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Original Article

Social risk and its association with tuberculosis mortality in a context of high inequality in South Brazil: A geo-epidemiology analysis

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ABSTRACT

Background: Tuberculosis (TB) is one of the top 10 causes of death worldwide; in 2016, over 95% of TB deaths occurred in low- and middle-income countries. Although the incidence and deaths from TB have decreased in Brazil in recent years, the disease has increased in the vulnerable population, whose diagnosis is more delayed and the chances for abandonment and deaths are significantly higher. This study aimed to identify high-risk areas for TB mortality and evidence their social determinants through a sensitive tailored social index, in a context of high inequality in South Brazil.

Methods: A multistep statistical methodology was developed, based on spatial clustering, categorical principal components analysis, and receiver operating characteristic curves (ROC). This study considered 138 spatial units in Curitiba, South Brazil. TB deaths (2008–2015) were obtained from the National Information Mortality System and social variables from the Brazilian Human Development Atlas (2013).

Results: There were 128 TB deaths recorded in the study: the mortality rate was 0.9/100,000 inhabitants, minimum–maximum: 0–25.51/100,000, with a mean (standard deviation) of 1.07 (2.71), and 78 space units had no deaths. One risk cluster of TB mortality was found in the south region ($RR = 2.64$, $p = 0.01$). Considering the social variables, several clusters were identified in the social risk indicator (SRI): income (899.82/1752.94; 0.024), GINI Index (0.41/0.45; 0.010), and overcrowding (25.07/15.39; 0.032). The SRI showed a high capacity to discriminate the TB mortality areas (area under ROC curve 0.865, 95% CI: 0.796–0.934).

Conclusions: A powerful risk map (SRI) was developed, allowing tailored and personalised interventions. The south of Curitiba was identified as a high-risk area for TB mortality and the majority of social variables. This methodological approach can be generalised to other areas and/or other public health problems.

Background

Although tuberculosis (TB) is a curable disease, it remains an important cause of mortality [1], mainly in low-income and middle-income countries where tuberculosis control is far from a reality. It is a significant challenge for countries with largescale inequalities, such as Brazil, to achieve the goal recommended by the World Health Organization (WHO): the end the disease by 2050 [2,3].

In the last ten years, the advance of TB in Brazil has shown a consistent decrease: the incidence rate has dropped from 37.9/100,000 (2006) to 32.4/100,000 inhabitants (2016), and the mortality rate has decreased from 2.6/100,000 to 2.2/100,000 inhabitants in the same period. Nevertheless, this decrease varied between Brazilian regions and municipalities, all of which showed significant differences [4]. These differences are present in other sectors also.

Brazil currently faces an economic, health and political crisis [5]; an increasing unemployment rate has seen the highest rate of the last five years (13.1%) [6]; cuts in the ‘Bolsa Familia’, which is the

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most extensive conditional cash transfer programme in Brazil, a lack of jobs, and around six million families without homes, among other social consequences [7,8].

The economic crisis and fiscal austerity has negatively affected many health conditions in Brazil, such as child mortality [8], and it is likely that it may jeopardise advances in tuberculosis control and dismantle the progress that has been made so far, mainly in the context of fragile social protection systems and high poverty rates [7].

The literature has evidenced the different dimensions associated with the development of TB, such as behaviour (e.g., smoking and alcohol use), chronic diseases such as diabetes, HIV [9], environmental, economic, and social conditions, a worse quality of life [10,11], migratory movements and demography [12,13].

Studies have linked social determinants and deaths due to TB [14], these being necessary to understand whether the risk factors for TB incidence and mortality are the same. One study [15] that looked at social causes of TB deaths produced controversial results: through a meta-analysis, the authors found no association between TB mortality and social dimensions. However, other studies have observed such associations [14,16,17].

Different methodological approaches have been observed in the literature to confirm the impact of social determinants in tuberculosis, yet few investigations have considered the neighbourhood effects on the social and economic risks [14,17]. It is relevant, therefore, to construct a social risk indicator (SRI) customised to geographically located tuberculosis mortality risk, with the aim of advancing knowledge in this area [17]. The study will then identify high-risk areas for TB mortality and evidence their social determinants through a sensitive tailored social index, in a context of high inequality in South Brazil.

Methods

Data, population and sources

An ecological study was conducted in the city of Curitiba, situated in South Brazil, with a population of 1,751,000 inhabitants and organised in 138 spatial units (SU) [18]. Curitiba is a city with a high human development index (DHI = 0.0823) and was ranked tenth among the 5565 Brazilian municipalities [18]. It has 111 basic public health units that offer free health care to the whole population [19]. TB treatment and drugs are free in Brazil [20].

Curitiba has shown a decrease in the incidence rate of TB: 22.7/100,000 inhabitants (2013) to 17.1/100,000 inhabitants (2016), but the mortality rates have shown an increase from 0.7/100,000 inhabitants to 1.0/100,000 inhabitants in the same period [21,22]. The period considered in this study was 2008–2015, and all TB deaths (of basic cause) were included. Data were obtained from the Mortality Information System (Sistema de Informações sobre Mortalidad; SIM) at the Secretaria de Saúde do Estado do Paraná (SESA). Population data were extracted from the Atlas de Desenvolvimento Humano [18].

The variables under study

The dependent variable was mortality rate (per 100,000 inhabitants), computed for each SU. Based on the literature [13–17] and information availability, 13 contextual variables were considered as potential TB determinants (Table 1) and were extracted from the Brazilian Human Development Atlas (PNUD 2013; [18]).

Analysis plan

As a first approach, descriptive analyses were applied considering both dependent and independent (social contextual) variables; the values were analysed to check their distribution pattern. A multistep methodology was then applied, as summarised in the following steps.

Bivariate analysis

The risk areas for TB mortality (dependent variable) were categorised = 1 and no risk areas were categorised = 0. To choose the relevant contextual variables in this high-risk areas approach, chi-squared tests for independency [24] were applied between mortality clusters and social clusters. Social clusters not statistically associated with TB mortality clusters were excluded. The dependent variable was tested with the Shapiro–Wilk test to choose the best approach.

Spatial clustering analysis

To identify the risk areas, a spatial clustering analysis was applied independently to all variables (mortality due to tuberculosis and contextual variables). Spatial scan statistics [23] were used, with a maximum default of 50% of the population at risk. Gaussian models were adopted to identify the clusters of social variables (continuous variables) and the discrete Poisson model to identify mortality rates. Variables with no critical areas (no clusters) were excluded.

Categorical principal components analysis (CATPCA)

CATPCA was used to select a subset of potentially independent and complementary variables, through the identification of the variables with higher coefficients on each of the principal components [24,25]. This method can enable a reduction in the number of variables, selecting the most powerful (with more information), complementary and independent variables. Varimax rotation was applied and those variables with a higher principal normalisation of each component were selected. The criterion to retain components was based on eigenvalues greater than one and explained variance >80% [24,25].

Construct a social risk indicator (SRI)

To develop an SRI overlapping critical areas, using the identified contextual variables (previous step), for each risk factor a number/value was assigned to each space unit, depending on whether they belonged to a significant cluster (1) or not (0) [17]. The sum of the values of all risk factors was defined as a risk indicator. To validate the discriminant capacity of SRI, the area under the receiver operating characteristic (ROC) was computed. The area below curve varied from 0 to 1 and the closer to 1, the greater the capacity of the models to discriminate the areas that presented the characteristics of interest [24].

Analyses were processed by Software Satscan 9.4.2, Statistical Package for the Social Sciences (SPSS) 21.0, and the maps were created in Arcgis 10.2.

Results

Table 2 shows the values of the descriptive analysis of all the social variables and TB mortality. All of them were scanned to detect risk cluster, and just eight were observed as significant cluster.

The Shapiro–Wilk (S–W) test was applied to test the normality of the tuberculosis mortality rates ($W = 0.412$, $p < 0.001$) and relative risk ($W = 0.196$, $p < 0.001$). When these parameters were not met, alternative models have been applied, according to the data distribution.

Table 1
The definition of social variables analysed from the PNUD 2013 [18]; information from the Census 2010).

Code	Variable name	Definition
LEX	Life expectancy	The average number of years that people are expected to live from birth if the level and age-standard of mortality prevailing in the Census year remain constant throughout life.
SURV	Survival probability	The probability of a newborn child living to the age of 60 if the level and age-standard of mortality prevailing in the Census year remain constant throughout life.
COL	College	The ratio of the total number of people of any age attending tertiary education (undergraduate, specialisation, masters or doctorate) and the population aged 18 to 24 years, multiplied by 100.
GINI	Economic distribution index	This measures the degree of inequality in the distribution of individuals according to per capita household income. Its value is 0 when there is no inequality (household income per capita of all individuals has the same value) and tends to 1 as inequality increases. The universe of individuals is limited to those living in permanent private households.
IPC	Income per capita	The ratio of the sum of the income of all individuals living in permanent private households and the total number of those individuals. Amounts in Reais R$ (Brazilian currency).
IPCP	Income per capita poorer	Average per capita household income of people with per capita household income equal to or less than R$ 255.00 per month. The universe of individuals is limited to those living in permanent private households.
THEIL	Income distribution index	This measures inequality in the distribution of individuals according to per capita household income, excluding those with zero per capita household income. It is the logarithm of the ratio between the arithmetic and geometric means of household income per capita of the individuals, being zero when there is no income inequality between them and tending to infinity when the inequality tends to the maximum.
WAT	Piped water	The ratio of the population living in permanent private households with piped water in at least one of their rooms and with an exclusive bathroom and the total population living in permanent private households, multiplied by 100. The water may come from a general network, from a well, a spring or reservoir supplied by rainwater or tank car. An exclusive bathroom is defined as a room that has a shower or bath and toilet
OVR	Overcrowded	The ratio of the population living in permanent private households with a density greater than two and the total population living in permanent private households, multiplied by 100. The density of the household is given by the ratio of the total number of dwellers in the household to the total number of rooms used as a dormitory.
GARB	Garbage collection	The ratio of the population living in households with garbage collection and the total population residing in permanent households, multiplied by 100. These include situations where the collection of garbage is carried out directly by a public or private company, or the garbage is deposited in a bucket, tank or tank outside the house for later collection by the service provider. Only permanent private families located in an urban area are considered.
SEW	Sewer	The ratio of people living in households whose water supply does not come from a general network and whose sanitary sewage is not carried out by a sewage system or septic tank and the total population living in permanent households multiplied by 100.
MWAL	Masonry walls	The ratio of people living in households whose walls are not masonry and the total population living in permanent households, multiplied by 100. Only permanent private households are considered.
EDU	Education	Sub-index that comprises the Index of Municipal Human Education Development, representing the educational level of the adult population. This is obtained from the indicator % of those 18 years old or over who had completed fundamental education (8 years of study).

LEX: life expectancy; SURV: survival probability; COL: college; GINI: income distribution index; IPC: income per capita; IPCP: income per capita poorer; THEIL: index distribution economic; WAT: piped water; OVR: overcrowded; GARB: garbage collection; SEW: sewer; MWAL: masonry walls; EDU: education.

Table 2
Descriptive information about each variable analysed per space unit.

	Min	Max	Mean	Median	Q1 - Q3	SD
TB	0.0	25.51	1.07	0.0	1.11	2.07
LEX	69.47	81.48	76.45	76.98	5.61	3.38
SURV	75.10	09.09	85.43	86.47	7.18	4.71
COL	7.86	118.74	49.63	38.05	58.36	33.33
GINI	0.33	0.63	0.42	0.41	0.09	0.05
IPC	439.73	4645.60	1332.56	934.40	954.5	986.40
IPCP	87.27	212.87	178.56	180.61	22.08	17.38
THEIL	0.18	0.76	0.33	0.31	0.13	0.10
WAT	95.46	100	98.72	99.04	1.57	1.05
OVR	1.2	37.02	17.06	16.74	19.58	10.74
GARB	99.2	100	99.83	100	0.26	0.25
SEW	0.0	1.76	0.09	0.0	0.08	0.21
MWAL	0.0	13.46	2.47	1.30	2.51	3.47
EDU	0.40	0.94	0.67	0.68	0.28	0.15

TB: mortality rates; LEX: life expectancy; SURV: survival probability; COL: college; GINI: income distribution index; IPC: income per capita; IPCP: income per capita poorer; THEIL: economic distribution index; WAT: piped water; OVR: overcrowded; GARB: garbage collection; SEW: sewer; MWAL: masonry walls; EDU: education.

The distribution of the social variables with a cluster detected is showed in Fig. 1, and displays lower values of some variables corresponding to a worse social situation (LEX, COL, GINI, IPC, THEIL and EDU); just for overcrowding, the higher values correspond to a worse social condition. It can be observed that for all variables, the worst situations were in the south.

The identified risk clusters of TB mortality and social variables are shown in Fig. 2. TB mortality presented a risk cluster with RR = 2.64, (95% CI = 1.79; 3.90), 35 cases in 18 SU in the south

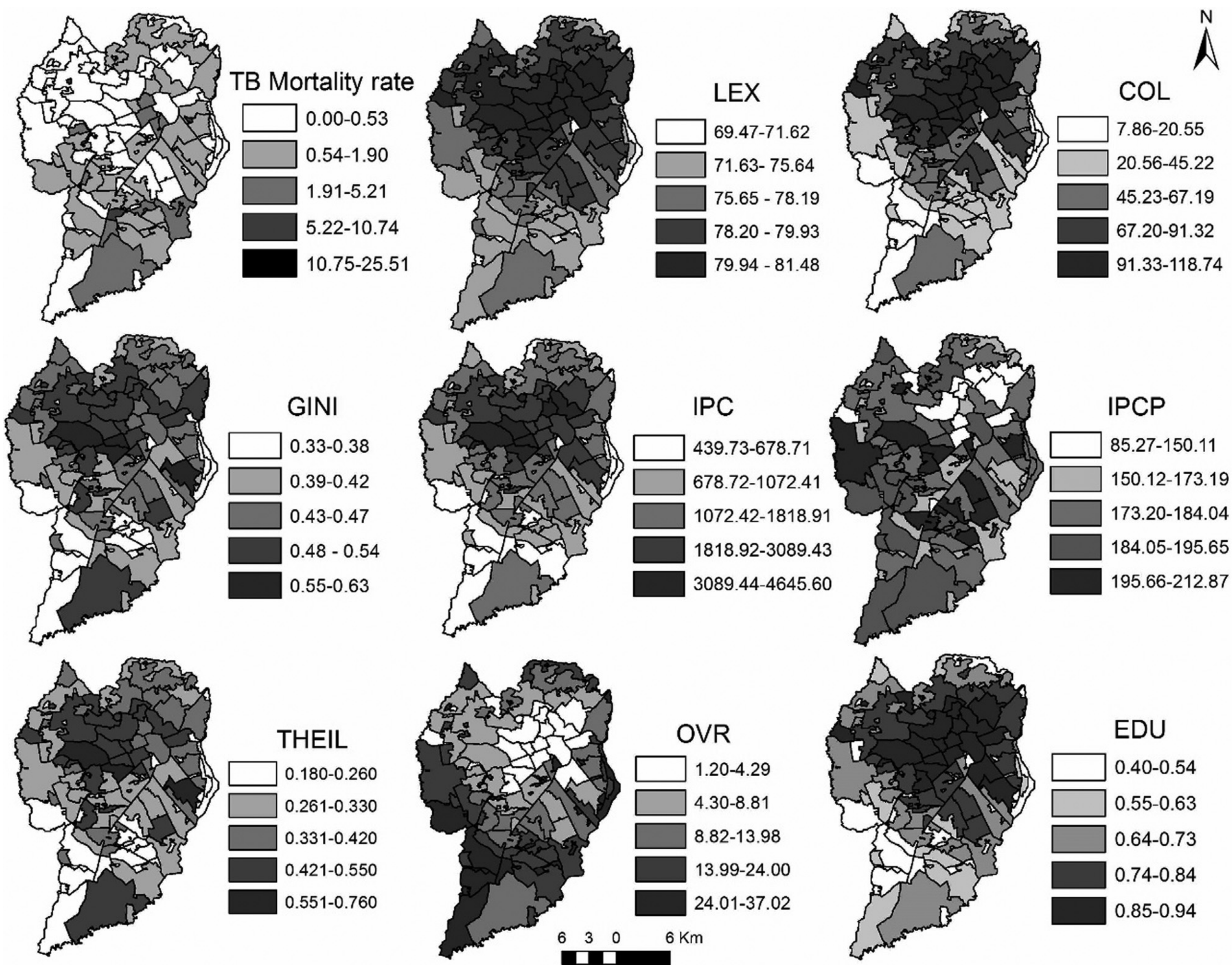

Fig. 1. The spatial distribution of social risk variables and TB mortality (per 100,000 inhabitants). LEX: life expectancy; COL: college; GINI: income distribution index; IPC: income per capita; IPCP: income per capita poorer; THEIL: economic distribution index; WAT: piped water; OVR: overcrowded; GARB: garbage collection; SEW: sewer; MWAL: masonry walls; EDU: education.

region and a rate = 2.0/100,000 inhabitants. Eight social variables presented risk clusters found mainly in the south: life expectancy, college, income per capita, poorer income per capita, GINI, THEIL, overcrowding and education. Only the variable IPCP had one risk cluster located in a different area – central region (Fig. 2).

In the south region, people have a lower life expectancy also have fewer years of study, a lower income, poorer education and are more overcrowded. GINI and THEIL were also most homogeneous in the south. Table 3 presents the information of each identified cluster.

Seven social clusters were associated ($p < 0.01$) with TB mortality clusters: LEX, COL, GINI, IPC, THEIL, OVR and EDU. Only one variable did not present an association (IPCP, $p = 0.148$) and was excluded from the next step.

The CATPCA results, using the seven selected variables, can be observed in Table 4, with five principal components corresponding to nearly 100% of the variance explained (99.76%). Representative high-value variables were chosen from each component.

After considering the proportion of variance and the magnitude of the eigenvalues, three components were selected (variance 97.34%), and after that, three variables were chosen, one from each component: IPC, GINI, and OVR. Lastly, a social risk indicator was developed, overlapping identified clusters (Fig. 3). The SRI showed a high capacity to discriminate high-risk areas of mortality (area under ROC = 0.865, 95% CI: 0.796–0.934).

Discussion

The aim of this study was to identify risk areas of TB mortality and to create a customised social risk indicator that can be related to mortality. A risk cluster of TB mortality was found in the south region. This area also had risks identified for all relevant social variables, showing the SRI to have a high capacity to discriminate critical mortality areas. The social determinants of health have been linked to the continuing transmission and the fatality of TB disease [10,13].

The south region showed critical areas (risk clusters) of life expectancy, college, GINI, income, THEIL, overcrowding and education. If income is high, better conditions of housing, work, food, transportation and health, can be more easily accessed. In addition, a higher level of education is related to a better income [10,26,27]. Income was the most important representative variable found from the first component, followed by GINI and overcrowding, respectively, from the second and third components; these three being used to compose the SRI in this study.

The role of social variables in TB risk is fully demonstrated in the literature [10,13,14,28], but few studies have developed spatial social risk indicators: One study [17] constructed a risk map of TB incidence and identified risk factors such as HIV/AIDS, overcrowded housing, populations residing in non-standard accommodation, unemployment, prison population and immigrant populations.

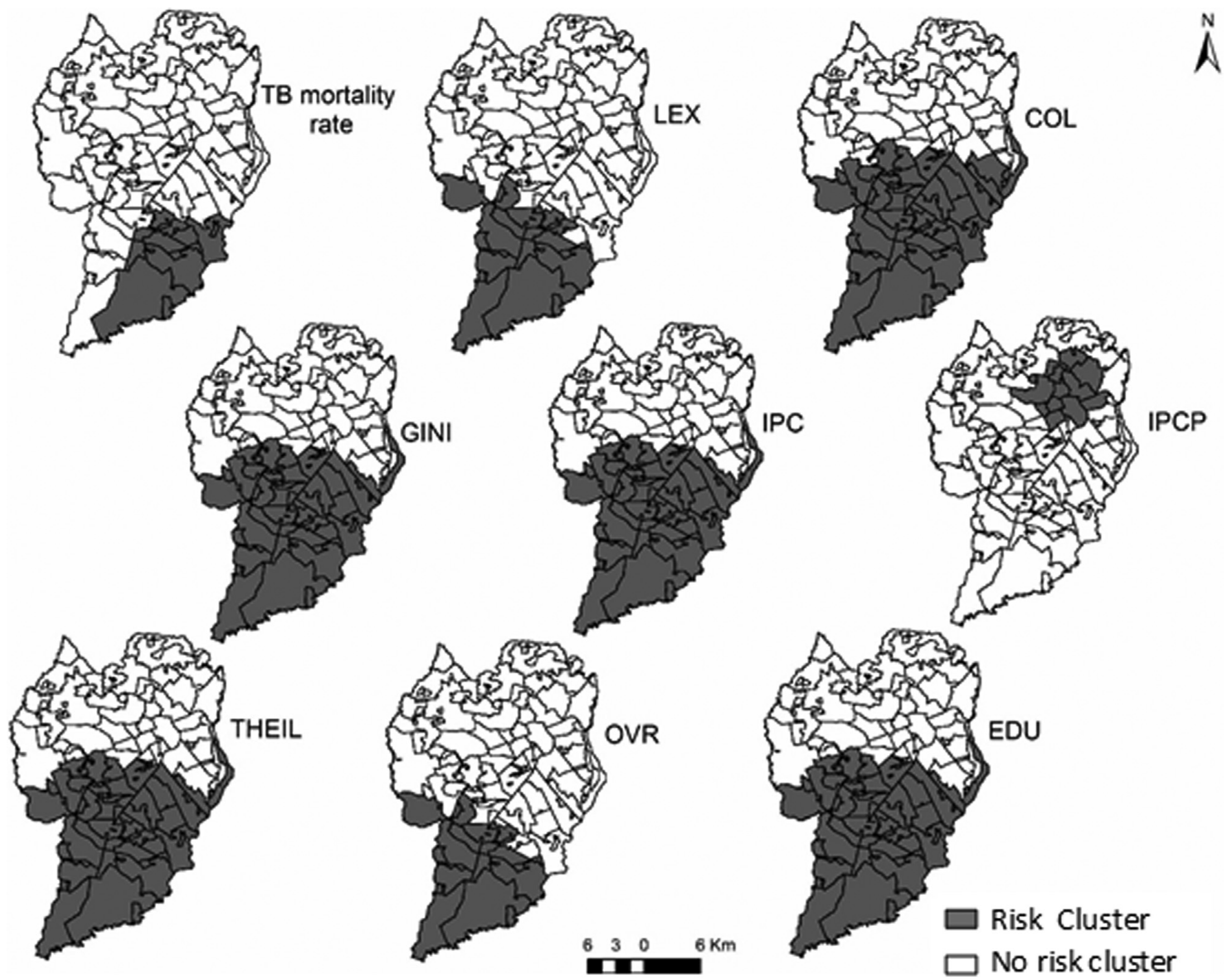

Fig. 2. The risk clusters of tuberculosis mortality and social variables in Curitiba, South Brazil. LEX: life expectancy; COL: college; GINI: income distribution index; IPC: income per capita; IPCP: income per capita poorer; THEIL: economic distribution index; WAT: piped water; OVR: overcrowded; GARB: garbage collection; SEW: sewer; MWAL: masonry walls; EDU: education.

Table 3
Cluster information.

	N. Space Units	Mean inside/Mean outside	Median	Q1 - Q3	Standard deviation	Log likelihood	*p*-Value
TX_TB	18	3.38/0.72	1.42	3.17	5.94	10.17	0.010
RRTB	18	6.04/0.85	1.74	3.05	17.07	10.17	0.010
LEX	27	74.13/77.02	74.34	3.11	3.20	8.382	0.046
COL	67	35.63/62.85	33.13	37.67	30.54	12.567	0.001
GINI	68	0.41/0.45	0.39	0.06	0.055	10.975	0.010
10IPC[a]	68	899.82/1752.94	732.58	571.07	892.67	14.281	0.024
11IPCP[a]	13	155.02/180.79	149.09	30.34	15.73	14.326	0.026
THEIL	68	0.29/0.37	0.29	0.08	0.096	17.621	0.045
OVC	24	25.07/15.39	25.42	8.78	10.14	8.562	0.032
EDU	67	0.60/0.73	0.54	0.19	0.14	13.121	0.002

TX_TB: mortality rates tuberculosis; RRTB: tuberculosis cluster; LEX: life expectancy; COL: college; GINI: income distribution index; IPC: income per capita; IPCP: income per capita poorer; THEIL: economic distribution index; OVR: overcrowded; EDU: education.

[a] Income in Brazilian currency (real R$).

Another study [14] constructed indicators related to TB mortality and found that equity in terms of income, schooling and urban occupancy was inversely associated with TB mortality.

The lowest income (IPCP) cluster was identified in the central region, a finding that corroborates the heterogeneity of large urban centres and their occupational problems, such as the presence of homeless people living in public shelters—this group is more prone to becoming ill from TB and is, therefore, a priority for disease control [29]. The Brazilian context is well represented and is similar to other developed countries [30], with economic heterogeneity demonstrated by the GINI and THEIL indices. It is worthwhile highlighting that higher values of both indices correspond to higher-income heterogeneities. Usually, lower heterogeneities are associated with better living conditions; it is expected that higher heterogeneities represent a mixture of poor and rich situations in the same area (extreme inequality). In our study, this situation can

Table 4
Analysis of the principal components: Eigenvalue and percentage variance of each variable in dimensions.

Dimensions	1	2	3	4	5
Variables			Component loadings		
LEX	0.794	0.092	0.570	0.004	0.188
COL	0.856	−0.375	−0.240	0.262	−0.009
GINI	0.526	0.816	−0.241	0.001	−0.004
IPC	0.873	−0.378	−0.276	−0.104	−0.004
THEIL	0.526	0.816	−0.241	0.001	−0.004
OVR	0.760	0.076	0.620	−0.010	−0.180
EDU	0.869	−0.388	−0.257	−0.149	0.003
% Variance	57.32	25.41	14.61	1.45	0.97
Eigenvalue	4.01	1.78	1.02	0.10	0.06

LEX: life expectancy; COL: college; GINI: income distribution index; IPC: income per capita; IPCP: income per capita poorer; THEIL: economic distribution index; OVR: overcrowded; EDU: education.

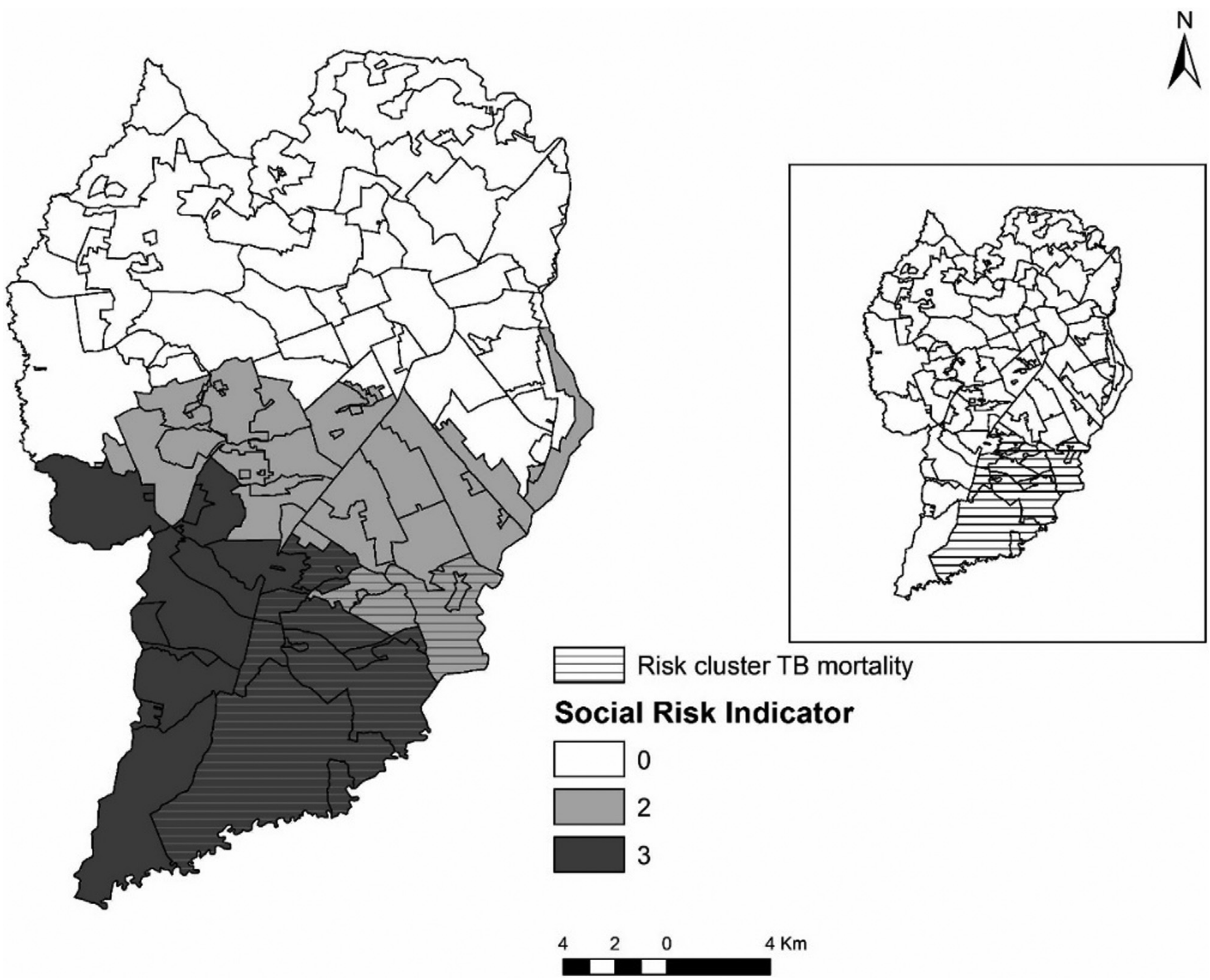

Fig. 3. Risk map of the social risk indicator (SRI) and tuberculosis mortality.

be identified in the central region with high values of GINI and IPC and lower values of IPCP, however, this was not an area with a cluster of mortality due to TB or other social variables.

Additionally, TB is an aggravating economic factor because it has been responsible for so-called 'catastrophic expenditures', especially in low- and middle-income countries, which can jeopardise 20% of the family budget, in addition to the national costs incurred [10]. Social programmes are tools for social protection, poverty alleviation and actions on other determinants of tuberculosis, as recommended by the 'End TB Strategy' [2].

Currently, Brazil faces a major economic and political crisis that affects the management of public health. The Constitutional Amendment 95 (EC 95) that was implemented, eliminated minimum federal expenditures on social protection and health (previously adopted in the 1988 National Constitution), and established limits in annual federal expenditure to reduce and control inflation for the next 20 years [5]. This has directly affected the coverage of social programmes such as the 'Bolsa Família' Programme, and 'Estratégia de Saúde da Família' (primary care), and is related to increased negative health indicators such as child mortality in the country. There is a projection that if fiscal austerity implemented in the country continues, child mortality rates will rise in the coming years [5,8]. This situation also represents a significant challenge to a health system that offers universal and free public access, focusing mainly on hospital services and not prioritising primary health care [5,31]. The decentralisation of the actions of detection, diagnosis and follow-up of tuberculosis for primary health care is considered one of the strong points in the national control TB programme [20].

Conclusion

This research found a relationship between worsening incomes, poverty, education and overcrowding with mortality due to tuberculosis, allowing the construction of a personalised social risk indicator for TB. As they are not independent, a potentially independent and complementary, but powerful subset was identified (income, GINI and overcrowding) and an SRI, a very simple indicator, was successfully developed. This study corroborates the importance of the social determinants of health and the need for multiple improvements in the living conditions of the population aimed at the control and elimination of TB.

With regard to the limitations of this study, we have used data from secondary sources; data may not be complete, which may have brought some bias to the study. The small disease count may be considered also a limitation of the study. Another point concerns the social variables considered, which were gathered from a demographic census, which, although it is a primary source for obtaining data from the population, its content is still limited for information regarding welfare, quality of life and access to or seeking health care. Among the Brazilian information systems, the Mortality Information System is regarded as the gold standard, because it is regularly updated.

Ending the TB epidemic requires a mix of interventions that should be adapted to national, regional and local contexts. This study is aligned with this challenge, proposing a methodological approach to developing social risk indicators that are both simple and powerful, allowing local tailored interventions by decision-makers.

Ethics approval and consent to participate

The study was approved by the Institutional Review Board at the University of Sao Paulo (USP) under CAAE No. 64515717.93001.5225. Informed consent was not required, as data were based on official data sets and were previously anonymised.

Availability of data and material

The database is carried out by the Epidemiological Surveillance Division and Secretary of Health of the State of Paraná, Brazil and restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. The first author has registered their details, as well as contact data in case of interest in collaborative work or further information.

Competing interests

None declared.

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Authors' contributions

Nunes C, Santos DT and Arcêncio RA conceived the study. Santos DT, Alves LS, Arroyo LH, collected, geoprocessing and analysed the data. Santos, DT and Nunes C constructed the results from the data. Santos DT, Nunes C, Arcencio RA, Arcoverde MC writing the manuscript, revised the results, M, Berra T, Ramos, ACV, Arroyo LH, Santos FL reviewed results, edited the figures and final version of manuscript. All authors read and approved the final manuscript.

Ethical approval

Not required.

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