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ENVIRONMENTAL IMPACTS AND VULNERABILITIES IN THE COASTAL ZONE OF AMAPÁ: ANALYSIS OF WASTE AND EFFLUENT POLLUTION AND ITS CONSEQUENCES ON PUBLIC HEALTH

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ABSTRACT

Coastal environments comprise some of the most vulnerable ecosystems on the globe, with an abundance and diversity of natural resources. Environmental impacts on these

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ecosystems have increased as coastal cities grow and pollutants generated by the population are improperly disposed of. The present work aims to characterize and delimit areas potentially impacted by waste and effluents within the limits of the Amapá Coastal Zone. For this, the stages of collecting information on environmental pollution by waste and effluents in the Coastal Zone of Amapá, the execution of descriptive statistics of the areas of the coastal municipalities, the correlation with waterborne diseases and the use of geoprocessing for data analysis were carried out. The results show that the disorderly growth of cities in the coastal zone is not accompanied by adequate policies for the development and monitoring of solid waste and effluents. This is reflected in studies that point to watersheds with high levels of pollutants and low sanitation rates, affecting the population unequally, with the northern mesoregion being the most impacted. This scenario affects public health with the emergence of pathologies, in which statistics describe a relationship between cases of acute diarrhea in municipalities and poor sanitation. This situation highlights the vulnerability of the coastal zone of Amapá, which needs more studies for better environmental, territorial and health management.

Keywords: Pollution. Environment. Biosystems.

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INTRODUCTION

Environmental pollution occurs in several forms, including air, water, soil, noise, radioactive, and visual pollution (Santos, 2017). The changes caused in fauna and flora by pollution alter environmental quality, triggering degradation processes resulting from direct or indirect activities to the environment, as established by the National Environmental Policy Law No. 6,938/1981.

The growth of large population centers and disorderly occupations favor environmental imbalance in areas unsuitable for habitation or contaminated by organic and inorganic pollutants in municipalities (Santos et al. 2025) These factors contribute significantly to pollution and environmental degradation resulting from solid waste and effluents.

The problem of solid waste (SR) is old, dating back to the beginning of the first human settlements, when the growth of populations and cities led to a vertiginous generation of waste. These residues are defined as solid or semi-solid matter (Guisar et al., 2006).

The anthropogenic pollution of water resources is even more accentuated due to the incorrect disposal of solid materials and effluents, compromising the quality of water and sewage (Libânio, 2005; Richter, 2009). Contaminated water can cause diseases transmitted by the environment and negatively affect human consumption.

Despite the advances in the rules related to the problem, the absence of adequate public policies in this area is harmful. The legislation and its applicability are flawed in the municipalities, as the lack of treatment of sewage dumped into bodies of water and the irregular collection of solid waste aggravate the environmental impacts. These impacts manifest themselves in floods, floods and contaminated areas, bringing serious public health problems (Mondal and Southworth, 2010; Braz and Longo, 2021).

The state of Amapá, located in the north of the country and the Amazonian coastal zone, has 11 municipalities located in the coastal zone. These areas are rich in biodiversity and natural resources, including biotic and abiotic factors (Silva et al., 2006; Takiyama and Silva, 2009; Rodrigues and Silva Júnior, 2021). However, the state has a lack of delimitation of areas for the correct disposal and treatment of solid waste (Silva, Silva Júnior and Paiva, 2023), which can cause negative impacts due to incorrect disposal and contamination by effluents.

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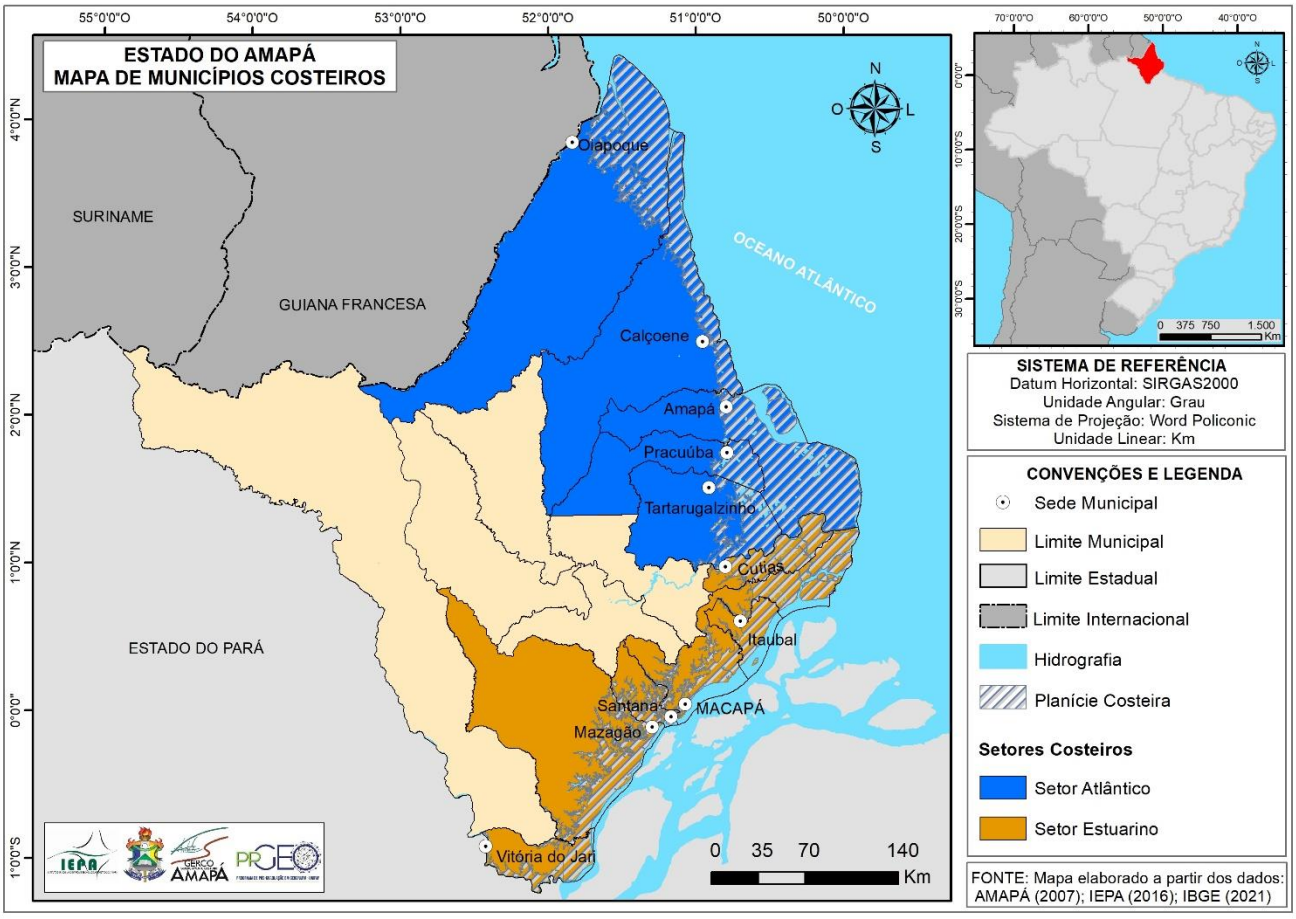
In this sense, the objective of this article is to characterize areas potentially impacted by pollutants within the limits of the Amapá Coastal Zone, as well as to evaluate the impact caused by organic and inorganic pollutants of water transmission based on environmental, socioeconomic and historical factors, in addition to collecting information and data on the areas affected by organic and inorganic pollutants in the environmental spheres, in the coastal zone of Amapá.

MATERIALS AND METHODS

FIELD OF STUDY

Amapá is located in the far north of the country, with about 16 municipalities, and is part of the Amazon coastal zone. The cities analyzed are located in the coastal plain of Amapá, namely: Amapá, Calçoene, Cutias, Itaubal, Macapá, Mazagão, Oiapoque, Pracuúba, Santana, Tartarugalzinho and Vitória do Jari (IBGE, 2022; Silva Júnior et al., 2021). The Map in Figure 1 shows the cities analyzed on the coast of Amapá.

Figure 1 - Division of coastal municipalities in the State of Amapá



Source: Silva Junior et al. (2022)

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According to the IBGE census (2022), more than 90% of the population of the state of Amapá is concentrated in coastal municipalities. Despite being one of the least populous states in Brazil, with 733 thousand inhabitants, Amapá has a high urbanization rate (89.7%), although it faces major deficiencies in its urban planning and basic sanitation.

Another relevant aspect is the issue of waste in the state. According to the Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE, 2022), Amapá was the lowest producer of urban solid waste per inhabitant in the country (0.61 kg/inhabitant/day). However, the management of this waste does not occur in a specialized manner and with proper disposal, mainly due to the difficulties of the municipalities in providing information that helps in the collection of accurate data.

In Amapá, only three cities send their urban waste to landfills: Macapá, Santana and Mazagão. In addition, Pedra Branca has its sanitary landfill. However, it is important to highlight that the landfills of Santana and Mazagão were deactivated by consortia, often irregular, and there are still problems related to the waste collection service (Araújo et al., 2015; Silveira Gomes et al., 2022; Carim et al., 2022; Silva et al., 2023; Official Gazette of Amapá, 2023).

The issue of solid waste, especially urban waste, is a significant challenge. When disposed of improperly, these materials can decompose over time. An example of this is microplastics, which originate from the partial degradation of larger plastics, which can spread through coastal systems and, through sea currents, reach different parts of the globe (Santos et al., 2023).

DATA COLLECTION

The research is descriptive and qualitative-quantitative, using data from secondary sources to review the literature and discuss the results. The data analyzed were applied to the municipalities of the state of Amapá, with a focus on coastal municipalities. The selected period covers from 2004 to 2024, with the search for national and international articles, state reports, monographs, dissertations and books through the Google Scholar platform, in addition to data collected from websites and institutions responsible for surveying sewage and water sources on official websites of the federal and state governments.

The data were obtained through projects such as the one in charge of technical training and preparation of the draft of the Municipal Plans for Basic Sanitation

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(TEDPLAN), the Brazilian Association of Public Cleaning and Waste Companies (ABRELPE), the Amapá Government Portal (GEA), the Brazilian Institute of Geography and Statistics (IBGE), the National Sanitation Information System (SNIS), the Instituto Trata Brasil, the Superintendence of Health Surveillance of the State of Amapá (SVS) and the Sanitation and Water Concessionaire of the State of Amapá (CSA).

DATA ANALYSIS

The statistical analysis used is descriptive, and the data were collected and tabulated in the Excel software, focusing on the coastal municipalities of Amapá. From this, the association between waterborne diseases and basic sanitation was made. The first stage of the analysis consisted of calculating the simple arithmetic mean of the incidence of acute diarrhea in the time series from 2013 to 2023, considering the cases registered per 1,000 inhabitants in the municipalities.

The second stage involved the use of Spearman's Correlation Coefficient, which allows analyzing the relationship between two nonlinear variables. The interpretation of the coefficient is based on the direction of change of the variables: when both increase or decrease together, the relationship is positive; when one increases and the other decreases, the relationship is negative (Hauke and Kossowski, 2011; Ali Abd AL-Hameed, 2022).

The coefficient formula is represented below, where "X" corresponds to the first variable and "Y" to the second variable. The value -1 indicates a negative and inverse relationship, while +1 indicates a positive relationship between the variables analyzed. In the case of this study, the variables are the incidence of diseases and basic sanitation in coastal municipalities.

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

ELABORATION OF MAPS

The preparation of the thematic maps was carried out using the Geographic Information System (GIS) software and ArcGIS. The coordinates were adjusted using cartographic databases and secondary data from the literature, adapted from sources such as the IBGE (2022), the Ecological-Economic Zoning (ZEE), the Institute of Scientific

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Research of the State of Amapá (IEPA) and the Superintendence of Health of the State of Amapá (SVS).

The generated maps present the distribution of waterborne diseases in polluted areas of the coastal municipalities studied, based on secondary data and statistical analysis.

RESULTS AND DISCUSSION

Amapá is recognized for its environmental preservation, supported by strong state and federal legislation. However, inspection failures, in line with ineffective public policies for cities, the absence of monitoring of solid waste, effluents, and anthropization, contribute to the contamination of important areas, such as rivers in the interior of the state and the Amazon River (França Neto, Pontes, Souza Júnior, 2019; Melém and Santos, 2021; Sousa, Araújo, Cavalcante, 2024).

The growth of cities without proper territorial planning stands out, which is a recurring problem in regions with high urbanization. An example of this is the cities of Macapá, Santana and Mazagão (RMM), where, as populations grow, the sanitary sewage and basic sanitation generated by the use and occupation of the geographic space of the municipalities do not keep up with their development (Toste et al., 2015; Silva Júnior, 2021).

In this context, the coastal zone of Amapá, when analyzing its population growth, presents results that indicate a significant increase in the urban and rural population in the municipal headquarters of the ZCEA. If not given proper attention, this can become harmful to the population. The following figure shows a higher concentration of cities with urban populations along the coast of Amapá, according to IBGE data (2021, 2023).

Through the analysis of the map in Figure 2, it is possible to observe that Macapá and Santana concentrate the largest urban populations on the coast of Amapá. The study by Abreu et al. (2024) points out, through a dispersion model, that Macapá and Santana are the cities with the highest sanitary contaminants in the rivers of Amapá. This is because they are the cities with the largest number of inhabitants and the fact that they do not have adequate basic sanitation.

The increase in these areas without the proper measures by the government hinders their spatialization, the identification of impacts and urban planning, as discussed by works such as Toste et al. (2015) and Chagas, Santos and Silva (2016). The environmental

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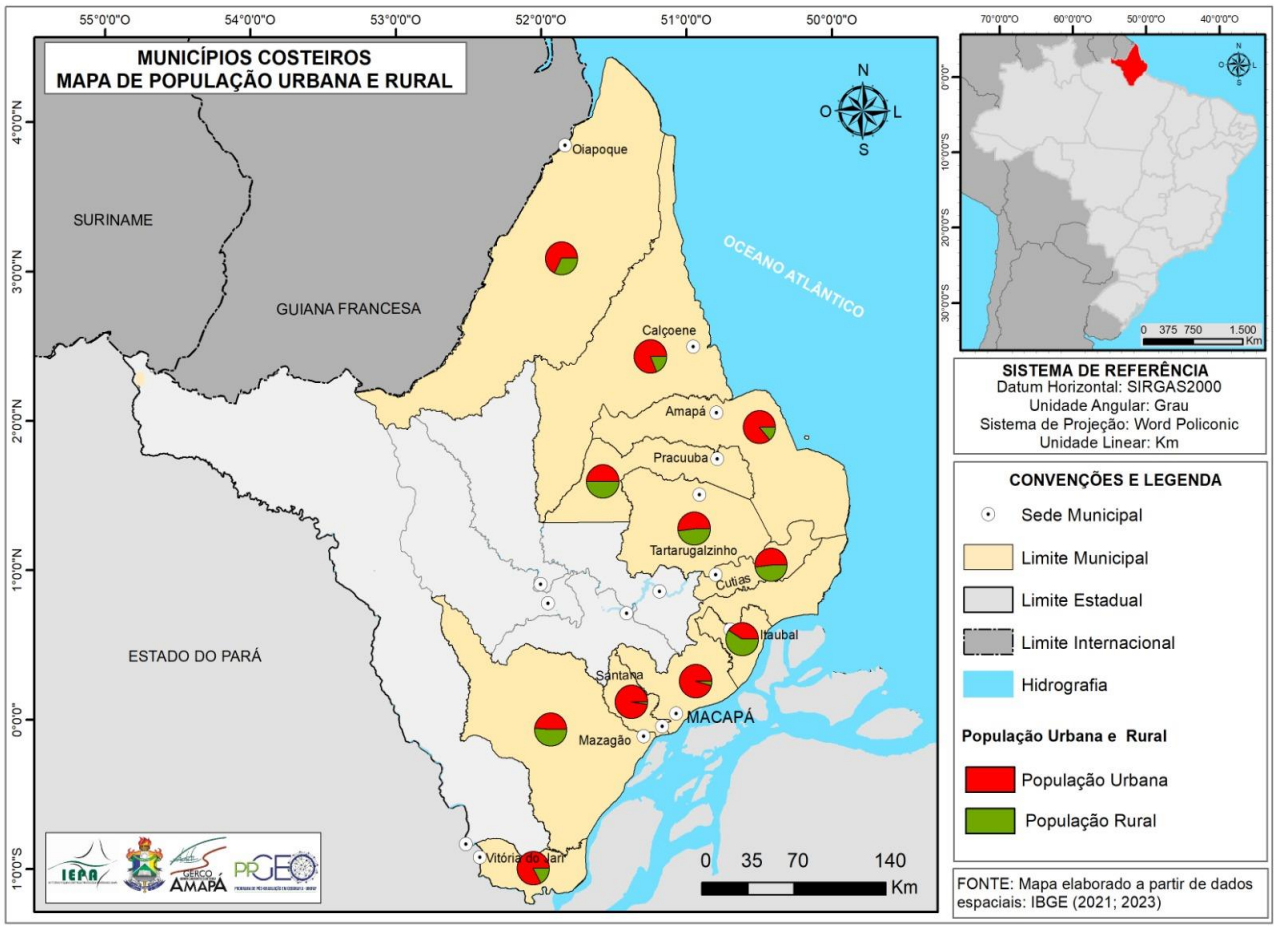
impact, in addition to the contamination of organisms and the triggering of pathologies, is configured as a conflict for the state, about environmental management and sanitation, the treatment of water, sewage and solid waste, placing cities in a situation of water vulnerability and soil contamination, when the standards established by NBR 7229/1999 are not followed.

This problem becomes even more worrying when considering the disposal of effluents in natura in coastal municipalities, as reported in the TEDPLAN project (2020), a very common practice in the state (Abreu et al., 2024). This disposal originates contaminants from organic and inorganic waste and effluents, which are not monitored and often do not comply with CONAMA resolution No. 274, of November 29, 2000, increasing their concentration.

Figure 2 - Cities with urban and rural populations



Source: Authors (2024)

Several studies highlight the contamination of the state's water bodies by pollutants. An example is the Oiapoque River, which has a high degree of contamination by fecal

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coliforms, indicating the disposal of raw effluents and the presence of traces of mercury (Silva Júnior et al., 2015). The Araguari River suffers the influence of hydroelectric dams and the decrease in oxygen, which causes fish mortality, in addition to the emission of greenhouse gases (Fearnside, 2015). The Cassiporé River basin is affected by heavy metal contamination in fish (Lima et al., 2015), while the Amazon River, a natural source of water abstraction in Macapá, contains cyanobacteria, releasing the toxin microcystin-LR, which can be fatal if left untreated (Oliveira et al., 2019). Other studies address the same situation in other rivers in the state (Cunha et al., 2004; Lima et al., 2021).

The infrastructure for the collection and disposal of waste should be highlighted in this context, as only three municipalities have access to sanitary landfills. Santana and Mazagão dispose of their waste to the Macapá landfill, while Pedra Branca became part of the framework with its sanitary landfill (Diário Oficial do Amapá, 2020; Silva, Silva Júnior, Paiva, 2023). The state is vulnerable about the waste generated due to the presence of areas inadequate for the creation of landfills. IMAP (2013) reports that it is common for waste to be transported out of cities, where it is incinerated. Only the municipality of Tartarugalzinho has a recent municipal law on solid waste (Municipal Law No. 487/2023), which establishes the Simplified Municipal Plan for Integrated Solid Waste Management (Tartarugalzinho, 2023).

Public policies still face challenges in the implementation and monitoring of actions. The search for a survey of the policy panorama, such as the preparation of the State Solid Waste Plan (PERS), in 2023, had not yet begun. The creation of the State Water Resources Plan (PERH) is under preparation, according to the GEA (2023). The state also has the Decentralized Execution Term for the Elaboration of the Municipal Plan for Basic Sanitation (PMSB-TEDPLAN), in partnership with FUNASA, to diagnose the municipalities related to sanitation in Amapá (Batista et al., 2015; GEA, 2023, 2024).

The fragility of the state about effluents and solid waste is exacerbated by urbanization. Studies point to exorheic watersheds, with greater anthropization of contaminants from waste and effluents from coastal cities, affecting adjacent areas. The impact is visible in health, with the emergence of pathologies, in the socio-economy, with fish contaminated by heavy metals, microplastics and high organic matter, in addition to the risk of eutrophication, pollution by the food chain and punctual and diffuse pollution in the municipalities (Viana, 2015; Abreu and Cunha, 2016; Souza et al., 2022; Souza, Araújo, Cunha, 2024; Abreu et al., 2024).

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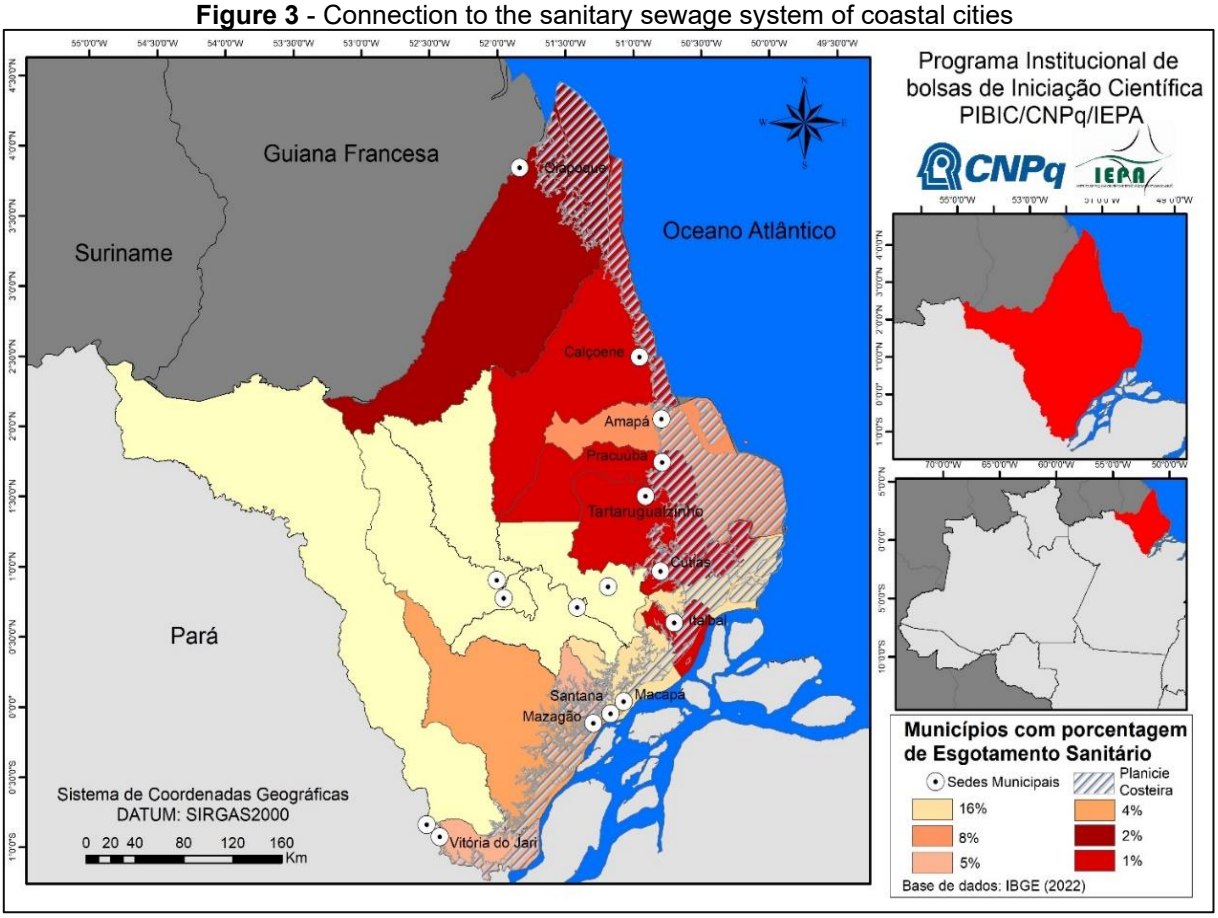
It is important to highlight the coverage rates of sanitation services, which constitute a social impact for the population, as they are affected in different ways by pre-existing factors of vulnerability, such as low-income people, residents of peripheral neighborhoods or in areas of undertow, and by access to public supply and infrastructure services. These factors amplify social, economic, and health sector inequalities, with the increase in diseases (Silva et al., 2020; SINIS, Trata Brasil, IBGE, 2021, 2022, 2023). The relationship between water bodies and waste is an essential pillar for adequate sanitation in the state, which can suffer from natural disasters, such as floods, floods and contaminated areas, harming the population, especially about social differences (Mondal and Southworth, 2010; Braz and Longo, 2021). Figure 3 illustrates the percentage of municipalities in the ZCEA with connection to sanitary sewage.

Figure 3 - Connection to the sanitary sewage system of coastal cities



Source: Authors (2024)

The northern mesoregion of Amapá is the most affected, with the municipalities of Cutias, Tartarugalzinho, Pracuúba, Calçoene and Oiapoque. In the southern mesoregion, the city of Itaubal also stands out. These are areas that suffer from the lack of sanitation in

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Amapá. Although these cities have a low population density, except for Oiapoque, which has approximately 27 thousand inhabitants, the case of these municipalities is distinguished by its small size and disorderly expansion, with irregular occupation, as discussed in the work of Melém and Santos (2021). In the TEDPLAN project (2020), the relationship between water systems and waste collection in these municipalities is raised, noting the absence of specific legislation. No plan is found for urban growth, sewage or waste in these cities, with septic tanks and disposal in rivers in the city itself being the most common practices.

The company responsible for sewage services in Amapá (CAESA), currently privatized, assigned to the Equatorial group (CSA/Equatorial) the responsibility for new works and improvements in the state's sanitation sector. However, the numbers are still considered lower, as can be seen in the figure, and, compared to other regions of Brazil, the North region has the lowest sanitation index (Grupo Equatorial, 2024).

In a letter sent to the Amapá Water Company, in 2024, Equatorial replied that it has completed works and others in progress, according to the municipalities. It is observed that the state, together with the Equatorial group, still has gaps in the standardization of information among the responsible departments, which makes it difficult to understand the situation of the priority coastal regions for technical studies and scientific research. These surveys take place, for the most part, in metropolitan regions, such as Macapá, Santana and Mazagão, while the other cities of the ZCEA are disproportionately reached, which makes it difficult to understand regional problems.

In addition, problems related to pathologies can be aggravated by the association of diseases and infections generated by inadequate basic sanitation, solid waste and effluents, affecting the population unequally. Understanding this relationship between coastal municipalities, pathologies and sanitary sewage is crucial for the development of the SACZ and for the implementation of efficient measures (Costa and Mendoza, 2007).

Inadequate sanitation and irregular waste disposal may indicate a correlation with the incidence of contaminated sites. Some studies discuss this topic, such as that of Rezende, Oliveira, and Kuhn (2024), who found heavy metal contaminants in landfills. Solid waste and effluents affect public health, causing diseases and an increase in cases of arboviruses (dengue, chikungunya, and zika), fecal-oral diseases (leptospirosis), cholera, hepatitis (A and E), as described in the work of Silveira Gomes and Oliveira Belém (2022), in addition to other problems, such as leachate, waste deposit in rivers and

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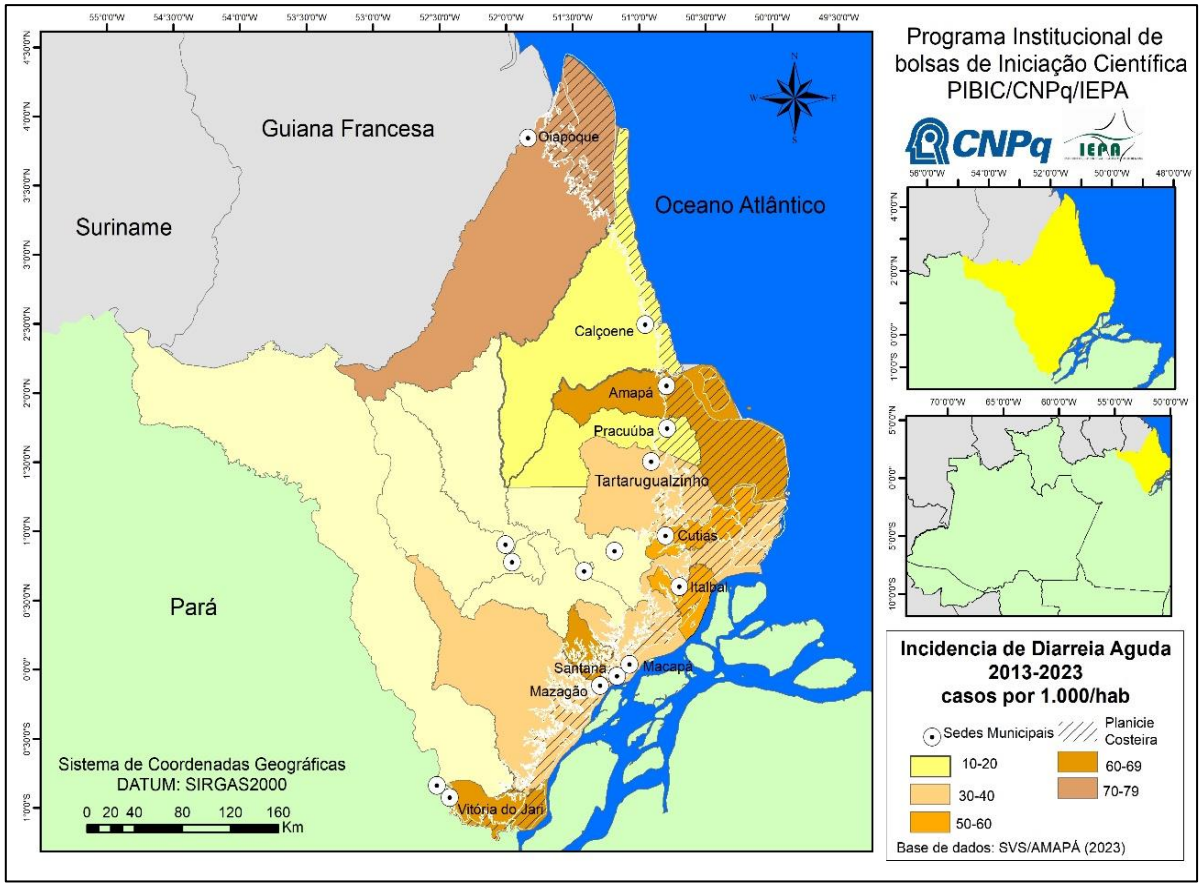
streams, and the performance of garbage collectors, among others. Acute diarrhea, due to other factors, is, however, related to inadequate sanitation, environmental water quality, and hygiene conditions (Correia et al., 2021; Moura, Landau, Ferreira, 2016). These diseases can be social indicators, further accentuating inequalities, as is the case with dengue, which is often associated with the accumulation of garbage (Gomes et al., 2020; Sobral et al., 2016).

Thus, the Superintendence of Health Surveillance of the State of Amapá (SVS/AP) provided data on the incidences of acute diarrhea, which show the coastal municipalities with the highest incidences of these cases, as illustrated in Figure 4, with the relationship for each coastal municipality.

Figure 4 - Map of the incidence of acute diarrhea by municipality



Elaborated by: Authors (2024)

When analyzing the municipalities with the highest incidences of acute diarrhea, it is observed that the largest number of cases is concentrated in Amapá and Oiapoque. One of the justifications for this is the relationship of low waste and effluent management rates, which could contribute to the reduction of these rates, as shown in the work of Mol,

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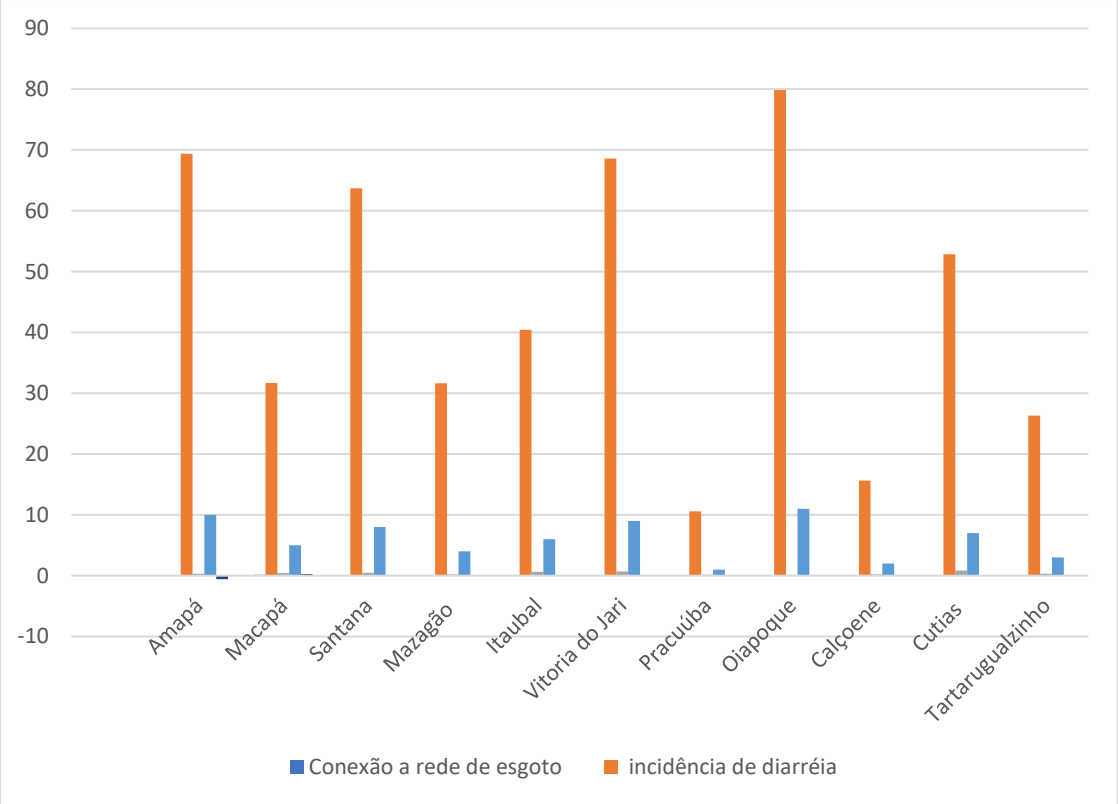
Queiroz, and Gomes (2020). Oiapoque, for example, has suffered for decades from the lack of an adequate landfill, as well as from the pollution of its waters (Silva Júnior, Fuckner, Freitas, 2014). The map identifies that the most affected municipalities have a high occurrence of cases, related to low sanitation rates, which may be linked to inadequate waste treatment in these municipalities (Figure 5).

The impacts caused on health, the environment, socioeconomics, water bodies and waste point to the need for adequate direction in urban, environmental and territorial management, in order to understand the risks and consequences of this theme for Amapá. Descriptive statistics, in this case, are able to relate the study variables between sanitation and acute diarrhea, in order to identify whether there is a correlation between these factors in the municipalities analyzed.

Figure 5 - Relationship between sewer connection and incidence of diarrhea



Source: Authors (2024)

The result of the statistic, using Spearman's correlation coefficient, indicates that there is an inversely moderate and weak relationship, as described by Martínez Ortega et al. (2009). The variables analyzed are addressed in other studies, such as that of Araújo et al. (2021), which describes the relationship between pathologies and acute diarrhea in the

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municipalities of Amapá. It is important to highlight that cases of diarrhea may be due to other factors, and in SVS notifications the specific cause of the diseases is not discussed, but only recorded. However, there is a relationship with sanitation, especially with regard to solid waste and effluents.

Amapá, in this context, is one of the most preserved states in the country and is part of the Amazon coastal zone, along with Pará and Maranhão. The region is known for its great environmental and economic relevance, being bathed by the Amazon River. The division of the coastal sectors encompasses the estuarine and oceanic sectors, with hydrodynamic conditions that shape the processes of erosion, sedimentation and transport, enabling great biodiversity (Batista et al., 2009; Shaw, 2019; Rodrigues and Silva Júnior, 2020; Santos et al., 2022).

The capital Macapá, for example, has wetlands in its urban area, occupied by undertows and floodplains that can be flooded, in addition to anthropization actions that interfere with ecosystems of great importance for places sensitive to change, such as the Amazon estuary (Takiyama et al., 2004; Nery, Oliveira, Freitas, 2015). Environmental interference due to the absence of inadequate basic sanitation treatment can accentuate these changes.

Macapá is among the 20 worst municipalities in terms of sanitation service, remaining in this position for a decade. The city consistently occupies a position among the ranking of the worst cities in terms of sanitary sewage, with little variation in its position, according to data from Trata Brasil (2023).

The growth of cities without adequate territorial planning leads to insufficient treatment of effluents, and sanitation coverage does not reach all population centers in coastal municipalities. However, the results of this are reflected in the biotic and abiotic environment.

Cities located in the coastal zone dispose of municipal solid waste and domestic effluents inadequately, which triggers downstream and upstream reactions. Coastal zone watersheds are important for connecting sediment flows, which can alter the environment. It is in the estuary that the effects of erosion of the basin's soil and the discharge into the river network of effluents rich in organic matter, nutrients and polluting pollutants can generate cumulative impacts (Kennish, 2002; Nicolodi, Zamboni and Barroso, 2009). The result of this is the proliferation of mosquitoes, pollution of water bodies and degradation of vegetation cover (Albuquerque and Souza, 2015; TEDPLAN, 2020).

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Research carried out in the state reveals the presence of contaminants in the estuarine sector, such as in the Cuñaní River (Calçoene). The cause of this may be related to the formation of sediments with high percentages of organic matter located in the Amazonian coastal zone. The study analyzed 23 chemical elements on the coast of Amapá, serving as a basis for identifying possible contamination (Siqueira et al., 2018; Arruda Xavier et al., 2020).

In 2015, studies revealed possible contamination by heavy metals, such as cadmium, chromium, copper, lead, zinc and mercury, in consumer fish, such as *Plagioscion squamosissimus.* The high concentration of metals indicates contamination in the Cassiporé River basin, with a risk to humans, which can cause neurological and genetic diseases. Inert pollutants, such as mercury found in the Amazon, especially in the cities of Amapá, in inland aquatic systems and in coastal cities, pose a risk to adults, women of childbearing age and children, due to the increase in mercury. The value exceeds that recommended by the World Health Organization by approximately 28%, most of which are in inland rivers in the region of the state of Amapá (Lima et al., 2015; Hacon et al., 2020).

Due to the history of mining companies in Amapá, some regions face problems related to metals, such as manganese exploration and inadequate storage of ores. Dumping in specific stretches, as in the case of the Amazon River and streams, used by the residents of Elesbão, presents contamination levels above those recommended by the Ministry of Health, which is considered a danger to human health (Pinheiro and Souza, 2017; Cardoso et al., 2021). Contamination by heavy metals is an undeniable reality for the state, evidencing the fragility of water bodies when they are not monitored or when areas are not identified, which causes damage to the physical environment, the ecosystem and public health.

Bioindicators of environmental quality and health, such as phytoplankton, are related to environmental factors in the aquatic environment. For example, in aquatic environments, such as Lagoa dos Índios, Lagoa Santa Clara and the Water Treatment Plant (ETA), some phytoplankton taxa present are indicative of toxic, acidic and eutrophic environments. At the Macapá WTP (WTP), the Chlorophyta group releases cyanotoxins into the water, which generates taste and odor in the medium, causing problems in the quality of the water consumed (Oliveira et al., 2019; Silva et al., 2021).

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CONCLUSION

Studies point to the quality of the water, which directly influences consumption, and contamination by organic and inorganic matter, which can occur naturally or intentionally. Contamination by effluents and the degradation of contaminating solid waste in areas of economic and ecological interest, in addition to the exposure of specific groups, can result in problems related to heavy metals. Basic sanitation and treated water are considered vulnerable and need more research to understand the degree of difficulty and mitigate solutions through public policies. It is essential for the state power to characterize coastal areas with solid waste and effluents.

The state of Amapá has a significant fragility with regard to sanitation, which, according to Law No. 11,445/2007, is the set of measures that proposes adequate conditions for the environment and for the promotion of health, specifying sanitation as the care of water bodies, due to pollution, such as contamination by heavy metals in rivers, and possibly the incidence of diarrhea, due to the urban effluents of the ZCEA and the inadequate practice of disposing of waste in natura in the municipalities. This affects the population disproportionately, in addition to affecting public health, as demonstrated by the statistics presented in this work.

It is necessary to pay more attention to effective public policies for the implementation of measures that reduce the problems that affect the areas of the ZCEA, with the aim of improving the quality of life of the people who occupy this region. Additional studies on the coastal environment of Amapá are essential to understand the relationship between urbanization in coastal cities and the consequences of anthropological origin, such as those of organic and inorganic matter from solid waste and effluents, which influence changes in the fauna and flora of coastal environments.

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