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ORIGINAL ARTICLE / *ARTIGO ORIGINAL*

Spatial analysis of tuberculosis and its relationship with socioeconomic indicators in a medium-sized city in Minas Gerais

Análise espacial da tuberculose e sua relação com indicadores socioeconômicos em um município de médio porte em Minas Gerais

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ABSTRACT: ***Objective:*** To analyze the tuberculosis spatial pattern and its relationship with socioeconomic indicators, from 2008 to 2015, in a priority city for tuberculosis control by the National Tuberculosis Control Program, Juiz de Fora, Minas Gerais. ***Methods:*** Ecological study in which the units of analysis were 81 urban regions of Juiz de Fora. Secondary data from Notifiable Diseases Information System and 2010 Demographic Census were used. Georeferenced data from 1,854 notifications were used to elaborate thematic maps in order to verify the distribution pattern of average tuberculosis rates and socioeconomic indicators within the city. Global spatial autocorrelation (Moran's I) and local (Local Indicator of Spatial Association) and multiple linear regression model were estimated to analyze the relationship between the average tuberculosis incidence rate and socioeconomic indicators. ***Results:*** The average tuberculosis incidence rate was 48.3 cases/100,000 inhabitants/year. It was found that the urban regions corresponding to central regions of the city had lower rates with a progressive increase toward the urban regions representative of the most peripheral neighborhoods. All variables showed significant spatial autocorrelation. The regression model showed an association between the average tuberculosis incidence rate and the proportion of poor, household density, and aging index. ***Conclusion:*** The dynamics of tuberculosis transmission in Juiz de Fora may be explained by the maintenance of social inequality and urban space organization process.

Keywords: Tuberculosis. Spatial analysis. Social conditions. Urban area.

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RESUMO: Objetivo: Analisar o padrão espacial da tuberculose e sua relação com indicadores socioeconômicos, entre 2008 e 2015, em um município considerado prioritário para o controle da tuberculose pelo Programa Nacional de Controle da Tuberculose, Juiz de Fora (MG). Métodos: Estudo ecológico no qual as unidades de análise foram as 81 regiões urbanas de Juiz de Fora. Foram usados dados secundários a partir do banco de dados de notificação do Sistema de Informação de Agravos de Notificação e dados do Censo Demográfico de 2010. Foram georreferenciadas 1.854 notificações e elaborados mapas temáticos para verificar o padrão da distribuição da taxa média de incidência de tuberculose e de indicadores socioeconômicos no município. Foram estimadas medidas de autocorrelação espacial global (coeficiente I de Moran) e local (Indicador Local de Associação Espacial) e modelo de regressão linear múltipla para verificar a relação entre a taxa média de incidência de tuberculose e os indicadores socioeconômicos. Resultados: A taxa média de incidência de tuberculose foi de 48,3 casos/100 mil habitantes/ano. As regiões urbanas correspondentes às regiões centrais do município tiveram taxas mais baixas, com aumento progressivo em direção às regiões urbanas representativas dos bairros mais periféricos. Todas as variáveis estudadas apresentaram autocorrelação espacial significativa. O modelo de regressão mostrou associação entre a taxa média de incidência de tuberculose e a Proporção de Pobres, Densidade Intradomiciliar e Índice de Envelhecimento. Conclusão: A dinâmica da transmissão da tuberculose em Juiz de Fora pode ser explicada pela manutenção da desigualdade social e pelo processo de organização do espaço urbano.

Palavras-chave: Tuberculose. Análise espacial. Condições sociais. Área urbana.

INTRODUCTION

Tuberculosis (TB) persists as an important and challenging public health problem. It is the result of social inequities in health and contributes to the maintenance of inequality and social exclusion in several countries. It is one of the most prevalent diseases among people living in poverty in the world, with a high mortality burden, along with the human immunodeficiency virus (HIV) and malaria[1].

Brazil is among the 30 high-burden countries for TB and HIV-associated TB, which are considered priorities by the World Health Organization for the control of the disease. In the last ten years, an average of 71,000 new TB cases per year have been diagnosed in the country[1].

It is a disease of multicausal manifestation, being dependent on the characteristics inherent to the microorganism, on the host's immune response, and on the conditions to which individuals are exposed throughout life[2]. The marked influence of living conditions on illness from TB is well known; demographic, social, and economic factors, such as income inequality, precarious housing, overcrowding, food insecurity, low education, and barriers to access health services, contribute to the maintenance and spread of the disease[1,3,4].

According to the National Health Surveillance Secretariat[5], in 2017, the state of Minas Gerais reached the lowest TB incidence coefficient (IC) (16.9/100,000 inhab.) in the Southeast (37.7 cases/100,000 inhab.). In the same year, however, some of its municipalities registered IC superior to those in the region where they are located. The studied municipality, Juiz de Fora, despite belonging to the group of cities with a high Human Development Index (HDI = 0.778)[6], in 2017, had the highest IC (45.1 cases / 100,000 inhab.) of TB in Minas Gerais, being considered a priority for TB control by the National Tuberculosis Control Program (*Programa Nacional de Controle da Tuberculose* – PNCT)[6-8].

According to Barcellos et al.[9], the health situation is the result of the relationship of social groups with their territory, since the spatial location generates a difference in access to resources and life opportunities. The occurrence of TB is related to the organization of urban space. Thus, the incorporation of the spatial dimension in the analysis of the disease can extract additional meanings for the understanding of this condition[10,11].

The application of spatial analysis instruments in small areas allows not only to locate where the problem occurs, but to understand the dynamics of the health-disease process and, thus, contribute to the planning of local public policies and the reduction of inequities.

Angelo[12] analyzed the urban space production process in the municipality of Juiz de Fora, from 1997 to 2005, using a set of social and economic indicators, whose scale of analysis was the urban regions (UR). The presence of two important indicators for the TB transmission process was pointed out: density of the poor and HIV co-infection. Given the possibility of changes in quality of life and territorial changes over a period of about ten years, it is important to assess whether the distribution of TB in the urban space has been modified.

In this context, the present study sought to analyze the spatial pattern of TB and its relationship with socioeconomic indicators, from 2008 to 2015, in the city of Juiz de Fora.

METHODS

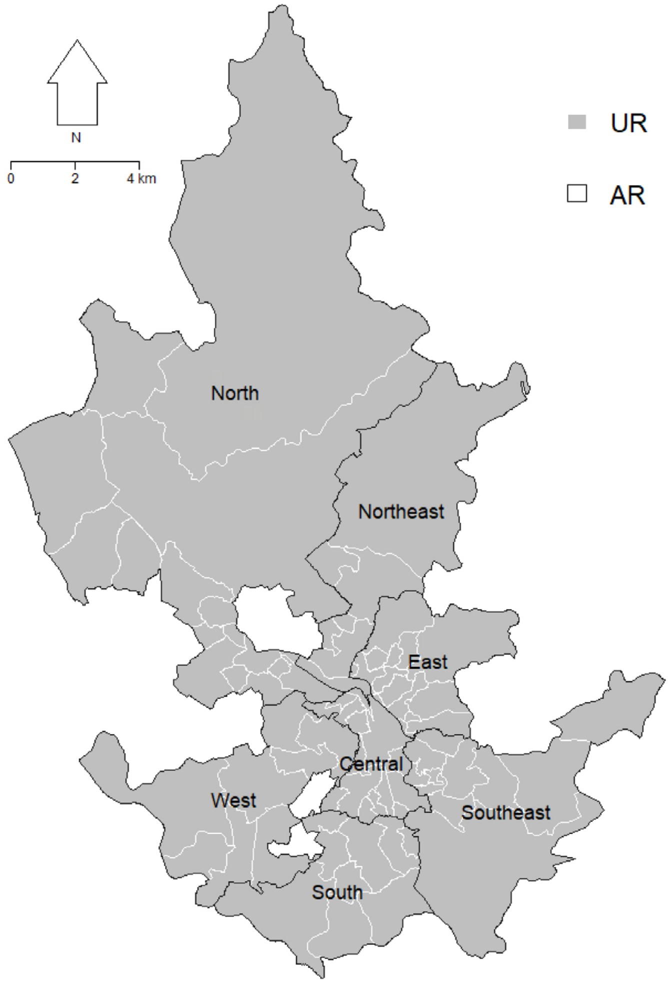
Ecological study of municipal scope, in which the analysis units were the 81 UR distributed in seven administrative regions (AR) (Figure 1) of a medium-sized municipality, Juiz de Fora, located in the southeastern state of Minas Gerais[13,14], with an estimated 2019 population of 568,873 inhabitants[6].

According to the Atlas of Human Development in Brazil[15], the municipality has great social inequality, expressed in the Gini Index of 0.56. In addition, in 2010, 0.88% of the population was extremely poor, 5.48% poor, and 17.73% vulnerable to poverty.

With regard to sanitation indicators, in 2017, 96.38% of households had water supply, and 95.25% had access to the sewerage network[15].

Secondary data from TB notifications (codes A15–A19 of the International Statistical Classification of Diseases and Related Health Problems – tenth version) of the Information System for Notifiable Diseases, provided by the Department of Epidemiology of the Municipal Health Department, for the period from 2008 to 2015, were used.

Data from 2,227 notifications were obtained; however, 230 corresponded to patients from neighboring cities and were excluded from the amount. For georeferencing, data from 1,923 patients were used, as 74 notifications were excluded for having incomplete addresses. Of these 1,923 patients, 1,583 home addresses were georeferenced with R software, version



UR: urban region; AR: administrative region.

Figure 1. Map of administrative regions and urban regions in the municipality of Juiz de Fora, Minas Gerais.

3.2.2 (ggmap package/geocode function), and 340 were georeferenced directly on Google Maps, due to a failure in the geocode function to find the address. Notifications were georeferenced by the full address; if not possible, the centroid of the neighborhood was used. Thus, 28 addresses were georeferenced by the neighborhood.

After georeferencing, 69 notifications were excluded for belonging to the rural area, since the unit of analysis is the municipality's UR. Such exclusion is justified because the occurrence of TB has historically been related to the spatial organization of cities[11]. Thus, 1,854 notifications were mapped.

Socioeconomic data were taken from the 2010 Demographic Census and served as a basis for building the indicators used in the analysis of data by UR.

The indicators of the present study (Chart 1) were chosen and calculated based on those used by other authors to seek an association with the TB transmission process and in order to contemplate the dimensions of income, education, race/color, housing conditions, and age: Health Vulnerability Index (HVI), Proportion of Poor (PP), Household Density (HD), Dependency Ratio, and Aging Index (AI).

The HVI is a combination of socioeconomic variables in a summary indicator, created by the Belo Horizonte Municipal Health Department to point out priority areas for intervention and resource allocation. It consists of eight variables with different weights and distributed in two dimensions: sanitation (weight 0.396) and socioeconomic (weight 0.604). Its value ranges from 0 (lowest vulnerability) to 1 (highest vulnerability)[16].

In order to know the socioeconomic status of the UR in Juiz de Fora, all the above indicators and the mean TB incidence rates (IR_m) were calculated for each UR. IR_m were calculated as the ratio of the average number of cases notified by UR in the period from 2008 to 2015, and the population of each UR in 2010, multiplied by 100,000.

Data from small areas are more instable as they regard smaller populations, with low numbers of events. To reduce the random fluctuation of incidence rates, the local empirical Bayesian estimator was used, which was calculated by weighting the incidence rates of each region using the observations of neighboring areas, generating smoothed rates[17,18]. The neighborhood matrix used was by contiguity. In the analyses that followed, it was decided to use this IR_m estimator, considering that is closer to reality.

Thematic maps of the distribution of the IR_m in the municipality and the indicators studied were prepared. The division of classes was done by quintiles. The three blank areas on the

Chart 1. Indicators selected according to different dimensions of living conditions.

Indicators	Description
Health Vulnerability Index (HVI)[a]	It consists of eight variables with different weights and distributed into two dimensions: sanitation and socioeconomic
Proportion of poor (PP)	Percentage of heads of household with income of up to two minimum wages
Household Density (HD)	Reflects the average number of residents per household
Aging Index (AI)	Ratio between the extreme age components of the population, represented by aged and young people
Depencency Ratio (DR)	Measures the relative share of the potentially inactive population contingent, which should be sustained by the potentially productive portion of the population

[a]Belo Horizonte[16].

maps correspond to regions with no resident population, being the campus of *Universidade Federal de Juiz de Fora* and two areas of forest reserve. Pearson's correlation matrix was also built to verify the association between variables.

The presence of spatial dependence was assessed by calculating Moran's coefficient I, which measures the correlation between first-order neighbors[18,19].

The Local Indicator of Spatial Association (LISA) was used, based on the neighborhood matrix generated with first-order neighbors. This indicator makes it possible to identify significant patterns of spatial association, that is, areas with their own spatial dynamics (clusters), where spatial dependence is even more pronounced[19].

Linear regression was used to assess the correlation between the dependent variable (IR_m) and the independent variables (indicators). Variables that better describe the occurrence of the disease with a statistically significant correlation at 5% using the Stepwise regression method were searched[20].

The quality of fit of the model was verified by analyzing its residues. As the existence of spatial dependence in the model could invalidate it, the global Moran I index was calculated for the residuals of the linear regression model obtained[21].

Statistical analyses and data mapping were performed using the softwares QGIS Desktop 2.18.4 and R version 3.2.2.

RESULTS

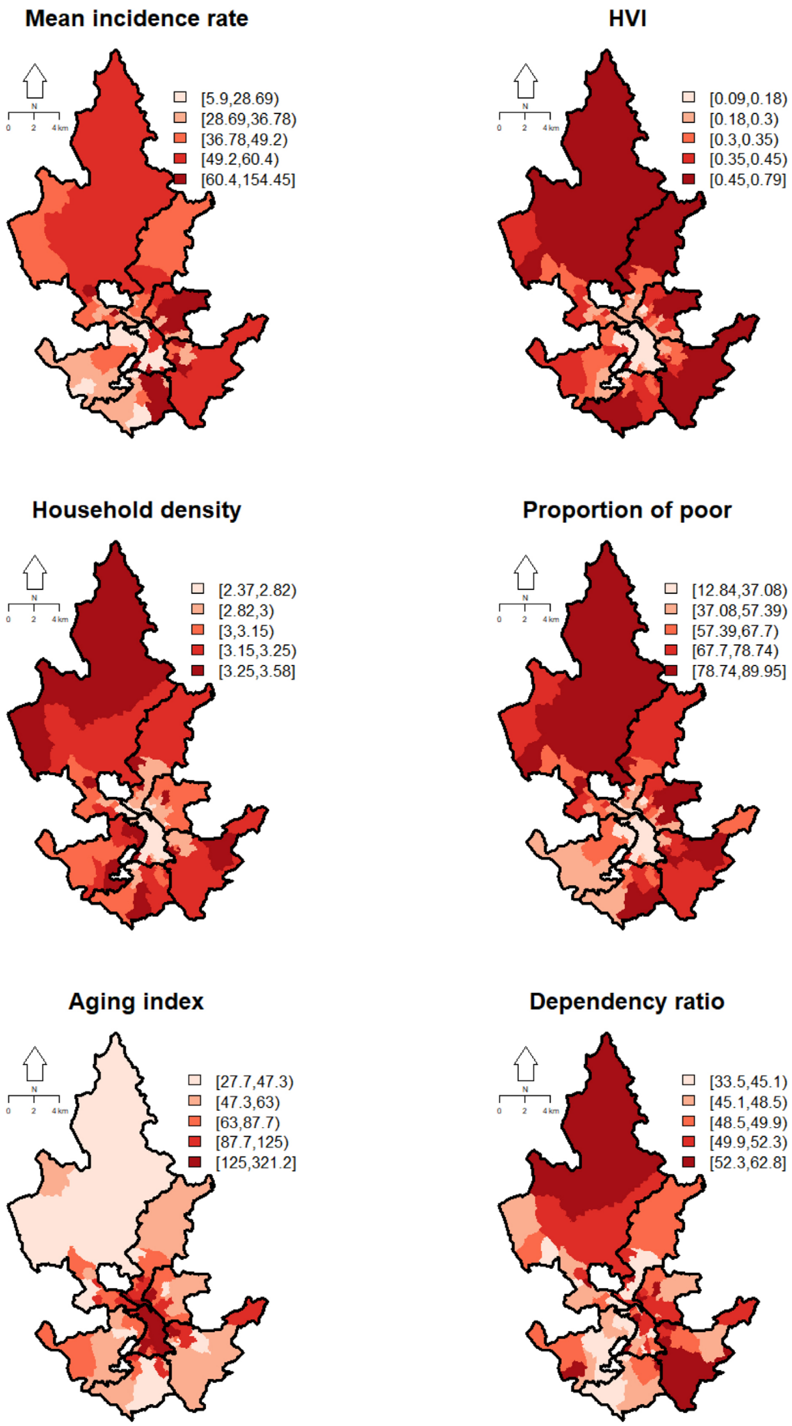
TB IR_m in the city of Juiz de Fora, in the period from 2008 to 2015, was 48.3 cases/100,000 inhabitants/year.

When observing Figure 2, it appears that the pattern of spatial distribution of TB in the municipality of Juiz de Fora was heterogeneous. The UR corresponding to the Central Administrative Region of the municipality had lower IR_m, with a progressive increase toward those representative of the most peripheral neighborhoods. The smallest IR_m predominated in the Central Administrative Region, and one UR (75.7/100,000 inhab.) is different from the other central UR when presenting a higher IR_m. The largest IR_m were found in the UR corresponding to the Southeast, East, and South Administrative Regions.

The thematic maps of the indicators showed similarities with the IR_m in their spatial distribution, with higher values in the most peripheral UR, indicating that regions with worse living conditions may be associated with higher TB rates. The AI indicator showed an inverse distribution pattern when compared to the other indicators, with higher values in the most central UR, showing the concentration of the elderly population in that location.

The largest proportion of poor people in the UR were mainly located in the Eastern, Southeast, South, and North Administrative Regions. The lowest proportion of poor people in the UR were those located in the Northeast, Central, and West Administrative Regions.

With the result of Pearson's correlation matrix, it was observed that all the independent variables studied showed correlation with each other and with the dependent variable.



HVI: Health Vulnerability Index.

Figure 2. Spatial distribution of the mean incidence rate of tuberculosis and other indicators in the urban regions of Juiz de Fora, Minas Gerais, 2008–2015.

The spatial autocorrelation at UR level of the dependent variable (IR_m) could be observed by the positive and statistically significant Moran coefficient I ($I = 0.24$, $p = 0.000$).

In Figure 3, it is possible to identify two UR clusters corresponding to regions with a high incidence of TB (high-high) and, therefore, of greater risk, located in the Eastern and Southeast Administrative Regions of the municipality. The cluster containing regions with low TB incidence (low-low) and lower risk is part of the Central and West Administrative Regions.

All independent variables were related to the outcome in the simple linear model. Table 1 summarizes the results of the multiple linear regression model whose adjustment proved to be adequate.

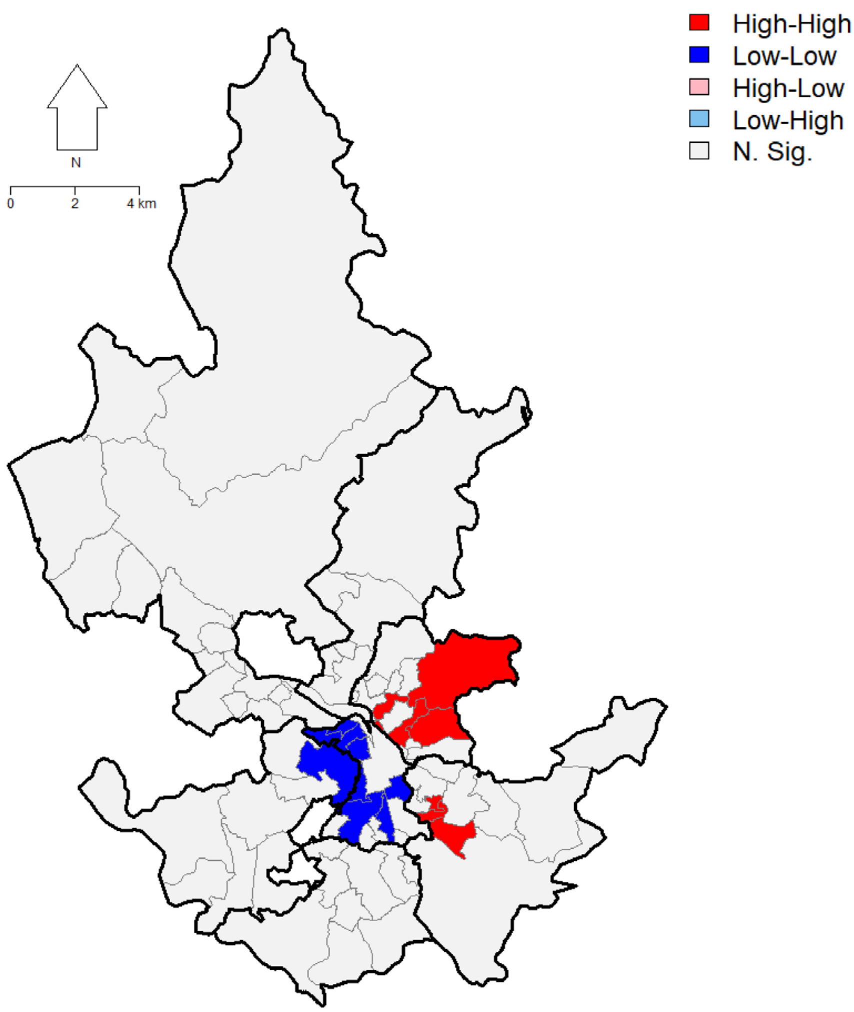


Figure 3. Map of the Local Spatial Autocorrelation Indicator showing areas with significant values for the mean incidence rate of tuberculosis in the urban regions of Juiz de Fora, Minas Gerais, 2008–2015.

Table 1. Multiple linear regression model explaining the mean tuberculosis incidence rate in Juiz de Fora, Minas Gerais, 2008–2015*.

Independent variables	Coefficient	Standard error	p-value
PP[a]	0.777	0.151	< 0.001
HD[b]	25.088	13.104	0.059
AI[c]	0.156	0.073	0.037

PP: Proportion of Poor (%); HD: household density (people/household); AI: aging index (%); *dependent variable: mean TB incidence rate (cases/100,000 inhab.).

The coefficient of determination of this model was $R^2 = 0.35$, that is, 35% of the IR_m variation can be explained by these three indicators together. It is observed that each 1% increase in the PP is associated with an increase in the TB incidence rate of 0.8 cases/100,000 inhabitants; each increase of 1 inhabitant per household is associated with an increase in the TB incidence rate of 25 cases/100,000 inhabitants. and that each 1% increase in the AI is associated with an increase in the TB incidence rate of 0.2 cases/100,000 inhabitants.

The assumptions of homoscedasticity, linearity, and normal waste distribution were met (analysis not shown). In addition, the value of the global Moran I index was 0.042, with $p = 0.367$, therefore, there is no spatial dependence on the model obtained, and it is not necessary to use spatial regression models.

DISCUSSION

This study showed that the distribution of TB cases in the city of Juiz de Fora is not uniform. The analysis of thematic maps and the LISA allowed the visualization of places of high incidence of the disease, which coincide with areas of concentration of poverty and worst living conditions.

Vicentin et al.[22] legitimize the study of the association between social and biological indicators in the development of TB, as well as the quantification of the strength of these associations through statistical procedures. The visual analysis of the maps was confirmed by the multiple linear regression model, which explained 35% of the variation in TB incidence rates.

Some studies have also shown the association between TB transmission and HD[21,23]. This indicator has great sensitivity to point out areas of higher risk for the occurrence of TB, since more concentrated and less airy home environments bring people in close contact, favoring the spread of airborne diseases, such as TB.

The PP indicator also showed explanatory power for the incidence of TB in the model. According to Angelo[12], this result is expected, since the income variable is one of the definers of socio-spatial segregation in capitalist cities. The largest proportion of poor people in the UR were located mainly in the Eastern, Southeast, South, and North Administrative Regions. These results are similar to that found by Angelo[12], however, a notable increase in the rates can be observed, signaling the increase of households whose income is up to two minimum wages in the municipality and the impoverishment of the population.

The AI was also associated with the incidence of TB. When analyzing the thematic map, this relationship seems to be contradictory, since the older population tends to be concentrated in the Central Administrative Region, and TB in the Eastern and Southeast Administrative Regions. However, some studies[24,25] suggest the displacement of the disease for elderly people, probably due to the aging population and the greater vulnerability to the disease.

Regarding the mean TB incidence rates (48.3/100,000 inhab./year), compared to the period 1997–2005 (55.2/100,000 inhab./year)[12], there is a slight reduction. The UR located in the Eastern and Southeastern Administrative Regions remained the areas with the highest TB incidence rates, with a significant increase in this indicator in areas considered to be at higher risk. One of these UR, which in the previous period had a IR_m of 93.7/100,000 inhab., in the present study, presented an increase of about 65% (154.4/100,000 inhab.). It is also possible to verify that the smaller IR_m persisted in the Central Administrative Region. In this region, there is an UR that is at odds with the others, with the highest IR_m (75.7/100,000 inhab.). This corresponds to a pocket of social periphery, being constituted, mainly, by subnormal agglomerates and population in worse living conditions.

A study conducted in Salvador suggests that the reduction in the incidence of TB by 37.1% may be due, in addition to the improvement in living conditions and the impact of the actions of the National Tuberculosis Control Program, the difficulty of georeferencing in the most vulnerable areas[26].

The regression model found explained part of the variation in the TB incidence rate. However, Valente et al.[11] emphasize that this relationship is not established in a direct and linear way, since illness from TB involves biological and social processes at different levels of organization. At the individual level, not covered in this study, biological and behavioral variables are associated, such as gender, age, comorbidities — HIV being the most important of them —, alcohol and drug use, and nutritional status[3]. At the collective level, the occurrence of the disease passes through the understanding of the particularities of the urban space that provided the conditions of receptivity for the transmission of TB[11,12].

As a regional hub city, especially in the areas of education and health, Juiz de Fora attracts people who migrate in search of better access to urban facilities and the labor market[27]. Many of the immigrants who seek better quality of life and opportunities end up not finding them and make up the lower circuit of the economy, submitting to informal employment and housing in peripheries and subnormal agglomerates[12].

The regions with the highest mean incidence rates of TB in the municipality were those where the process of occupation of urban space in the municipality began. Since their origin, these areas have been marked by a lack of infrastructure[28], being the home of a low-income population, not part of the formal labor market, without social protection and with high workloads, which makes them more vulnerable to illness from TB[12,29].

In recent years, the configuration of a process of modernization of the city has been perceived that does not reach all places at the same time or with the same intensity, which follows the interests of the capital and not the needs of the population living there, leaving no solutions for the serious social problems of a certain portion of the population and reproducing the inequality already manifested[30,31]. This contributes to more isolation and spatial segregation of the vulnerable population, which, in addition to being more exposed to conditions such as agglomerations, poor ventilation, poor food and poor working conditions, are still excluded from urban planning with regard to access to urban equipment, services health, leisure, housing supply and infrastructure provision. In the present study, there was a significant increase in TB IR_m levels and worsening of social indicators, specifically in the places of greatest risk, reflecting the exclusion process of these individuals.

The PNCT reiterates the importance of developing intersectoral actions, of a structural nature, as a way of expanding access to health and social rights, especially among groups in situations of vulnerability[1]. It also guides the decentralization of TB control measures to Primary Health Care, aiming at integration with the Community Health Agents Program (*Programa de Agentes Comunitários de Saúde* – PACS) and the Family Health Strategy (*Estratégia de Saúde da Família* – ESF), which link professionals to an assigned territory[1].

When discussing the relationship of TB with the development process of the urban space of Juiz de Fora, we can infer that there is a prioritization of actions aimed at the diagnosis and treatment of patients at the expense of local structural changes that reduce the conditions of receptivity for the transmission of the disease. Therefore, it is paramount to reflect on the necessary articulation of the Municipal Tuberculosis Control Program with other municipal public sectors responsible for the elaboration and implementation of policies that act on the determinants of illness.

The limitations of this study are related to the use of secondary data, being subject to underreporting and 4% of incomplete addresses that did not allow georeferencing. In view of the minimal data loss, there was probably no significant impact on the results. Still, since it is an ecological study, there are no variables at the individual level, such as behavioral and biological factors, which are also related to the incidence of TB.

It is concluded that the TB transmission process in the municipality is influenced by the historical and social development of the space, in addition to biological conditions. The spatial analysis techniques used in this study identify the most vulnerable regions and those most exposed to the risk of disease transmission.

Thus, it is a priority to plan actions that take into account the specificities of intra-urban territories and that promote changes in the context of people's lives, such as stimulating socioeconomic development in more peripheral regions with structuring of urban settlements, improvement of the road system, provision of basic infrastructure, and access to urban health and education facilities. Still, it is essential to intensify the programmatic actions of TB screening by the FHS teams in the areas of greatest incidence.

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