JIDC | THE JOURNAL OF INFECTION IN DEVELOPING COUNTRIES

Original Article

Environmental and social effects on the incidence of tuberculosis in three Brazilian municipalities and in Federal District

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Abstract
Introduction: The territorial characteristics, heterogeneities of landscapes, and the regional profiles of Brazil show great disparities in the spatial distribution of tuberculosis burden. Objective of this study is to analyze the effects of environmental and social factors on tuberculosis incidence in three Brazilian municipalities and in the Federal District of Brazil.
Methodology: We performed an ecological study carried out with 131,576 new cases of tuberculosis registered in the Brazilian national disease notification system. For our research we used climatic data, topographic data and socioeconomic data.
Results: Wind speed and vapor pressure increased the risk of tuberculosis infection between 4.6 and 5.8 times in the 3 municipalities, in comparison with the Federal District. In Recife socioeconomic aspects showed a greater association with tuberculosis. Lack of garbage collection, poor basic sanitation, and access to drinking water, respectively, increased 49, 33, and 28 times the risk of infection. In the multiple regression analysis, Rio de Janeiro showed several environmental characteristics – such as precipitation ($p = 0.002$), radiation ($p = 0.020$) and water vapor ($p = 0.055$) – and social characteristics associated with tuberculosis – such as the lack of sewage treatment, which revealed a 13.5-fold higher risk of infection ($p < 0.001$).
Conclusions: Incidence in the areas studied was influenced by environmental and social conditions at different levels depending on the territory where the problem was identified. The results make it possible to guide an urban and social policy to reach the targets set out in the WHO End tuberculosis Strategy in large Brazilian urban agglomerations.

Key words: Tuberculosis; social determinants; environmental variables.

J Infect Dev Ctries 2021; 15(8):1139-1146. doi:10.3855/jidc.13674

(Received 12 August 2020 – Accepted 21 February 2021)

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Introduction
According to the literature, environmental factors – such as solar radiation [1,2], precipitation levels [3,4], altitude [5,6], wind speed [7], and high temperature – seem to increase the incidence of tuberculosis (TB), as observed in China [8] and in Pakistan [9]. Also, changes in temperature associated with humidity [3] modify the rainfall regime and raise pollution levels due to ecosystem modification and/or biogeochemical cycles. In this context, large urban centers, due to the high concentration of buildings and population density, suffer from higher heat generation and thermal absorption [10]. The findings on the additional contribution of environmental and geographic aspects to a higher incidence of infectious diseases – among them respiratory diseases such as TB – are robust [11,12].

In addition, urban agglomerations in developing countries show poor housing conditions, low schooling and income, lack of sanitation, and difficulty accessing health services [13,14,15]. These limitations, associated with other vulnerabilities (living on the street, living in shelters, using drugs, among others) constitute an ideal scenario for TB dissemination [16]. It is worth mentioning that, despite the evidence that TB is part of the determination of poverty [13,14,15], it is important to know the different production scenarios and the associations of this disease to climatic conditions in the country.

Regarding TB burden, Brazil ranks 18th among countries with the highest incidence, with a prevalence of 33.5/100,000 population in 2017. According to specific regions, in the Federal District (FD) the coefficient is about 10.5/100,000 population; in Porto

Alegre, 80.4/100,000 pop.; in Rio de Janeiro, 84.2/100,000 pop; and in Recife, 90.4/100,000 pop., which shows the disparity in the distribution of TB burden between these municipalities and the FD. In this context, the main purpose of this study is to analyze the following research questions: is there association of TB indicators in such disparate scenarios? How do environmental and/or social variations influence TB burden in different geographic environments? And, if so, what are the risk factors involved in this phenomenon? Therefore, we analyze four areas of large Brazilian agglomerates whose TB loads are diverse to offer a better understanding of the distribution of the disease in those spaces in order to support local programs to reach the WHO End TB Strategy. The objective of the present study is to analyze the effects of environmental and social factors on the incidence of TB in three Brazilian municipalities and in the FD.

Methodology

We performed an ecological study [17] carried out with the Brazilian municipalities of Porto Alegre, Rio de Janeiro, Recife, and the FD, located in the South, Southeast, Northeast, and Midwest regions, respectively. The sample selection was based on the epidemiological data with the highest TB burden in the South, Southeast, and Northeast regions and the lowest in the Central-West region [18]. The population involved 74,080 cases from Rio de Janeiro, 24,422 from Porto Alegre, 29,590 from Recife and 3,484 from the FD, for a total of 131,576 TB cases between 2003 and 2014, incidence yearly. All new cases of TB (pulmonary, extrapulmonary, and pulmonary and extrapulmonary according to the Ministry of Health classification) [19] registered in the Brazilian National Notification Information System (Sistema de Informação e Notificação de Agravos à Saúde - SINAN/TB) were included. All cases in database had TB incidence (dependent variable = 1). Cases with the address information section missing, of non-residents in the studied municipalities, and with change of diagnosis were excluded.

TB incidence in the three municipalities and in the FD was considered a dependent variable. Environmental and socioeconomic variables were considered as independent variables. We extracted the

Table 1. Distribution of tuberculosis cases according to clinical and demographic characteristics of the FD, Porto Alegre, Recife, and Rio de Janeiro - 2003 to 2014.

Variables	Total	Federal District	Porto Alegre	Recife	Rio de Janeiro	*p*-value ***
	n / %	n / %	n / %	n / %	n / %	
Gender						
Male	86,485/65.7	2,138/61.4	16,167/66.2	19,810/66.9	48,370/65.3	< 0.001
Female	45,077/34.3	1,346/38.6	8,255/33.8	9,774/33.1	25,702/34.7	
Age group						
Younger than 15	5,947/4.5	161/4.6	810/3.3	1,635/5.5	3,341/4.5	
16 to 30 years old	43,227/32.9	8,90/25.5	7,649/31.3	8,839/29.9	25,849/34.9	
31 to 45 years old	40,850/31.0	1,109/31.8	8,617/35.3	9,782/33.1	21,342/28.8	< 0.001
46 to 60 years old	27,944/21.3	753/21.6	5,033/20.6	6,313/21.3	15,845/21.4	
Older than 60	13,608/10.3	571/16.5	2,313/9.5	3,021/10.2	7,703/10.4	
Race/Skin color**						
Caucasian	52,296/68.4	1,205/72.8	16,284/73.7	5,628/60.0	29,179/67.3	
Black	22,803/29.9	376/22.7	5,689/25.8	3,112/33.2	13,626/31.4	< 0.001
Brown	1,372/1.8	73/4.5	107/0.5	636/6.8	556/1.3	
AFB						
Positive	64,755/49.2	1,350/38.7	13,711/56.1	14,233/48.1	35,461/47.9	
Negative	29,103/22.2	1,231/35.3	5,481/22.4	4,456/15.1	17,935/24.2	< 0.001
Not performed	37,718/28.6	903/25.9	5,230/21.4	10,901/36.8	20,684/27.9	
Sputum culture						
Positive	10,723/8.1	534/15.3	3,302/13.5	1,406/4.8	5,481/7.4	
Negative	5,536/4.3	494/14.2	1,421/5.8	1,032/3.5	2,589/3.5	< 0.001
Not performed	115,317/87.6	2,456/70.5	19699/80.7	27,152/91.8	66,010/89.1	
Clinical form						
Pulmonary	103,624/78.7	2,424/69.6	17,550/71.9	23,927/80.9	59,723/80.6	
Extrapulmonary	20,449/15.6	949/27.2	4,540/18.6	4,261/14.4	10,699/14.4	< 0.001
Pulm. + Extrap.	7,503/5.7	111/3.2	2,332/9.5	1,402/4.7	3,658/4.9	
Total	**131,576/100.0**	**3,484/100.0**	**24,422/100.0**	**29,590/100.0**	**74,080/100.0**	

* Excluded cases ignored regarding gender; ** Excluded cases ignored regarding race/skin color; *** *p*-value for the chi-square test.

climatic information from Worldclim Version 2, with a spatial resolution of approximately 1 km [20]. In order to evaluate the effect of the relief, we used elevation data generated by the Shuttle Radar Topographic Mission, with spatial resolution of approximately 90 meters [21]. For the linkage between cases and environmental factors, only home addresses were used. Socioeconomic data were obtained from the Brazilian Institute of Geography and Statistics [22].

We also used negative binomial regression, considering the counting process as a distribution to estimate the association between the dependent variable and the TB incidence coefficient in the three municipalities and in the FD, based on 13 independent variables: 6 environmental variables – average temperature (° C), precipitation (mm), solar radiation (kJ m^{-2} day^{-1}), wind speed (ms^{-1}), water vapor pressure (kPa), and altitude – and 7 sociodemographic variables – mean of people per household, per capita income, drinking water supply, sewage treatment, garbage collection, percentage of illiterates, and the number of bathrooms per household. TB incidence was calculated from the quotient between TB cases and the population of each municipality and of the FD multiplied by one hundred thousand. Multiple values TB Incidence were used in the comparison in respect to independent variables.

In the exploratory research, each environmental and social variable was adjusted by bivariate analysis, including the interaction between the factors, in order to identify the increased risks in each of the three municipalities and in the FD, considering those variables with association and a significance level less than or equal to 0.05. Multiple regression models were adjusted for each of the three municipalities and the FD because they reflect sufficiently distinct contexts to justify this approach. The choice of the final model for each of the three municipalities and the FD was performed by stepwise regression, where the probability considered for entry into the regression was 0.10 and for removal from the regression was 0.20 [23]. The research was approved by the Research Ethics Committee of the University of Brasília, Opinion Nº 1,098,421.

Results

We observed a predominance of TB (Table 1) in men with a variation from 61.4% to 66.9% of the cases. The most affected age group was 31 to 45 years in Recife (33.1%), Porto Alegre (35.3%) and in the FD (31.8%). In Rio de Janeiro, however, the age group of

Table 2. Estimates of the risk for TB infection according to environmental variables in the univariate analysis. Federal District, Porto Alegre, Recife, and Rio de Janeiro, 2003 to 2014.

Environmental variables	RR	95% CI	p-value
Precipitation (Federal District)	0.970	0.964 - 0.975	< 0.001
Porto Alegre	1.024	1.021 - 1.028	< 0.001
Recife	1.027	1.024 - 1.030	< 0.001
Rio de Janeiro	1.018	1.015 - 1.021	< 0.001
Radiation (Federal District)	0.998	0.9997 - 0.9998	< 0.001
Porto Alegre	1.000	1.0001 - 1.0002	< 0.001
Recife	1.002	1.0001 - 1.0002	< 0.001
Rio de Janeiro	1.000	1.0001 - 1.0002	< 0.001
Temperature (Federal District)	0.843	0.816 - 0.871	< 0.001
Porto Alegre	1.157	1.134 - 1.180	< 0.001
Recife	1.177	1.155 - 1.199	< 0.001
Rio de Janeiro	1.136	1.116 - 1.156	< 0.001
Vapor (Federal District)	0.138	0.095 - 0.202	< 0.001
Porto Alegre	5.485	4.378 - 6.871	< 0.001
Recife	6.722	5.363 - 8.427	< 0.001
Rio de Janeiro	4.603	3.733 - 5.676	< 0.001
Wind (Federal District)	0.157	0.110 - 0.224	< 0.001
Porto Alegre	5.864	4.613 - 7.453	< 0.001
Recife	6.443	5.139 - 8.078	< 0.001
Rio de Janeiro	4.660	3.761 - 5.772	< 0.001
Altitude (Federal District)	0.997	0.997 - 0.998	< 0.001
Porto Alegre	1.001	0.998 - 1.005	0.406
Recife	1.013	1.000 - 1.025	0.051
Rio de Janeiro	0.999	0.997 - 1.000	0.196

RR: Risk rato; 95% CI.

16 to 30 years (34.9%) prevailed. TB was more frequent in white people in Porto Alegre (73.7%), Recife (60.0%), Rio de Janeiro (67.3%) and in the FD (72.8%). In the 12 years of study, considering the four regions studied, pulmonary TB prevalence prevailed (from 69.6% to 80.9%). Bacilloscopy was positive in 38.7% of the patients and the sputum microscopy was mostly not performed (from 70.5% to 91.8%), with all variables significant ($p < 0.001$).

Regarding environmental conditions (Table 2), we verified that the FD showed a lower risk of TB infection than the other municipalities when temperature, vapor, and wind parameters were evaluated ($p < 0.001$). On the other hand, the low wind velocity and the vapor pressure in the FD contributed to the reduction of TB infection in relation to the other municipalities ($p < 0.001$). In this case, wind speed and vapor increased the risk of developing TB by 4.6 to 6.4 times and by 4.6 to 6.7 times, respectively, when comparing the three municipalities with the FD.

The bivariate analysis of the social indicators in the three municipalities of the study and in the FD revealed that the lack of a bathroom at home indicated a 119-fold higher risk of developing TB in Porto Alegre, 153-fold in Recife and 37-fold in Rio de Janeiro, compared to the FD. Also, the lack of garbage collection increased by 49.7 times the risk of having TB in Recife, 38.4 times in Porto Alegre and 23.4 times in Rio de Janeiro, in comparison with the FD. In addition, lack of sewage interfered with TB infection, increasing the risk for the disease by 33 times in Recife, 30 times in Porto Alegre, and 19 times in Rio de Janeiro. The lack of potable water contributed with a risk for TB infection 28 times higher in Recife and Porto Alegre and 17 times in Rio de Janeiro, when compared to the FD. Illiteracy rate, per capita income, and number of residents per household showed no difference in the risk of TB infection in all municipalities and in the FD (Table 3).

The final multiple regression models (Table 4) were distinct in the 3 municipalities and in the FD. For the FD, the final model was defined with the variables *precipitation*, *radiation*, *garbage*, *altitude*, and *water*. We observed that *precipitation*, *radiation,* and *garbage* were positively associated with TB infection, with a

Table 3. Estimates of the risk for TB infection according to social variables in the univariate analysis. Federal District, Porto Alegre, Recife, and Rio de Janeiro, 2003 to 2014.

Social variables	RR:	95% CI	*p*-value
people/household (Federal District)	1.000	1.000 - 1.000	< 0.001
Porto Alegre	1.000	1.000 - 1.000	0.204
Recife	1.000	1.000 - 1.000	0.010
Rio de Janeiro	1.000	1.000 - 1.000	< 0.001
Drinking water (Federal District)	0.007	0.003 - 0.016	< 0.001
Porto Alegre	27.620	18.041 - 42.285	< 0.001
Recife	28.161	18.332 - 43.260	< 0.001
Rio de Janeiro	16.596	11.237 - 24.511	< 0.001
Sewage Treatment (Federal District)	0.020	0.011 - 0.037	< 0.001
Porto Alegre	30.474	18.071 - 51.389	< 0.001
Recife	33.153	18.666 - 58.884	< 0.001
Rio de Janeiro	19.048	11.843 - 30.639	< 0.001
Waste Collection (Federal District)	0.010	0.003 - 0.033	< 0.001
Porto Alegre	38.393	23.720 - 62.142	< 0.001
Recife	49.720	31.153 - 79.351	< 0.001
Rio de Janeiro	23.472	14.995 - 36.740	< 0.001
Bathroom/household (Federal District)	0.009	0.039 - 0.020	< 0.001
Porto Alegre	119.332	55.027 - 258.787	< 0.001
Recife	153.153	68.061 - 344.634	< 0.001
Rio de Janeiro	37.589	17.902 - 78.926	< 0.001
Illiteracy (Federal District)	0.040	0.026 - 0.060	< 0.001
Porto Alegre	0.006	0.000 - 5752.455	0.368
Recife	1.451	0.003 - 694.936	0.906
Rio de Janeiro	0.000	0.000 - 0.001	< 0.001
Per capta income (Federal District)	1.000	1.000 - 1.000	< 0.001
Porto Alegre	1.000	1.000 - 1.000	0.247
Recife	1.000	1.000 - 1.000	0.804
Rio de Janeiro	1.000	1.000 - 1.000	0.927

RR: Risk rato; 95% CI.

31.1-fold increase in risk associated with precipitation and 30 times with the lack of garbage collection.

In Porto Alegre, temperature was the factor that most explained the risk for TB infection, with an 18-fold increase in risk, whereas precipitation was a protective factor; that is, it reduced the risk for the disease by 19.0%. The other variables showed no significant increases in the risk for TB infection.

In Recife the variables associated with the risk for TB infection were *lack of bathrooms*, *altitude*, *potable water,* and *income*. It is noteworthy to mention that the presence of bathrooms in this city reduces the risk for infection by 0.012 times. Potable water, in turn, reduces the risk by 0.014 times. The other variables (altitude and income) were not significantly associated with the risk for TB infection.

In Rio de Janeiro, the variables associated with the risk for TB infection were *precipitation*, *radiation*, *temperature*, *vapor*, *wind,* and *lack of bathroom*, *water,* and *sewage*. The variables *sewage*, *wind*, and *temperature* were the most significant, increasing the risk for infection in 13.6, 3.6, and 1.5 times, respectively. The variables *vapor*, *absence of bathroom*, and *absence of drinking water* were shown as a protection factor; that is, they reduce the risk for infection in 81.7%, 92.8%, and 98.7%, respectively.

Discussion

Wind speed and vapor pressure increased between 4.6 and 5.8 times the risk for TB infection in the three municipalities, in comparison with the FD. In the case of the wind in Rio de Janeiro, the risk was 4.6 times higher, in Recife 6.4 times, and in Porto Alegre 5.8 times. Research shows that wind velocity contributes to improved ventilation in the environment, which, in combination with other interventions, helps reduce the risk for airborne infection [24]. However, wind speed can contribute to the spread of bacteria and favor the increase of TB cases, with a consequent increase in the risk for TB infection [7]. In general, wind speed allows the circulation of the TB bacillus in enclosed places, confining the disease to certain ghettos, especially in large agglomerations, where the houses are small, with few windows and no solar access [14].

In this series, water vapor increased the risk for infection in Recife by 6.7 times, in Rio de Janeiro 4.6 times, and in Porto Alegre 5.4 times. This aspect is important for the survival of the Koch's bacillus in the environments, considering that when germs find aired spaces, 20% of them remain viable for up to 3 hours, 50.0% for up to 6 hours and 30.0% for 9 hours [25]. These findings are relevant and strengthen the understanding of the problem of both the production

Table 4. Estimates of tuberculosis risk ratio according to social and environmental variables by municipality in the multivariate model, 2003 to 2014.

Municipality	Variables	RR:	95% CI	*p*-value
Federal District	Precipitation	1.311	1.061 – 1.621	0.012
	Radiation	1.011	1.004 – 1.018	0.002
	Garbage	29.937	4.983 – 179.854	< 0.001
	Altitude	0.987	0.975 – 0.999	0.045
	Water	0.115	0.005 – 2.530	0.170
Porto Alegre	Precipitation	0.816	0.670 – 0. 993	0.042
	Radiation	1.002	1.001 – 1.003	0.001
	Temperature	18.165	2.803 – 117.729	0.002
	Income	1.000	1.000 – 1.000	< 0.001
	Altitude	0.992	0.984 – 0.999	0.046
Recife	Bathroom	0.012	0.003 – 0.056	< 0.001
	Altitude	0.978	0.964 – 0.991	0.002
	Water	0.014	0.002 – 0.083	< 0.001
	Income	1.000	1.000 – 1.000	0.055
Rio de Janeiro	Precipitation	0.969	0.950 – 0.989	0.002
	Radiation	0.999	1.000 – 1.000	0.020
	Temperature	1.472	1.137 – 1.905	0.003
	Vapor	0.183	0.032 – 1.035	0.055
	Wind	3.653	1.110 – 12.021	0.033
	Bathroom	0.072	0.036 – 0.144	< 0.001
	Water	0.013	0.002 – 0.112	< 0.001
	Sewage	13.590	3.800 – 48.599	< 0.001

RR: Risk rato; 95% CI.

and the maintenance of TB infection, especially in the peripheries of large cities, as found in this study.

Considering the social conditions, Recife revealed a higher risk for TB infection associated with the lack of bathrooms, sewage, garbage collection, and drinking water. In Rio de Janeiro and Porto Alegre, the risk for infection was more associated with the lack of bathroom, sewage, garbage collection, and drinking water. Our findings corroborate results observed in India [13], where the results highlighted that malnutrition, poor living conditions in the Kaccha home (built with natural materials) and smoking were the main risk factors for TB. Also, Latin America and the Caribbean showed that absolute and relative inequality had an influence on the incidence of TB, and the indicators in countries that invest less in health and have low coverage of basic sanitation, among other social aspects, seem to guarantee high persistence TB [15].

This scenario of social exclusion, widely observed in large Brazilian cities, reinforces the relationship between the determination of TB burden in socially vulnerable areas and the involvement of populations that reside in small, poorly ventilated houses, without access to solar radiation. Aggregate factors such as lack of income, low levels of education, and problems with infrastructure and basic sanitation also contribute to TB infection [14].

Multiple regression analysis after adjustment of variables in each municipality and in the FD revealed that, while some of these variables were associated with the risk for TB infection, others revealed to be a protection factor. This difference is justified by the fact that the analysis simultaneously evaluates (in a single model) the effect of all selected variables on TB incidence in the study. In this case, one can understand that the influence of each social or environmental variable was controlled by the effect of the other variables. Since, in general, there are associations between the explanatory variables, it is common that statistically significant variables in the univariate analysis lose importance in the multivariate analysis, as observed in this case series. In this sense, the use of this model affected the multiple regression analysis of the study. Although Recife showed indicators and social situation of extreme vulnerability, such as the lack of drinking water and bathrooms in households, for example, these factors were classified as protectors against TB infection. There are some possible explanations for these findings, including that the existence of precarious social codes may result in greater difficulty in accessing tuberculosis diagnosis services.

Considering the multivariate approach, Rio de Janeiro revealed a greater number of environmental variables associated with the TB outcome, which include precipitation, radiation, water vapor, and temperature. Also, wind velocity – which in Rio de Janeiro shows an average of 8.35Km/h and, in the FD 6.44Km/h – probably favored an increase in the dispersion of germs in the most vulnerable population niches of that municipality. The varied geographical composition – including hills, islands, bays, and mountain ranges – and the high-density poor-quality buildings also increase the incidence of TB in Rio de Janeiro. The characteristics of these urban constructions may interfere with wind trajectories and can sometimes cause the bacilli to be confined to areas with high population densities and lack of land use planning. This means that restriction of space and ventilation and lack of urban planning favor the spread of the infection [26]. Research in Mainland China has shown that wind was a protective factor (20 km/h with a TB incidence rate of 93/100,000 pop.) and that each one-unit increase in wind speed reduced the relative risk for TB infection by 0.83518 [7], fact not observed in the present case series.

Porto Alegre was more influenced by the action of water vapor regarding TB infection, reflecting the importance of the environment conducive to the survival of the Koch's bacillus, a fact observed in Africa, where climatic characteristics of high rainfall and humidity were associated with larger records of TB cases in the rainy season when compared to the dry season [3,4].

The environmental variable *average temperature* (24º C to 26º C) reflected an 18.1 times greater risk for TB infection in Porto Alegre and 1.4 times greater in RJ, a fact also evident in cases of TB diagnosed at temperatures between 21º C and 39° C in China [8] and Pakistan [9]. Under temperature conditions between 20° C and 30° C and humidity of 70.0%, some of the aerobic Koch's bacilli remain viable for a longer time [27,28,29]. Probably this environmental condition of moisture found in RJ, an average of 66.0%, has favored the maintenance of living bacillus in those risk niches.

Regarding social variables, the absence of sewage treatment in RJ resulted in a 13.5 times greater risk for TB infection ($p < 0.001$). In the FD, the lack of garbage collection revealed a 29-fold greater risk in relation to areas with adequate garbage collection. Income was significantly associated with TB only in Recife and Porto Alegre ($p < 0.001$). Corroborating these findings, several studies show that the deterioration of living and health conditions of the vulnerable population due to the socioeconomic determinants reproduce the TB disease [13,14].

Among the limitations of the study, the fact that the data were obtained from a secondary source (SINAN-TB) may have led to a methodological bias due to inconsistent information such as incomplete, erroneous and/or blank records. Also, it may have occurred that some patients who were treated in the FD did not reside in that territory. It should be noted that the comparisons considered heterogeneous units of analysis, both from the point of view of the size of the area, the population, and the proportion of the urban area occupied as well as socioeconomic and environmental aspects of each municipality and the FD.

Conclusions

This present study revealed the existence of an association between the incidence of TB and environmental and social conditions, and this relationship presents differences in the risks depending on the territory and the environmental situations where the disease is found. Finally, it was possible to understand that the health sector should, together with other public policies, such as infrastructure, design strategies to support the implementation of a policy involving large cities, in order to reduce the burden of TB in the peripheries of large urban agglomerations. In addition, there is a need for urban and environmental planning in the large Brazilian capitals with a view to improving the population's living conditions. Other studies are still required with a focus on the most significant environmental indicators in each municipality in order to deepen the knowledge of the associations described herein with a view to creating strategies to achieve the end of TB epidemic in Brazil.

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Conflict of interests: No conflict of interests is declared.