# Hyperendemicity, heterogeneity and spatial overlap of leprosy and cutaneous leishmaniasis in the southern Amazon region of Brazil

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## Abstract

Neglected tropical diseases characterized by skin lesions are highly endemic in the state of Mato Grosso, Brazil. We analyzed the spatial distribution of leprosy and Cutaneous Leishmaniasis (CL) and identified the degree of overlap in their distribution. All new cases of leprosy and CL reported between 2008 and 2017 through the national reporting system were included in the study. Scan statistics together with univariate Global and Local Moran's *I* were employed to identify clusters and spatial autocorrelation for each disease, with the spatial correlation between leprosy and CL measured by bivariate Global and Local Moran's *I*. Finally, we evaluated the demographic characteristics of the patients. The number of leprosy (N = 28,204) and CL (N = 24,771) cases in Mato Grosso and the highly smoothed detection coefficients indicated hyperendemicity and spatial distribution heterogeneity. Scan statistics demonstrated overlap of high-risk clusters for leprosy (RR = 2.0; P <0.001) and CL (RR = 4.0; P <0.001) in the North and Northeast mesoregions. Global Moran's *I* revealed a spatial autocorrelation for leprosy (0.228; P = 0.001) and CL (0.311; P = 0.001) and a correlation between them (0.164; P = 0.001). Both diseases were found to be concentrated in urban areas among men aged 31-60 years, of brown-skinned ethnicity and with a low educational level. Our findings indicate a need for developing integrated and spatially as well as socio-demographically targeted public health policies.

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## Introduction

Neglected Tropical Diseases (NTDs) are a diverse group of currently 20 treatable and preventable conditions that affect more than 1 billion people, mainly in low-income countries in the tropics and subtropics (Mitjà *et al*., 2017; WHO, 2017). To efficiently treat NTDs, there is a need to improve the quality and effectiveness of health services. Shared epidemiological, demographic, and geographic parameters call for integration of NTDs control programmes (Standley *et al*., 2018). A distinct group of NTDs presents with skin manifestations, including leprosy and Cutaneous Leishmaniasis (CL). Although causing limited mortality, they present a chronic disease course that may result in significant morbidity due to physical disabilities and social stigma (Engelman *et al*., 2016; WHO, 2017).

Leprosy is mainly caused by the intracellular bacterium *Mycobacterium leprae*, with the infection predominantly transmitted through prolonged contact between susceptible individuals

and untreated patients, most likely through the inhalation of respiratory droplets. The broad clinical spectrum of leprosy is related to the immune response developed by the host, which can result in different types of skin lesions, nerve damage and deformities (Rodrigues and Lockwood, 2011). Annually, more than 200,000 new leprosy cases are reported worldwide, with 80% of new cases concentrated in three countries, *i.e.* India, Brazil and Indonesia. Brazil reports approximately 90% of all leprosy patients in Latin America (WHO, 2017). In 2018, a total of 28,660 new leprosy cases were observed nationwide, translating into an incidence of 13.7 cases per 100,000 inhabitants (WHO, 2019).

CL is caused by protozoa of the genus *Leishmania*, which are transmitted by the bite of female sand flies (Diptera: Psychodidae). The disease affects the skin and mucous membranes and has a wide range of clinical manifestations. Variations are due to the infecting *Leishmania* species and, similarly to leprosy, the pattern of the immune response developed by the patient. According to the Ministry of Health (MoH) of Brazil between 0.7 and 1.3 million new leishmaniasis cases are reported every year from approximately 85 countries (MoH, 2017). Brazil is among the ten countries that together report 70 - 75% of the global CL incidence. Between 1995 to 2014, the country reported an average of 25,763 new CL cases per year (Alvar *et al.*, 2012; MoH, 2017).

For both leprosy and CL, the surveillance and control strategies currently recommended in Brazil are based on early diagnosis and treatment of cases, epidemiological surveillance and health education. In addition, for leprosy, strategies also include the prevention and treatment of physical disabilities, as well as contact examination. For CL, vector monitoring and control should be conducted (MoH, 2016; 2017).

Leprosy and CL share many epidemiological features that commonly overlap geographically (Martínez *et al*., 2018). Geographical Information Systems (GIS) has been widely employed to identify spatial patterns and priority areas for leprosy (Silva *et al*., 2017) and CL, but their co-endemicity has seldom been evaluated (Melo *et al*., 2017). Indeed, studies addressing the joint spatial patterns of leprosy and CL are scarce despite the relevance for the development of targeted and integrated control and surveillance programs (Engelman *et al*., 2016). The aim of this study was to assess the joint spatial distribution of leprosy and CL in the state of Mato Grosso, Brazil where both diseases are highly endemic. To that end, an epidemiological and ecological study in that area was conducted over the period 2008-2017.

## Materials and methods

### Study area

The state of Mato Grosso is located in central-western Brazil in the southern Amazon region (Figure 1A). It occupies an area of 903,202.5 km² and presents the three main continental biomes of the country: *Amazônia* (rainforest), *Pantanal* (wetland) and *Cerrado* (savanna). According to the Institute of Geography and Statistics of Brazil (IBGE) the population, distributed across 141 municipalities and five mesoregions (Figure 1B), was estimated at 3,484,466 individuals in 2019 (IBGE, 2019). According to the latest MoH Epidemiological Bulletin, Mato Grosso reported the highest average detection rates of leprosy (92.6 cases/ 100,000 inhabitants) of all states between 2009 and 2018 (MoH, 2020). In addition, it currently ranks third among the Brazilian states with respect to the number of reported CL cases, with an annual average of 2,510 cases between 2009 and 2018 (DATASUS, 2020).

### Data sources and study variables

In Brazil, leprosy and CL cases are diagnosed through both passive surveillance and active case detection. As notifiable diseases, data on epidemiological, clinical, and laboratory features of all confirmed cases should immediately be recorded in a specific form of the Brazilian Notifiable Diseases Information System (Sistema de Informação de Agravos de Notificação, SINAN). The reporting trig-

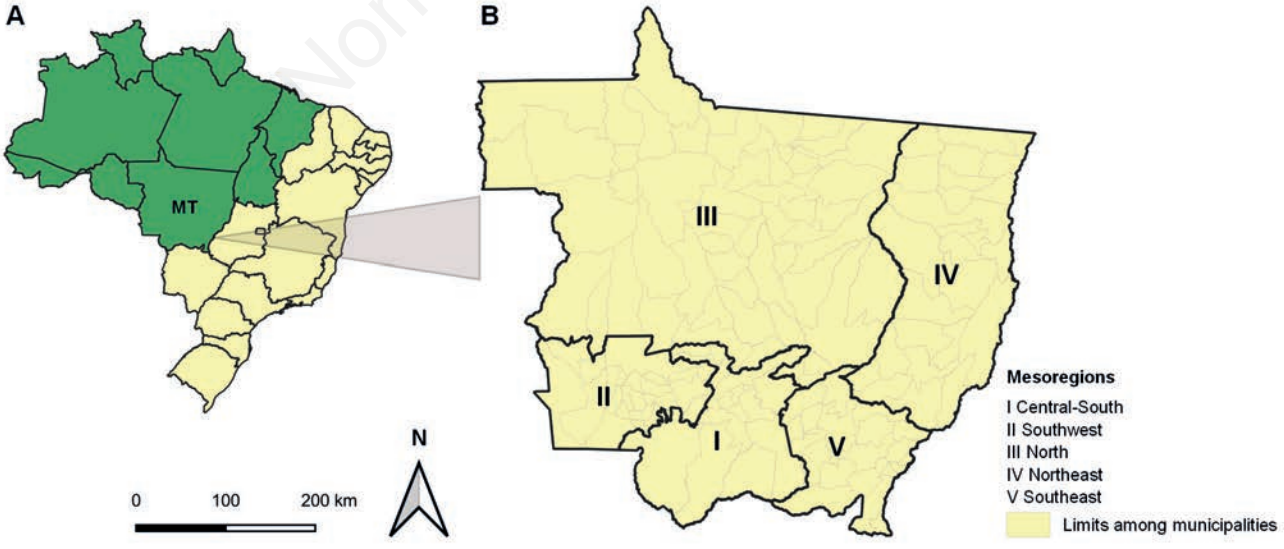


**Figure 1. Geographic characterization of the study area. (A) Location of the state of Mato Grosso (MT) in the Brazilian Amazon region green area; (B) Division of the state into five mesoregions with gray lines corresponding to the municipality borders.**

gers investigation and follow-up by local surveillance department until the clinical outcome has been established.

The primary data source was the SINAN. Specifically, we analyzed the leprosy and CL sub-databases provided by the Epidemiological Surveillance Sector of the Health Department of the state of Mato Grosso. The records of the sociodemographic variables related to the leprosy and CL patients are kept in a database that includes sex, age group, ethnic group/colour, schooling, area of residence, and municipality of residence. All new cases due to both diseases reported between 2008 and 2017 were included in the analysis after excluding duplicates, non-autochthonous records (patients diagnosed in Mato Grosso but resident elsewhere), error or change in diagnosis, and relapses. Annual estimates of the total population for all municipalities and the municipal cartographic shape files were obtained from the IBGE (IBGE, 2020).

## Data analysis

Data management and analysis were performed using Microsoft™ Office Excel 2010 (Microsoft Corp., Santa Rosa, CA, USA) and STATA/SE 12.0 (Stata Corp LP, College Station, TX, USA). The crude annual infection detection coefficient per 100,000 inhabitants was calculated by dividing the number of cases diagnosed in a particular year by the estimated population of the state that year. Next, the absolute and relative frequencies of the sociodemographic variables were calculated for each disease with 95% confidence interval using the Wald method. In addition, a Chi-square ($\chi^2$) test was applied to compare the proportions. Differences with $p$ <0.05 were considered statistically significant.

For spatial analysis, the data were aggregated according to the municipality of the patients. First, the detection coefficient for leprosy and CL for each municipality was smoothed using the Global Empirical Bayesian Estimator (GEBE), in GeoDa 1.10 software (University of Chicago, Chicago, IL, USA). The GEBE decreases the effect of random fluctuations and data instability by smoothing the crude rate towards an overall mean (Assunção *et al*., 1998). Smoothed detection coefficients were presented as quartiles in thematic maps.

Kulldorff's spatial scan statistics (Kulldorff and Nagarwalla, 1995) were used to identify potential spatial clusters of both diseases. A purely spatial analysis was conducted based on a discrete Poisson distribution of probabilities and employing the following parameters: number of cases of each disease, average population size of the municipalities and geographic coordinates of their centroids (Lambert Conformal Conic Projection, metric units). Spatial clusters were detected considering a maximum radius of the circular geographic window that aggregates until 50% of the population at risk, as advised by Kulldorff and Nagarwalla (1995). For each cluster, a likelihood ratio test was applied to test the null hypothesis of spatial randomness versus the alternative hypothesis that the risks within and outside the circular window were different. A 5% level of cluster significance was obtained through 999 Monte Carlo simulations. Only significant clusters with high risk for disease occurrence were considered. The analysis was conducted with the SaTScan™ 9.3 software (National Cancer Institute, Bethesda, MD, USA).

Global Moran's *I* was calculated to investigate the overall presence of patterns or spatial autocorrelation in the smoothed detection coefficients over the unit of analysis for each disease. In summary, spatial autocorrelation measures the influence that the values in neighbouring municipalities have on the observed value of each municipality (Aturinde *et al*., 2019). The Moran's *I* ranges from -1 to +1; values close to zero suggest spatial randomness while values close to +1 or -1 indicate positive (cluster) and negative (scatter) spatial autocorrelation, respectively. In addition, the Local Moran's *I* or Local Indicator of Spatial Association (LISA) was employed to identify the local spatial clusters. The analysis took into account the smoothed detection coefficient of each municipality to verify the presence of similarities with neighbouring municipalities. A queen contiguity-based spatial weights matrix was employed to define neighbours. Areas were classified as High-High (municipalities with positive spatial autocorrelation and positive values among the neighbours) and Low-Low (municipalities with negative spatial autocorrelation and negative values among the neighbours; Carvalho *et al*., 2004).

Finally, the Bivariate global and Local Moran's *I* (also known as BiLISA) was calculated as a measure of spatial correlation between the occurrence of leprosy in one municipality and CL in the neighbouring municipalities (Aturinde *et al*., 2019). All Moran's *I* analyses were performed with the GeoDa 1.10 software. The statistical significance of the *I*'s were checked in a pseudo sig-

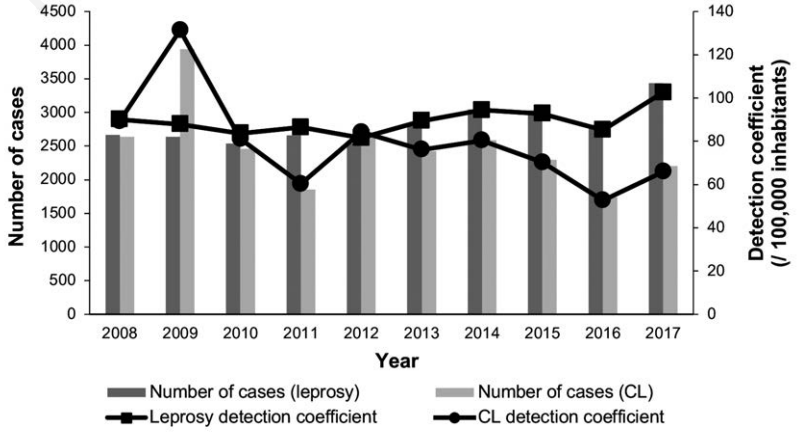


**Figure 2. Annual absolute number of reported cases and crude detection coefficient of leprosy and Cutaneous Leishmaniasis (CL) in the state of Mato Grosso, Brazil 2008-2017.**

nificance test based on 999 random permutations of the values among the evaluated areas. The spatial autocorrelation and correlation was considered significant at P<0.05. All products of the spatial analyzes were transformed into thematic maps in QGIS 3.4.0 software (QGIS, 2018).

## Results

From 2008 to 2017, 28,204 leprosy cases and 24,771 CL cases were reported in the state of Mato Grosso, with an annual average of 2,820 and a Standard Deviation (SD) of 281.3 and 2,477 (SD: 601.0), respectively. The crude detection coefficient of leprosy followed no obvious trend over the years, with an average of 89.4 (SD: 6.1) cases/100,000 inhabitants and a recent peak in 2017 (102.6 cases/100,000 inhabitants). In contrast, CL presented an average detection coefficient of 79.1 (SD: 21.5) cases/100,000 inhabitants, with a peak in 2009 (131.3 cases/100,000 inhabitants) followed by a strong decrease in 2010 and 2011 (60.2 cases/100,000 inhabitants). After that, the detection coefficients of CL were generally even or followed a slightly decreasing trend (Figure 2).

Autochthonous cases of leprosy and CL were reported from all municipalities of Mato Grosso. The absolute numbers ranged from 3 to 2,726 for leprosy, and from 1 to 1,262 for CL. Cuiabá, Juína, Rondonópolis, Sinop and Tangará da Serra were municipalities with the highest absolute numbers of cases for both diseases. While Cuiabá reported the highest number of leprosy patients (N = 2,726) or 9.7%, Sinop had the highest number of CL cases (N = 1,262) or 5.1% (Figure 3A and 3B).

Smoothed leprosy detection coefficients ranged from 19.5 to 456.6 cases/100,000 inhabitants, with a mean of 100.2 cases/100,000 inhabitants (SD: 69.1) heterogeneously distributed across the state territory. The highest rates were found to be concentrated in the North and Northeast (Figure 3C). For CL, the coefficients demonstrated a greater amplitude, with minimum of 2.3 and a maximum of 759.6 cases/100,000 inhabitants showing a mean of 139.9 cases/100,000 inhabitants (SD: 126.3). The highest CL detection coefficients were predominantly observed among the municipalities of the northern, north-eastern and south-eastern mesoregions (Figure 3D).

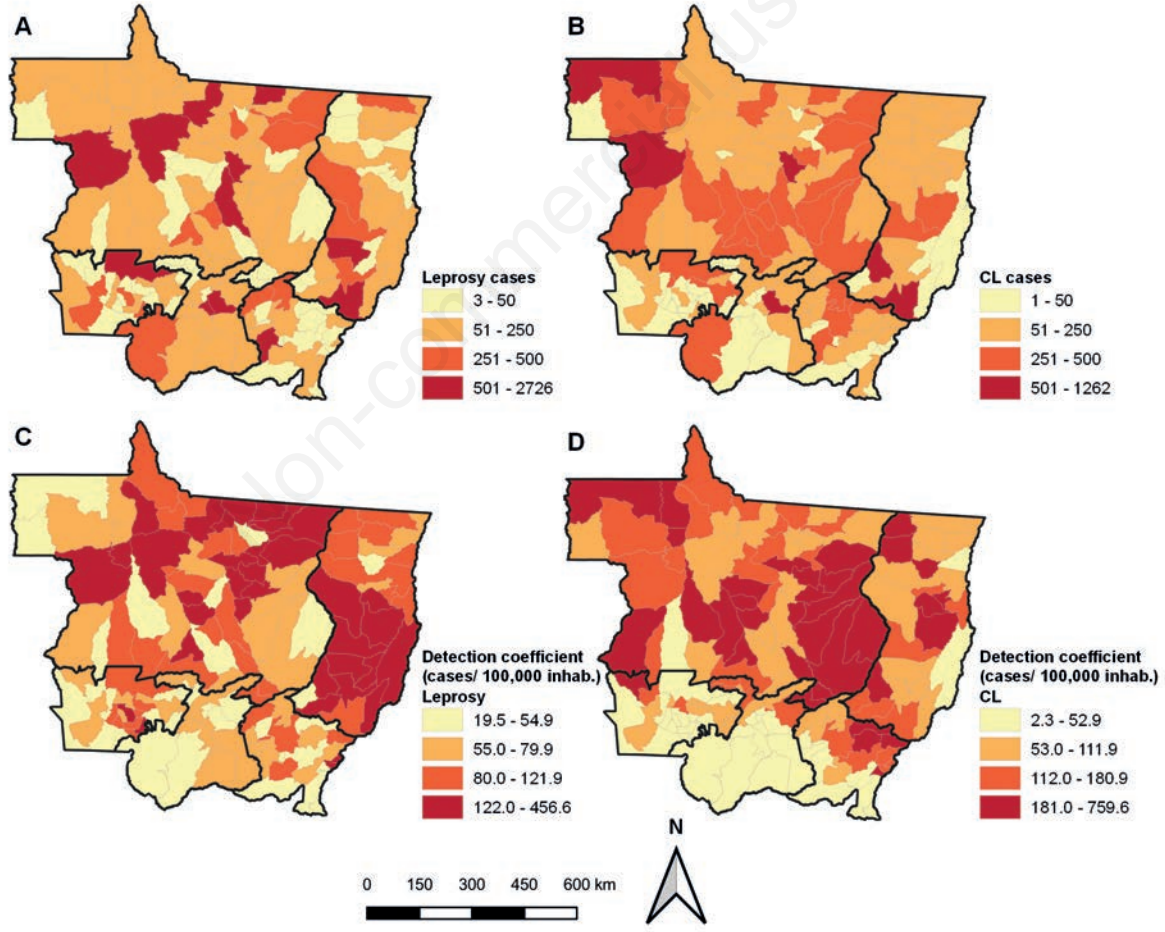


**Figure 3. Cumulative number of cases and detection coefficient of leprosy and Cutaneous Leishmaniasis (CL) in the state of Mato Grosso, Brazil 2008-2017. (A) and (B) show the absolute number of cases per municipality; (C) and (D) the detection coefficient smoothed by the global empirical Bayesian estimator (cases/100,000 inhabitants) for leprosy and CL, respectively. The black lines correspond to the division of the state into mesoregions and the gray lines correspond to the borders of the municipalities.**

Kulldorff's spatial scan statistic demonstrated the existence of three high-risk spatial clusters for leprosy and two for CL. For leprosy, the clusters included 50.4% (71/141) of the municipalities and 35.6% (1,122,707/3,150,671) of the population of the study area. In these areas, the relative risk (RR) for disease occurrence varied from 1.5 to 5.6 times higher than the risk outside them. For CL, 66.0% (93/141) of the municipalities, with 43.4% (1,368,557/3,150,671) of the state population, represented high-risk areas, with RR for disease occurrence ranging from 1.7 to 4.0 compared to other areas. Of note, an important overlap of the high-risk clusters for leprosy (RR = 2.0; P<0.001) and CL (RR = 4.0; P<0.001) was identified in the northern and north-eastern mesoregions. This overlap included 45.4% (64/141) of the municipalities and 32.1% (1,012,032/3,150,671) of the total population of the state of Mato Grosso (Figure 4A and 4B).

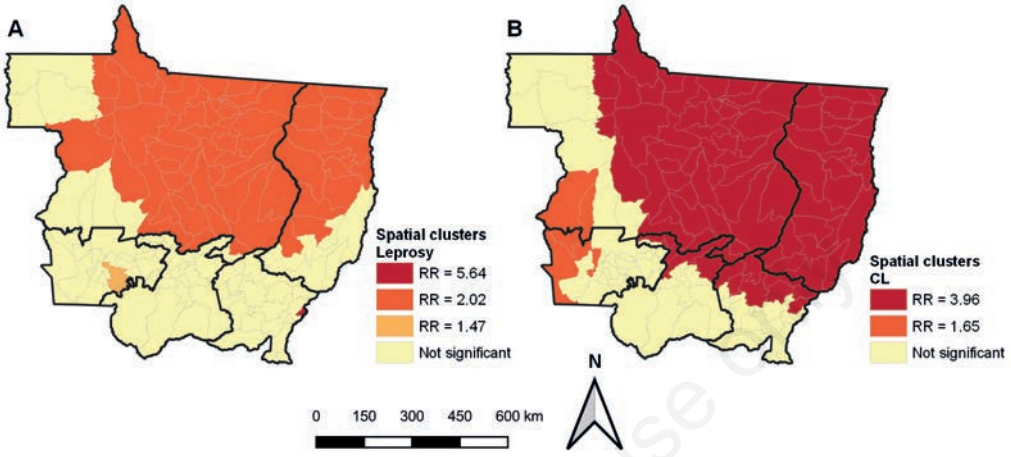


**Figure 4. Leprosy and Cutaneous Leishmaniasis (CL) high-risk clusters in the state of Mato Grosso, Brazil 2008-2017 detected by the Kulldorff's spatial scan statistics. (A) Leprosy and (B) CL. The black lines correspond the division of the state into mesoregions and the gray lines correspond the borders of the municipalities.**

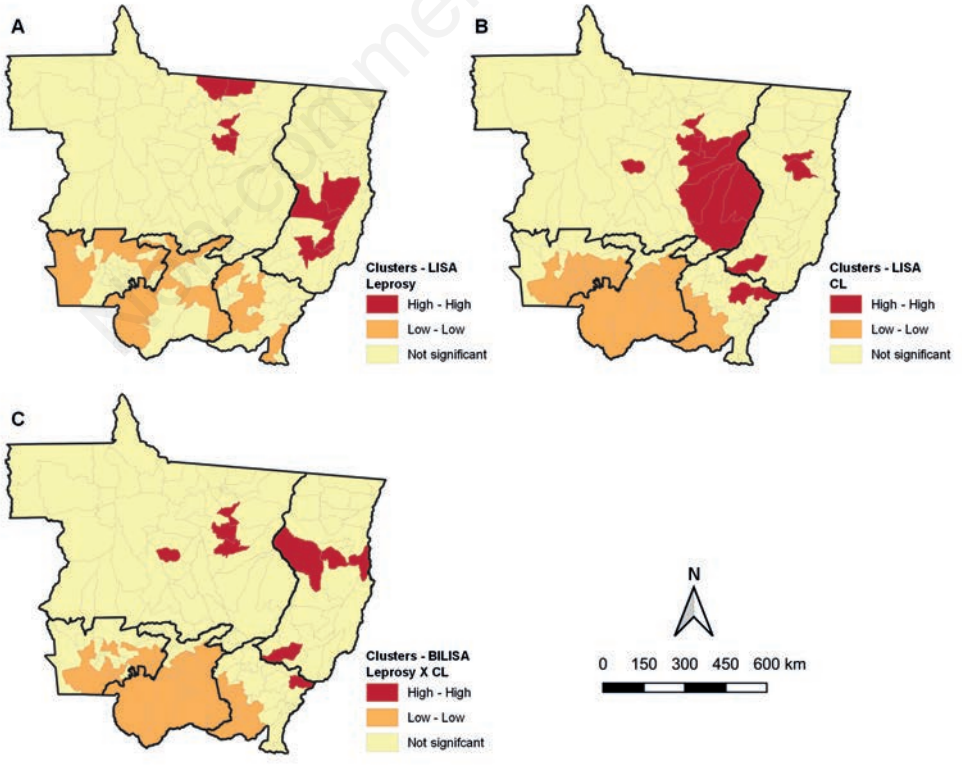


**Figure 5. Local Moran's I analysis for the smoothed detection coefficients of leprosy and Cutaneous Leishmaniasis (CL) in the state of Mato Grosso, Brazil 2008-2017. (A) and (B) show the Local Indicator of Spatial Association (LISA) map for leprosy and CL, respectively; (C) shows the bivariate LISA (BiLISA) map for leprosy and CL.**

Global Moran's *I* for the smoothed detection coefficients revealed a significant and positive overall spatial autocorrelation for leprosy (0.228; P=0.001) and CL (0.311; P=0.001). Figures 5A and 5B show that 8 and 14 municipalities were classified as High-High for leprosy and CL, respectively. Of note, most of them are located in the North and Northeast of the state. Low-Low municipalities were found to be exclusively located in the Southwest, Central-South, and Southeast.

The spatial correlation between leprosy and CL showed a positive and significant bivariate Global Moran's *I* (0.164; P=0.001). The BiLISA statistics revealed that leprosy detection coefficients were positively influenced by CL coefficients in neighbouring areas in nine municipalities (High-High). Of these, eight were distributed across the northern and north-eastern mesoregions, as clusters or individually. On the other hand, a single cluster composed of 26 municipalities with low coefficients (Low-Low) was detected in the Southwest, Central-South, and Southeast (Figure 5C).

Table 1 summarizes the sociodemographic characteristics of the leprosy and CL patients. Both diseases were seen to disproportionately affecting males of brown-skinned ethnicity, aged 31-60 years, with a low educational status and residing in urban/peri-urban areas. However, when compared to each other, there were important differences between the two cohorts. For CL, the proportion of male patients was much higher (80.7%) than for leprosy (54.6%). For leprosy, there was a stronger predominance of individuals aged 31-60 y (59.7%) while for CL patients this age group only represented 48.4% of the total patient cohort. With regard to education, the leprosy patients had a lower level (41.3% with up to four years of schooling) than the CL patients (31.7%), and compared to the CL patients (53.6%), they were far more concentrated in urban/peri-urban areas (81.2%).

## Discussion

To the best of our knowledge, this is the first study jointly evaluating the distribution of two of the most important NTDs characterized by skin lesions - leprosy and CL - in the Brazilian state of Mato Grosso. At the municipality level, we observed an important concentration in certain regions and heterogeneity in the spatial distribution for both leprosy and CL cases. We also noted a remarkable overlap of the most endemic areas.

Mato Grosso is a historic leprosy focus (Magalhães *et al*., 2011). The sustained detection of leprosy patients at hyperendemic levels (>40/100,000 inhabitants) (MoH, 2020) in most municipalities of the state may in part be associated with operational improvements in the health services including better coverage and decentralization. These reforms are the result of rolling out primary care services across Mato Grosso thanks to the Family Health

**Table 1. Stratification of reported cases of leprosy and cutaneous leishmaniasis (CL) according to socio-demographic characteristics in the state of Mato Grosso, Brazil 2008-2017.**

| Variable | Disease | | | | | | P |
|---|---|---|---|---|---|---|---|
| | Total leprosy cases (N = 28,204) | | | Total CL cases (N = 24,771) | | | |
| | N | % | CI 95% | N | % | CI 95% | |
| Sex | | | | | | | < 0.001* |
| Male | 15,396 | 54.6 | 54.0-55.2 | 19,984 | 80.7 | 80.2-81.2 | |
| Female | 12,808 | 45.4 | 44.8-46.0 | 4,787 | 19.3 | 18.8-19.8 | |
| Age group (years) | | | | | | | < 0.001* |
| 0 - 15 | 1,917 | 6.8 | 6.5-7.1 | 2,614 | 10.6 | 10.2-10.9 | |
| 16 - 30 | 5,015 | 17.8 | 17.3-18.2 | 7,512 | 30.3 | 29.7-30.9 | |
| 31 - 60 | 16,843 | 59.7 | 59.1-60.3 | 11,998 | 48.4 | 47.8-49.0 | |
| > 60 | 4,219 | 15.0 | 14.5-15.4 | 2,214 | 8.9 | 8.6-9.3 | |
| Missing information | 210 | 0.7 | - | 433 | 1.8 | - | |
| Ethnic group | | | | | | | < 0.001* |
| Brown (mixed) | 14,513 | 51.5 | 50.9-52.0 | 11,188 | 45.2 | 44.5-45.8 | |
| White | 9,463 | 33.5 | 33.0-34.1 | 9,059 | 36.6 | 36.0-37.2 | |
| Black | 3,589 | 12.7 | 12.3-13.1 | 1,947 | 7.9 | 7.5-8.2 | |
| Asian | 242 | 0.9 | 0.7-1.0 | 290 | 1.2 | 1.0-1.3 | |
| Indigenous | 124 | 0.4 | 0.4-0.5 | 1,751 | 7.0 | 6.7-7.4 | |
| Missing information | 273 | 1.0 | - | 536 | 2.1 | - | |
| Schooling (completed years) | | | | | | | < 0.001* |
| 0 - 4 | 11,660 | 41.3 | 40.8-42.0 | 7,860 | 31.7 | 31.2-32.3 | |
| 5 - 8 | 7,127 | 25.3 | 24.8-25.8 | 7,396 | 29.9 | 29.3-30.4 | |
| > 8 | 6,867 | 24.4 | 23.8-24.8 | 5,406 | 21.8 | 21.3-22.3 | |
| Missing information | 2,550 | 9.0 | - | 4,109 | 16.6 | - | |
| Residential area | | | | | | | < 0.001* |
| Urban / peri-urban | 22,911 | 81.2 | 80.5-81.4 | 13,265 | 53.6 | 53.0-54.2 | |
| Rural | 4,724 | 16.8 | 16.3-17.1 | 10,925 | 44.1 | 43.4-44.7 | |
| Missing information | 569 | 2.0 | - | 581 | 2.3 | - | |

Source: Brazilian Notifiable Diseases Information System (Sistema de Informação de Agravos de Notificação, SINAN). CI 95%: confidence interval at 95%; %: relative frequency; *significant at P<0.05.

Strategy. These reforms have resulted in an increase in the number of trained health professionals and improved access to primary health care. However, prevalence data should be interpreted carefully, especially because most of the notifications still refer to passive surveillance (Magalhães *et al*., 2011). In addition, it should also be taken into account that the disease is often detected in areas that undergo a disorderly population growth. In fact, it was previously observed that the highest leprosy detection rates in Mato Grosso took place in areas that experienced high rates of population growth over the past decades (Magalhães *et al*., 2011).

Given that the economic development and associated inflow of migrants are focused in the North and Northeast, it appears plausible that these demographic shifts are linked to the observed spatial heterogeneity of leprosy. Indeed, we observed a concentration of the highest detection coefficients and high-risk clusters for the disease in the municipalities located in the northern and north-eastern mesoregions of Mato Grosso. A heterogeneous spatial distribution of leprosy was already reported for the whole country (Silva *et al*., 2017), with the Amazon region, where the state of Mato Grosso is partly located, being the most important endemic area nationwide (MoH, 2020).

The municipalities in the northern and north-eastern mesoregions also differ from the others with regard to environmental aspects. They represent the Amazon biome in Mato Grosso, which suffers from recent agricultural and livestock breeding expansion characterized by increasing deforestation and contact between inhabitants and remaining natural areas (Silva *et al*., 2010; Magalhães *et al*., 2011). Previous studies have already speculated about a relationship between environmental factors and the occurrence of leprosy. Rocha *et al*. (2017) concluded that the detection rates of the disease in Brazil present a seasonality pattern with specific variations between different geographic regions, climates, and biomes. In fact, there is evidence that changes in temperature and humidity may influence the dynamics of *M. leprae* in the environment, with environmental transmission possibly related to the intensity of exposure of the individual to contaminated soil and water (Valois *et al*., 2015).

All municipalities in Mato Grosso reported autochthonous CL cases with higher detection coefficients compared to the rest of the country (MoH, 2019). This concentrated occurrence is probably associated with favourable eco-epidemiological characteristics of the state. It has already been demonstrated that phlebotomine sand flies of medical importance have a wide distribution and diversity in Mato Grosso (Ribeiro *et al*., 2007) and naturally infected reservoirs also exist (de Freitas *et al*., 2012).

Although widely dispersed, CL high-risk areas were also concentrated in the North and Northeast. In these areas, as described above, forest fragments are more frequent, supporting the presence of vectors and reservoirs. In addition, an important part of the population is exposed to sand flies' bites in these areas due to the high prevalence of individuals pursuing agricultural, livestock, extractive and/or recreational activities. In fact, the demographic pattern demonstrates a concentration of infections among males, particularly in the productive age group and among rural residents, which strongly suggests a relationship between CL and exposure to outdoor activities, as already reported from the Brazilian states of Acre (Melchior *et al*., 2017) and Paraná (Melo *et al*., 2017). In contrast, the CL cases among children, the elderly and women suggest the presence of a peri-domestic transmission cycle, possibly due to adaptation of sand fly species to these relatively new environments and the existence of susceptible reservoirs in or around habitations (Thies *et al*., 2016).

The positive and significant spatial correlation between the two diseases and the overlap of high-risk areas for both leprosy and CL are both noteworthy. Given that this co-occurrence has also been observed in other parts of Brazil, integration of control activities with regard to both these diseases should be considered (MoH, 2018), similar to what is proposed for vector-borne diseases (Golding *et al*., 2015) and implemented for leprosy, geo-helminthiasis, trachoma and schistosomiasis among schoolchildren (MoH, 2012). For the NTDs that predominantly affect the skin, the integration of control programs is recommended, especially because it increases cost-effectiveness and expands the geographical coverage, both with favourable impact on public health (Mitjà *et al*., 2017). In addition, the integrated control of leprosy and CL facilitates targeted training of health professionals for the differential diagnosis of these two diseases, which is essential for a better prognosis (Moschella and Garcia-Albea, 2016; Mitjà *et al*., 2017). The occurrence of leprosy may also be influenced by the occurrence of CL, specifically in the areas highlighted by the BiLISA statistics, as has already been proposed for other infectious diseases in Brazil (Phillips *et al*., 2017) and abroad (Aturinde *et al*., 2019). These two diseases share certain clinical, immunological and epidemiological aspects (Martínez *et al*., 2018) as reported in relation to some cases of co-infection in Brazil (Costa *et al*., 2009; Mercadante *et al*., 2018). This emphasizes the need for further detailed investigations on the extent of co-endemicity and the frequency and outcomes of leprosy and CL co-infections.

The present study has some limitations. First, we used secondary data which is generally susceptible to missing information and underreporting. However, leprosy and CL are both notifiable diseases in Brazil, and reporting is mandatory for subsequent treatment (Phillips *et al*., 2017). Second, due to the database structure it is not possible to determine whether diagnoses concern the same individual, nor can any causal relationship between them be identified.

Despite these limitations, the study successfully identified spatial patterns of leprosy and CL distribution in the state of Mato Grosso, with important overlaps in the North and Northeast. The results may be used to guiding surveillance and control interventions by public health authorities in the area. The identification of overlapping risk areas for leprosy and CL in the southern Amazon may further support the development of integrated public health policies to more effectively control these NTDs. In addition, it encourages new investigations addressing the co-infection between leprosy and CL on population and individual levels in Brazil and worldwide.

## Conclusions

Leprosy and CL occur at hyperendemic levels and have heterogeneous spatial distribution in the Brazilian state of Mato Grosso, with extensive overlaps between the most endemic areas.

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