

**SPATIAL DISTRIBUTION OF TUBERCULOSIS IN THE STATE OF MARANHÃO-BRAZIL, 2011-2023****DISTRIBUIÇÃO ESPACIAL DA TUBERCULOSE NO ESTADO DO MARANHÃO-BRASIL, 2011-2023****DISTRIBUCIÓN ESPACIAL DE LA TUBERCULOSIS EN EL ESTADO DE MARANHÃO (BRASIL), 2011-2023**

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**ABSTRACT**

Tuberculosis (TB) remains a serious global public health problem. This study aims to map the spatial distribution of TB cases in Maranhão, identifying areas with the highest concentration of cases. This is an ecological study using TB data reported in the Notifiable Diseases Information System (SINAN) in Maranhão between 2011 and 2023. Exploratory spatial analysis was conducted to determine the dynamics of TB. Case density was classified using the Kernel Density Estimator, with geocoding of the residential addresses of cases using Google Earth Pro. A total of 18,668 TB cases were reported in Maranhão. The spatial analysis revealed a heterogeneous distribution of cases, with significant concentrations in the North and East regions of the state, especially in the municipalities of São José do Ribamar and São Luís. Most cases were registered in the areas covered by the Regional Health Units (RHU) of the North, West, and East districts, with the South region presenting a lower density of cases. The identification of hotspots in the northern and eastern regions of Maranhão should guide the allocation of resources and the development of more effective control

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programs. The findings provide a solid basis for future research and public health actions to combat TB.

**Keywords:** Geoprocessing. Kernel Density Estimator. Spatial Analysis. Tuberculosis.

### RESUMO

A tuberculose (TB) continua sendo um grave problema de saúde pública global. Este estudo tem como objetivo mapear a distribuição espacial dos casos de TB no Maranhão, identificando as áreas com maior concentração de casos. Trata-se de um estudo ecológico que utiliza dados de TB notificados no Sistema de Informação sobre Doenças Notificáveis (SINAN) no Maranhão entre 2011 e 2023. Foi realizada uma análise espacial exploratória para determinar a dinâmica da TB. A densidade de casos foi classificada utilizando o Estimador de Densidade Kernel, com geocodificação dos endereços residenciais dos casos utilizando o Google Earth Pro. Um total de 18.668 casos de TB foram notificados no Maranhão. A análise espacial revelou uma distribuição heterogênea dos casos, com concentrações significativas nas regiões Norte e Leste do estado, especialmente nos municípios de São José do Ribamar e São Luís. A maioria dos casos foi registrada nas áreas cobertas pelas Unidades Regionais de Saúde (RHU) dos distritos Norte, Oeste e Leste, com a região Sul apresentando menor densidade de casos. A identificação de pontos críticos nas regiões Norte e Leste do Maranhão deve orientar a alocação de recursos e o desenvolvimento de programas de controle mais eficazes. Os resultados fornecem uma base sólida para pesquisas futuras e ações de saúde pública no combate à TB.

**Palavras-chave:** Geoprocessamento. Estimador de Densidade Kernel. Análise Espacial. Tuberculose.

### RESUMEN

La tuberculosis (TB) sigue siendo un grave problema de salud pública a nivel mundial. El objetivo de este estudio es cartografiar la distribución espacial de los casos de TB en Maranhão, identificando las zonas con mayor concentración de casos. Se trata de un estudio ecológico que utiliza los datos sobre TB registrados en el Sistema de Información sobre Enfermedades de Declaración Obligatoria (SINAN) en Maranhão entre 2011 y 2023. Se realizó un análisis espacial exploratorio para determinar la dinámica de la TB. La densidad de casos se clasificó utilizando el estimador de densidad kernel, con geocodificación de las direcciones residenciales de los casos mediante Google Earth Pro. Se notificaron un total de 18 668 casos de TB en Maranhão. El análisis espacial reveló una distribución heterogénea de los casos, con concentraciones significativas en las regiones norte y este del estado, especialmente en los municipios de São José do Ribamar y São Luís. La mayoría de los casos se registraron en las áreas cubiertas por las Unidades Regionales de Salud (RHU) de los distritos Norte, Oeste y Este, mientras que la región Sur presentó una menor densidad de casos. La identificación de los puntos críticos en las regiones norte y este de Maranhão debería orientar la asignación de recursos y el desarrollo de programas de control más eficaces. Los resultados proporcionan una base sólida para futuras investigaciones y acciones de salud pública para combatir la tuberculosis.

**Palabras clave:** Geoprocésamiento. Estimador de Densidad Kernel. Análisis Espacial. Tuberculosis.



## 1 BACKGROUND

Tuberculosis (TB) still represents a major challenge for global public health, especially in developing countries such as Brazil (PAHO, 2024; Brasil, 2022; Andrade *et al.*, 2020). In the Brazilian context, the state of Maranhão occupies a prominent position, presenting high incidence rates of the disease compared to other states in the federation, which demands a close and in-depth look at the behavior of the disease in the region (Andrade *et al.*, 2020; Bastos; Gomes; Campos, 2021). According to the World Health Organization (WHO, 2024) and a study conducted by Imtiaz *et al.* (2023), the state of Maranhão faces socioeconomic factors that contribute to the persistence of TB, such as social inequality, precarious housing conditions, low coverage of basic sanitation, and difficulties in accessing quality health services. These factors reflect a pattern observed in regions with a high burden of the disease, where undernutrition, poverty, and poor infrastructure significantly influence tuberculosis incidence rates (Iiyew *et al.*, 2024; Flores-Treviño *et al.*, 2019).

According to data from the Ministry of Health (2023), the state of Maranhão has one of the highest TB incidence rates in Brazil, with a significant impact on vulnerable populations, such as homeless people, indigenous people, and individuals deprived of liberty. These factors make studying TB in Maranhão essential to understanding the local particularities of the disease and assisting in the development of effective public policies for its control. The importance of studying TB lies in the fact that, although the disease is under control in many parts of the world, it is still a serious problem in regions with unfavorable socioeconomic conditions. Understanding the epidemiological behavior of TB in states such as Maranhão is crucial to developing regional strategies to combat the disease, taking into account the local factors that favor its spread, such as urban agglomerations, low education levels, and limited access to health services (Flores-Treviño *et al.*, 2019).

Furthermore, TB is one of the conditions that contribute to the increase in mortality from infectious diseases in Brazil. According to WHO data, Brazil is among the 30 countries with the highest number of tuberculosis cases in the world (PAHO, 2024). Therefore, knowing the peculiarities of the disease in states such as Maranhão and understanding its behavior in the region as a whole is essential for the development of public policies that reduce infection rates, guarantee access to treatment, and promote effective preventive actions.

Therefore, studying the behavior of TB, especially in the most affected regions such as Maranhão, is crucial to identify the main challenges in controlling the disease. In view of the above, the study proposes to map the health regions of the state of Maranhão and identify areas with the highest concentration of TB cases.



## 2 MATERIALS AND METHODS

### 2.1 STUDY SETTING

Ecological study carried out in the state of Maranhão, located in the Northeast region of Brazil. It has a territorial extension of approximately 330 thousand km<sup>2</sup>, a resident population of 6,776,699 people, and a population density of 20.56 inhabitants/km<sup>2</sup>. According to data from the State Department of Health, in 2023 Maranhão registered 3,542 cases of TB, of which 2,788 were confirmed, resulting in 529 deaths. So far, in 2024, the state has reported 421 cases, with 325 confirmations and 35 deaths related to the disease (SESMA, 2024).

### 2.2 POPULATION, INFORMATION SOURCES AND CRITERIA

The study included all cases of pulmonary and extrapulmonary TB reported in Maranhão from 2011 to 2023, as recorded in the Notifiable Diseases Information System (SINAN). SINAN is the Brazilian information system responsible for recording and processing information on notifiable diseases throughout Brazil, such as TB, providing epidemiological bulletins and reports, and is one of the main surveillance systems in the country.

The inclusion criteria were all confirmed cases of TB, of any age group, reported in SINAN between 2011 and 2023, of people residing in the state of Maranhão. In the case of duplicate records, only the most recent one was considered. Those who did not fill in the variable regarding their residential address were excluded from the study.

### 2.3 DATA ANALYSIS

Exploratory spatial analysis was performed to determine the dynamics of TB, in order to verify whether spatial variation occurs randomly in space or whether there is a pattern around the Basic Health Units (UBS) and TB referral hospitals in the state of Maranhão.

The Kernel density estimator was used to classify the health regions of the state of Maranhão according to the density of TB cases. Initially, it was necessary to geocode the cases by obtaining the geographic coordinates (latitude and longitude) of the residential addresses of the TB cases using the Google Earth Pro tool. Information related to the patient's residential address (street name, city, zip code, house number, and state) was used, which was concatenated into a single cell. Subsequently, this data was taken to the online package Google Sheets and geocoded using the Geocode by Awesome Tables extension. Based on the values of the geographic coordinates obtained, georeferencing was performed using the QGIS 3.28.12 software.



After the georeferencing process of the cases was completed, the point density analysis was performed, defined as the Kernel intensity estimator, using the ArcGIS 10.5 software. This consists of an exploratory interpolation method based on the definition of circular areas of influence around points where a phenomenon occurs, generating a density surface to identify vulnerable areas (Prado Junior; Virgilio; Medronho, 2024; Queiroz *et al.*, 2018).

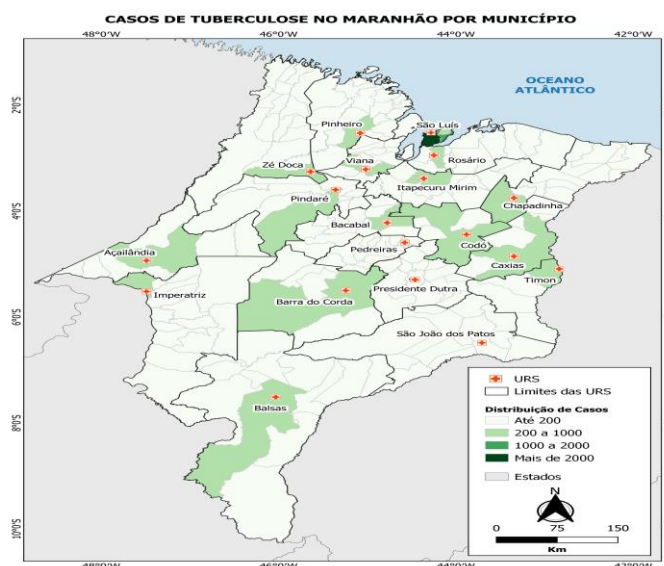
The Kernel estimator has as its basic parameters the radius of influence, which defines the neighborhood of the point to be interpolated and controls the degree of smoothing of the generated surface (a radius of 15 km was considered), and an estimation function with properties for smoothing the phenomenon. Thus, the Kernel estimator is very useful for providing an overview of the distribution of sample points, as well as being an indicator of the occurrence of clusters (Queiroz *et al.*, 2018; Duarte *et al.*, 2018).

#### 4 RESULTS

Between 2011 and 2023, 18,668 cases of TB were reported in the state of Maranhão. Figure 1 shows the distribution of TB cases reported in Maranhão according to the municipality of residence. It is possible to note that, although most municipalities in Maranhão registered less than 200 cases, the distribution of municipalities that presented between 200 and 1,000 cases occurred in a heterogeneous manner in space, with no large clusters being observed. The municipalities of São José do Ribamar, which registered between 1,000 and 2,000 cases, and the capital São Luís, with more than 2,000 cases, stand out.

**Figure 1**

*Distribution of tuberculosis cases in the state of Maranhão by municipality*



Source: author's own work, 2025.



Table 1 shows the number of TB cases according to RHU, ranging from 350 cases in São João dos Patos to 13,060 cases in São Luís.

**Table 1**

*Number of tuberculosis cases registered in Maranhão, according to Regional Health Units (2011-2023)*

<b>Regional Health Unit</b>	<b>N of TB cases</b>
São João dos Patos	350
Balsas	541
Presidente Dutra	654
Pedreiras	785
Açailândia	804
Timon	821
Rosário	881
Chapadinha	898
Barra do Corda	906
Viana	1017
Zé Doca	1139
Itapecuru-Mirim	1170
Bacabal	1192
Caxias	1193
Codó	1316
Pinheiro	1386
Imperatriz	1762
Santa Inês	1853
São Luís	13060
<b>Total</b>	<b>18.668 cases</b>

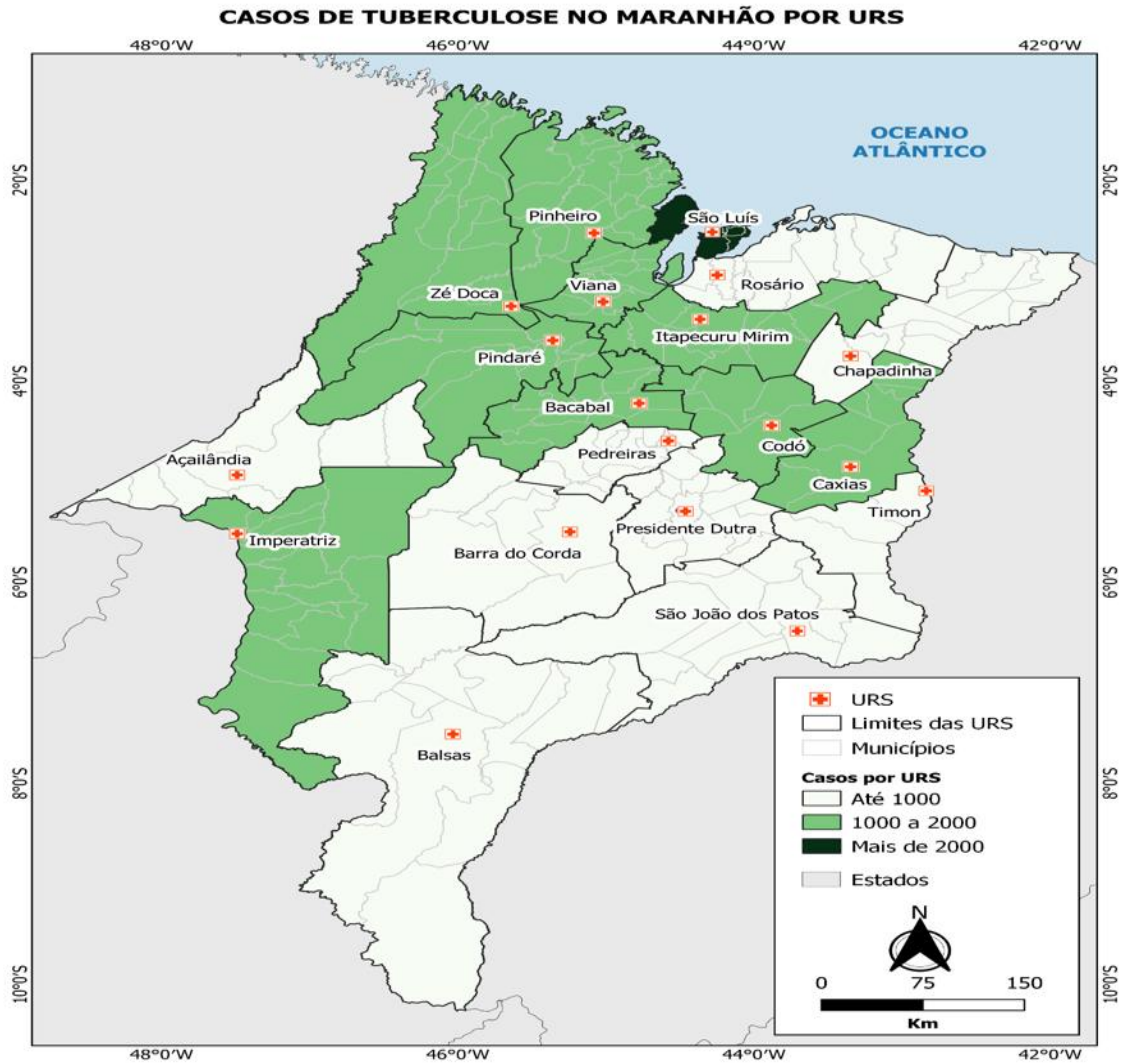
Source: author's own work, 2025.

Corroborating the findings in Table 1, Figure 2 shows how these cases are distributed in the space of TB cases according to the RHU ratio, ranging from 350 cases in São João dos Patos to 1,853 cases in Santa Inês. It is possible to observe that the majority of cases affected people living in the areas covered by the URSs of the North, West, and East districts of Maranhão, with emphasis also on the South region, with the formation of clusters and not being randomly distributed in space.



Figure 2

Distribution of tuberculosis cases in the state of Maranhão by health regions.



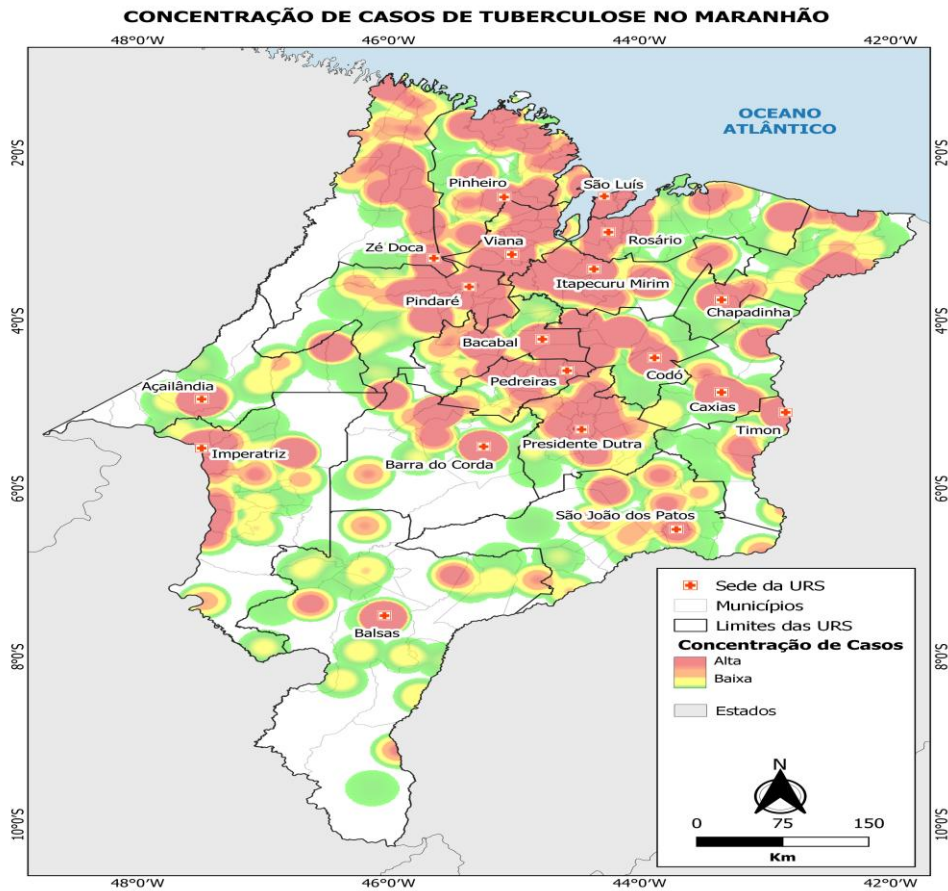
Source: author's own work, 2025.

Using the Kernel intensity estimator, it was possible to identify hotspots and coldspots distributed throughout the state of Maranhão. In Figure 3, we can see that the areas with the highest density of cases are located in the North and East regions of the state, while the South region has a lower concentration of cases.



**Figure 3**

*Kernel map based on the georeferencing of TB cases by year of notification in the state of Maranhão*



Source: author's own work, 2025.

## 5 DISCUSSION

The analysis of the spatial distribution of TB cases in the state of Maranhão between 2011 and 2023 reveals important insights into the epidemiology of the disease in the region and is important for identifying priority areas for public health interventions aimed at reducing the incidence of TB.

The results show a heterogeneous distribution of cases, with emphasis on the capital São Luís and the municipality of São José do Ribamar, which recorded the highest concentrations of cases. Approximately 96% of the municipalities recorded up to 500 cases, and the municipality of São Luís is responsible for approximately one-third of the total cases, demonstrating the disproportionality in the spread of the disease in relation to the size of the population and the health infrastructure (SESMA, 2024).

This concentration of cases is not an isolated phenomenon and has also been observed in other regions of Brazil. A study conducted in Rio de Janeiro highlighted an uneven distribution, with most cases concentrated in densely populated urban areas, such



as favelas, where overcrowding and inadequate housing conditions favor the spread of TB (Pereira *et al.*, 2018). The situation in São Luís is similar, where population density and socioeconomic challenges aggravate the spread of the disease, concentrating cases in urban areas.

Compared to other regions of Brazil, it can be observed that the distribution of TB in Maranhão also presents similarities with that of Rio Grande do Sul, where there is also a high concentration of cases in urban areas and specific regions (Soeiro; Caldas; Ferreira, 2022). However, the situation in Maranhão is aggravated by the poorer health infrastructure and greater socioeconomic disparities, which can make it difficult to control the disease (Aragão *et al.*, 2024). In Maranhão, the high incidence of TB in areas with lower population density and limited infrastructure reinforces the need for public policies that address not only the treatment of the disease but also the underlying social conditions (Aragão *et al.*, 2024).

The classification of municipalities in Maranhão into case count ranges—up to 200, 200 to 1,000, 1,000 to 2,000, and over 2,000—reflects a pattern that can also be observed in other developing countries. In India, georeferencing studies of TB cases have shown a similar division, with most cases concentrated in large urban centers, while rural areas had lower absolute numbers but significant diagnostic and treatment challenges due to poor access to health services (Singh *et al.*, 2020).

This concentrated distribution is often explained by socioeconomic and demographic factors. In countries such as Brazil and India, the most vulnerable urban populations are the most affected, and rural areas, although with a lower density of cases, face difficulties in treatment and prevention due to a lack of resources and health infrastructure (Oliosí *et al.*, 2019). The context in Maranhão, with São Luís leading the number of cases, reflects these structural and social challenges, similar to those observed in other parts of the world.

A relevant example is the state of Pernambuco, where a study (Rodrigues *et al.*, 2023) showed that TB is also highly concentrated in metropolitan areas, such as Recife, which leads in the number of TB cases, while municipalities in the interior have a lower incidence. This pattern of concentration is largely attributed to population density, precarious housing conditions, and social inequality, factors that are similar to those observed in São Luís (Bógus; Magalhães, 2022). As in Maranhão, in Pernambuco, cases are distributed in intervals, where regions with higher urban concentrations, such as the Metropolitan Region of Recife, are associated with more than 2,000 cases, while municipalities in the interior generally have less than 500 cases.

Another point in common between the two states is the impact of social determinants of health, such as poverty, inadequate housing, and lack of access to health services, which



contribute to the perpetuation of the disease in the most populated and vulnerable urban areas. A study carried out in Pernambuco reinforces the importance of public policies aimed at controlling tuberculosis in urban areas and the need to improve health infrastructure in regions with the highest incidence of the disease (Barreto, 2017).

The use of spatial analysis and geoprocessing techniques is essential for studying TB, as they allow the identification of disease distribution patterns and the association with socioeconomic and environmental factors. This study, which mapped the distribution of TB cases between 2011 and 2023, is of great importance for public health, as it provides critical data for the formulation of more effective control and prevention policies. The use of geoprocessing techniques, such as the Kernel Intensity Estimator, makes it possible to identify hotspots, or areas of high concentration of cases, and coldspots, areas with lower incidence. These methods are essential for directing resources and efforts to the most affected regions, promoting a more efficient and equitable allocation of health services (Pereira *et al.*, 2018).

In the context of Maranhão, the identification of regions with a high density of cases, such as the North and East regions, and the lower concentration in the South region, reinforces the need for specific and targeted interventions. Spatial analysis allows not only the visualization of the distribution of cases, but also the understanding of the factors that contribute to the spread of the disease, such as population density, health infrastructure, and socioeconomic conditions (Nogueira *et al.*, 2019).

In the international context, countries such as India have also used Kernel-Based Heat Mapping to map the distribution of tuberculosis in urban and rural areas. In New Delhi, the use of this technique revealed concentrations of cases in areas with high population density and poor sanitary conditions. The analysis allowed the creation of alert zones, facilitating the targeting of resources and interventions in areas of greatest risk (Singh *et al.*, 2020).

In addition to the above, this study innovates by using the state's RHU as the unit of analysis, as it allows for more precise and segmented mapping of the distribution of TB. This type of mapping by health region is essential for decision-making in public policies, since the concentration of cases within a URS may indicate the need for more targeted and effective intervention. By using this information, health managers can allocate resources more efficiently, prioritizing the URS with the highest number of cases, which require special attention, not only in terms of disease control, but also in prevention campaigns, improved diagnosis, and expanded access to treatment. This also makes it possible to compare different URS and understand the local dynamics that contribute to the spread of the disease, such as socioeconomic conditions, population density, and access to health services.



In other states, such as Minas Gerais, analysis by health regions has been essential for identifying disease hotspots and organizing public health interventions. Studies conducted in Belo Horizonte, for example, have shown that the use of geospatial data to define priority regions allows for more strategic planning in the fight against tuberculosis, focusing on areas with the highest incidence of cases and conditions of vulnerability (Santos *et al.*, 2021).

Similarly, countries such as Mexico also use segmentation by health regions to monitor the incidence of tuberculosis and identify areas that require more incisive actions. A study conducted in Mexico City demonstrated that analysis by regions facilitates the implementation of public policies and ensures that resources are distributed more equitably, reaching the most affected areas (Silva *et al.*, 2022).

It is important to highlight that the present study has some limitations that should be considered when interpreting the results. First, the use of secondary databases may introduce biases related to the quality and completeness of the data. Data from mandatory notifications, for example, may be subject to underreporting or recording errors, which may affect the accuracy of the analyses [25]. Furthermore, the reliance on secondary data limits the ability to collect additional information that could be relevant to the study, such as details on the socioeconomic conditions of the patients. Another important limitation is the ecological nature of the study. Ecological studies analyze aggregate data rather than individual data, which may lead to erroneous inferences about the relationship between variables at the individual level (ecological fallacy) (Queiroz *et al.*, 2024). Although these studies are useful for identifying patterns and trends in large populations, they do not allow for establishing direct causality between the factors analyzed and the incidence of TB.

Georeferencing, although a powerful tool for spatial analysis, also presents challenges. The accuracy of geographic data may vary, especially in rural or less developed areas where mapping infrastructure may be limited (Pavinati *et al.*, 2024). Furthermore, spatial analysis requires advanced statistical techniques to address spatial autocorrelation and other factors that may influence the distribution of TB cases. Despite these limitations, the findings provide a solid basis for future research and public health action. Continued investment in epidemiological surveillance systems and health infrastructure is essential to improve data collection and quality, as well as to develop more effective control strategies.

## 6 CONCLUSIONS

This study contributes significantly to the understanding of TB epidemiology in Maranhão and provides a solid basis for the development of more effective control strategies. The application of geoprocessing and spatial analysis techniques is crucial to address the



challenges of TB, especially in regions with large socioeconomic disparities and limited health infrastructure. Thus, the importance of URS case mapping data in Maranhão is directly related to the ability to plan and execute interventions based on concrete and regional data, allowing a more agile and effective response to combat TB.

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