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Potential for contamination of groundwater by necrochorume in Bragança – Pará

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ABSTRACT

The objective of this research was to evaluate the potential for groundwater contamination by cemetery activity in Bragança, Pará, through geospatial analysis of the areas directly affected by the necropolises: Santa Rosa de Lima and Campo da Saudade. To prepare the geomorphological, pedological, relief, and altitude characterization of Bragança, we used free images from high-resolution satellites – Planet, Dove sensor and Alos Palsar, Alos sensor, which were processed in the ArcGis 10.5 software. Later, an on-site visit and photographic recording of the cemeteries were also conducted to check for non-compliance with current burial legislation. As the main results, it can be deduced that the current situation of the analyzed cemeteries is worrying, as they are in soils whose ability to retain trace elements (heavy metals) and humorous liquids is low, on minimum slopes and at inappropriate distances between graves and aquifers underground. Furthermore, it was observed that Bragantino cemeteries disagree with cemetery legislation, but there is an understanding that there are techniques and technologies for adaptation. It is believed that involving the population and pluralizing environmental and sanitation issues can support negotiations on how and when they will manage their burial activities to guarantee the perpetuity of the maximum quality of Bragança's water and soil resources.

KEYWORDS: Cemetery. Heavy metals. Sanitation.

1 INTRODUCTION

Death and its consequent "eternal resting place" cause a strange interest that attracts, rejects, and sometimes frightens human beings. Some ancient peoples adopted euphemistic forms to address these concepts, for example, the term to name the burial site – cemetery, a noun taken from the Greek koimetérion and the Latin coemiteriu, both with the connotative meaning of "dormitory" or "place of rest" (BITTAR, 2018).

The conventional use of these burial sites for bodies began in the Middle Ages. At that time, numerous epidemics were expected since victims were placed in open tombs inside churches and thus contributed to the spread of pathogenic agents and the continuous emanation of odors generated by decomposition (CARNEIRO, 2009).

It is assumed that for these reasons, the funeral rituals have changed, and the bodies, from then on, have been buried inside an urn in land specifically designated for this purpose and located far from the urban area (DE MORAIS, 2019).

Nevertheless, intense and uncontrolled urbanization has fully integrated cemeteries into the urban perimeter, a fact that has brought a potential risk of contamination of soils and especially of groundwater through a liquid effluent resulting from the decomposition of corpses, whose appearance is viscous, grayish-brown, gives off an unpleasant odor and is composed of a higher percentage of water, followed by mineral salts and organic substances called necroleachate (CAUDURO, MÜLLER and CAVALER, 2019).

Necroleachate contains viruses and pathogens that the corpse, in life, was a carrier of, as well as chemical and even radioactive substances residual from the treatments to which it was subjected. In addition, it may also contain toxic substances from thanatopsis, embalming, and funeral ceremony ornaments, such as synthetic resins and heavy metals, which do not degrade with the corpse and sometimes infiltrate the soil and groundwater (SANTOS and MENGHINI, 2019).

Groundwater contamination is a reality in all Brazilian states. The Brazilian Sanitation Panel reports that the northern region of the country is home to 17,354,884 inhabitants, and

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85.7% of these citizens do not have sewage collection. This situation is worse in cities in the interior of the states, such as Bragança —Pará. The same Institute reveals that the municipality does not have sewage collection (100%) and uses the septic tank-sump system (BRASIL, 2024).

Santos and Menghini (2019, p.178) confirm that "[...] in a faulty or non-existent sewage system, contact with microorganisms from the necro-leach is direct, since the population uses water from wells or rivers collected directly and without treatment", that is, insufficient sanitation and the population's exposure to these sepulchral effluents can increase the risk of contamination or even death.

For these reasons, cemeteries are recognized as sources of environmental and public health contamination. Therefore, environmental licensing must be complied with and guided by the Resolution of the National Environmental Council (CONAMA) No. 335 of May 28, 2003, and its amendments (CONAMA Resolutions No. 368/06 and No. 402/08).

However, cemeteries are still often unsuitable for the criteria of burial legislation, whether in large urban centers or small cities in Brazil. Even though there is growing concern and mobilization among public managers to address these scenarios, there still needs to be more local technical work. This work is crucial as it could empower local authorities to make informed decisions, optimize the progress of cemetery activities, and minimize the environmental and health impacts resulting from them.

2 OBJECTIVES

2.1 General

This research aimed to evaluate the potential for groundwater contamination by cemetery activity in Bragança, Pará, through geospatial analysis of the areas directly affected by the necropolises. The findings of this research could pave the way for more effective management of cemetery activities, leading to a significant reduction in environmental and health impacts.

2.2 Specific

To prepare geomorphological, pedological, climatological, and hypsometric maps of Bragança - Pará;

Identify and quantify the areas of the geomorphology, soil, relief, and altitude classes of the Santa Rosa de Lima and Campo da Saudade cemeteries;

Verify whether the Santa Rosa de Lima and Campo da Saudade cemeteries comply with the legal framework of CONAMA Resolution No. 335/2003 and its amendments (CONAMA Resolution No. 368/06 and CONAMA Resolution No. 402/08).

3 METHODOLOGY

3.1 Location of the study area

Bragança is one of the oldest cities in Pará. It is located on the banks of the Caeté River in the Northeast Mesoregion of Pará, specifically in the Bragantina Microregion (SAKAGUCHI and RIBEIRO, 2020), Figure 1. It has a population of 123,082 inhabitants and an area of 2,124.734 km² (IBGE, 2024).

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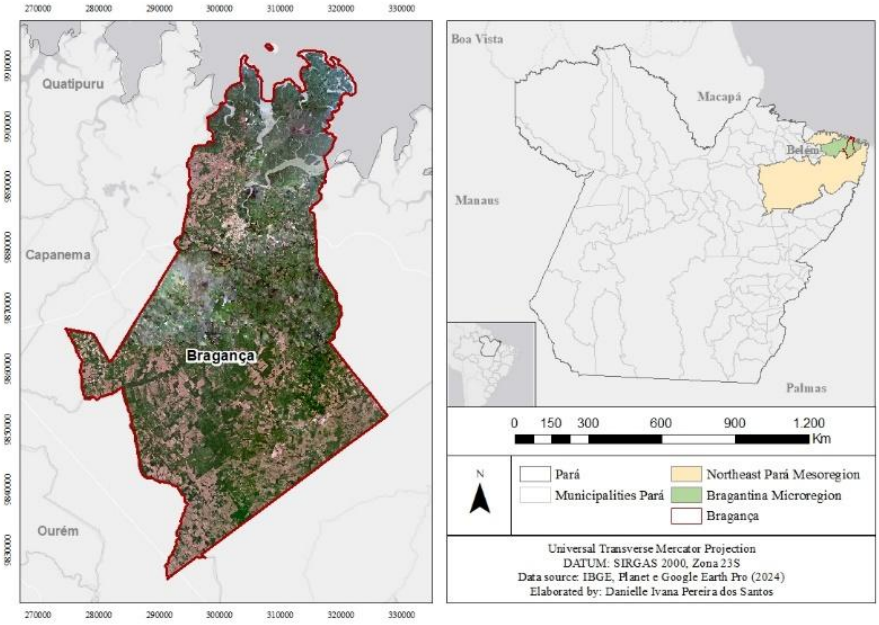
Figure 1 – Location map of Bragança, Pará.



Source: SANTOS, 2024.

The climate varies from Mesothermal to Megathermal humid, typical of the Amazon region, given the occurrence of high temperatures (minimum ranges between 22°C and 23°C and maximum between 30°C and 34°C) and high relative humidity (85% to 91%). The region is classified, according to Köppel, as equatorial hot and humid (Amw), as it has an abundant rainy season (December to May) and a dry season, with an annual average of 2,500 mm in the remaining months of the year (MARTORANO, PEREIRA and NECHET, 1993).

Historically, its origins date back to July 8, 1613, with the formation of a captaincy by the French expedition of Daniel La Touche, who is considered the first European to explore the Caeté region (or Caité = coa + y + eté = good, actual forest, in the Tupi language). Years later, it was elevated to the category of city by order of the President of the Province, Lieutenant Colonel Sebastião do Rego Barros, through Resolution No. 252 of October 2, 1854, in which it received the name of Bragança (CORDEIRO et al., 2017).

However, cemetery activities in the municipality were officially recorded from the inauguration of the "Santa Rosa de Lima" cemetery (Figure 2 - P01) on June 23, 1888, during the administration of Intendant Colonel Antônio Pedro da Silva Pereira and later with the implementation of the "Campo da Saudade" cemetery (Figure 2 - P02) built in 1987 under the mandate of the mayor at the time, Mr. João Alves da Mota (RODRIGUES, 2024; OLIVEIRA and BAHIA, 2024). These cemeteries comprise the study area and are located within the urban perimeter in the northwest direction of Bragança.

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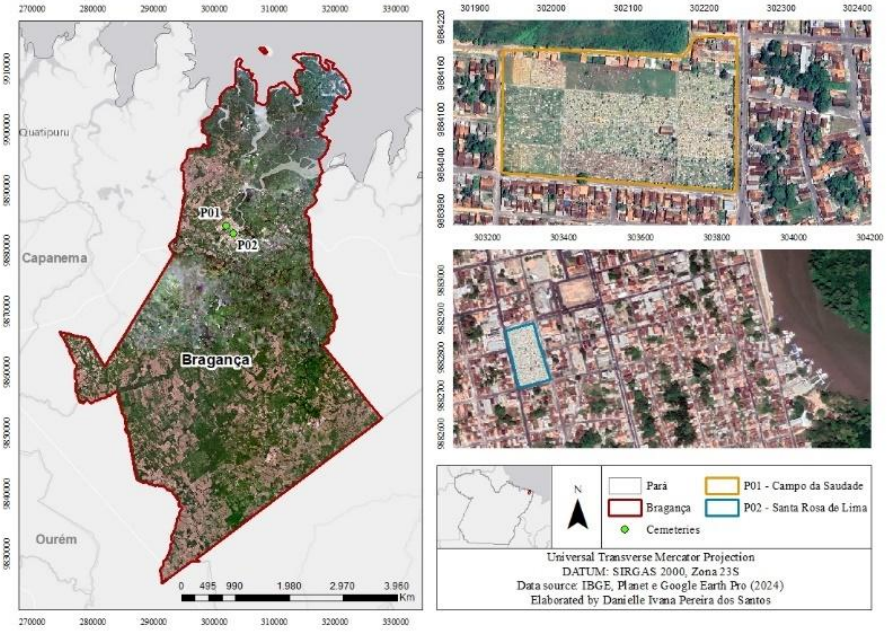
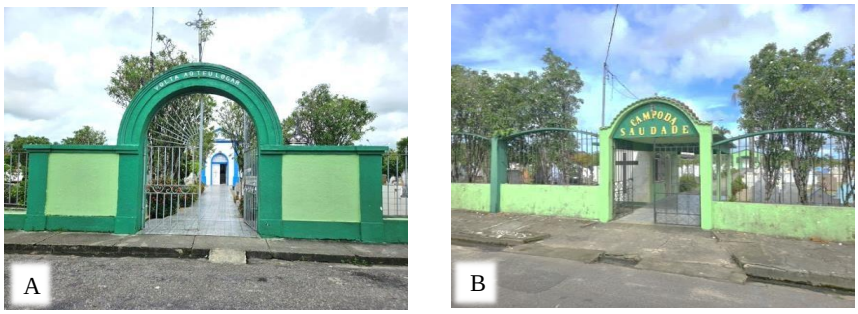
Figure 2. Location map of cemeteries in Bragança, Pará.



Source: SANTOS, 2024.

The "Santa Rosa de Lima" cemetery (Figure 3A) has a total area of 1.24 ha. It is located between coordinates 1° 3'35.30"S and 46° 46'3.33"W, in the Alegre neighborhood, approximately 2.00 km from the city's coast, on the banks of the Caeté River. The "Campo da Saudade" cemetery (Figure 3B), in turn, has a total area of 5.30 ha and is located at latitude 1° 2'54.19" South and longitude 46° 46'38.27" West, in the Vila Sinhá neighborhood. Both necropolises are adjacent to residential areas.

Figure 3. Cemeteries: A - “Santa Rosa de Lima” and B - “Campo da Saudade”, both in Bragança, Pará.



Source: CALDAS, 2024.

3.2 Data acquisition and processing for geospatial analysis

The vector data (shapefiles) of the "territorial grid" and "environmental information" of Pará were acquired from the IBGE database (https://www.ibge.gov.br/geociencias/downloads-geociencias.html). Regarding acquiring raster images, Planet, ALOS PALSAR, and Google Earth Pro were used, all considered high-resolution (Table 1).

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Table 1- Characterization of the raw data used in this research.

Image used	Spatial Resolution (m)	Satellite	Number of Scenes	*Download*
Planet	3,0	DOVE	14	https://www.planet.com/nicfi/
ALOS PALSAR	12,5	ALOS	06	https://search.asf.alaska.edu/#/
Google Earth Pro	10,0 a 1,5	SPOT-6	02	https://www.google.com/intl/pt-BR/earth/versions/#earth-pro

Source: SANTOS, 2024.

Data processing was performed in a Geographic Information System (GIS) environment using ArcGIS 10.5 software. Initially, the vector data "territorial grid" and "environmental information" were processed, imported, and cropped based on the boundaries of the municipality of Bragança.

For the raster data, mosaics were previously created for the Planet and ALOS PALSAR images, and then the area of interest was cropped. Once this was done, these croppings were reprojected to the Datum SIRGAS 2000, zone 23S, to obtain the Universal Transverse Mercator System - UTM (Plane Coordinate System in meters).

The digital elevation model (DEM) was extracted from the reprojected cropping of the ALOS PALSAR data and corrected with the fill tool to eliminate false altitudes. With the corrected DEM, the slope algorithm was used to extract the declivity and construct the clinographic map of Bragança. To develop the hydrography vectorization and the hypsometric map of Bragança, the corrected DEM was also used, applying the flow direction, flow accumulation, and the stream link.

3.3. On-site inspection and photographic record

On-site inspections were carried out during the Amazon winter (March 2024) to observe and obtain photographic records of the study area. After this, the images that exposed the non-conformities with the cemetery legislation were selected. These photos were then used to supplement the notes of this research, providing visual evidence to support the findings.

4 RESULTS

As a result, cartographic documents were generated whose applicability can support the planning and adequate management of the Bragança municipal territory. According to this research, Figure 4 shows the geomorphological and pedological classifications of Bragança, and the cemeteries analyzed are in the Coastal Tablelands and in Dystrophic Yellow Latosols (LAd).

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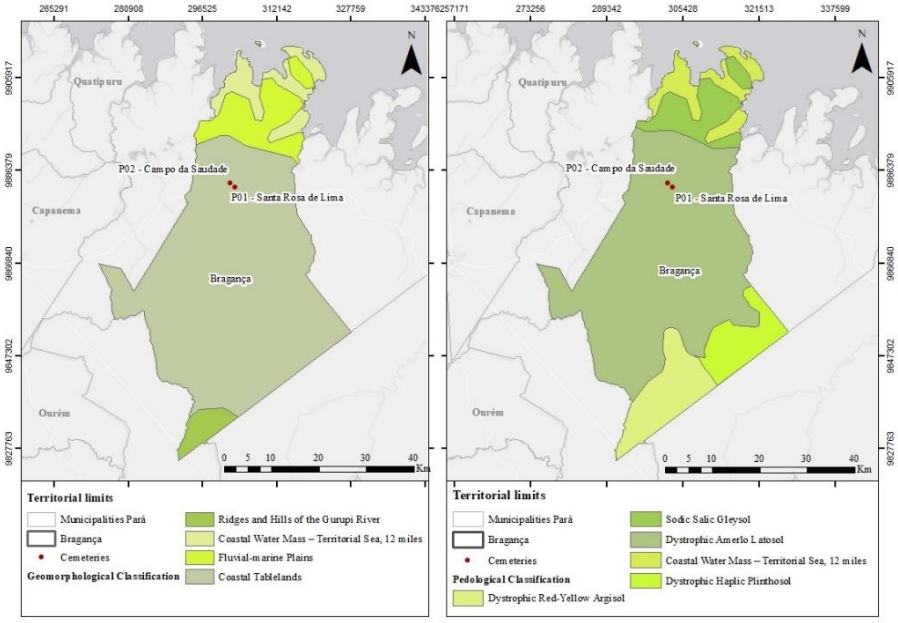
Figure 4. A - Geomorphological Classification and B – Pedological Classification of Bragança, Pará.



Source: SANTOS, 2024.

Vilas Boas and collaborators (2001) explain that the Coastal Tablelands constitute a geomorphological unit (table-shaped surface) developed on the Barreiras Group. This, in turn, is composed of an essentially siliciclastic sedimentary cover, of continental and marine origin, with an age between the lower/middle Miocene and the Pliocene. Pereira and Cestaro (2012) explain that the area of occurrence extends along the Brazilian coast from Amapá to Espírito Santo.

Studies conducted by Nunes et al. (2019) corroborate that Yellow Latosols predominate in the Coastal Tablelands. According to the same researchers, these soils originate mainly from muddy sandstones of the Barreiras Group.

When analyzing the geomorphology and pedology of Bragança (Table 02), it is possible to infer that this correlation also occurred, given that the area of the Coastal Tablelands and the incidence of LAd were the most representative among the investigated classes, 79.86% and 66.67%, respectively.

Table 2- Geomorphology and Pedology of Bragança, Pará.

Geomorphological Classes	Area (km²)	Area (%)
Ridges and Hills of the Gurupi River	62,10	2,96
Coastal Water Mass - Territorial Sea	149,00	7,01
Fluvial-Marine Plains	216,18	10,17
Coastal Tablelands	1.697,04	79,86
Total Area	2.125,04	100
Pedological Classes		
Dystrophic Red-Yellow Argisol	223,50	10,52
Sodic Salic Gleysol	176,03	8,28
Dystrophic Yellow Latosol	1.416,85	66,67
Coastal Water Body - Territorial Sea	148,93	7,01
Dystrophic Haplic Plinthosol	159,74	7,52
Total area	2.125,04	100

Source: SANTOS, 2024.

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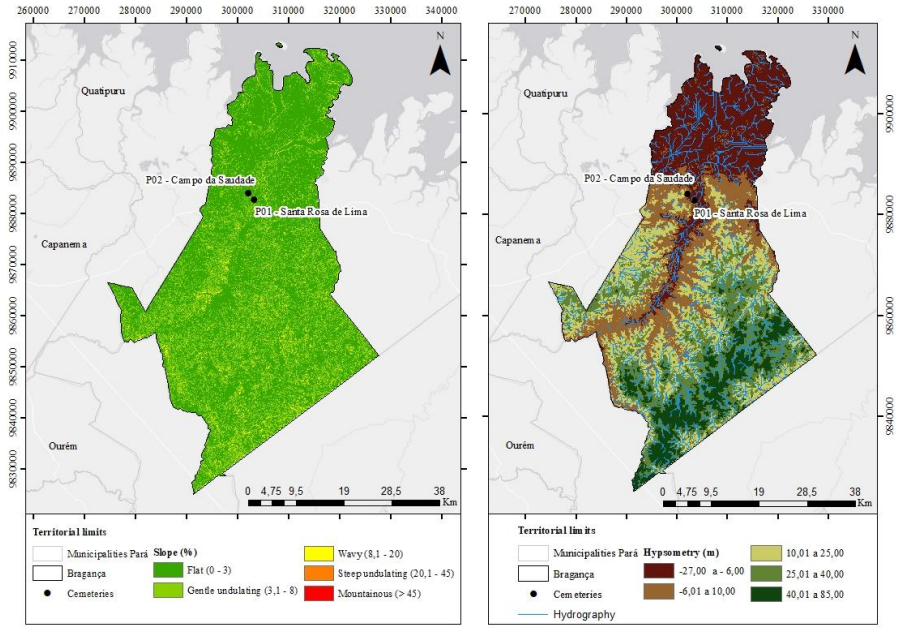
According to the Brazilian Soil Classification System (SBCS), Yellow Latosols (LA) have homogeneous horizons and uniformity in color, texture, and structure. According to the same author, they are deep, well-drained, and have low cation exchange capacity – CEC. LAds are often located in flat to gently undulating relief, where the slope is rarely greater than 7% (EMBRAPA, 2024).

Figure 5 shows the clinographic and hypsometric map of the municipality. From these thematic maps, it was possible to see that the Santa Rosa de Lima and Campo da Saudade cemeteries are in areas with a slope of 0 to 8%, denoting a flat to gently undulating relief and with altitudes between -6 and 25 m.

Figure 5. A - Clinography and B - Hypsometry of Bragança, Pará.



Source: SANTOS, 2024.

The areas with the most representative slopes were flat (69.44%) and gently undulating (28.65%), both covering approximately 98.10% of the studied area (Table 3). These are briefly uneven areas with minimal slopes. Under these conditions, it is assumed that infiltration will be optimized, and the soil will quickly exceed their infiltration capacity, which will, therefore, increase surface runoff.

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Table 3 - Quantification of the areas of the slope and altimetry classes of Bragança, Pará.

Relief classes	Area (km²)	Area (%)
Flat (0 – 3%)	1.475,56	69,44
Smooth Wavy (3 – 8%)	608,89	28,65
Wavy (8 – 20%)	40,56	1,91
Severe Wavy (20 – 45%)	0,02	0,00
Mountainous (45 – 75%)	-	-
Steep (>75%)	-	-
Total area	2.125,04	100
Altimetric classes (m)		
-27,00 a - 6,00	525,52	24,73
-6,01 a 10,00	427,16	20,10
10,00 a 25,00	515,70	24,27
25,01 a 40,00	442,66	20,83
40,01 a 85,00	214,01	10,07
Total area	2.125,04	100

Source: SANTOS, 2024.

Table 3 also shows that the necropolises are not located at the highest elevations of Bragança. Lower altitudes mean shorter distances between the necropolis leachate and the water table. For this reason, Leite (2009) recommends that cemeteries should not be located at lower elevations to which rainwater will naturally converge.

For Baum and Becegato (2018), establishing cemeteries is an activity that requires municipalities to be careful about their allocation in urban space and the environment. This is a crucial responsibility of the local administration, as it is the local administration's responsibility to organize its cemetery services. In the case of Bragança, the need for careful planning is even more pronounced, given the potential for contamination of its water resources resulting from cemetery activities.

Despite the jurisdiction of the Union and the State, as stated in its Organic Law, Art. 11: "VI - to protect the environment and combat pollution in any of its forms, including on the coasts, rivers, and lakes,"[1] it is believed that the municipal deliberations under the environmental and health biases are insipid or even non-existent regarding the potential for contamination of its water resources arising from cemetery activities in Bragança.

In Figure 6, where the controversial scenario is made explicit using the soothing solution to the flooding within the study areas, in which "drains" were opened, indicated by the yellow arrows, in the walls of the cemeteries. This mechanism aims to drain rainwater, probably contaminated by leachate, directly onto public roads where vehicles and the population pass.

[1] Original Portuguese passage “VI - proteger o meio ambiente e combater a poluição em qualquer de suas formas, inclusive nas orlas marítimas, fluvial e lacustre”

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Figure 6. Overflows for surface water drainage in the Santa Rosa de Lima cemetery, Bragança, Pará.

Source: CALDAS, 2024

However, Resolution No. 368/2006 of the National Environmental Council (CONAMA) provides clarifications and guidelines in its Article 5 regarding the adequacy of this non-conformity: "II - the perimeter and interior of the cemetery must be provided with an adequate and efficient drainage system, designed to capture, direct and dispose of rainwater runoff safely and prevent erosion, flooding, and earth movements;"[2]

In Figure 7, the second cemetery, Campo da Saudade, also does not have a drainage system inside and part of its perimeter is not waterproofed, which could allow excessive infiltration of rainwater, quickly exceeding the infiltration capacity of the soil, causing surface runoff (yellow arrow) and allowing maximum contact of surface and groundwater with the necroleachate.

Figure 7. Surface water runoff at the Campo da Saudade cemetery, Bragança, Pará.

Source: CALDAS, 2024.

Another aggravating factor verified in the field was the dissonance of Art. 5, IV, Resolution No. 355/2003: "[...] the burial area must maintain a minimum setback of five meters about the perimeter of the cemetery."3 However, in the Figure, the graves border the walls.

[2] Original Portuguese passage “II - o perímetro e o interior do cemitério deverão ser providos de um sistema de drenagem adequado e eficiente, destinado a captar, encaminhar e dispor de maneira segura o escoamento das águas pluviais e evitar erosões, alagamentos e movimentos de terra;”

[3] Original Portuguese passage “[...] a área de sepultamento deverá manter um recuo mínimo de cinco metros em relação ao perímetro do cemitério”

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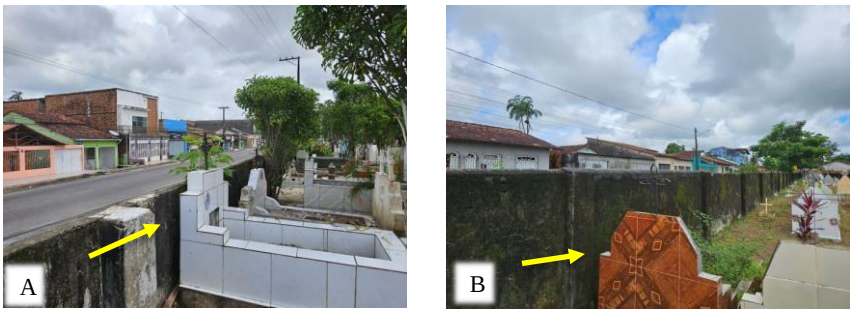
Figure 8. Setback of less than five meters in relation to the cemetery perimeter: A – Santa Rosa de Lima and B – Campo da Saudade, Bragança – Pará.



Source: CALDAS, 2024.

Although it is known that the Bragança necropolises are old and were established before the promulgation of the Brazilian Federal Constitution (1988), especially Article 225, which imposes on the Public Authorities and the community "the duty to defend and preserve the environment for present and future generations"[4] does not justify non-compliance with Article 11, CONAMA No. 402/2008: "State and municipal environmental agencies must establish criteria by December 2010 for the adaptation of cemeteries existing in April 2003"5.

Figure 9 shows that more than a decade after the established deadline, burials remain inadequate and largely directly in the ground. The yellow arrows reveal the water reservoirs for human supply and suggest the proximity of groundwater collection, possibly under the influence of necro leachate.

Figure 9. A - Graves located directly in the dystrophic Yellow Latosols and B - water reservoirs for human supply.

Source: CALDAS, 2024.

Like Bragança, the neighboring municipality of Tracuateua (Pará) also has homes with wells around cemeteries. For this reason, Gonçalves and Oliva (2019) performed microbiological analyses of groundwater from these wells and found Total and Thermotolerant Coliforms.

Thus, based on Ordinance No. 2,914/2011 of the Ministry of Health, the researchers concluded that such water did not meet the standards of potability for human consumption and represented a risk to the health of the inhabitants who consumed it. Despite the non-

[4] Original Portuguese passage “o dever de defender e preservar o meio ambiente para as gerações presentes e futuras”

[5] Original Portuguese passage “Os órgãos estaduais e municipais de meio ambiente deverão estabelecer até dezembro de 2010 critérios para adequação dos cemitérios existentes em abril de 2003”

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conformities arising from its tombs, Bragança shows slight progress when in its Master Plan (Law No. 3,875/2006), Art. 22, IV discusses the differentiation of locations for the installation of cemeteries, observing all the criteria in use by the legislation in force; VI - make a diagnosis of the current situation of the Santa Rosa de Lima Cemetery, but there is no reference to Campo da Saudade.

The Pará State Department of Environment and Sustainability (SEMAS) provides a checklist for environmental licensing of cemeteries. Its transparency portal states that environmental licenses are only granted for private cemeteries (SEMAS, 2024).

On the other hand, several municipalities have made significant progress in their cemetery activities, especially in neutralizing leachate, given that they have institutionalized jurisdiction and made it mandatory for all burials carried out in private, public or other cemeteries to use solutions that guarantee the accommodation and isolation of the corpse in the coffin, so that the grave, soil and water table are not contaminated by this liquid, for example, the reality in the city of Tubarão, in Santa Catarina (Decree No. 3498/2016); Goiânia, in Goiás (Decree No. 2,813/2019) and Macaíba – Rio Grande do Norte (Law No. 2,112/2020).

The scientific literature presents some technologies for mitigating and treating necro leachate as an alternative, such as microbiological tablets and absorbent blankets (LONGATTI, SANTOS, and PERON, 2020). For Hino (2015), bacterial tablets consume organic compounds that are difficult to metabolize, such as fats, oils, greases, and lipids, transforming them into carbon dioxide and water, while the blanket has a layer of powdered cellulose, which, when in contact with the necro leachate, will transform into a gel, which in turn will retain the funerary liquor and prevent it from overflowing during the colliquation process, a term used to describe the liquefaction of the corpse during decomposition (FRANCISCO et al., 2017).

Therefore, even though the cemeteries in Bragança are not in compliance with the principal legal regulations in force, it is understood that there are techniques and technologies for adaptation. However, it is necessary to involve the population in pluralizing environmental and sanitation issues so that citizens and the municipality can deliberate on the negotiations: how and when they will manage their burial activities to guarantee the perpetuity of the maximum quality of Bragança's water and soil resources.

5 CONCLUSION

Based on the above, it can be deduced that the current situation of the cemeteries in Bragança - Pará is worrying, as they are located in soils whose ability to retain trace elements (heavy metals) and humorous liquids is low, on minimal slopes and at inappropriate distances between graves and underground aquifers, thus configuring a situation of high risk and speed with which contaminants may reach the aquifers, whether they are superficial or underground.

However, a caveat is in order here: the results of geoprocessing and remote sensing indicate evidence of the presence of contaminating substances in soil and water resources and are not sufficient to guarantee the occurrence of contamination. For this purpose, physical-chemical and microbiological analyses of soil and water samples are mandatory to determine the degree of contamination in an area.

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Even so, it is essential to share these results to reiterate the importance of informing citizens about the risks of consuming water contaminated by leachate and its harmful effects on the environment and public health.

Therefore, adopting participatory management for the implementation of public policies may be a premise that reduces or even solves the inefficiency of environmental sanitation listed in this research.

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