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A spatial analysis of social and economic determinants of tuberculosis in Brazil

Guy Harling [a,*], Marcia C. Castro [b]

[a] Department of Social and Behavioral Sciences, Harvard School of Public Health, 677 Huntington Avenue, Boston, MA 02115, USA
[b] Department of Global Health and Population, Harvard School of Public Health, 665 Huntington Avenue, Boston, MA 02115, USA

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ABSTRACT

We investigated the spatial distribution, and social and economic correlates, of tuberculosis in Brazil between 2002 and 2009 using municipality-level age/sex-standardized tuberculosis notification data. Rates were very strongly spatially autocorrelated, being notably high in urban areas on the eastern seaboard and in the west of the country. Non-spatial ecological regression analyses found higher rates associated with urbanicity, population density, poor economic conditions, household crowding, non-white population and worse health and healthcare indicators. These associations remained in spatial conditional autoregressive models, although the effect of poverty appeared partially confounded by urbanicity, race and spatial autocorrelation, and partially mediated by household crowding. Our analysis highlights both the multiple relationships between socioeconomic factors and tuberculosis in Brazil, and the importance of accounting for spatial factors in analysing socioeconomic determinants of tuberculosis.

1. Introduction

Brazil faces a considerable health burden related to tuberculosis and is designated one of 22 High-Burden Countries by the World Health Organization (WHO). The WHO estimates that there were 83,000 incident tuberculosis cases in Brazil in 2011, an annual incidence rate of 42 cases per 100,000 population (World Health Organization, 2012). Incidence is estimated to have been falling steadily over the past two decades, however while over 90% of estimated cases are detected and reported nationally, treatment success rates remain below the target level needed to eradicate the disease in the near future (IPEA, 2010).

Tuberculosis disease is often associated with demographic and behavioural factors, including age, occupation, alcohol and tobacco consumption, poor nutrition and household crowding (Dye and Floyd, 2006). While these factors are important proximal determinants of tuberculosis, they can be considered to be mediators of more distal individual- and group-level socioeconomic factors, including education, employment and income (Dubos and Dubos, 1992; Gandy and Zumla, 2003; Lonnroth et al., 2009). This view is closely connected to Link and Phelan's conceptualization of social conditions as 'fundamental causes' of ill health (Link and Phelan, 1995). Recently the WHO has begun to promote efforts to address social determinants as an important component of global tuberculosis control (Rasanathan et al., 2011).

Much of the epidemiological tuberculosis literature relies on notified cases. In order for a case to be reported, it is necessary first for an individual to become latently infected, then for them to progress to active disease, and finally for them to be diagnosed by a health professional. Socioeconomic risk factors affect all three of these stages: high population density would be expected to increase the rate of tuberculosis bacillus spread through increased contact between infectious and susceptible individuals; low socioeconomic individuals may have poorer immune defence profiles, making them less able to suppress tuberculosis replication and thus avoid active disease; and poorer individuals are likely to be less able to afford or reach a setting in which they will be diagnosed.

Associations between tuberculosis rates and community socioeconomic structures – including low levels of education, limited social support, high unemployment, poverty and income inequality – have been consistently found in Europe (Bhatti et al., 1995; Parslow et al., 2001; Spence et al., 1993; Tocque et al., 1999), North America (Cantwell et al., 1998; Krieger et al., 2003; Oren et al., 2012), and Hong Kong (Chan-Yeung et al., 2005; Pang et al., 2010). Evidence from ecological and multilevel studies in Brazil, Mexico and South Africa also supports the existence of this relationship in middle-income countries (Alvarez-Hernandez et al., 2010; Harling et al., 2008; Munch et al., 2003; Souza et al., 2000). In lower-income settings, however, evidence is more mixed, with a supporting study from southern India (Shetty et al., 2006), but

* Corresponding author. Tel.: +1 617 432 1135.
E-mail addresses: gharling@hsph.harvard.edu (G. Harling), mcastro@hsph.harvard.edu (M.C. Castro).

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findings of an inverse gradient in Malawi and Zambia, even after adjusting for HIV status (Boccia et al., 2009; Glynn et al., 2000), and equivocal results in Western Africa (Gustafson et al., 2004, 2007; Lienhardt et al., 2005).

Given the infectious nature of tuberculosis, and the geographical autocorrelation of socioeconomic factors, any analysis of the socioeconomic determinants of tuberculosis should at least consider spatial patterning. A number of previous investigations of the spatial distribution of tuberculosis have been conducted in the context of socioeconomic factors, at various levels of aggregation. City-based studies have found tuberculosis to cluster around drinking establishments in peri-urban Cape Town, South Africa (Munch et al., 2003), in high-deprivation areas of Hermosillo, Mexico and Antananarivo City, Madagascar (Alvarez-Hernandez et al., 2010; Randremanana et al., 2009), amongst migrant populations in Beijing, China (Jia et al., 2008; Li et al., 2011), and in areas with high migrant levels in Cologne, Germany (Kistemann et al., 2002).

Regional analyses have found tuberculosis clusters surrounding a homeless shelter in an urban centre in Texas (Moonan et al., 2004), near a tuberculosis treatment centre in India (Tiwari et al., 2006), and in urban and industrial areas of Japan (Onozuka and Hagihara, 2007). National analyses found clustering around the major urban centres in Portugal (Couceiro et al., 2011; Nunes, 2007), and in the north-west and south-east of Spain (Gomez-Barroso et al., 2009).

Within Brazil, most spatial or socioeconomic analyses of tuberculosis have been conducted at the city or state levels. Aside from a nationwide study of treatment outcomes (Duarte et al., 2009), the only study considering tuberculosis rates nationally appears to be a multilevel study of notification rates in 28 metropolitan regions between 2001 and 2003 (Gonçalves et al., 2009); the authors found both area-level poverty and population density to be positively associated with tuberculosis rates.

At the city level, spatial studies of tuberculosis in various parts of the country have found associations with broad social deprivation indices, low education and asset ownership – both individual and community-wide – and household crowding (Hino et al., 2011; Maciel et al., 2010; Santos et al., 2007; Souza et al., 2000, 2007; Vendramini et al., 2006, 2010; Ximenes et al., 2009).

At the state or regional level, studies have found clustering of cases around urban areas (Sales et al., 2010; Vieira et al., 2008) and associations between tuberculosis and both low education and indigenous reserves (Melo et al., 2012; Penna et al., 2009).

Despite all these studies, a comprehensive analysis of sociodemographic and socioeconomic determinants for the entire country is not available. This study addresses this gap in the literature. It uses reported tuberculosis cases in Brazil (2002–2009), at a fine spatial scale, and has two specific objectives. First, it characterises the spatial pattern of tuberculosis in Brazil; second, it analyses how tuberculosis rates are correlated with social factors, treating existing spatial patterns as a potential confounder of the socioeconomic-tuberculosis relationship. For the second objective, we focus particularly on the role of low community socioeconomic status, given the considerable evidence of an association between low SES and tuberculosis in other locations, at other levels of aggregation, and in non-spatial models.

2. Methods

We performed a secondary data analysis of Brazilian notification and survey data. All data used were grouped at the *município* (municipality) level, the fifth administrative level in Brazil (the country is divided into macroregions, states, mesoregions, microregions and municipalities). There are currently 26 states and one federal district (Brasília) in the country (see Fig. 1). These are divided into 5565 municipalities (IBGE, 2011).

A geographic map of the municipalities was created using files from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística; IBGE). All spatial information was projected using WGS 1984 UTM Zone 22S, which is the central longitude Universal Transverse Mercator band in Brazil. Map design and management was conducted in ArcGIS (ESRI; Redlands, CA).

In 2002 there were 5507 municipalities in Brazil. We excluded the Fernando de Noronha archipelago since it lies 350 km from the mainland, and thus had no geographically-contiguous neighbours. There were therefore 5506 municipalities in the study dataset. For the 58 new municipalities created between 2002 and 2009, we merged data back into the municipality from which they had been carved, in the 40 cases where they had been created from a single municipality. For the 18 municipalities that had been created from territory taken from multiple prior municipalities such a process was not possible, so we excluded case data from such locations. Excluded municipalities accounted for 0.009% of all reported cases in the period; a further 0.15% of cases had no age attached, while 0.53% more had no reporting municipality recorded. In total 0.69% of tuberculosis cases were excluded.

2.1. Data sources

Tuberculosis is a notifiable disease in Brazil, and all notified cases are stored in the Information System for Notifiable Diseases (Sistema de Informação de Agravos de Notificação: SINAN) (SINAN). Since notification is passive it is not possible to ascertain whether years in which a municipality reported no cases were due to there being no cases actually occurring in that period, or due to a failure to report cases. An initial assessment of missingness found that the number of municipalities reporting cases each year was relatively constant, and that very few municipalities consistently reported no cases. We therefore assumed that all zero counts represented a true absence of cases in that year.

We obtained municipality-level data from SINAN, for each year from 2002 to 2009, detailed by age and sex of the patient; age was stratified into ten categories: <1; 1–4; 5–9; 10–14; 15–19; 20–39; 40–59; 60–69; 70–79; and 80+. Age/sex-standardized notification rates were calculated for each municipality based on these age categories, using the national Brazilian population structure as the standard for each year. Population data were estimated by IBGE based on decennial census data and other sources (IBGE, 2013c).

We additionally calculated the average age/sex-standardized tuberculosis rate in each municipality across all eight years. This was done by summing the counts of tuberculosis and the number of person–years in each age/sex strata, and then standardizing the quotient of these two figures to the national average population structure across the eight years.

Population density for each year and municipality were calculated by dividing the population data for each year by the area calculated from the map of municipalities. Proportions of individuals in each municipality from each of the five primary race classifications used in Brazil – White, Brown, Black, Yellow (Asian) and Indigenous – were taken from the 2000 census (IBGE, 2013b). The proportion of individuals living in an urban setting within each municipality was calculated as the mean of the urban proportion at the 2000 and 2010 censuses (IBGE, 2013a).

Municipality-level measures of socioeconomic status (SES) were produced from the 2000 census by the Applied Economic Research Institute (Instituto de Pesquisas Econômicas Aplicadas; IPEA), a government body (IPEA, 2003). Our primary indicator of SES was the headcount extreme poverty level within each municipality, defined as the percentage of households within the