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Tuberculosis and living conditions in Salvador, Brazil: a spatial analysis

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ABSTRACT

Objective. *To investigate spatial tuberculosis (TB) distribution patterns and the association between living conditions and incidence of the disease in Salvador, Bahia, Brazil.*

Methods. *An ecological study with neighborhood as the unit of analysis. Data was collected from the Notifiable Diseases Information System (*Sistema de Informação de Agravos de Notificação, SINAN*) and the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística, IBGE*). Rates of TB incidence were transformed and smoothed. Spatial analysis was applied to identify spatial auto-correlation and "hotspot" areas of high and low risk. The relationship between TB and living conditions was confirmed by spatial linear regression.*

Results. *The incidence of TB in Salvador displayed heterogeneous patterns, with higher rates occurring in neighborhoods with poor living conditions in 1995–1996. Over the study period, disease occurrence declined, particularly in less-privileged strata. In 2004–2005, the association between living conditions and TB was no longer observed.*

Conclusions. *The heterogeneous spatial distribution of TB in Salvador previously reflected inequalities related to living conditions. Improvements in such conditions and health care for the less privileged may have contributed to observed changes.*

Key words Tuberculosis; tuberculosis, prevention & control; spatial analysis; social inequity; risk groups; Brazil.

Tuberculosis (TB) infection is considered an important public health issue across the world (1). Currently, about 9.4 million new cases occur per year; 80% of these are in countries on the Asian and African continents, where incidence exceeds 100/100 000 inhabitants.

TB incidence in Brazil in 2008 was 38.8/100 000; among all states in the country, Bahia had the ninth highest rate (38.9/100 000) (2). In Bahia's capital city of Salvador, incidence was 69.7/100 000, ranking it sixth among state capitals (2)

Studies undertaken in this municipality during previous decades indicated a relationship between TB occurrence and level of social development. Populations experiencing poor living conditions were found to have the highest risk of both disease (3) and mortality (4–6) from TB.

TB incidence is associated with precarious living conditions, a relationship which has been explored through spatial analysis techniques. This approach contributes to a better understanding of the epidemiological situation; it both highlights spatial inequalities and produces more accurate information to support the definition of intersectoral activities and the planning of interventions (7–18) for prevention and control.

In 2005, Brazil had a Human Development Index (HDI) of 0.800—5th in South America; however it also had the fourth worst Gini Index in this region (19). These measures describe acute social inequality, a factor that increases the likelihood of TB occurrence. It is not, therefore, surprising that Brazil is among the 22 countries worldwide with the largest burden, including the fifth highest estimated incidence in South America (1).

The incidence of TB in Brazil declined approximately 22% from 1994 to 2008 (2).

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During this period, control plans were implemented to reduce the magnitude of the disease (20–22). Moreover, starting in the 2000s, social and economic policies aimed at improving people's living conditions were introduced (23). In the context of these changes, it is important to assess whether disease distribution in the urban space was also modified.

This study aims to identify and characterize spatial distribution patterns of TB and to examine the relationship between living conditions and TB incidence in neighborhoods in Salvador over two periods in different decades.

MATERIALS AND METHODS

An ecological and spatial study was carried out during 1995–1996 and 2004–2005 in the city of Salvador, State of Bahia (BA), in the Northeast region of Brazil (latitude: –12° 58′ 23′′; longitude: –38° 30′ 16′′). In 1995, Salvador's population was estimated at 2 262 731 inhabitants. By 2005 it had risen to 2 673 560, with a density of 3 782 inhabitants per km^2, of which more than 80% were of black or mixed race (24). The city's 183 neighborhoods constitute the study's units of analysis.

TB is a notifiable disease in Brazil. A new case is defined as an individual who presented with respiratory symptoms when accessing health services and had a smear-positive test for *Mycobacterium tuberculosis.* In the presence of a negative sputum smear, diagnosis was also considered confirmed by a positive culture or clinical history of TB associated with complementary tests, such as radiological findings (25).

Information about new TB cases was obtained from the Notifiable Diseases Information System (*Sistema de Informação de Agravos de Notificação*) of the Ministry of Health (SINAN/MS). Demographic and socio-economic data by census tract (CT) (based on the 1991 and 2000 national censuses) (24) were acquired, and a Digital Municipal Grid (DMG)—comprising digital boundaries for geographic neighborhood units for both periods—was provided by the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística,* IBGE).

TB case addresses were georeferenced using Google Earth version 4.3 (Google, Inc., Mountain View, CA); a standard routine was used to identify latitude and longitude. To assess the reliability of this routine, a Garmin eTrexLegend personal navigation device (Garmin International, Inc., Olathe, KS) was used to obtain Global Positioning System (GPS) coordinates for a sample of 226 cases, which were compared with those from Google Earth using the Concordance Correlation Coefficient (CCC) (26). The CCC measures agreement between two variables, with a value of 100% denoting perfect concordance; a value of zero indicates a lack of correlation. The procedure proved reliable, with concordances of 94% for latitude and 91% for longitude.

TB cases and demographic and socio-economic data were represented in their respective geographic frameworks using ArcView GIS software, version 3.3 (ESRI, Redlands, CA, USA) and TerraView (Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, SP, Brazil). The TB data for 1995–1996 were matched with 1991 census data and CT boundaries, and compatibilized with the 1996 DMG. The TB data for 2004–2005 were similarly matched with 2000 census data and CT boundaries and the 1996 DMG. However, whereas the 1991 CT boundaries matched the DMG, a change in the number of CTs before the following census led to a situation where some CTs in 2000 were found to belong to more than one DMG neighborhood. Therefore, the proportion of each partial CT within each neighborhood polygon was estimated and divided by the total area—this resulted in a "weight" that was applied to all demographic and socio-economic variables from each 2000 CT; subsequently, neighborhood variables were aggregated.

To minimize random fluctuations in data from small areas and thus provide greater stability for the indicators used, the 2-year average rate of TB incidence in 1995–1996 and 2004–2005 was calculated for each neighborhood, using the sum of the annual population of each neighborhood as the denominator for each period. The descriptive analysis aimed to identify extremely high or low outliers and the standard distribution of study variables. Because rates did not exhibit a normal distribution, they were transformed using the Freeman-Tukey method, a square-root transformation that minimizes random fluctuations due to small TB case numbers in some census tracts, allowing for the identification of spatial patterns and thus permitting the evaluation of relationships mediated through space. Also, rates were smoothed via empirical Bayes estimation (EBE) (27). The latter expresses the true estimate of incidence in a small area as a weighted function of the observed incidence in that area and the mean rate in all areas within the study region. A spatial matrix was constructed using shared borders as a criterion for adjacency. Spatial dependence for an average rate in a given time period was calculated for each neighborhood using the Global Moran Index (27), which measures similarities between outcomes in neighboring areas (i.e. spatial autocorrelation). Moran's Local Index of Spatial Autocorrelation (LISA) was used to identify areas of high or low risk. The LISA for each observation gives an indication of the extent of significant spatial clustering of similar values around that observation. A significance level of 0.05 was adopted. The LISA was used to classify "high-high" and "low-low" areas, which corresponded to neighborhoods with high rates of TB incidence bordering neighborhoods with similarly high rates, and neighborhoods with low rates bordered by neighborhoods with similarly low rates. Excess risk maps were constructed using standardized morbidity ratios (SMR) (27).

For the spatial descriptive analysis, thematic maps were constructed of both average neighborhood TB incidence rates over the two study periods and their classification at the census tract level according to a living conditions index (LCI) (28). This measure was proposed by Paim et al. (28) and has proven to be a good indicator of living conditions in Salvador (28–30). The index was constructed based on five indicators as proxy of living conditions: (i) *Income*: Proportion of heads of permanent households with an average monthly income less than or equal to two minimum wages; (ii) *Education*: Proportion of literacy among people aged from 10 to 14 years old; (iii) *Crowding*: Ratio between the average number of residents per house and the average number of rooms that serve as a dormitory (i.e. bedroom); (iv) *Sanitation*: Proportion of households with an indoor connection to the main water supply; and (v) *Slum (Favela)*: Proportion of substandard, crowded houses in relation to total households.

The variables suggested by Paim et al. (28–30) were used for the 1991 data. For data from 2000 the crowding indicator comprised the ratio of residents to rooms (i.e. as opposed to bedrooms), since census data on the number of rooms that served as bedrooms were unavailable. Census tracts were given scores for each indicator based on their relative ranks, with three (*slum*, *income and crowding*) listed in increasing order, and two (*education* and *sanitation*) in decreasing order. The sum of these scores resulted in an LCI for each census tract. These were listed in increasing order and grouped into relatively homogenous quartiles, corresponding to strata of the population whose living conditions were classified as high, intermediate, low or very low. Higher LCI scores correspond to poorer living conditions.

Spatial and non-spatial linear regression analyses were carried out to assess the association between average TB incidence rate, the dependent variable, and relative LCI. Anselin's (31) recommendations were followed in the construction of the spatial regression model. In particular, a baseline ordinary least squares regression was conducted, and then spatial dependence in the residuals was assessed using the Moran's I test (27). A spatial regression model was then constructed incorporating the spatial dependence error detected through this process. In particular, the analysis made use of Simultaneous Autoregressive Regression (SAR), which includes adjustments for spatial autocorrelation (31). Data analysis was performed using STATA v.9 (Stata Corp LP., College Station, Texas, USA) and ArcView 3.3 software with the spatial analysis module S-Plus 6.0 (Mathsoft Inc., Seattle, Washington, USA) and GeoDa0.9.5-i beta (Spatial Analysis Laboratory, University of Illinois, Urbana-Champaign, Illinois, USA).

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RESULTS

Of the 10 842 new cases of notified TB in 1995, 1996, 2004 and 2005, 10 406 (96.0%) were georeferenced. The average number of georeferenced cases was 99% during the first three years but fell to 83.8% in 2005. The average incidence rate for the city of Salvador was 135/100 000 inhabitants in 1995–1996 and 85.6/100 000 in 2004–2005.

The number of neighborhoods with rates above 100/100 000 inhabitants fell from 60.7% in 1995–1996 to 30.6% in 2004–2005. The number of neighborhoods with rates below 10/100 000 fell from 6.5% to 2.7%. The number of neighborhoods with rates from 10 to 24.9 and from 50 to 99.9 per 100 000 both increased (see Table 1).

In the first study period, areas with high risk of TB (> 100/100 000) were found in the central and north-west regions of the city, while in 2004–2005 they were situated in the center-west (Figure 1). Living conditions improved from one decade to the next (Figure 2). The number of neighborhoods displaying an excess risk of 4–12 times higher than the average expected risk for the municipality declined, while those with excess risk of 1.00–1.99 or 2.00–3.99 times the average increased.

The Global Moran Index, which measured 0.091 (P = 0.02) for the first period and 0.205 (P < 0.001) for the second, indicated spatial dependency between the transformed TB incidence rates.

"High-high" areas represent neighborhoods with high TB incidence rates which bordered neighborhoods with similarly high rates; in 1995–1996 these were situated in the north-west, center and south-west of Salvador and in 2004–2005 in the central-west and south-west. In the north-east region the number of "low-low" areas appeared to rise from the first period to the second (Figure 3).

A decline in median TB incidence rates across all living condition strata was observed between the two study periods. The greatest reduction was in the stratum for very low living conditions (42.1%), followed by low (38.7%), intermediate (34.8%), and high (9.3%) (Figure 4).

An improvement in LCI was observed between the two study periods. For example, in the low living condition stratum, average number of residents per room decreased from 2.7 to 0.7, the percentage of heads of households with low incomes from 76.8% to 68.5%, and the percentage of substandard, crowded housing from 32.9% to 20.7%. Access to piped water rose from 58.6% during the first study period to 83.9% in 2004, and literacy rose from 75.7% to 91.7%.

Linear regression analysis indicated a statistically significant positive effect for LCI on average TB incidence rate during the first study period (β = 0.12, P < 0.001). A similar association was identified in the second period, but this was not statistically significant (β = 0.015, P = 0.466). Statistically significant spatial auto-correlation of the residuals was observed in both periods. The Global Moran Index was 0.11 (P < 0.007) for 1995–1996 and 0.21 (P < 0.001) for 2004–2005. Because the residuals of the simple linear regression model showed spatial dependency, a spatial autoregressive model was used (22). A statistically significant association was also found between LCI and incidence rate for the 1995–1996 period alone (β = 0.01, P < 0.001). The estimated parameters of the spatial regression model were more precise than those of the simple linear model.

DISCUSSION

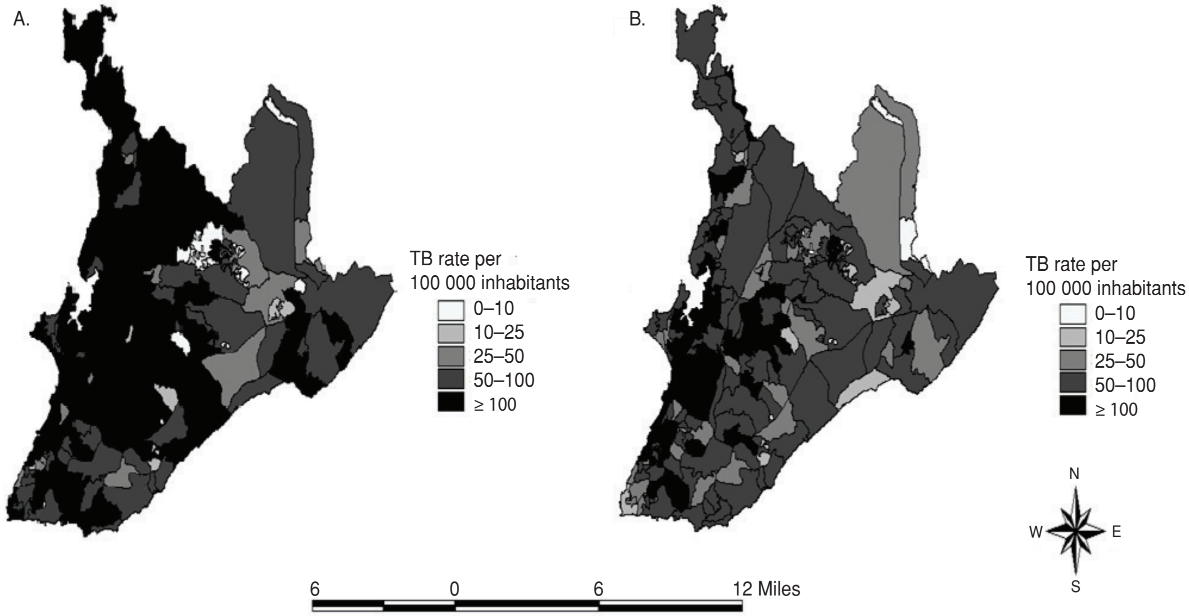
TB was heterogeneously distributed in the intra-urban areas of Salvador. Higher risks were observed in the central and north-west areas of the city during the first study period (1995–1996) and in the center-west during the second

TABLE 1. Neighborhoods by average tuberculosis incidence in 1995–1996 and 2004–2005, Salvador, Bahia, Brazil

Average incidence rate (per 100 000)	Neighborhoods (1995–1996)		Neighborhoods (2004–2005)	
	No.	%	No.	%
<10	12	6.5	5	2.7
10–25	7	3.8	9	4.9
25–50	12	6.5	30	16.4
50–100	41	22.4	83	45.4
≥100	111	60.7	56	30.6
Total	183	100	183	100

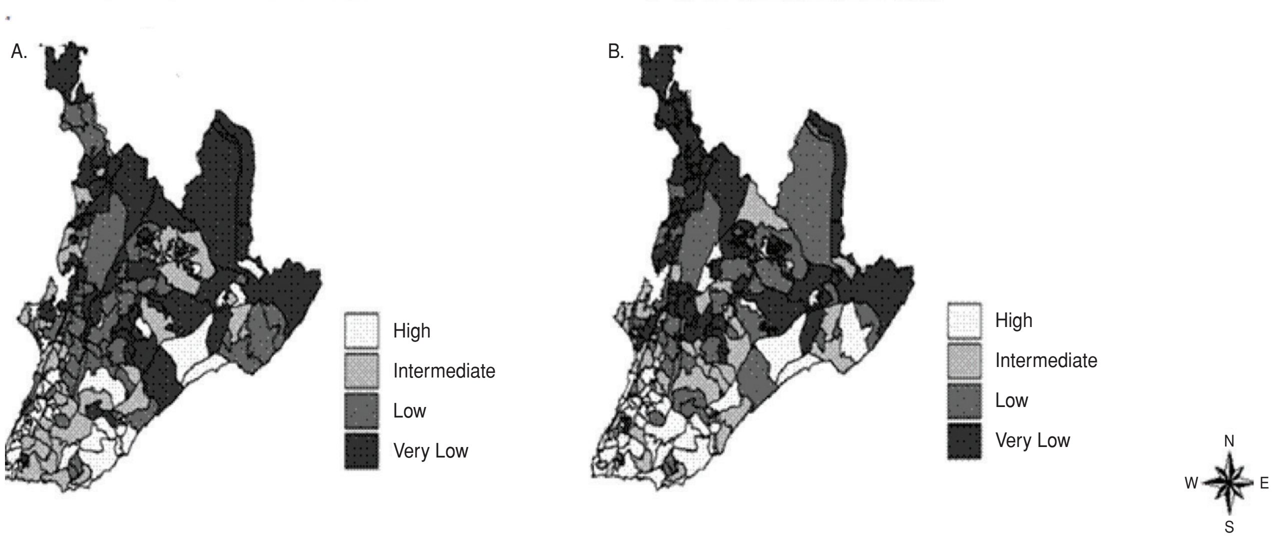
Data source: *Sistema de Informação de Agravos de Notificação* (SINAN), Ministry of Health.

FIGURE 1. Spatial distribution pattern of average incidence rate of tuberculosis (TB) by neighborhood, Salvador, Bahia, Brazil



A: 1995–1996; and B: 2004–2005. Image produced using ArcView v3.3.
Data source: *Sistema de Informação de Agravos de Notificação* (SINAN), Ministry of Health.

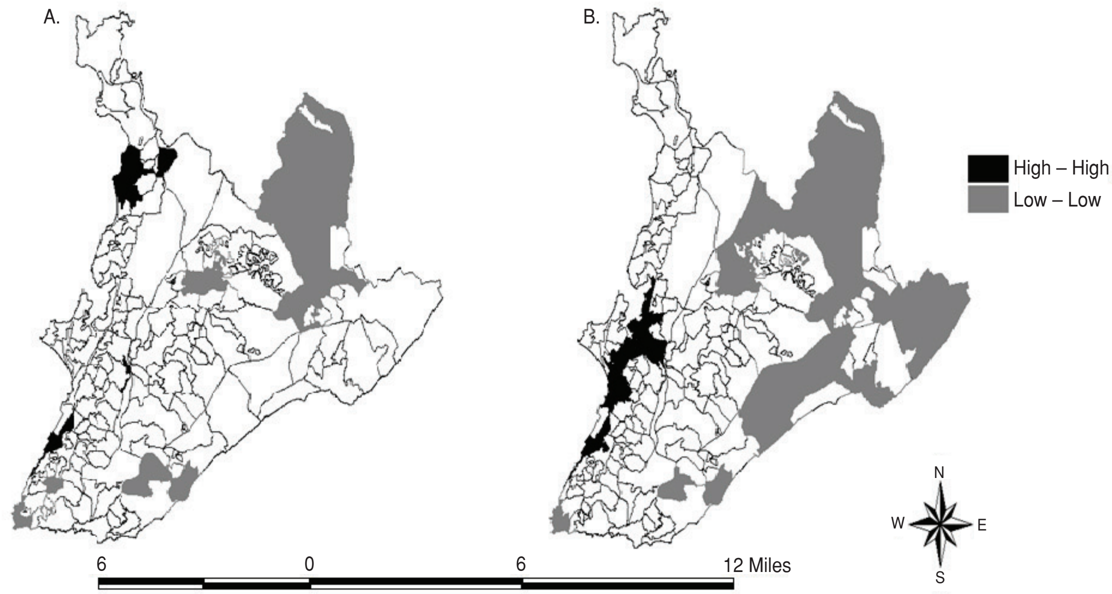
FIGURE 2. Spatial distribution pattern of living condition index (LCI) by neighborhood, Salvador, Bahia, Brazil



A: LCI 1991; and B: LCI 2000. Image produced using ArcViewv. 3.3.
Data source: Censuses of 1991 and 2000.

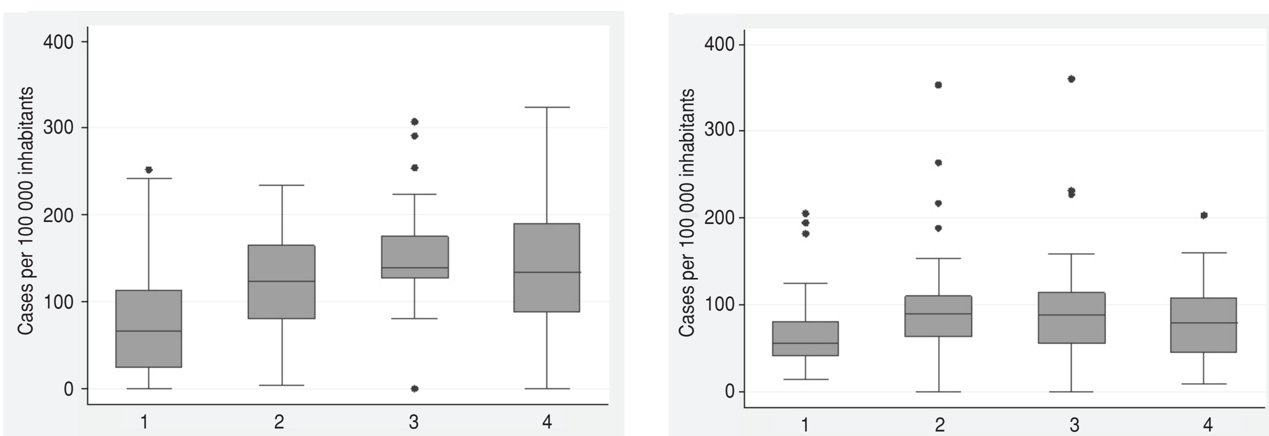
(2004–2005). Generally, these areas correspond to those neighborhoods experiencing low or very low living conditions. A strong association between LCI and TB was observed for 1995–1996. These findings are similar to those of previous studies conducted in the city in 1980 and 2000 (3–6). Other studies pointed to a similar conclusion, where aggregation of TB cases is observed in more vulnerable groups, providing consistent evidence for a link between TB occurrence and social inequality and poverty (11, 32–34). However, this association was not observed in the second period (2004–2005). It is likely that improvements in living conditions and TB control activities targeting less privileged populations contributed to these changes; since the 2000s, such policies have been implemented in Brazil, focused mainly on health and

FIGURE 3."Hot spot" areas of homogeneous high or low risk obtained from the average rate of tuberculosis by neighborhood, Salvador, Bahia, Brazil**



A: 1995–1996; and B: 2004–2005. Image produced using ArcView v3.3.
Data source: *Sistema de Informação de Agravos de Notificação* (SINAN), Ministry of Health.

FIGURE 4. Box plot of incidence rate of tuberculosis by strata of the living conditions index (LCI) (1 = high, 2 = intermediate, 3 = low, 4 = very low) in Salvador-Bahia, Brazil



Left panel: 1995–1996; and right panel: 2004–2005. Image produced using Stata v9.
Data source: *Sistema de Informação de Agravos de Notificação* (SINAN), Ministry of Health and censuses of 1991 and 2000.

directed toward improving the socio-economic condition of poor groups (20–23).

The high TB incidence found in some neighborhoods with better living conditions may be explained by the existence of pockets of poverty within these areas (5, 28). This makes it patently clear that surveillance and control activities cannot be neglected even in more privileged areas, given that TB is an infectious respiratory disease with an airborne transmission pathway, for which control activities are centered on the treatment of patients who represent the source of infection.

One intriguing finding is the absence of association between TB occurrence and living conditions in Salvador in 2004–5. The decline in the percentage of georeferenced addresses in this period may have contributed to this finding, since cases with incomplete or non-registered addresses correspond to areas with less favorable living conditions. The role of the TB control program must also be considered.

Another important finding is the reduction (37.1%) of TB incidence in Salvador. TB in Brazil is a notifiable disease, requiring mandatory reporting and free treatment for all patients diagnosed within health services. Control measures are implemented to improve the integrated health care of individuals and population groups (22, 35). Such measures, allied to improvements in living conditions (36), may have contributed to the observed decline.

Despite this morbidity reduction in 2004–5, global TB incidence for Salvador is still higher (85.6/100 000 inhabitants) than that observed in many developed countries (1). This decline has not led to a change in the distribution pattern of "hot spots," suggesting the persistence of sources of infection and highlighting the need for activities aimed at reducing disease transmission.

The results must be interpreted with a certain caution since they arise from an ecological study of spatial aggregation based on pre-defined geographic-administrative divisions. Nevertheless, the populations that lived in each area were characterized by living conditions according to socio-economic indexes. Moreover, the scale utilized and difficulties in the geocoding of addresses may have affected the results. Nevertheless, although the use of secondary data often yields problems in quality and coverage and may lead to an underestimation of incidence rates, in this case the study in question is situated in a state capital with a well-developed health information system; it seems likely, therefore, that the tuberculosis data and results are reasonably accurate.

Despite the decline of TB rates between the study periods, this study concludes that a non-random spatial distribution pattern persists in Salvador's urban areas.

TB control requires a surveillance system that considers the spatial distribution of disease, thus enabling the identification of high-risk areas. This approach favors the targeting of existing resources for the development of effective surveillance activities for disease prevention and control. Spatial analysis techniques may support health managers in planning more efficient surveillance activities for TB control, particularly in priority TB surveillance areas.

Conflicts of Interest. None.

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RESUMEN

Tuberculosis y condiciones de vida en Salvador, Brasil: un análisis espacial

Objetivo. Investigar las pautas de distribución espacial de la tuberculosis (TB) y la asociación de las condiciones de vida con la incidencia de esta enfermedad en Salvador, estado de Bahía (Brasil).

Métodos. Estudio ecológico que tomó el vecindario como unidad de análisis. Se recopilaron datos del Sistema de Información de Enfermedades de Notificación Obligatoria (*Sistema de Informação de Agravos de Notificação*, SINAN) y el Instituto Brasileño de Geografía y Estadística (*Instituto Brasileiro de Geografia e Estatística*, IBGE). Se transformaron y suavizaron las tasas de incidencia de la TB. Se aplicó análisis espacial para establecer la autocorrelación espacial y las áreas "conflictivas" de alto y bajo riesgo. Se confirmó la relación entre la TB y las condiciones de vida mediante regresión lineal espacial.

Resultados. La incidencia de la TB en Salvador mostró modelos heterogéneos, con tasas mayores en los vecindarios cuyas condiciones de vida eran desfavorables en 1995 y 1996. A lo largo del período de estudio, disminuyó la aparición de nuevos casos de la enfermedad, en particular en los estratos menos privilegiados. En el 2004 y el 2005, ya no se observó la asociación entre TB y condiciones de vida.

Conclusiones. La distribución espacial heterogénea de la tuberculosis en Salvador reflejaba anteriormente las desigualdades relacionadas con las condiciones de vida. Las mejoras de dichas condiciones y la atención de salud dirigida a los menos privilegiados pueden haber contribuido a los cambios observados.

Palabras clave Tuberculosis; tuberculosis, prevención & control; análisis espacial; inequidad social; grupos vulnerables; Brasil.