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Review Article

# Spatial distribution of leprosy in Brazil: a literature review

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## Abstract

Leprosy remains a public health problem in developing countries. Among communicable diseases, it is one of the leading causes of permanent disability. Brazil had not reached the goal of reducing cases to less than 1 per 10,000 population. This study aimed to analyze the spatial distribution of leprosy cases in Brazil, using a literature review. The search strategy included the LILACS and MEDLINE databases with no language or period restriction. Ecological studies with spatial data analysis were considered as a criterion for the inclusion. We found 38 studies for review after the selection criteria. Among the epidemiological indicators of the disease, the most common was the new case detection rate. Several articles have explored the association between spatial distribution of leprosy and socioeconomic, demographic, and environmental factors. The most common unit of analysis was the municipality. The spatial distribution methods mostly used were: empirical Bayesian method, autocorrelation (Moran's I index) and Kernel estimates. The distribution of leprosy was very heterogeneous, independent of the unit of analysis. There was a decrease in the rate of detection and among under-15-year-olds, but some regions maintained high endemicity during the study period. The distribution and risk of illness were directly related to living conditions of the population. Improved access to health services was associated with increased detection rate in some regions. Spatial analysis seems to be a very useful tool to study leprosy and to guide interventions and surveillance.

**Keywords:** Leprosy. Brazil. Spatial analysis. Review.

## INTRODUCTION

Leprosy is still a public health problem in low and middle-income countries. It is a leading cause of permanent disability and social stigma[1], and stands out as one of the neglected infectious diseases in those countries. Despite the magnitude and impact on health, leprosy has little investment regarding therapeutic research and development[2,3].

Economic, political, social, and demographic changes that occurred during the last 40 years in Brazil impacted the social determinants of health in the country[4]. Consequently, the incidence of infectious diseases declined, but the impact on leprosy is not yet fully clear[5,6]. Studies point out that cash transfer policies were related to the decrease in disease incidence, while the expansion of the Family Health Care Strategy improved the detection of new cases[6,7].

In 2015, 28,761 new cases were reported, corresponding to a case detection rate (CDR) of 14.07/100,000 inhabitants, which is considered high. Brazil is about to reach the World Health Organization's target of control, but 535 municipalities are still classified as hyperendemic, with CDRs higher than 40/100,000 inhabitants[8]. The geographical distribution of leprosy is uneven and the disease persists in regions with higher levels of poverty and malnutrition, showing a close relationship with precarious conditions of living, low educational level, social inequality, and also with migratory movements[9,10].

To best understand the differences in the distribution of infectious diseases, ecological studies with spatial data analysis have increased during the past 30 years in Brazil[11]. Different spatial scales were taken into account, usually with geographic and administrative references, such as states and administrative districts. Other potential spatial units of data aggregation are the census sector, neighborhood, hydrographical basin, and sanitary district[12].

In this context, we reviewed the spatial distribution of leprosy and methods used for spatial analysis in Brazil, according to different scales, and its relationship with demographic and socioeconomic factors.

## METHODS

We performed a literature review, according to the recommended steps for systematic reviews, except for quantitative analysis (meta-analysis)[13].

The bibliographical search was performed in the Latin American and Caribbean Literature on Health Sciences

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(LILACS) and Medical Literature Analysis and Retrieval System (MEDLINE) databases. In the LILACS database we combined the descriptors *Spatial Analysis, Analysis by Conglomerates, Spatial Distribution of the Population, Ecological Study, Geographic Information System*, with *leprosy* and *Brazil*, using the Boolean operator *AND*. Each combination was done separately, as the system did not accept merging the syntax terms with the operator *OR*.

In the MEDLINE database, we used the syntax *leprosy* AND (*Spatial Analysis* OR *Cluster Analysis* OR *Residence Characteristics* OR *Ecological Studies* OR *Geographic Information Systems*) AND *Brazil*.

There was no restriction on language or publication period. The lists of references in the identified articles were searched to identify items not captured in the electronic search. The search was conducted in 2015 and updated in March 2016.

The paired review system was used in the selection of articles; two researchers evaluated the titles to be included in the abstracts to be read. At least one author approved the titles to increase the sensitivity at this stage. After reading the abstracts of the articles, those approved by both authors were included to be read in full. When there were divergent views, a third researcher read the summary to give an opinion before exclusion.

Ecological studies with spatial data analysis were included in the study; those articles not assessing the spatial distribution of the disease were excluded.

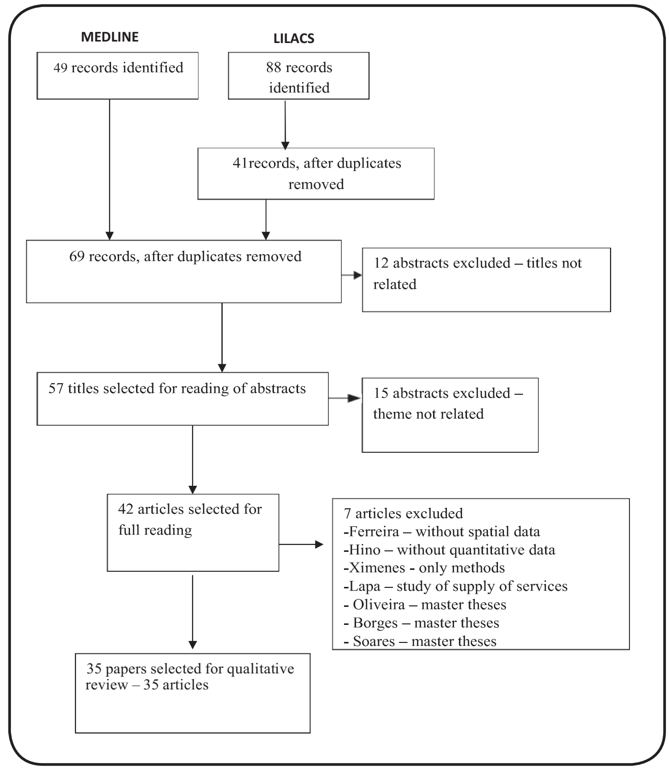


**FIGURE 1 -** Flow diagram of studies selected.

## RESULTS

Using the established bibliographical review criteria, 35 studies were selected (**Figure 1**): 35 articles.

**Table 1, Table 2** and **Table 3** show the articles' summaries according to the scale used: two evaluated regions/mesoregions[14,15]; 13 used the scale of municipalities[10,16-27]; 4 evaluated districts[28-31]; 6 studied neighborhoods[32-37]; 7 analyzed the census tracts[38-44]; and 3 investigated households[45-47]. Within each scale, the articles were organized by location: Brazil, Northern, Northeast, Midwest, and Southeast regions. In all, 4 approached Brazil[10,16-18], 7 studied the Northern region or the states of the Amazon region[14,19,20,38-40,45], 11 focused on the Northeast region[21-23,28,32-36,40,41], 4 the Midwest region[15,29,37,46], and 12 the Southeast region[24-27,30,31,36,37,42-44,47].

As a data source for the cases of leprosy, the Notifiable Diseases Information System (SINAN) was hegemonic, and among the epidemiological disease indicators, the most widely used was the new case detection rate (NCDR) in the population without distinction by age group. Seven studies[10,19,20,23,32,33,36,38] evaluated the NCDR indicator of individuals under 15 years of age, 3 evaluated the disability-degree indicator[19,20,22] and one article explored the spatial distribution of mortality due to leprosy[18].

Some studies showed descriptive data of spatial distribution, while others looked into socioeconomic, demographic and environmental conditions that could contribute to the understanding of the spatial distribution of leprosy. The socioeconomic variables mostly evaluated were income, education, sanitation conditions, number of residents per house – individually or as composite indicators, such as the social deprivation index[42]. For these indicators, the most used data source was the Brazilian Institute of Geography and Statistics (IBGE). Two of the articles used the Gini index[17,23] as a measure of inequality. Regarding demographic conditions, population density was studied (on the scales of neighborhoods and census sectors), as well as the level of urbanization. The distance between households was also studied, and as an environmental condition, deforestation was evaluated in two articles[14,15].

The most commonly used methods of spatial analysis were the following: empirical Bayesian method, autocorrelation (Moran index) to verify the existence of spatial conglomerates (clusters), and Kernel estimates to show areas with greater intensity (hot spots). Kriging methods and scan tests were also used. The two studies[14,15] that covered mesoregions and microregions have shown a correlation between the evolution of deforestation and an increase in NCDR, besides the effect of migration movements on coefficients of detection and focuses (new and old) of the disease.

In the analyses by municipalities, three studies examined the NCDR of the country at different moments in time[10,16,17], and showed concentration in the North and Midwest regions, and in the Northeastern states located in Legal Amazon. The study by Freitas et al.[17] looked at risk factors, estimated rate ratios (RR), and identified a high NCDR in the Midwest and North regions compared to the South, large cities and greater urbanization, median and high illiteracy rate,

**TABLE 1**

Studies on spatial distribution of leprosy in Brazil, 1995 – 2015, by Meso-Regions, Micro-Regions, and Municipalities.

| Author/year | Local/year of study/ sample size | Data source | Maps | Analysis | Results |
|---|---|---|---|---|---|
| **Unit of analysis: meso-regions and micro-regions** | | | | | |
| Silva et al. 2010[14] | Amazon Region 2006 | SINAN; IBGE; INPE; PNUD. | – Distribution of new leprosy cases<br>– Distribution of indicators | Local empirical Bayesian analysis<br>Kernel technique<br>Pearson´s correlation | NCDR positively correlated with deforested area (0.50) and septic tank (0.46), inversely correlated with HDI (-0.36). |
| Magalhães et al. 2011[15] | Mato Grosso 1960 to 2006 | ATDS; SINAN; IBGE; Department of Planning of Mato Grosso. | – Population growth rates of micro-regions in the 90's/ detection rates 2004-2006.<br>– Attraction degree and effective migratory participation 1970-2000/ detection rates | Not detailed | Greatest NCDR in meso-regions North, Northeast e Southwest of the state.<br>Progression of deforestation coinciding with NCDR elevation.<br>Migration explaining appearance and evolution of leprosy. |
| **Unit of analysis: municipalities** | | | | | |
| Magalhães & Rojas. 2007[10] | Brazil; 1998 to 2000 and 2000 to 2002 47,026 cases | SINAN; IBGE; SIGEpi | – NCDR;<br>– NCDR in people younger than 15 years;<br>– Mean percentage of new cases with tuberculoid presentation | ArcView | Higher NCDR - capitals and metropolises (Manaus, Roraima e Belém). Focal distribution in east/west Amazon. Concentration on Atlantic coast (RJ and Recife) and metropolitan regions of Vitória, ES. Association of high social exclusion and high NCDR (Sergipe, Piauí, Maranhão and Amazonas). |
| Penna et al., 2009[16] | Brazil 2005 to 2007 65.357 cases | SINAN; IBGE. | – 10 leprosy clusters | Spatial scan statistics<br>Poisson model | Five clusters in Amazon region and another three contiguous regions. One cluster in Metropolitan Recife and other in the joint region of Minas Gerais northeast, extreme south of Bahia and north of Espirito Santo. |
| Freitas et al. 2014[17] | Brazil 2009 to 2011 | SINAN; IBGE | – Mean smoothed NCDR per 100,000 inhabitants, 2009-2011. | ArcGIS<br>Local empirical Bayesian analysis<br>Hierarchical Multivariate analysis | Factors for high NCDR (values of IRR): Center-West (4.62) and North (3.14) regions, metropolises (I1.92), urbanization rate (1.53), median/ high illiteracy rate (2.41/2.15), Gini index> 0.55 (1.26), high number of dwellers/room (1.41) and inadequate sanitation (1.63). |
| Martins-Melo et al. 2015[18] | Brazil 2000 to 2011 | SIM; IBGE | – Average annual age-adjusted leprosy-related mortality rates<br>– Average annual crude mortality rates<br>– Average annual Bayesian-smoothed mortality rates<br>– LISA cluster analysis (Moran Map)<br>– Scan space-time clusters analysis | Local empirical Bayesian analysis<br>Global Moran's I index<br>LISA<br>Kulldorff's space-time scan statistics | Most clusters for mortality: Center-West, North, and west of Northeast regions. Secondary cluster: northwest of Paraná state and frontier of Minas Gerais and Espirito Santo states.<br>Factors for higher mortality: male sex (RR=2.57); age (gradient); black color (RR=1.65) Center-West (RR=2.84) and North (RR=2.04) regions.<br>Decreasing trend of leprosy-related mortality. |

Continue...

**TABLE 1 - Continuation.**

| | | | | | |
|---|---|---|---|---|---|
| Alencar et al., 2012[19] | Maranhão, Pará, Piauí e Tocantins; 2001 to 2009 82,463 cases | SINAN; IBGE. | – Rate of new cases<br>– Rate of new cases <15 years<br>– Rate of new cases with grade 2 disabilities<br>– Proportion of new cases with grade 2 disabilities | ArcGIS<br>Local empirical Bayesian analysis<br>Kulldorff's scan statistics | 68.0% of municipalities hyperendemic.<br>Higher total NCDR and in < 15 years-old: Municipalities of Pará and Center of Maranhão states.<br>Five clusters for total NCDR: 3 in Pará, one in Maranhão (center) and one in the frontier (Pará, Maranhão and Tocantins states).<br>Clusters for grade 2 disabilities: Southeast of Pará and Maranhão. Overlap of clusters for new cases, grade 2 disabilities, and cases in people aged < 15 years. |
| Monteiro et al., 2015[20] | Tocantins 2001 to 2012 | SINAN; IBGE. | – Crude and smoothed detection rates and Moran map<br>– New leprosy case detection rate;<br>– Case detection rate in < 15 years old;<br>– The detection rate of grade 2 disability. | Local empirical Bayesian analysis<br>Global Moran's I index | 77.0% of municipalities hyperendemic;<br>65.4% of municipalities hyperendemic for NCDR in < 15 years old<br>Overlap of total NCDR, NCDR in < 15 years-old and grade-II disabilities: North and West of the state. |
| Montenegro et al. 2004[21] | Ceará 1991 to 1999 | Health Office, Ceará State; IBGE. | – Annual incidence rates<br>– Trend surface - smoothed incidence rates | LOESS model<br>Moran's I index | Clusters of higher incidence rates in the northwestern, central, and southeastern regions. Higher incidence in more urbanized municipalities and on the North-South axis. |
| Oliveira et al. 2012[22] | Sergipe 2005 to 2010 3,039 cases | SINAN; IBGE. | - New leprosy cases and frequencies of grades 1 and 2 disabilities in 2005 and 2010. | Spring e ArcGIS<br>Odds Ratio (OR) | Hyperendemic municipalities: 15 (2005) and 8 (2010).<br>Male sex associated with grade 1 (OR 2.8) and grade 2 disabilities (OR 2.9) and multibacillary form (OR 2.9).<br>Without map analysis. |
| Cabral Miranda et al., 2014[23] | Bahia (BA) 2005 to 2011 1,674 cases in those younger than 15 years | SINAN; IBGE; DASUS; FIRJAN | – Biomes in the State of Bahia (BA).<br>– Leprosy < 15 years (2005-2011): (a) Relative risk in the state, (b) spatial clusters, (c) Relative risk in BA and vicinal states (d) clusters in BA and vicinal states.<br>– Variables: (a) average number of dwellers by residence, (b) % urban population, (c) % of residents born in BA, (d) Gini Index. | ArcGIS<br>Multivariate analysis<br>Spatial scan statistics | Decreasing trend but high NCDR< 15y: 7.9% of total NCDR.<br>Four high- and 6 low-risk clusters.<br>Cases in < 15 years-old highly influenced by surrounding states, mainly in the north-western and southern regions of BA.<br>Relative risks associated with: higher % of water bodies, greater Gini index, higher % of urban population, greater average number of dwellers by residence, lesser % of residents born in BA |
| Opromolla et al.[24,25] (2 articles) 2005 and 2006 | São Paulo (SP); 1991 to 2002<br>22,250 cases | Epidemiological Surveillance Center, São Paulo State; IBGE. | – Detection rates<br>– Municipalities of residence of cases.<br>– Surface map of new cases. | Surface mapping<br>Kriging method | Higher NCDR in West and Northwest regions of the state.<br>Spatial dependency: 30km |
| Rodrigues Jr et al. 2008[26] | São Paulo (SP); 2004 to 2006 | SINAN; SEADE Foundation. | – NCDR geographical distribution | Kriging method<br>Pearson´s correlation | High NCDR in north and northwest regions and in the coast. Inverse correlation with wealth (-0.530; p=0.028).<br>Positive correlation<br>with education (0.510; p=0,020) and longevity (0.557; p=0,036) |
| Sampaio et al., 2012[27] | Espírito Santo (ES); 2004 to 2009 7,653 cases | Health Office of Espírito Santo State | – NCDR (average)<br>– Moran spatial correlation of cities (conglomerates of leprosy detection). | Terra View<br>Local empirical Bayesian analysis<br>Moran's I index | Heterogeneous distribution – higher NCDR in the north of the state, northwest (São Pedro Bay) and Maruípe region. |

**ATDS:** Technical Area – Sanitary Dermatology; **NCDR**: case detection rate; **CDSSES-MG**: Sanitary Dermatology Coordination of State Office of Health, Minas Gerais; **CP:** Prevalence coefficient; **FIDEM:** Metropolitan Developing Foundation; **GEIPMBH**: Epidemiology and Information Office of Municipality of Belo Horizonte; **GIS:** Geographical Information Systems; **HDI**: Human Development Index; **IBGE:** Brazilian Institute of Geography and Statistics; **IRR:** Incidence rate ratio; **LISA:** Local Index of Spatial Association; **LOESS**: locally weighted scatterplot smoothing; **PCR**: polymerase chain reaction; **RR:** rate ratio; **SEADE:** State Data Analysis System Foundation; **SIGEpi:** Geographical Information in Epidemiology System; **SIM:** Mortality Information System; **SMS**: Municipal Office of Health; **SINAN:** Brazilian Disease Surveillance System. To homogenize results, we described NCDR for 100,000 inhabitants and CP for 10,000 inhabitants.

**TABLE 2**

Studies on spatial distribution of leprosy in Brazil, 1995 – 2015, by districts and neighborhoods.

| Author/year | Local/year of study/sample size | Data source | Maps | Analysis | Results |
|---|---|---|---|---|---|
| **Unit of analysis: districts** | | | | | |
| Lima et al., 2015 [28] | Fortaleza (CE)<br>2009 to 2010<br>185 cases | Dona Libânia National Reference Centre for Sanitary Dermatology | – Spatial kernel density of specific repetitive element – RLEP/PCR positive nasal samples<br>– Leprosy cases with positive bacilloscopy index and RLEP, PCR on nasal samples (positive/negative) | ArcGIS and ArcMap<br>Spatial Analyst extension<br>Kernel density estimation | Cases and controls concentrated in the southwest and western (lower socioeconomic level), External group (no cases) - clusters in northeast region (wealthier area).<br>Factor associated (OR): age (1.04), male (6.24) social class D/E (3.34), and previous contact with a leprosy case (3.86). No association with RLEP (+). |
| Martelli et al. 1995[29] | Goiânia<br>1991-1992<br>711 cases (complete information) | Local surveillance system | – Spatial distribution according to risk strata | Risk ratios (RR) estimation | Cases in 86% of districts. Approximately 83% of the population in intermediate and high-risk areas.<br>Higher NCDR: low socioeconomic level (RR=5.3) and outskirts of the city. |
| Sampaio et al.[30, 31], 2013a and b | Vitória (ES);<br>2005 to 2009<br>379 cases | SINAN; IBGE; Geo-Foundations. | – Mean and smoothed NCDR<br>– Moran's spatial correlation<br>– Urban Quality Index | Terra View<br>Local and global empirical Bayesian analysis - LISA | Higher NCDR on northwest of the city, North and in the continental region. Higher NCDR in areas with low Urban Quality Index |
| **Unit of analysis: neighborhoods** | | | | | |
| Souza et al., 2001[32] | Recife (PE)<br>1993 to 1997<br>799 cases<br>< 15 years | SINAN; IBGE. | <u>Maps</u> (Arcview/SPLUS):<br>– NCDR in < 15 years-old<br>– Corrected NCDR in < 15 years-olds<br>– Difference between observed and expected cases; multibacillary cases. | Local empirical Bayesian analysis | Cases < 15 years-old: 17.3% of total NCDR<br>Crude spatial distribution: irregular pattern: high NCDR neighborhoods next to low ones. Range: 0 to 1,440 cases/100,000. Smoothed spatial distribution: Three high NCDR areas with high demographic density and low living conditions. |
| Dias et al. 2005[33] and 2007[34] | Mossoró (RN)<br>1998 to 2002<br>281 geo-referred (78.5%)<br>2005 - 30 new cases | SINAN and registration books from municipal administration; ENGESAT | – New leprosy cases<br>– Density map of new cases in the area of greater occurrence<br>– New leprosy cases in < 15 years old<br>– Areas of case-finding campaigns | ArcView<br>Georeferencing. | Higher endemicity areas – low socioeconomic level, low sanitary status, high demographic density<br>Overlap of high NCDR, high NCDR in < 15 years-old and grade 2 disability. Campaigns guided by spatial analysis improved diagnosis of new cases. |

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**TABLE 2 - Continuation.**

| Author/year | Local/year of study/ sample population | Data source | Maps | Analysis | Results |
|---|---|---|---|---|---|
| **Unit of analysis: neighborhoods** | | | | | |
| Moura et al. 2013[35] | Mossoró (RN) 2006 82 cases, intra-domiciliary (N=209) and extra-domiciliary contacts (N=408) | Municipal Health Office; questionnaire (socioeconomic data) dermato-neurologic examination. | – Spatial distribution of new and previous paucibacillary and multibacillary cases. | ArcMap Geo-referencing. | No difference between intra or extra-domiciliary contacts: NCDR: 2.9/100 vs. 2.1/100 (p=0.555)<br>No differences regarding age, sex, and income.<br>Clustering of newly diagnosed cases and association with residential coordinates of previously diagnosed multibacillary cases. |
| Gauy et al., 2007[36] | Ribeirão Preto (SP); 2004 37 cases | Epidemiological Surveillance Service of Municipal Health office. | – Distribution of geocoded new cases. | MapInfo Georeferencing. | Concentration of cases in the Northern region of the city, in poor neighborhoods. |
| Duarte-Cunha et al. 2012[37] | Duque de Caxias (RJ); 1998 to 2006 2,572 cases | SINAN; IBGE | – Population density of neighborhoods<br>– New cases (total and periodic), and unities of USF and case-finding campaigns<br>– Crude and adjusted NCDR<br>– LISA MAP and Box Map | Terra View<br>Local empirical Bayesian analysis<br>Global Moran's I index<br>LISA | Association of detection of new cases with campaigns (r=0.55; p=0.0001), but not with decentralized units (USF). Cluster in South-Northwest. Decline of grade-II cases (13.6% to 8.6%; p= 0.04) and increase of indeterminate cases (10.3% to 18%; p = 0.00). Absence of overlap, higher NCDR, and higher population density. |

**CP:** prevalence coefficient; **GIS**: Geographical Information Systems; **IBGE**: Brazilian Institute of Geography and Statistics; **LISA**: Local Index of Spatial Association; **PCR:** polymerase chain reaction; **NCDR:** case detection rate; **PRODATER:** Teresinense Data Processing Company; **RLEP**: specific repetitive element; **RR:** rate ratio; **SINAN:** Brazilian Disease Surveillance System; **USF**: Health Family unities. To homogenize results, we described NCDR for 100,000 inhabitants and CP for 10,000 inhabitants.

**TABLE 3**

Studies on spatial distribution of leprosy in Brazil, 1995 - 2015, by census tracts and residences.

| Author/year | Local/year of study/sample size | Data source | Maps | Analysis | Results |
|---|---|---|---|---|---|
| **Unit of analysis: census tracts** | | | | | |
| Imbiriba et al. 2009[38] | Manaus (AM); 1998 to 2004 4,104 cases in < 15 years old | SINAN and medical records; IBGE | – Mean NCDR (neighborhoods);<br>– Mean NCDR (sectors)<br>– Bayesian estimative of mean NCDR. | MapInfo<br>Local empirical Bayesian analysis<br>Logistic Regression. | Among sectors, 34% were hyperendemic.<br>Cases < 15 years-old: 10.8% of total NCDR<br>Intraurban heterogeneity related to social inequities (low living conditions, OR=4.42) and concentration of < 15 years-old cases (OR=2.43). |
| Barreto et al. 2014[39] | Castanhal (PA) 2004 to 2010 90 cases and 302 contacts. 188 students from 4 public schools | SINAN; IBGE | – Kernel density estimation<br>– Clusters of leprosy (LISA and Kulldorff)<br>– Surveyed household contacts and school children<br>– Space-time links: cases/ students | Geocoding<br>Local empirical Bayesian analysis<br>Kernel density estimator, LISA, Kulldorff, Ripley's k-function | Cases < 15 years-old: 10% of total. Close proximity to spatial clusters. Overlap of high NCDR and high population density. Household density higher (p=0.0001) in those residences with individuals affected by leprosy. 81.3% of mapped cases near other cases in space/time |
| Lapa et al. 2006[40] | Olinda (PE) 1991 to 2000 | SINAN; IBGE; FIDEM. | – Disease intensity<br>– Domain areas of care for each health facility or unit. | Bidimensional Kernel estimation | Changes in domain areas of care.<br>Increase in the detection, treatment and contacts investigation by the municipalities themselves. |
| Mencaroni et al., 2004[42] | Fernandópolis (SP); 1997 to 2002 160 cases in the urban area | SINAN; IBGE; Planning Sector of the Municipality of Femandópolis | – Mean NCDR by census tract<br>– Social Deprivation Index by census tract<br>– Collective risk area (merging ICS and NCDR). | SPRING<br>Cases geocoded by census tract | High-risk area (low or intermediate living conditions and high NCDR): twelve census tracts, comprising 17.6 % of the population. |
| Amaral & Lana 2008[43] | Almenara (MG); 1998 to 2006 866 geocoded cases | CDSSES-MG; IBGE; GEIPMBH; SIM | – Mean census tract NCDR<br>– Census track distribution by NCDR cluster | MapInfo<br>Moran's I Index<br>Kulldorf's scan Statisti<br>Poisson model | 126 census tracts with at least one case: 86 urban and 40 rural.<br>Concentration of cases in the center and east of the micro-region. |
| Cury et al. 2012[44] | São José do Rio Preto (SP) 1998 to 2007 379 geocoded cases | Leprosy Project database; IBGE; São José do Rio Preto Municipality | – Distribution of incidence rates<br>– Distribution of socioeconomic levels<br>– Distribution of population density | Choropleth maps (MapInfo, ArcGIS):<br>Kriging method | Big cluster in the North zone and two smaller clusters in extreme east and southeast, showing a positive association with low socioeconomic levels (p<0.0001) but not with population density.<br>Disparity between clusters of disease and localization of health units. |

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**TABLE 3 - Continuation.**

| Author/ Year | Local/ Year of study/ Sample size | Data Source | Maps | Analysis | Results |
|---|---|---|---|---|---|
| **Unit of analysis: residences** | | | | | |
| Barreto et al., 2015[45] | Castanhal and Oriximiná (PA) | SINAN; IBGE; Mapping in the field | – Spatial distribution of cases and households of surveyed school children | ArcGIS<br>Cohort study<br>Kulldorff's spatial scan statistics<br>Fisher's exact test<br>Odds Ratio | Higher incidence ($p < 0.05$) among those who tested positive to anti-PGL-I. Most significant increase of IgM titers in the group that developed disease. Cases with residence near other cases (16.4% - about 50m, 62% - 100m and 90.3 % - 200m). Greater proportion of new cases detected at the schools selected based on spatial distribution of cases than in randomly selected schools ($p < 0.05$). |
| Garcia et al. 2013[46] | Cáceres (MT)<br>2001 to 2007<br>34 cases | Notification form of a USF; IBGE | – Distribution of leprosy cases diagnosed in USF.<br>– Distribution of cases: a radius of 50 m | Geocoding<br>Buffer (Scale: radius of 50 m) | 12 cases (35.3%) in a radius of 50 meters of any other case diagnosed in that territory (household or neighborhood) |
| Paschoal et al. 2013[47] | São José do Rio Preto (SP)<br>1998 to 2010<br>425 cases | Leprosy Control Program | – Distribution of paucibacillary and multibacillary cases<br>– Ten clusters (households of cases – first and second order) | MapInfo<br>Kernel estimator<br>K-function | Greatest cluster (1st order) in North of city<br>Higher number of cases in urban areas with greatest population density (north and northeast of city) |

**CDSSES-MG:** Sanitary Dermatology Coordination of State Office of Health, Minas Gerais; **CP:** prevalence coefficient; **FIDEM**: Metropolitan Developing Foundation; **GEIPMBH:** Epidemiology and Information Office of Municipality of Belo Horizonte; **GIS**: Geographical Information Systems; **HDI**: Human Development Index; **IBGE**: Brazilian Institute of Geography and Statistics; **LISA**: Local Index of Spatial Association; **NCDR:** case detection rate; **RR:** rate ratio; **SIM:** Mortality Information System; **SINAN:** Brazilian Disease Surveillance System; **USF**: Health Family unities. To homogenize results, we described NCDR for 100,000 inhabitants and CP for 10,000 inhabitants.

income inequality (Gini index), domiciles' agglomeration, worse sanitation condition, and percentage of cases with grade 2-disability.

Regarding health care indicators, there was an association between an increased Family Health Care Program coverage and the number of contacts investigated. The study by Martins-Melo et al. was the only one that evaluated the spatial distribution of mortality due to leprosy[18]. Both crude and smoothed rates showed greater mortality in the Midwest and North regions, in black individuals, in males, and had a gradient relationship with aging. High mortality clusters were identified in the Midwest, North and Northeast regions, as well as Northwest of Paraná State.

Mortality decreased in Brazil from 2000 to 2011, but has remained stable in North and Northeast regions. Other studies using the scale of municipalities identified clusters and heterogeneity in the distribution of the disease associated with low socioeconomic indicators[23,26] and increased urbanization[21,23], apart from indicators that overlap with high values – global NCDR, NCDR in children under 15 years, and grade 2 disability[19,20]. In the Northern region and the Amazonian States, high percentages of hyperendemic municipalities (NCDR >40/100,000 inhabitants) were accentuated.

Regarding districts, areas with greater detection rates for leprosy corresponded with lower socioeconomic status, measured by social class and urban quality index[28,31]. The study by Lima et al. was the only one that assessed the carrier status, and used a case-control approach, besides an external group. Spatial distribution of carriers was also characterized by clusters[28].

In the analysis by neighborhood, heterogeneity was also partly explained by low socioeconomic pattern[32-34], basic sanitation deficit[33,34], and high population density[32-34].

Studies in Mossoró (Rio Grande do Norte state) have used geographic information systems to guide case-finding campaigns[33,34]. In the scale of census tracts, it was observed that low socioeconomic levels[42,44] and high population density areas[39,41] showed a positive association with higher incidence.

The study by Imbiriba et al. refined the analysis with data on occupation from different census tracts, showing that migration and great poverty contributed in different parts of Manaus[38] (Amazonas State). In Castanhal (Pará State), Barreto et al. described the distribution of houses and investigated contacts, and the relationship with serological levels of anti-phenolic glycolipid-I (anti-PGL-I)[39]. The studies that observed households[45-47] or schools identified that new cases emerged in small distances of cases previously diagnosed[45,46], and clusters of disease were located in poorer areas and those with higher population densities[47].

## DISCUSSION

We have identified 35 studies on the spatial distribution of leprosy in the last 20 years. Although the most affected areas were the North and the Midwest, the scientific literature was not proportional to the intensity of the disease; almost a third of the studies were carried out in the Southeast region. Probably the proximity of research institutions accounted for this disproportion.

Most articles used the SINAN as a source of information; however, it is known that there are problems of completion and consistency in this system[48,49]. Another point to be considered is the difficulty experienced by various authors in making geographical references of leprosy cases, because of the incompleteness of the addresses in the SINAN, or insufficient information. Such instances were more frequent on the outskirts of the cities, where the NCDR was higher and it would be more relevant to obtain this information[37,40]. Most of the authors used the local Bayesian empirical model to smooth the leprosy detection coefficients in an attempt to alleviate random fluctuations in the indicators, a consequence of rare events in small populations[50]. Smoothing of detection rates can improve early detection of cases, increase the number of regions classified as hyperendemic and the number of people needed to be followed to detect one new case of leprosy[39,45].

Also, the combination of geographic information systems and spatial analysis can identify clustering of leprosy cases, select areas for more focused interventions, and monitor disease control[51]. We must highlight that heterogeneity was observed in the distribution of the disease in all scales used, regardless of the analytical method used.

The epidemiological indicator most used was the NCDR. Despite the high levels of leprosy in children aged less than 15 years in the country and the importance of the degree of disability to identify diagnosis delay, few studies have addressed these indicators. For all indicators, the results showed that despite the decrease in the number of leprosy cases reported in temporal studies in the country[7,52], there are areas with stagnation or growth of these indicators. Some endemic areas showed an overlap of indicators, adding a high risk of transmission and clusters of late diagnosis[19,29,33].

Some studies also evaluated contacts (intra and extra-domiciliary) and the transmission of leprosy. The importance of intra-domiciliary transmission was confirmed by comparing it with the probability that multibacillary carriers will be infected even before the clinical manifestation of the disease[17,35,46]. Transmission was also identified in the neighborhood and school environment[39,45]. It must be pointed out that the study by Barreto et al. incorporated anti-PGL-I serology as an adjuvant to surveillance activities merged with spatial analysis in the early detection of new cases[45].

This may be a promising approach to the strategy of active search attached to the administration of immunoprophylaxis and/or chemoprophylaxis, which are proposals to *zero out* the transmission of leprosy[53]. These authors emphasize the effectiveness of large-scale school surveys, mainly in hyperendemic areas or clusters of the disease. There is some controversy regarding health services and indicators of leprosy. Some authors[36,37] report that despite the decentralization of services and leprosy control activities, as well as the increased coverage of the Family Health Care Strategy, health services are centered on passive surveillance, with less impact on the control of endemic diseases.

As these services serve spontaneous demand patients mostly, hidden prevalence remains. In Duque de Caxias, a municipality of Rio de Janeiro[37], a positive correlation between new cases and targeted campaigns showed no correlation between the number of new cases and the number of decentralized units of service for leprosy, both USF and decentralized reference units. A study on the delay in disease diagnosis in Brazil identified that misdiagnosis of cutaneous lesions is one of the predisposing factors, and recommended strengthening the medical curricula[54].

On the other hand, some studies reaffirm trend evaluations, showing that the increase of NCDR related to coverage of health services does not reflect a true increase in the incidence[40], but an increase in the detection of new cases that would otherwise remain undiagnosed – the hidden prevalence. However, the trend, for the next few years, would be a decrease in disease incidence[55]. Additionally, NCDR can vary due to distortions caused by the different qualities of municipal surveillance systems.

Furthermore, trend comparisons are certainly hampered by changing municipalities, and redefinition of geographical areas occurring in recent decades in the country, in addition to population migratory movements. Spatial analysis has contributed to the knowledge of the magnitude and dynamics of leprosy as a disease. Although the country shows decreases in prevalence and in the detection of new cases, priority regions of high endemicity were identified, where it is necessary to intensify actions to eliminate the disease.

Although the studies presented in this review are susceptible to ecological fallacy, the association of leprosy with low socioeconomic status was corroborated at different levels of spatial aggregation and with different indicators, findings similar to tuberculosis shown in a recent review[56]. Therefore, this confirms the importance of health policies aimed at more vulnerable populations. Another possible limitation, considering the lack of effective surveillance in low endemic areas, is the occurrence of *pseudo-silent areas*.

New studies with spatial analysis and geographic information systems resources[51], highlighting recent transmission indicators and diagnostic delays are essential to deepen the knowledge, to guide case-finding campaigns, and to monitor interventional results in the elimination of leprosy in Brazil.

**Conflict of interest**

The authors declare that there is no conflict of interest.

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