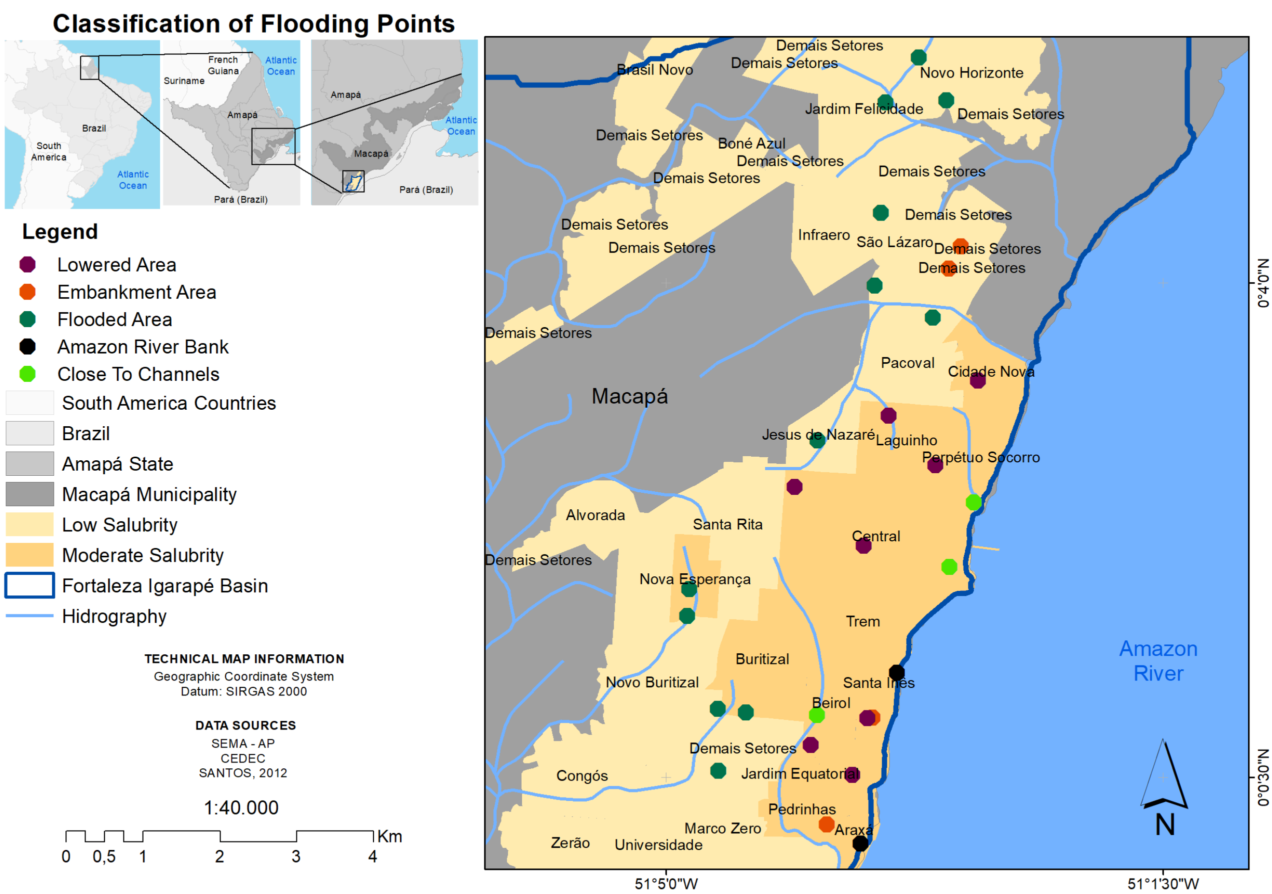

Figure 2. Classification of flooding points in Macapá, in 2015.

This profile leads to the city's incapacity to retain its rainwater in appropriate locations. Besides, it is also where one observes greater surface waterproofing and higher rates of non-planed urbanization growth.

However, this reality is similar to that recorded for a significant fraction of the world population (≈80%) living in cities in developing countries (Tumwebaze et al., 2022). Therefore, urban expansion must be followed by technologies used to reduce flooding intensity, which are based on more sustainable compensation techniques and drainage systems (Zubelzu, 2020).

Category "flooded area" (**Figure 2**, dark green spots) accounted for 27.58% of the total number of flooding points. These locals have been suffering intense grounding processes for reason unorganized occupation, and their susceptibility to flooding has been related to low terrain elevation rates (1 to 6 meters), that remain very susceptible to tidal oscillations in drainage systems close to them.

"Embankment areas" are effectively sloped, and their elevation ranges from 6 to 9 meters. They often undergo excavations, consequently, they present some risk of facing landslide events (**Figure 2**, orange spots). This category accounted for 13.79% of the analyzed flooding points.

Category "close to the channels" (**Figure 2**, light green spots) accounted for 10.34% of the flooding points located close to macro-drainage channels in the city. Because these channels are also open for tide variations, they present history of flooding events in the rainy season (Bastos, 2010). Locations described in typology "Amazon Riverbank" (**Figure 2**, black spots) accounted for 6.92% of the flooding points—it was the lowest rate.

It is essential informing that there are only two observed salubrity categories: the low and middle ones. Approximately 62.07% of flooding points are located in areas recording moderate ESI (**Figure 2**, dark yellow) and 37.93% of them are in areas with low ESI (**Figure 2**, light yellow). In general terms, the literature has been suggesting that low salubrity is often related to intensified impact of flooding (Braga et al., 2022). However, based on data collected, in Macapá the opposite happens, the most part of flooding points are more concentrated in moderate ESI. This is due to the existence of an old sanitation system in the city without proper maintenance, that reducing its efficiency.

3.2. Flooding Risk Areas

Although Fortaleza Igarapé Basin is not often subject to flooding, according to its physiographic parameters such as *Kc* and *Kf*, it counts on 28 risk areas (**Figure 3**), which were defined by CEDEC (2018).

These combined areas occupy approximately 5.65 km^2 of the urbanized area in Macapá (61.49 km^2, in total). Therefore, the percentage of risk areas is close to 9.19% of the total area. These finding evidences that this percentage is considerable, even for Amazonian urbanization standards. The same situation of Macapá can be observed in other Brazilian cities, for exemple, São Paulo, where rapid urbanization and poor urban planning are the main causes of disasters resulting from flooding (Rodrigues & Listo, 2016).

In summary, among the 28 Risk areas analyzed in Macapá, 4 are of low risk (green color) (14.29%), with approximately 0.105 km^2; 7 are moderate risk (pink color) (25%) and occupy approximately 0.49 km^2; and 17 are of high risk (red color) (60.71%), with 5.06 km^2 (**Figure 3**). The high-risk areas are the most significant ones; they are usually located in subnormal agglomerate zones around the "lowered area". This profile makes the risk of flooding more likely to happen in the rainy season and to be potentiated during tide elevations (da Cunha et al., 2021).

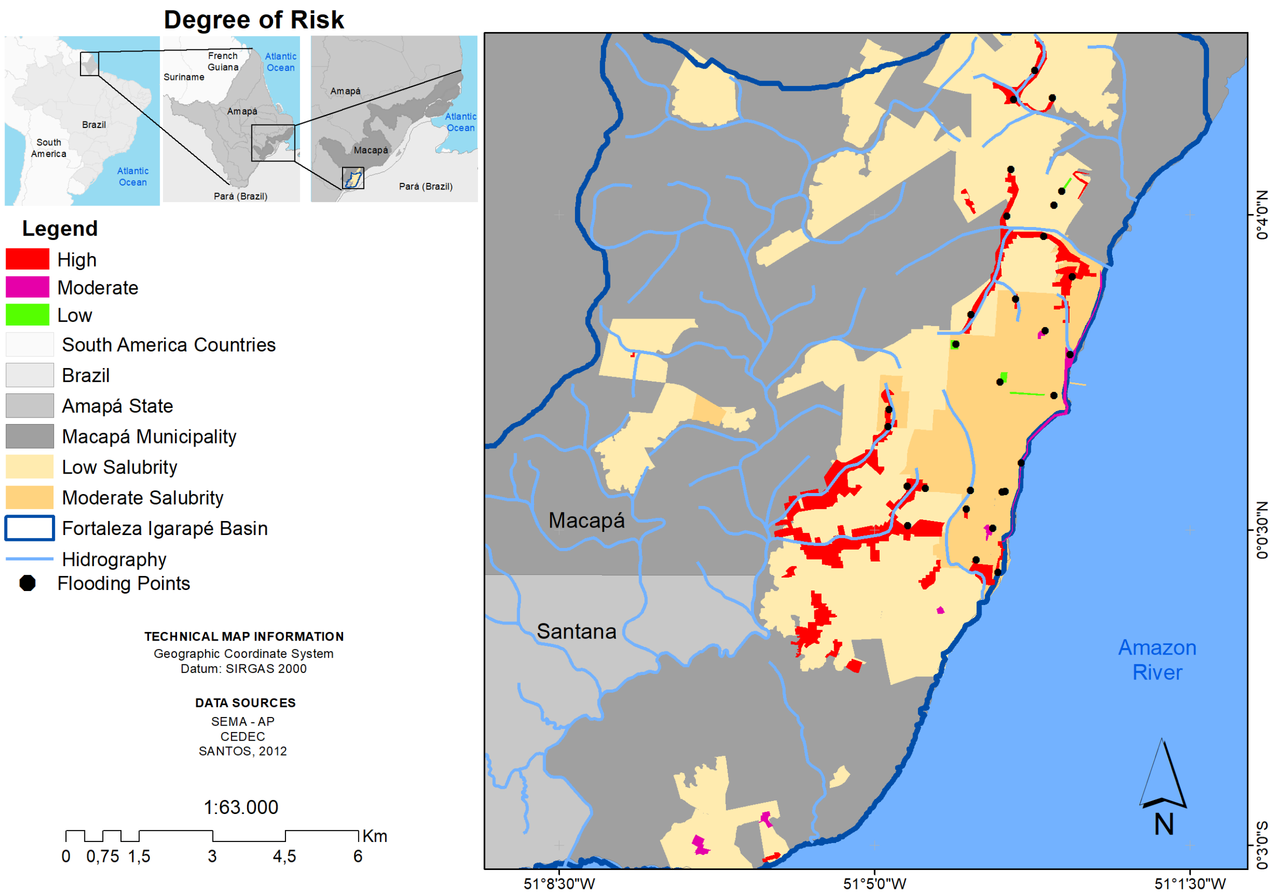

Figure 3. Flooding risk sites in Macapá in 2018.

There are 28 official neighborhoods (IBGE, 2023) in Macapá; 23 (82.14%) of them were identified with risk areas; and only 5 (17.86%) had no risk areas in them. It is essential pinpointing that similar conditions can be observed in other Amazonian cities. Belém City, for instance, often suffer from almost the same hydrographic effects from the Amazon River observed in Macapá, because it faces frequent flooding episodes of significant regional representativeness (Mansur et al., 2018). However, similar cases have also been seen even in urban settlements to the South of Sahara, in Africa, where social and environmental infrastructure features often influence flooding risk and the risk of waterborne disease outbreaks (Abu & Codjoe, 2018).

3.3. Integrated Analysis of Sanitary and Environmental Variables

A significant fraction of the urban population in Macapá does not have access to conventional drinking water supply networks (<45%). This population looks for alternatives, such as consuming well-water (either in urban or peri-urban zones), due to generalized sanitary deficiency (Araújo et al., 2021; Viegas et al., 2021).

This situation in group of other environmental and sanitary variables observed in preliminary risk areas (RA) can compromise the quality of groundwater fountains, since these relatively shallow wells present maximum depth of 45 meters (Grott et al., 2018).

Accordingly, **Table 4** was plotted to show the statistical correlations between degrees of preliminary risk and sanitary and environmental variables, these correlations were classified based on their respective Buffers of 500 and 750 meters. Is important to emphasize the variables that were not-significantly correlated to risk areas, they were removed from **Table 4**.

Some quality parameters applied to well-water (TC, NO_3 and NH_3) were correlated to risk sites (RA500 and RA750); TC was significant, but only in the rainy season. Such a fact has suggested the connection between well-water quality to flooding, because although the drainage system was originally conceived to the exclusive type, it became a unitary system. In this case this can be influencing the concentration of these microorganisms in well-water due to the likely contact of it with domestic sewage—which gets mixed to both rainwater and groundwater (PMSB, 2016).

This has indicated the precariousness and sanitary vulnerability of groundwater fountains in Macapá, as well as explained in studys, that show the frequent acute diarrhea cases and quality of the water is compromised recorded in the city (Araújo et al., 2021; Viegas et al., 2021).

Nitrate ion (NO_3), for instance, has presented significant correlation with a flood preliminary risk in both seasonal periods (**Table 4**), either in the 500 meters or in the 750 meters Buffer. Assumingly, this ion is associated with the presence of domestic sewage mixed to rainwater (mineralization of organic matter's nitrogen phase). The excess of such a mix poses risk to human health and is extremely toxic to the environment (Nabi et al., 2019).

Ammonia (NH_3), in this case, can be related to recent waste contamination, which was only significant in the dry season and in the 750 meters Buffer (**Table 4**). The concentration of NH_3 also worked as indicator of bacteria found in water, including total coliforms (TC) (Yeboah et al., 2022).

Table 4. Influence of sanitary and environmental parameters, (Present research, Grott et al. (2018), Santos (2012) on flood risk areas in buffers of 500 and 750 meters.

Independent variable	Risk area—buffer of 500 meters (RA500)		Risk area—buffer of 750 meters (RA750)	
	Rainy	Dry	Rainy	Dry
Total Coliforms (TC)	0.059	NS	0.074	NS
Nitrate (NO_3)	0.194	0.020	0.033	0.116
Ammonia (NH_3)	NS	NS	NS	0.033
Environmental Salubrity (ESI)	NS		0.434	
Number of flooding points in the risk area (NPts)	0.004		0.144	
Drainage typology (Type750)			−1.00 (Firm and Lowered Land)	
Mean elevation the terrain (Elev500/Elev750)	0.04		0.084	

Environmental Salubrity is only correlated to the 750 meters Buffer's preliminary risk area (**Table 4**). It happened because the 500 meters Buffer only covered 14 intersection locations (26.92% of the total of 52 well-water samples collected by Grott et al., whereas the 750 meters Buffer covered 22 flooding points (42.3% of the total of 52 samples indicated in the map—**Figure 1**). This finding suggests that the 750 meters Buffer was the most statistically adequate scale to represent the observed RA variations, as well as their correlations to sanitary and environmental parameters and to the quality of water.

The number of flooding points was also correlated in both Buffers and seasonal periods. However, the drainage typology was significant only in 750 meters Buffer. They were more evident in typology "lowered areas" and "firm ground areas", because they were more densely populated and lacking planning, a fact that impairs the functioning of the drainage system and natural flow in the watershed.

Mean elevation the terrain has presented significant correlation with a flood preliminary risk in both seasonal periods (**Table 4**). it was possible observing that the lower the topographic elevation of the terrain, the higher the risk of flooding, regardless of the zone of influence the Buffer. And this effect is stronger in the rainy season, in wells located in places with low elevations.

Many countries worldwide, mainly some cities in China, have been using the concept of "sponge city". This initiative has been having positive impact because they aim greater interaction between drainage systems and other sanitation variables (sewage, solid waste and water supply) in order to reach better urban development and interaction with local ecological ecosystems (Jiang et al., 2018; Meng et al., 2022).

Brazil is taking the first steps towards this process and, although Amazonian cities present natural vocation for such an integration, they did not evolve in the last decades because lack of public policies applicable to this sector. The consequence of such a negligence reflects on intensified insalubrity level, on environmental and sanitary deterioration of water, and flooding.

4. Conclusion

The interdisciplinary approach based on the geographic information system and on univariate statistical analysis was herein adopted to assess the degree of preliminary flooding risk in Macapá's urban zones. This assessment was substantiated by a series of sanitation and environmental variables, which led to the following conclusions:

- There is effective infrastructure deficit in the drainage system (≈90%) in the urban zone, the system is fundamentally defective and little consolidated at this sector's policy level;
- The degree of preliminary risk of flooding is closely related to serious reduction in water quality and environmental sanitary conditions that can vary depending on salubrity level, drainage, and on the elevation of the terrains;

- Land use and occupation without urban planning have encouraged the formation of subnormal agglomerates in "lowered areas". The consequence of this process, at watershed and urban zone level, is expressed by the trend of new areas presenting flooding risk to emerge throughout time.

Research in the area of urban drainage and sanitation is still scarce in the Amazon region, specifically in the state of Amapá. However, projects and research are being developed, such as the creation of Municipal Basic Sanitation Plans for several municipalities in Amapá, which previously did not have these important tools for urban development. But it is still necessary to promote adaptive techniques and mitigation strategies, which allow the cities of Amapá to increase their support capacity and resilience in situations of climatic or hydrological extremes, such as floods.

Acknowledgements

Coordination for the Improvement of Higher Education Personnel-CAPES. Federal University of Amapá—UNIFAP and National Council of Scientific and Technological Development—CNPq.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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