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ORIGINAL ARTICLE

Temporal trend, distribution and spatial autocorrelation of leprosy in Brazil: ecological study, 2011 to 2021

Tendência temporal, distribuição e autocorrelação espacial da hanseníase no Brasil: estudo ecológico, 2011 a 2021

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ABSTRACT

Objective: To characterize the temporal trend and spatial behavior of leprosy in Brazil, from 2011 to 2021. **Methods:** This is an ecological study, with data from the Notifiable Diseases Information System, obtained in June 2022. The annual detection rate of new leprosy cases per 100 thousand inhabitants was calculated. To estimate the trend of the 2011–2019 and 2011–2021 series, the polynomial regression model was used, testing first-, second-, and third-order polynomials. For spatiality, natural breaks were used and, later, the univariate global and local Moran's indexes. A significance level of 5% was adopted and the analyses were performed using SPSS®, GeoDa®, and QGIS® software. **Results:** The findings indicated an upward trend in the incidence of leprosy in Brazilian regions and in 20 federative units between 2011 and 2019. However, there was a decrease in most of the country when considering the COVID-19 pandemic years. Spatiality showed that the highest detection rates throughout the period were observed in the North, Midwest, and Northeast regions, with high-risk clusters, and the lowest detection rates in the South and Southeast regions, with low-risk clusters. **Conclusion:** The leprosy detection rate showed an upward trend in Brazil between 2011 and 2019, with greater spatial concentration in the North, Northeast, and Midwest regions. Nevertheless, the study raises an alert for the programmatic sustainability of leprosy control in Brazil, considering the drop in the COVID-19 pandemic, presumably due to the influence of the reorganization of the development of initiatives and provision of services in face of COVID-19.

Keywords: Ecological studies. Leprosy. Spatio-temporal analysis. Public health.

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CONFLICT OF INTERESTS: nothing to declare.

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INTRODUCTION

Leprosy is a chronic infectious condition caused by *Mycobacterium leprae*, which mainly affects the skin and peripheral nerves, with the potential to cause disability[1]. Its record is millenary, but several advances have been achieved in recent decades[1], mainly by the Global Leprosy Strategy (2016—2020 and 2021—2030) proposed by the World Health Organization (WHO)[2].

In 2020, 127,396 new leprosy cases were detected worldwide, representing a 37.1% drop compared with 2019 as a possible consequence of the new coronavirus (COVID-19) pandemic[2]. Together, Brazil, India, and Indonesia accounted for 74.0% of the total number of cases of the disease recorded in 2020[2]. In addition, Brazil is among the 22 countries with the highest burden of the disease, occupying the 2nd position of highest incidence of cases[1].

Within this context, leprosy persists as a public health issue in Brazil, despite the existence of guidelines for surveillance, care, and eradication of the disease[1,3]. The complexity of leprosy is aggravated by the inherent social and economic determinants associated with the disease, which, in addition to causing physical deformities and disability, carries the social burden of stigma and discrimination among the affected people[1,4].

In Brazil, the fight against leprosy has been implemented since the publication of *Diretrizes Nacionais para Vigilância, Atenção e Eliminação da Hanseníase como Problema de Saúde Pública* ("National Guidelines for the Surveillance, Care, and Eradication of Leprosy as a Public Health Issue") in 2016[5], and, more recently, by the publication of *Estratégia Nacional para Enfrentamento da Hanseníase (2019–2022)* ("National Strategy to Combat Leprosy [2019—2022]"), from 2020, which aims to strengthen management, fight the disease and its complications, and promote the social inclusion of the affected people[1].

However, it is known that leprosy has heterogeneous behavior, as its occurrence is influenced by social, environmental, economic, and demographic factors[1,6]. Thus, to investigate the spatiotemporal behavior of leprosy considering the different territorial scenarios of a location is imperative, mainly because its prevalence is higher in disadvantaged social strata[7].

Considering the high burden of leprosy in Brazil and recognizing the heterogeneity of the occurrence of the disease, especially in more vulnerable socioeconomic contexts, the temporal and spatial pattern of leprosy in the country must be investigated. Therefore, we aimed to characterize the temporal trend and spatial behavior of leprosy in Brazil, from 2011 to 2021.

METHODS

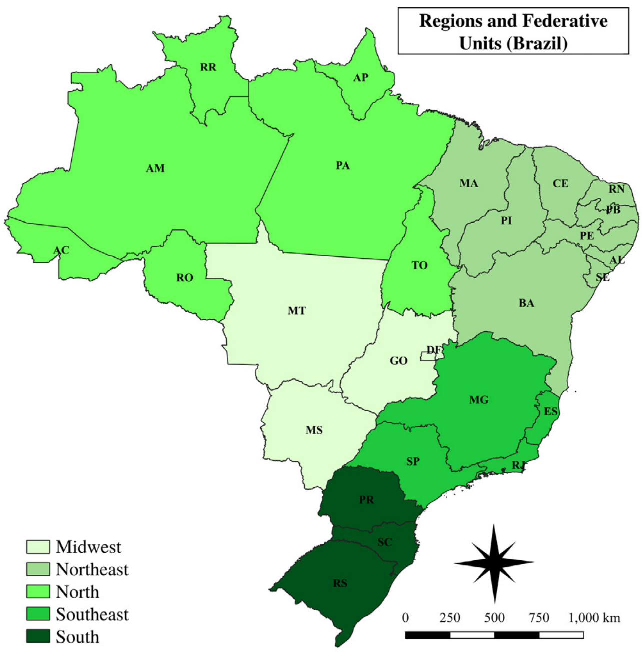
This is an epidemiological study, with an observational and ecological design, in which analyses according to time and space were performed. Data were extracted on June 20, 2022 from the Notifiable Diseases Information System (*Sistema de Informação de Agravos de Notificação* – SINAN) and the Brazilian Institute of Geography and Statistics (IBGE), on the website of the Department of Informatics of the Brazilian Unified Health System (DATASUS).

Brazil, the study location, has 26 states and the Federal District, named federative units (FU), which are organized into five regions: North, Northeast, Southeast, South, and Midwest, which correspond to the estimated population of 213,317,639 inhabitants and the territorial extension of 8,510,345,540 km² (Figure 1)[8].

The study population was defined as the leprosy cases recorded in SINAN between 2011 and 2021, considering the most recent data available at the time of the study. New cases were selected according to place of residence (FU, regions, and Brazil), diagnosed in the respective years under analysis.

The annual detection rate of new cases of leprosy per 100 thousand inhabitants was calculated, an indicator recommended by the Brazilian Ministry of Health to measure the strength of morbidity, magnitude, and trend of the endemic disease[5]. The estimation was based on the ratio of new cases resident in a given place and year, by the projection of the total resident population, in the same place and period, and the result was multiplied by 100 thousand.

Subsequently, trend analysis was performed using polynomial regression models, in which the rate was considered the dependent variable (y) and the years, the independent variable (x)[9]. Considering the possible influence of the COVID-19 pandemic period on the historical series, the



Source: Adapted from IBGE, 2022.

Figure 1. Map of Brazil, according to regions and federative units.

temporal trend was estimated in two periods, 2011–2019 and 2011–2021, aiming to analyze and compare the behavior of the incidence of leprosy in the context of COVID-19.

To avoid serial correlation, the artifice of transforming the variable year into the year-centered variable was used, and to smooth the rates, the smoothing artifice using the three-point moving average was used. First- ($y=\beta0+/-\beta1x$), second- ($y=\beta0+/-\beta1x+/-\beta2x^2$) and third-order ($y=\beta0+/-\beta1x+/-\beta2x^2+/-\beta2x^2+/-\beta3x^3$) models were tested. The one with the best statistical significance ($p<0.05$), coefficient of determination (r^2) closest to 1.00, and analysis of residues without bias was chosen[9].

In this type of modeling, with high statistical power and easy interpretation, β0 is characterized as the average rate of the historical series (intercept); and β1, β2, and β3 as the regression (evolution) coefficients, representing the average annual variation/acceleration of the rate. The sign of the coefficients determines the upward (+) or downward (-) trend. When the criteria were similar for the polynomials, the simplest model (i.e., of the lowest order) was chosen[9].

For the spatial distribution, data were grouped into three periods: 2011–2014, 2015–2017, and 2018–2021. Considering the possibility of random fluctuations, the rate for each period was estimated by the sum of the new cases, by the sum of the population of each year in the same place, and the result was multiplied by 100 thousand. The maps were drawn considering FU as the unit, based on the shapefile obtained from IBGE, by intervals of natural breaks in which dark colors represent higher rates and light colors, lower rates.

Moreover, the spatial dependence of the detection rate on the Moran's spatial autocorrelation coefficient was analyzed, which is subdivided into the global Moran's index (I) and the local Moran's index (I_i). The queen neighborhood criterion was used. Initially, the univariate global Moran's index was estimated for each period, and the significance was determined by the pseudo-significance test with 999 permutations. When significant ($p<0.05$), the univariate local Moran's index (local indicator of spatial association – LISA) was determined, identifying clusters with similar risk[10].

LISA clusters were divided into: high-high (HH), states and neighbors with high rates; low-low (LL), states and neighbors with low rates; low-high (LH), states with low rates and neighbors with high rates; high-low (HL), states with high rates and neighbors with low rates; and not significant (NS), states and neighbors with no clear spatial trend[10]. The following software were used: the statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS)®, v.20.1; the spatial analyses were performed in GeoDA®, v.1.20; and the maps were drawn in QGIS®, v.2.8.

As this research uses data from secondary sources, without identification of subjects and whose access is in the public domain, there was no need to submit it to the Research Ethics Committee, as recommended by Resolution No. 510, of 2016, of the National Health Council of the Brazilian Ministry of Health. However, it should be noted that the ethical precepts of the current legislation were followed and respected.

RESULTS

In the period from 2011 to 2021, 309,638 new cases of leprosy were recorded in Brazil. Between 2011 and 2019, the detection trend was significantly increasing for the country ($r^2=0.99$; $p<0.001$) and its regions, with the most significant increase perceived in the Midwest ($r^2= 0.97$; $p=0.008$). When considering the COVID-19 pandemic years, we observed a downward trend for Brazil ($r^2=0.92$; $p<0.001$) and its regions, except for the South ($r^2=0.99$; $p<0.001$) (Table 1).

In the analysis between 2011 and 2019, there was an upward trend for 19 states and the Federal District, with Mato Grosso ($r^2=0.94$; $p=0.003$) and Tocantins ($r^2=0.92$; $p=0.005$) the states with the highest annual increase. Conversely, among the seven declining states, the largest decreases were observed in Amazonas ($r^2= 0.96$; $p<0.001$), Sergipe ($r^2=0.93$; $p<0.001$), and Bahia ($r^2=0.92$; $p=0.001$). In the historical series comprising 2020 and 2021, 12 out of the 19 states changed from increasing to decreasing (Table 1).

The spatial distribution of the cases demonstrated that, in the three grouping periods of the analysis (2011–2014, 2015–2017, and 2018–2021), the highest rates of disease detection were concentrated in the North, Northeast, and Midwest regions, especially the states of Mato Grosso and Tocantins. Similarly, we noticed lower rates in the South and Southeast regions (Figure 2).

The global Moran's indices and the respective pseudo-values of p for 2011–2014 ($I=0479$; $p=0.001$), 2015–2017 ($I=0.393$; $p=0.007$), and 2018–2021 ($I=0.304$; $p=0.013$) showed significant positive spatial dependence, in such a way that LISA was considered, with significant clusters at 5% ($p<0.05$). We observed high-high autocorrelation for the states of Mato Grosso, Tocantins, and Pará in the three periods. In addition, we verified low-low clusters for the states of the South and Southeast regions (Figure 3).

DISCUSSION

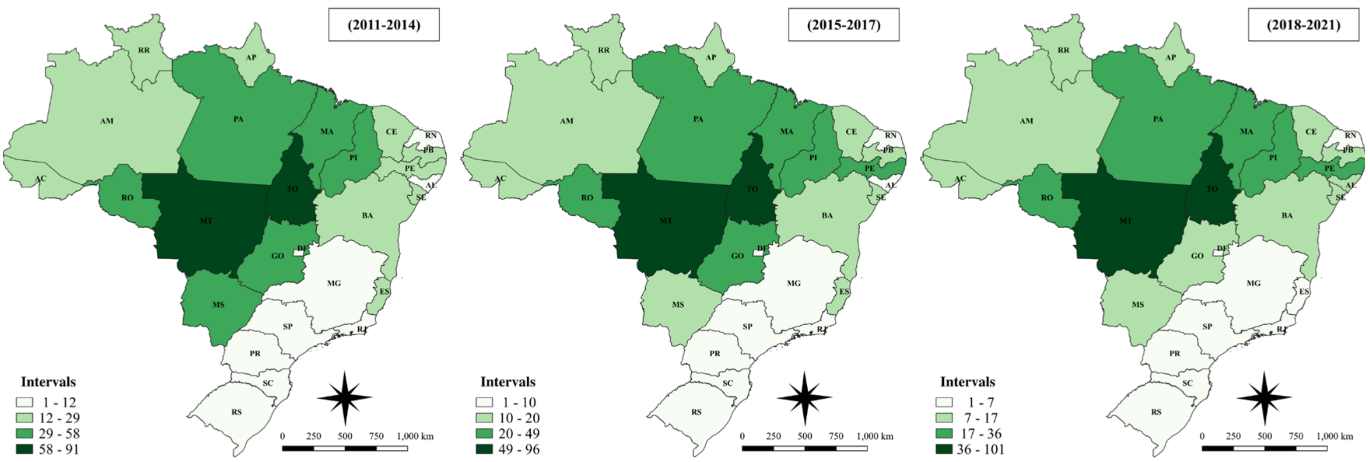
Our findings pointed to an upward trend in the incidence of leprosy in Brazilian regions and in 20 federative units between 2011 and 2019. However, there was a decrease in most of the country when considering the COVID-19 pandemic years. Spatiality showed that the highest detection rates throughout the period were observed in the North, Midwest, and Northeast regions, with high-risk clusters, and the lowest detection rates in the South and Southeast regions, with low-risk clusters.

Leprosy is considered a neglected tropical disease that persists as a public health issue in several countries, especially underdeveloped or developing ones such as Brazil and India[11,12]. The higher occurrence of leprosy in these countries is related to worse living conditions, as situations

Table 1. Trend models of the rates of new leprosy cases, according to Brazilian federative units and regions, 2011 to 2021.

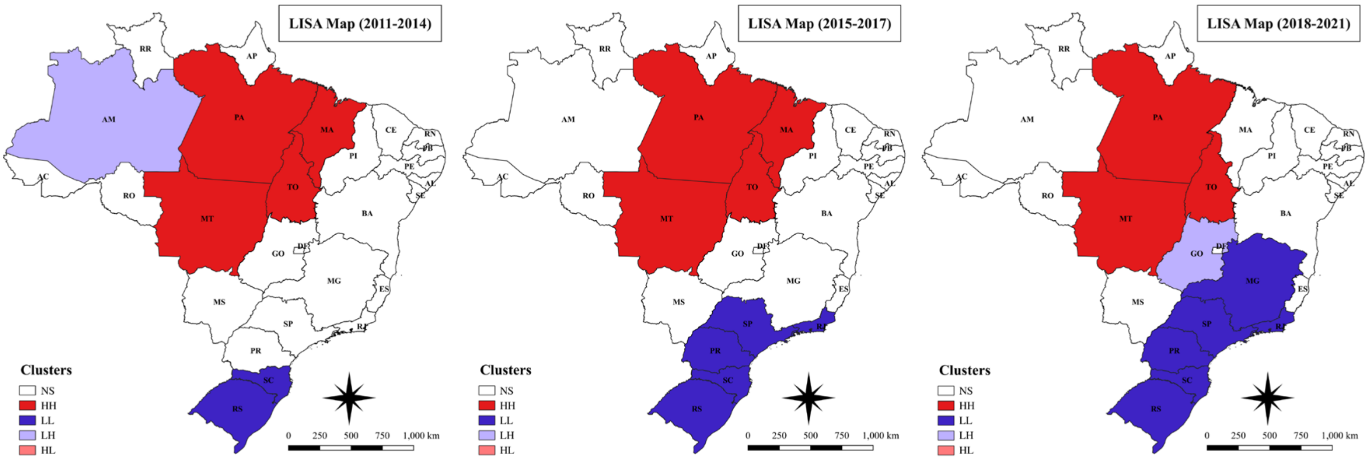
Location	2011–2019				2011–2021			
	Model	r²	p	T	Model	r²	p	T
North region	y=31.90-1.78+0.38	0.98	<0.001	↓/↑	y=31.21-0.84+0.00-0.09	0.96	<0.001	↓/↑/↓
Rondônia	y=34.31-2.78+0.66	0.94	0.003	↓/↑	y=34.43-2.70	0.87	<0.001	↓
Acre	y=16.17-0.85+0.39-0.09	1.00	<0.001	↓/↑/↓	y=15.45-0.48+0.16-0.07	0.99	<0.001	↓/↑/↓
Amazonas	y=13.91-1.32	0.96	<0.001	↓	y=12.66-1.27	0.97	<0.001	↓
Roraima	y=18.50-0.62+0.72	0.79	0.044	↓/↑	y=19.83+1.07-0.04-0.20	0.86	0.014	↑/↓/↓
Pará	y=36.98-4.18+0.27+0.14	1.00	<0.001	↓/↑/↑	y=35.04-3.11	0.97	<0.001	↓
Amapá	y=14.07-1.60+0.34+0.04	0.99	<0.001	↓/↑/↑	y=13.63-0.47+0.09-0.06	0.97	<0.001	↓/↑/↓
Tocantins	y=70.92+5.25+1.45	0.92	0.005	↑/↑	y=80.05+10.25-0.78-0.67	0.92	0.003	↑/↓/↓
Northeast region	y=22.64-1.48+0.06+0.07	1.00	<0.001	↓/↑/↑	y=21.58-1.18	0.95	<0.001	↓
Maranhão	y=52.02-2.88+0.02+0.08	1.00	<0.001	↓/↑/↑	y=50.30-2.96-0.25	0.98	<0.001	↓/↓
Piauí	y=33.32-0.72	0.94	<0.001	↓	y=33.06-0.73-0.28-0.06	0.97	<0.001	↓/↓/↓
Ceará	y=21.05-1.80+0.01+0.08	0.99	<0.001	↓/↑/↑	y=19.81-1.25	0.98	<0.001	↓
Rio Grande do Norte	y=7.56-0.40	0.91	0.001	↓	y=7.17-0.40	0.95	<0.001	↓
Paraíba	y=13.35-1.50+0.25+0.08	0.99	<0.001	↓/↑/↑	y=12.94-0.72+0.13	0.90	0.029	↓/↑
Pernambuco	y=25.11-1.91+0.26+0.14	0.98	0.003	↓/↑/↑	y=25.05-1.03	0.83	0.001	↓
Alagoas	y=9.95-0.54+0.13	0.98	<0.001	↓/↑	y=9.74-0.23+0.03-0.02	0.97	<0.001	↓/↑/↓
Sergipe	y=16.91-1.05	0.93	<0.001	↓	y=15.88-1.04	0.97	<0.001	↓
Bahia	y=15.85-0.57	0.92	0.001	↓	y=15.51-0.79-0.09	0.98	<0.001	↓/↓
Southeast region	y=4.89-0.39+0.06	1.00	<0.001	↓/↑	y=4.64-0.25+0.02-0.01	0.99	<0.001	↓/↑/↓
Minas Gerais	y=5.61-0.30+0.05	0.99	<0.001	↓/↑	y=5.43-0.17+0.01-0.01	0.99	<0.001	↓/↑/↓
Espírito Santo	y=14.48-1.81+0.30	0.99	<0.001	↓/↑	y=13.50-1.08+0.03-0.07	0.98	<0.001	↓/↑/↓
Rio de Janeiro	y=6.60-0.66+0.11	0.99	<0.001	↓/↑	y=6.16-0.42+0.05-0.01	0.99	<0.001	↓/↑/↓
São Paulo	y=3.06-0.19+0.30	0.99	<0.001	↓/↑	y=2.93-0.13+0.01-0.00	0.99	<0.001	↓/↑/↓
South region	y=3.41-0.33+0.03	0.99	<0.001	↓/↑	y=3.13-0.29+0.02	0.99	<0.001	↓/↑
Paraná	y=6.31-0.69+0.08	0.99	<0.001	↓/↑	y=5.76-0.60+0.05	0.99	<0.001	↓/↑
Santa Catarina	y=2.35-0.18	0.94	<0.001	↓	y=2.11-0.15+0.01	0.97	<0.001	↓/↑
Rio Grande do Sul	y=1.12-0.12+0.00+0.01	0.98	0.002	↓/↑/↑	y=1.05-0.08	0.97	<0.001	↓
Midwest region	y=36.89-2.25+0.34+0.23	0.97	0.008	↓/↑/↑	y=36.87-1.07	0.55	0.021	↓
Mato Grosso do Sul	y=26.99-7.45-0.39+0.52	0.99	<0.001	↓/↓/↑	y=22.04-5.53+0.09+0.19	0.95	0.001	↓/↑/↑
Mato Grosso	y=93.44+5.59+1.73	0.94	0.003	↑/↑	y=106.15+10.61-0.80-0.68	0.77	0.044	↑/↓/↓
Goiás	y=25.97-2.93+0.15+0.08	1.00	<0.001	↓/↑/↑	y=24.50-2.22	0.98	<0.001	↓
Federal District	y=7.45-0.89-0.14+0.06	0.96	0.012	↓/↓/↑	y=6.65-0.83-0.00+0.04	0.90	0.005	↓/↓/↑
Brazil	y=14.31-0.98+0.11+0.04	0.99	<0.001	↓/↑/↑	y=13.92-0.76	0.92	<0.001	↓

r²: coefficient of determination; T: trend; ↑: upward; ↓: downward.
Source: Research data, 2022.



Source: Research data, 2022.

Figura 2. Maps of spatial distribution of the rates of new leprosy cases, by natural breaks, according to Brazilian federative units, 2011 to 2021.



LISA: local indicator of spatial association.
Source: Research data, 2022.

Figure 3. Maps of spatial autocorrelation of the rates of new leprosy cases, based on the univariate local Moran's index, according to Brazilian federative units, 2011 to 2021.

of precariousness and socioeconomic inequality are determinants of the disease[12,13].

Thus, understanding the polysemic phenomenon represented by leprosy allows us to comprehend its behavior in several aspects, especially the epidemiological one[13,14]. In this sense, the behavioral disparities in leprosy in Brazil, whose territorial extension reaches continental proportions, may be related to the social, economic, and programmatic inequalities existing between the regions of the country, already demonstrated in previous studies[6,15].

The downward trend in the leprosy detection rate observed between 2011 and 2019 is in line with other studies conducted at FU of Brazil[16,17]. This decline can be attributed to the adequate implementation of *Programa Nacional de Controle da Hanseníase* (National Leprosy Control Program) in Brazil, which stimulated and provided the decentralization of actions to combat the disease to Primary Health Care (PHC)[14,18].

Conversely, there was an increase in cases for most of the states, with higher concentration in Mato Grosso, Tocantins, and Pará, located in the Midwest, Northeast, and North regions, respectively, as observed in other studies[14,19]. It is known that, historically, the North, Midwest, and Northeast regions have concentrated most cases of leprosy in Brazil and persisted with high rates of disease endemicity[1,20].

Despite the slight increase observed at the end of the historical series in the South and Southeast regions, states in these regions have had the lowest disease detection rates[1,14]. These findings suggest that there is better implementation of leprosy prevention and control measures in these regions[14], with an increase in the active search for cases, epidemiological surveillance, and health education for the population[14,21].

Furthermore, the contrast of leprosy behavior between regions must consider not only programmatic effectiveness, but also socioeconomic aspects that influence the illness process. Regional disparities in the Brazilian territory are historically related to the epidemiology of certain infectious and contagious conditions, mainly due to development indicators[15,20].

The Southeast and South regions are in the considerably favorable socioeconomic strata, whereas the Northeast, North, and Midwest regions are in unfavorable contexts[20]. Thus, it is understood that social, economic, and health disparities in Brazil act as factors of vulnerability for the higher occurrence of leprosy[17], favoring heterogeneous regional behavior.

Inequalities in the distribution of resources are responsible for causing health inequities in the country, especially with regard to social determinants of health. Inequities are conceptualized as disparities in health outcome metrics due to avoidable differences in social, economic, geographical, or health resources, which are unfair and make the human right to health unfeasible[22].

Within this context, we must still consider that, in Brazil, there are weaknesses related to the underdiagnosis and underreporting of new cases of leprosy[19]. This problem may be associated with the low qualification of surveillance and healthcare systems, with greater evidence in areas with high endemicity and worse development indicators, which impacts the capacity to develop strategies to control the disease[19].

The scenario becomes even more critical when considering the current consequences of tackling the COVID-19 pandemic, which imposed the need to reorganize healthcare services and systems to enable responses to the health emergency, which often prevailed in the face of other health issues. The lack of health care caused by access restrictions or people's fear of seeking health services culminated in situations of instability in the programmatic control of chronic conditions and increased their morbidity and mortality[23].

Accordingly, we observed the care burden of the three levels of health care and also of health surveillance.

This situation may have hampered and interfered with the maintenance of programs for the control of chronic, communicable, and noncommunicable diseases, which, consequently, ended up influencing the number of notifications and the detection rate of leprosy in most of the country, as observed in this study.

Furthermore, there is need for surveillance, health care, and eradication of leprosy to be based on regional particularities, focusing on interventions for the early detection of cases and the interruption of the transmission chain[17]. To this end, epidemiological studies, such as the present one, are of paramount importance to understand the spatiotemporal behavior of communicable conditions as well as to evaluate and direct public policies.

We consider that our findings are reflected in priority scenarios, opening up possibilities for the development, adaptation, and/or operationalization of more assertive strategies to the Brazilian FU with the highest burden of the disease, considering regional particularities. The effective control of social determinants of health requires a complex and comprehensive approach, based on intersectoral coordination, especially in Brazil, where the development of health initiatives and provision of healthcare services is unequal[6,20].

It should be noted that this study has limitations. The first refers to the chosen type of epidemiological design, which prevents the observation of the specific health context of Brazilian municipalities. The other limitation concerns the use of secondary data, as there may be errors in completing notifications and underreporting of cases, especially in the COVID-19 pandemic context.

All in all, we conclude that the leprosy detection rate showed an upward trend in Brazil between 2011 and 2019, in the regions and in most of the FU, with the highest spatial concentration in the North, Northeast, and Midwest regions. Accordingly, we verified a disparity in the behavior of the disease in the country, requiring further studies to understand the social, economic, and health contexts that may be associated with the occurrence.

We raise an alert for the programmatic sustainability of leprosy control in Brazil, considering the drop evidenced in the COVID-19 pandemic, presumably due to the influence of the reorganization of the development of actions and provision of services in face of COVID-19. Thus, healthcare and surveillance strategies must be strengthened, as leprosy persists as a public health issue in Brazil, requiring greater attention from society, health professionals, researchers, and managers.

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RESUMO

Objetivo: Caracterizar a tendência temporal e o comportamento espacial da hanseníase no Brasil, de 2011 a 2021. **Métodos:** Estudo ecológico, com dados do Sistema de Informação de Agravos de Notificação, obtidos em junho de 2022. Calculou-se a taxa de detecção anual de casos novos de hanseníase por 100 mil habitantes. Para estimar a tendência das séries 2011–2019 e 2011–2021, empregou-se o modelo de regressão polinomial, testando polinômios de primeira, segunda e terceira ordem. Para a espacialidade, utilizaram-se as quebras naturais e, posteriormente, as estatísticas univariadas de Moran global e local. Adotou-se o nível de significância de 5% e as análises foram realizadas no *Statistical Package for the Social Sciences* — SPSS®, GeoDa® e QGIS®. **Resultados:** Os achados apontaram para a tendência crescente da incidência de hanseníase no Brasil, nas regiões e em 20 unidades da federação entre 2011 e 2019; contudo, houve decréscimo em grande parte do país ao se considerarem os anos pandêmicos. A espacialidade revelou que as maiores taxas de detecção, em todo o período, foram observadas nas Regiões Norte, Centro-Oeste e Nordeste, com *clusters* de alto risco, e as menores nas Regiões Sul e Sudeste, com aglomerados de baixo risco. **Conclusão:** A taxa de detecção da hanseníase apresentou tendência crescente no Brasil entre 2011 e 2019, com maior concentração espacial nas Regiões Norte, Nordeste e Centro-Oeste. Entretanto, o estudo traz um alerta para a sustentabilidade programática do controle da hanseníase no Brasil, dada a queda evidenciada na pandemia, presumivelmente por influência da reorganização da oferta de ações e serviços anteposta à COVID-19.

Palavras-chave: Estudos ecológicos. Hanseníase. Análise espaço temporal. Saúde pública.

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