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# Spatial analysis of tuberculosis and its relationship with socioeconomic factors in Paraíba: An ecological study

## Análise espacial da tuberculose e sua relação com fatores socioeconômicos na Paraíba: um estudo ecológico

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## ABSTRACT

**Objective:** To analyze the spatial distribution of tuberculosis and its association with socioeconomic factors. **Method**: A mixed-methods ecological study with spatial analysis of tuberculosis cases in the state of Paraíba, reported from 2015 to 2018. **Results:** A total of 6,082 cases were reported, with a mean incidence of 37.4/100,000 inhabitants. No municipality was classified as having "very low" development, although statistical significance exists between the incidence rates and the socioenvironmental factors. **Conclusion:** The Moran Index pointed out a positive autocorrelation between areas with high incidence values. The Moran Map reveals clusters that indicate a concentration of the infection between *Zona da Mata* and *Agreste Paraibano*, the largest of which comprises 19 municipalities.
**Descriptors:** Spatial Analysis; Tuberculosis; Health Information Systems.

## RESUMO

**Objetivo:** Analisar a distribuição espacial da tuberculose e sua associação com fatores socioeconômicos. **Método**: Estudo ecológico, misto, com análise espacial dos casos de tuberculose no estado da Paraíba, notificados no período de 2015 a 2018. **Resultados:** Foram notificados 6.082 casos, com incidência média de 37,4/100 mil habitantes. Nenhum município foi classificado com desenvolvimento "muito baixo", embora exista significância estatística entre as taxas de incidência e os fatores socioambientais. **Conclusão:** O índice de Moran apontou autocorrelação positiva entre as áreas com altas incidências. O *Moran Map* releva *clusters* que indicam concentração da infecção entre a Zona da Mata e o Agreste Paraibano, sendo o maior deles formado por 19 municípios.
**Descritores:** Análise Espacial; Tuberculose; Sistemas de Informação em Saúde.

## INTRODUCTION

Tuberculosis is an infectious and contagious disease caused by a bacterium in the *Mycobacterium tuberculosis* complex, popularly called Koch's Bacillus. It mainly affects the lungs (pulmonary form) but can reach several organs or tissues (extrapulmonary form). Despite having therapy instituted free of charge and is curable, it is the single-agent infectious disease that kills the most people in Brazil and the world, only surpassed by SARS-CoV-2 in the pandemic scenario since 2020[1,2].

Therefore, the disease remains a challenge to health authorities worldwide. It is estimated that, in 2021, Brazil reported nearly 68,271 new Tuberculosis (TB) cases, representing an incidence coefficient of 32 cases per 100,000 inhabitants, showing a declining trend when compared to previous years, but which can be justified by the impacts of the COVID-19 pandemic on health services and systems[3,4].

As well as other important diseases in the epidemiological scenario, the occurrence of TB and its distribution in the geographical space are closely related to sociodemographic factors. Knowing the clinical panorama of tuberculosis in the population, the distribution patterns in the territory, and its relationship with social factors, can provide important information for planning and decision-making, potentially contributing to the management and allocation

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of health resources[5,6].

Tuberculosis infection has always been described by countless scholars as a disease closely related to living conditions, with poverty as one of the strongest determinants for its occurrence and determining the deterioration of the disease symptoms[7,8]. Its occurrence is strongly associated with social and economic indicators: type of housing, subnormal clusters, *per capita* income, eating habits, access to health services, preexisting diseases (mainly immunosuppressive ones), and comprehensive basic sanitation service[9-12].

The World Health Organization (WHO) recognized tuberculosis as a public health emergency, considering its magnitude and social and economic impacts, and, in recent decades, it has encouraged countries to develop policies and actions to fight against the infection. The goal is to reduce its incidence to less than 10 cases per 100,000 inhabitants[13]. To this end, it started to recommend carrying out various actions, including a partisan commitment of the federated bodies with an increase in human resources, as well as the guarantee of financial funds that enable elaborating and executing plans in order to contain and control TB infection, also counting on social participation[14]

Therefore, the use of spatial statistics in public health becomes an essential tool for planning managerial actions in fighting against tuberculosis, as it allows identifying vulnerable areas and populations at increased risk taking into account socioenvironmental factors, allowing to understand the variables involved in ecological and individual studies of the infection through appropriate analysis techniques, supporting collective risk surveillance in order to understand and control endemic processes[15,16].

This article aims to analyze the spatial distribution of tuberculosis, verify the existence of spatial dependence between the Paraíba municipalities, and investigate the possible association of the disease with socioeconomic factors, data that objectively characterize the living conditions of the Brazilian population according to the classifications proposed by the Brazilian Institute of Geography and Statistics.

## METHODS

A mixed-methods ecological study with spatial analysis of tuberculosis cases in the state of Paraíba, reported from 2015 to 2018.

The study was conducted in Paraíba, on the East coast of northeastern Brazil. The state has a territory of 56,468.435 km², divided into 223 municipalities. In 2010, Paraíba had 3,766,528 residents, with a "moderate" Municipal Human Development Index (MHDI), a "low" Social Vulnerability Index (SVI), and "high" social prosperity, according to the 2010 Census[17].

The data used were those from the Notifiable Diseases Information System (*Sistema de Informação de Agravos de Notificação*, SINAN), made available by the Center for Endemic Diseases and the Department for Combating Tuberculosis of the State Health Department. Notifications that presented duplicity had no information on the municipality of residence, and those that displayed a change in diagnosis were excluded. The information on socioeconomic, sociodemographic, and population conditions came from the 2010 demographic census conducted by the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*, IBGE)[17-19]. All data were collected in March 2021.

The mean coefficient (per 100,000 inhabitants) of the tuberculosis cases for each year related to the study was used as the dependent variable. To describe the socioeconomic context, the following variables were used: population in households with piped WATER "*T AGUA*"; population in households with bathroom and piped water "*T BANAGUA*"; population in households with a density greater than two people per bedroom "*T DENS*"; population in households with garbage collection "*T LIXO*"; population in households with electricity "*T LUZ*"; people in households with ab inadequate water supply and sewage "*AGUA-ESGOTO*"; Municipal Human Development Index "*IDHM*"; and proportion of literate individuals "*T ANAL*". The abbreviations used follow those employed by the IBGE (in Portuguese).

The MHDI reflects on population longevity, schooling level, and income and is categorized into 4 strata ranging from 0 to 1; such measures are directly proportional and classified as follows: "Very low" MHDI = (from 0.000 to 0.499); "Low" MHDI = (from 0.500 to 0.599); "Medium" MHDI = (from 0.600 to 0.699); "High" MHDI = (from 0.700 to 0.799) and "Very high" MHDI = (from 0.800 to 1.000)[20].

To identify the concentration of cases (clusters) and disease transmission areas, the mean incidence per 100,000 inhabitants for each year was considered individually to allow time evaluation, visualizing the spatial disposition of the TB notifications throughout the state. For the calculation, the accrued mean of notifications from 2015 to

2018 was considered to minimize possible variations and improve test stability, mainly in the units (municipalities) with very small population density values.

To verify the similarity in the measurements of the attributes related to the areas in the study region in a visual way, the maps of quartiles, Moran scatter plot, and Moran Map were prepared. The Moran scatter diagram is a supplementary methodology for visualizing spatial dependence. Formulated based on normalized values (values of attributes subtracted from their mean and divided by the standard deviation), it allows analyzing the spatial variability pattern. It is calculated by spatial autocorrelation between neighbors.

To verify spatial autocorrelation, the Global and Local Moran Indices (GMI and LMI) were used, then representing a tool to test global autocorrelation and detect spatial objects with influence on global and local indicators in the study. This index varies from -1 to 1, where greater proximity to the extremes indicates significant autocorrelation, and greater proximity to zero indicates complete randomness under the null hypothesis of the nonexistence of a spatial autocorrelation structure across the study's municipalities[21].

The Local Moran Index was used to show places with greater dependence and autocorrelation. Unlike its Global counterpart, it produces specific indicators for each geographical space under study, in this case, the municipalities that make up the state of Paraíba, allowing the identification of groups that produce similar (clusters) or different (outliers) values and spatial regimes not perceived through the global results.

Application of this technique allows distributing the units under study (municipalities) into different previously classified quadrants and translating the spatial association, namely: (high-high) quadrant, municipality with high incidence values surrounded by municipalities with also high incidence values; (low-low) quadrant, municipalities with low incidence values surrounded by municipalities with low incidence values, indicating positive spatial autocorrelation; (high-low) quadrant, municipalities with high incidence but surrounded by municipalities with low incidence; and (low-high) quadrant, represented by municipalities with low incidence surrounded by municipalities with high incidence, indicating transition areas with negative spatial autocorrelation.

The Moran Map was used to visually represent the results obtained from the scatter diagram, considering a significance level <5%. Areas with high risk for disease transmission and high incidence values were considered according to the neighborhood pattern, with municipalities presenting similar characteristics. The geographical coordinates referring to the state of Paraíba came from the IBGE online database, in vector format stored by *shapefiles* (.shp), geographic arrangement display system (latitude, longitude), and Geocentric Reference System for the Americas (*Sistema de Referência Geocêntrico para as Américas*, SIRGAS 2000).

At a second moment, the possible association of the socioeconomic and sociodemographic variables with the dependent variable (TB) was evaluated using the linear and spatial regression model. Selection of the appropriate model for each year was carried out using the Akaike Information Criterion (AIC), where the most appropriate model was the one that obtained the lowest AIC value.

The R Core Team free domain statistical software, version 1.2.5, was used for cartographic data processing, analysis and presentation, calculation of the spatial autocorrelation indicator, and production of the choropleth maps. The Research Ethics Committee of the State University of Paraíba approved the research project under opinion No. 4,257,968.

## RESULTS

In the period from 2015 to 2018, 6,082 TB cases were diagnosed and reported in individuals living in the state of Paraíba, maintaining an incidence rate per 100,000 inhabitants higher than the one expected for the country, with a major increase in 2018, when its population structure borders the standardization margin for previous years (Table 1). In turn, when analyzing the MHDI in the 223 municipalities of the state, 152 of them are classified as with low development.

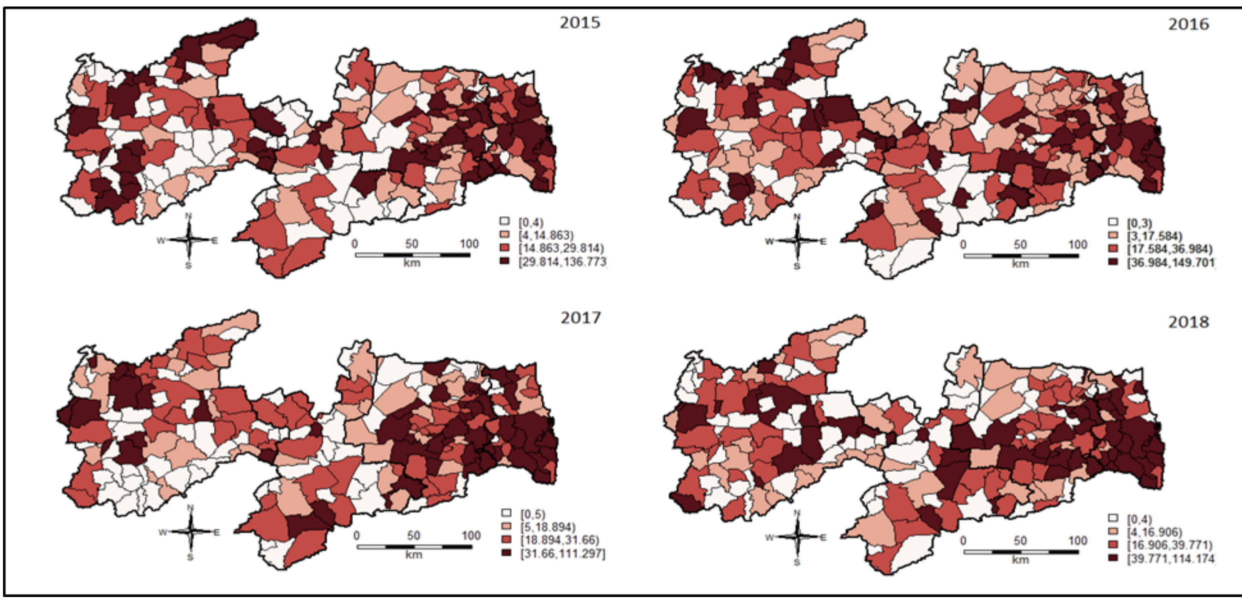
In the distribution of quartiles presented in the Box Map (Figure 1), it is possible to verify that the municipalities with the highest TB incidence for all years were those that belong to *Mata Paraibana* and *Agreste Paraibano*, also called the coastal region, with 86 of these municipalities considered priorities for coping with TB, presenting greater cluster formation in all years.

Between 2015 and 2018, the *Sertão Paraibano* mesoregion municipalities were in second place regarding the TB incidence rate. This may be justified because it is the mesoregion with the largest territorial extension, comprised of 83 municipalities, with Cajazeiras, Souza, and Patos

**Table 1 -** Annual incidence rate of tuberculosis (per 100,000 inhabitants) in the state of Paraíba, from 2015 to 2018. Campina Grande, PB, Brazil, 2021

| Years analyzed | Population | Total cases | Incidence of cases per 100,000 inhabitants |
|---|---|---|---|
| 2015 | 3,972,202 | 1,345 | 33.86031224 |
| 2016 | 3,976,851 | 1,491 | 37.49197543 |
| 2017 | 4,002,896 | 1,483 | 37.04817712 |
| 2018 | 3,973,940 | 1,763 | 44.36403167 |

Sources: SINAN; IBGE, 2020.




Source: Prepared by the authors, 2021.

**Figure 1 -** Distribution of the tuberculosis incidence rate for the municipalities of Paraíba from 2015 to 2018. Campina Grande, PB, Brazil, 2021

among them. These three cities form an important educational center, comprising important educational institutions and attracting an important immigration flow, a process responsible cities' overcrowding and forming agglomeration spaces, which can provide an ideal environment for disease transmission.

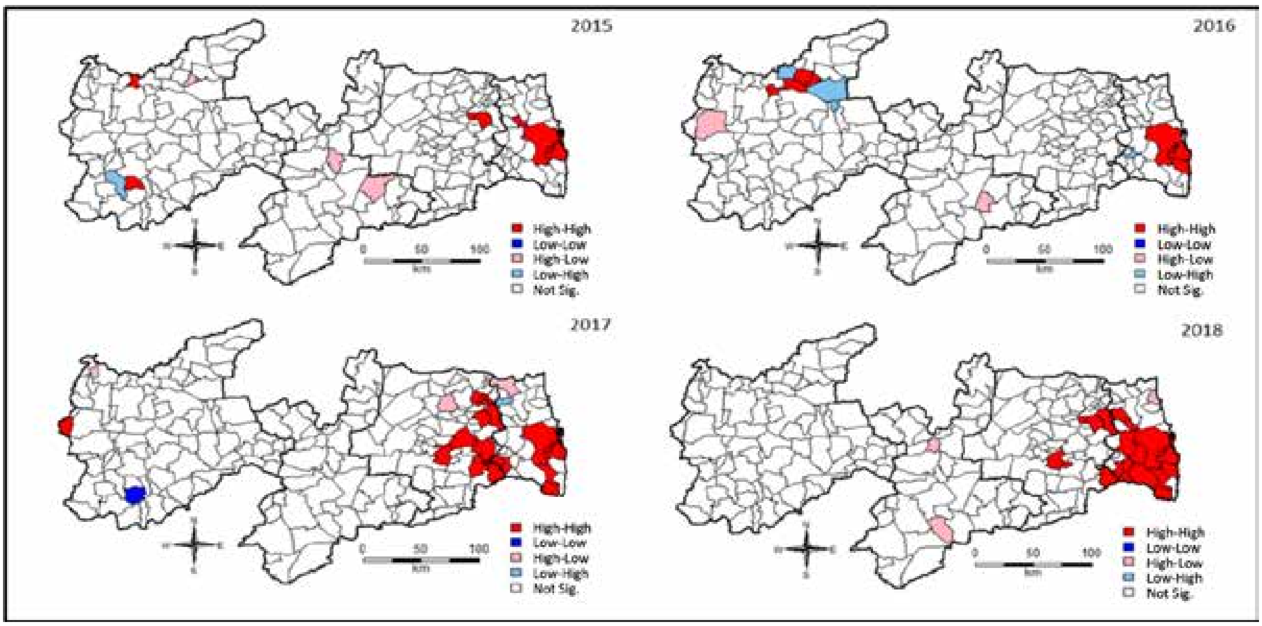
Observing the Global Moran Index results (Table 2), it is possible to conclude the existence of positive spatial autocorrelation across the municipalities for 2015, 2017, and 2018, indicating that TB occurrence is somehow associated with its location and with the social characteristics of those places. On the contrary, the global autocorrelation is negative for 2016, and when corrected for the application of the Local Moran Index, it also shows a positive autocorrelation (Figure 2). The Moran Map (Figure 2) revealed a persistent concentration of cases in 19 municipalities belonging to the *Mata Paraibana* and *Agreste Paraibano* mesoregions. They appear as municipalities with a high proportion of the indicator, surrounded by others with high proportions (high-high).

Application of the linear and spatial regression model verified statistical significance for the occurrence of tuberculosis with the following variables: MHDI, illiteracy; piped water and appropriate sewage; no bathroom with water; and subnormal clusters, characterized by more than two residents per bedroom and electricity in the house (Table 3).

**Table 2 -** Global Moran Index per year based on the total incidence from 2015 to 2018 in the state of Paraíba. Campina Grande, PB, Brazil, 2021

| Years | Global Moran Index | Statistics | p-value |
|---|---|---|---|
| 2015 | 0.090965439 | 0.01188 | <0.05 |
| 2016 | 0.028012094 | 0.2205 | |
| 2017 | 0.262587045 | 1.46E-07 | <0.05 |
| 2018 | 0.163606041 | 3.81E-02 | <0.05 |

Source: Prepared by the authors, 2021.




Source: Prepared by the authors, 2021.

**Figure 2 -** Moran Map: It shows areas with local autocorrelation for the tuberculosis incidence rate in the municipalities of Paraíba from 2015 to 2018. Campina Grande, PB, Brazil, 2021

## DISCUSSION

It can be noticed that the high incidence values for tuberculosis occur in an inhomogeneous way throughout the state but more expressively in the municipalities located in *Zona da Mata* and *Agreste Paraibano*. Although these regions have a fair MHDI, some scenarios that characterize social inequality, such as lack of access to sanitation services in an integral way and home environments incompatible with the family structure. It should be noted that no municipality has its MHDI classified as "very low" or "very high".

When analyzing the municipalities with "high incidence" together with their MHDIs, all are classified with the development between "low" and "medium", but in an increasing trend, opposing the literal scenario on the distribution of neglected diseases in Brazil, suggesting that there is a need for improvement or rescheduling of health and tuberculosis control actions in the state. It is noteworthy that, for most studies, the commonality is a higher prevalence of neglected diseases associated with "very low" MHDI values[22,23].

Despite the marked heterogeneity of the spatial distribution of TB cases, it is necessary to point the spotlight to the municipalities at a high risk of active disease transmission. The formation of clusters of municipalities with high incidence rates in *Zona da Mata* and *Agreste Paraibano* demarcates those deserving attention and priority interventions. However, it is necessary to highlight a high number of municipalities with "zero" incidence, which may indicate underreporting. This finding makes it difficult to interpret the

**Table 3 -** Tables of the estimated coefficients from the Regression models – From 2015 to 2018. Campina Grande, PB, Brazil, 2021

| 2016 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Covariates** | **ML** | **p-value** | **SAR** | **p-value** | **SEM** | **p-value** | **SDM** | **p-value** |
| Intercept | - | | -78.1835 | 0.0220 | - | | - | - |
| *IDHM* | - | | 128.2398 | 0.010585 | - | | 239.52397 | 0.003558 |
| *T ANALF* | - | | 0.89717 | 0.002733 | - | | 1.0411 | 0.0400 |
| *T DENS* | - | | - | - | - | | 0.82801 | 0.022248 |
| *AIC* | - | | 2,094.2 | | - | | 2,097.5 | |
| *RHO* | - | | 0.0069419 | | - | | -0.00082534 | |
| Test residual | - | | 0.2993 | | - | | 0.045231 | |
| 2017 | | | | | | | | |
| **Covariates** | **ML** | **p-value** | **SAR** | **p-value** | **SEM** | **p-value** | **SDM** | **p-value** |
| Intercept | -80.12 | 0.002377 | -70.0609 | 0.0038 | -48.777 | 0.034746 | -7.2996 | 0.825248 |
| *IDHM* | 96.517 | 0.020025 | 88.2267 | 0.021442 | 117.896 | 0.002657 | 125.3356 | 0.002314 |
| *T AGUA* | 0.4835 | 5,59E-05 | 0.33342 | 0.002414 | - | | - | |
| *AGUA-ESGOTO* | 0.6404 | 0.000244 | 0.42674 | 0.007742 | - | | - | |
| *AIC* | 1,988.1 | | 1,968.8 | | 1,972.1 | | 1,973.7 | |
| *RHO* | - | | 0.39984 | | 0.47421 | | 0.47299 | |
| Test residual | - | | 2.2173 | | - | | 0.99671 | |
| 2018 | | | | | | | | |
| **Covariates** | **ML** | **p-value** | **SAR** | **p-value** | **SEM** | **p-value** | **SDM** | **p-value** |
| Intercept | -58.15 | 0.00211 | -51.7999 | 0.0047 | - | | - | |
| *IDHM* | - | | - | - | 129.528 | 0.033896 | 187.0095 | 0.0006585 |
| *T BANAGUA* | 0.7771 | 7,93E-06 | 0.67707 | 6,27E-05 | 0.57887 | 0.002113 | - | |
| *T DENS* | 0.6347 | 0.02282 | 0.53629 | 0.049116 | 0.67619 | 0.028996 | - | |
| *T LIXO* | - | | - | - | - | | -5.6458 | 0.0238475 |
| *T LUZ* | - | | - | - | -4.9328 | 0.046781 | - | |
| *AGUA-ESGOTO* | 0.6681 | 0.00223 | 0.58313 | 0.006367 | 0.61145 | 0.007584 | - | |
| *AIC* | 2,081.7 | | 2,079.5 | | 2,078.1 | | 2,084.3 | |
| *RHO* | | | 0.18117 | | 0.18356 | | 0.30773 | |
| Test residual | | | 6.6309 | | - | | 4.2141 | |

Source: Prepared by the authors, 2021.

epidemiological situation of the disease in a real scenario[24,25].

Underreporting of diseases and other health problems may be gross failures that directly the impair planning of health actions and are almost always linked to misrepresentations of the health situation[24]. A similar situation was described in a study in Espírito Santo carried out in the 2000s, where municipalities had "zero incidence" for tuberculosis and were surrounded by others with "high incidence". The outcome suggested that there was centralization of the diagnosis and that many cases were not reported to the municipality of origin. Returning to the current study, underreporting requires a detailed investigation[26].

It is noted that the spatial distribution of high unadjusted incidence rates is concentrated in the state's largest urban centers, Campina Grande, and the capital city, João Pessoa. This finding meets those of Fortaleza between 2000 and 2011, Rio de Janeiro in 2005, and São Paulo between 2008 and 2013. These results must be linked to the large population flow in urban centers, to the constant migration and immigration process, and mainly to the emergence of unqualified housing spaces due to the housing deficit that affects our population(27-29).

Although the unadjusted numbers indicate the spatial distribution of TB, they present instabilities in polygons with small populations, a frequent situation among the municipalities of the state. Thus, to obtain more reliable results, we opted for the autocorrelation analysis with smoothed coefficients, concluding that the presence of clusters is more defined between *Zona da Mata* and *Agreste Paraibano*.

This scenario confirms the severity of tuberculosis for the state, as its distribution significantly affects even the municipalities with the highest development degree and greater response potential from the education and health sectors, given that the largest and best health devices are located in these regions, such as university hospitals and better Primary Health Care coverage.

In this study, it was possible to detect areas with statistical significance of risk for the disease, collaborating to identify priority areas for health interventions. Four clusters comprised 19 communities between *Zona da Mata* and *Agreste Paraibano*.

This finding showed the spatial association in these areas and was in line with the results of other studies that used the Moran I index and identified spatial autocorrelation areas and active transmission clusters, highlighted in the Moran Map, demarcating the priority locations for confronting the disease(6,26,30).

In this scenario, evaluating the tuberculosis spatial distribution using the Moran I Index made it possible to identify critical areas for the disease, as well as sectors with positive autocorrelation, that is, sectors that influence their neighbors in maintaining and propagating these incidence values.

By performing a spatial regression model, the study improved the way of observing the occurrence of an event in space, providing more palatable means for identifying its causes. This enables better-targeted planning of health actions. The results ratify that spatial analyses are powerful allies in the health management context and that further studies should be encouraged to understand endemic tuberculosis in all Brazilian states better.

## CONCLUSION

Given the results herein presented, it is possible to conclude that the municipalities that make up *Zona da Mata* and *Agreste Paraibano* are priorities for developing tuberculosis control actions, as they show maintenance of the incidence during all the analysis years, as well as spatial characteristics that favor the occurrence of this condition, then being characterized as areas with increased risk for TB infection.

Including spatial elements in the regression model proved to be efficient, as it allowed for a better social characterization of the spaces affected by high incidence values and revealed spatial autocorrelation between high tuberculosis rates and socioeconomic factors.

A limitation of this study can be related to using secondary information. Although the data come from the National Notifiable Diseases System, they are subjected to underreporting failures, causing serious inconsistencies in interpreting the epidemiological scenario. However, these data are official and widely used in technical and scientific papers and the planning of health policies throughout the country.

Applying spatial methods to area data requires refinement of the statistical methods to avoid false information. This study applied the Local Moran Index to correct possible interferences related to the distance between the areas analyzed. In this way, the implementation of this study contributes to improving health policies and actions aimed at combating tuberculosis and provides guidelines for the care practices to be implemented by Nursing and Health teams in an interdisciplinary way.

*Paper extracted from the master's dissertation "Analysis of the spatial distribution of tuberculosis cases in the state of Paraíba and verification of associated factor", presented to the State University of Paraíba, Campina Grande, PB, Brazil.

## CONFLICT OF INTERESTS

The authors have declared that there is no conflict of interests.

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