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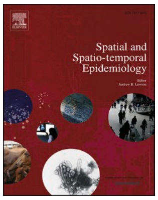

Spatio-temporal distribution and contributing factors of tegumentary and visceral leishmaniasis: A comparative study in Bahia, Brazil

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ABSTRACT

Tegumentary (TL) and visceral (VL) leishmaniasis are neglected zoonotic diseases in Brazil, caused by different parasites and transmitted by various vector species. This study investigated and compared spatio-temporal patterns of TL and VL from 2007 to 2020 in the state of Bahia, Brazil, and their correlations with extrinsic factors. The results showed that the total number of cases of both TL and VL were decreasing. The number of municipalities with reported cases reduced for TL over time but remained almost unchanged for VL. There were few municipalities with reported both diseases. Statistical analysis showed that local TL incidence was associated positively with natural forest. Local VL incidence was associated positively with Cerrado (Brazilian savannah) vegetation. This study identified different patterns of occurrence of VL and TL and the risk areas that could be prioritized for epidemiological surveillance.

1. Introduction

Leishmaniasis is one of the most neglected zoonotic vector-borne diseases in the world. It is estimated to cause 0.7 to 1.0 million new infections annually (World Health Organization, 2019). The disease has two distinct clinical forms: visceral leishmaniasis (VL), which causes generalized symptoms, such as fever and weight loss, and can be lethal if untreated (Pastorino et al., 2002); and tegumentary leishmaniasis (TL), characterized by localized lesions of the skin, mucosa or muco-cutaneous region, with the presence of ulcerative nasobronchial and oral nodules in mucosa (Reithinger et al., 2007). In addition to these symptoms, the two clinical forms of leishmaniasis differ by causative parasite of the *Leishmania* genus (Pace, 2014) and by vector species, which are sandflies belonging to the Phlebotominae subfamily (Diptera: Psychodidae). Female sandflies are hematophagous and can feed on several host species, including humans, and domestic and wild animals. The immature forms of sandflies develop in shaded and moist micro-habitats that are rich in organic nutrients. These micro-habits can be found at tree bases, in animal burrows, animal feces and cave crevices (Feliciangeli et al., 2006), all of which are sensitive to climatic factors, such as temperature and rainfall (Chaniotis et al., 1971). Temperature also influences the vector competence of sandflies and the gonotrophic cycle duration (Chaves and Pascual, 2006; Galvis-Ovallos et al., 2017b).

Many studies have reported that *Leishmania* species, sandflies and reservoirs can coexist in natural forests with little human modification (Costa, 2005; Maia-elkhoury et al., 2008; Moskovskij and Duhanina, 1971). The spread of human settlements for agriculture results in forest fragmentation, and hence increases the likelihood of human contact with infected vectors (Basano and Camargo, 2004). These changes in the ecosystem modify the ecology between parasites, vectors and reservoirs, favoring the emergence of leishmaniasis in anthropic environments (Shaw, 2007). Thus, VL and TL are present in geographic regions with distinct characteristics (Karagiannis-Voules et al., 2013) as a result of complex pathogen-vector-host interactions in a particular environment (Reisen, 2010). This study describes the evolution of VL and TL from 2007 to 2020 in Bahia, Brazil, and evaluates differences between the two

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leishmaniasis types in terms of the human cases, spatial distribution, and associated factors (environmental, climatic, socioeconomic).

In Brazil, 218,174 cases of TL were reported between 2008 and 2020, with an average of 16,783 cases per year, and an annual average incidence of 9.3 cases per 100,000 inhabitants. The average incidence remained almost constant between 2008 and 2015 at around 10.6, and decreased to 7.45 from 2016 to 2020 (Brazil, 2021). The state of Bahia is located in the Northeast Region of Brazil and had 16.7% (35,576) of the country's total cases between 2008 and 2020.

Regarding VL, 43,749 cases were reported between 2008 and 2020 in Brazil, with an average of 1.57 cases per 10,000 inhabitants. The annual incidence remained around 1.74 per 10,000 inhabitants until 2018 and decreased to 0.97 after that. The lethality of VL remained at an average of 7.2 until 2014 and increased to an average of 9.0 thereafter (Brasil, 2022). During the period studied, among Brazilian states, Bahia was in fifth place in terms of the number of VL cases (3810), accounting for 10.9% of the country's total cases (Bahia, 2020; Fontoura et al., 2020).

2. Material and methods

2.1. Data collection and preprocessing

2.1.1. Human-related data

First, the human case data of both VL and TL between 2007 and 2020 were obtained from the State Health Secretariat of Bahia (SESAB, 2020), with indication of patients' residence at the municipal level, the year of diagnosis of TL cases, and the year of first symptoms of VL. Second, the estimated population of municipalities in Bahia, along with income indices, were obtained from the Brazilian Health Information System (TABNET-DATASUS, (Ministério da Saúde, 2020)). These datasets were used to calculate the disease incidences (cases per inhabitant) by municipality and by year.

2.1.2. Socioeconomic data

We used the data regarding garbage disposal types, available from the Brazilian Health Information System (TABNET-DATASUS, (Ministério da Saúde, 2020)), as a proxy for municipality socioeconomic status and ideal conditions to vector. There are three types of garbage disposal: public collection service, burning or burial by residents, and deposit in open areas (e.g., streets, vacant land, rivers, and lakes). The last type of disposal had been considered as a risk factor for VL, given its strong correlation with the presence of vectors in urban areas (Costa et al., 2005).

2.1.3. Environmental data

Data on land use and cover (LUC) for each year were obtained from MapBiomas - collection 4.0 (MapBiomas, 2020) as 30 m raster grids. Six LUC categories were considered for analysis: (i) natural forest formation; (ii) planted forest (e.g., pine or eucalyptus); (iii) grassland and savanna; (iv) farmland and pasture for livestock; (v) urban area with infrastructure; and (vi) water bodies (rivers, lakes, and wetlands). For each year, the areal proportion of each category in a municipality was calculated using R program (version 3.6.1), and the rate of urban sprawl (urban expansion) with respect to the previous year were also estimated.

2.1.4. Climate data

Climatic variables include the annual thermal amplitude (the range of monthly temperatures in a year), annual rainfall amplitude (the range of monthly rainfalls in a year), annual average temperature, and annual average rainfall. Both rainfall and temperature databases were obtained from weather stations monitored by the National Institute of Meteorology (INMET), as processed by Alvares et al. (2013).

2.2. Analyses

2.2.1. Generalized linear mixed model (GLMM)

Multivariate mixed models were developed for each disease incidence (VL and TL) by municipality by year as the dependent variable against aforementioned socio-economic (garbage disposal on the open area), environmental and climatic variables as independent variables. Thematic maps of these variables are presented in Supplemental Fig. 1.

First, independent variables were selected to enter in the model when the significance level of correlation with the dependent variable (*p*-value) was less than 0.2. Altitude was not considered due to its strong correlation with the annual average temperature ($\rho = -0.91$, $p<0.05$) and savannah cover ($\rho= -0.69$, $p<0.05$). Likewise, the annual average rainfall was excluded because its strong negative correlation with savannah ($\rho= -0.60$, $p<0.05$) and natural forest ($\rho= -0.63$, $p<0.05$). It is worthy of mentioning that the socio-economic variable was not considered in the analysis of TL, since the cases of TL were prevalent in rural areas (Brasil, 2017; Pedrosa and Ximenes, 2009), where the urban public garbage collection often not served. For the same reason, the percentage of urban area was also not considered for TL either, but there was considered urban expansion once the is common cases in *peri* urban regions, due to anthropic expansion invading forest and rural areas (Saude, 2007).

Second, GLMM Poisson regression analysis was performed with the logarithm of incidence of each disease as the dependent variable, environmental, social, and climatic variables as fixed effects, along with the spatial coordinates of municipals (centroids) and the year as spatio-temporal random effects. As compared to the original incidence rates, the log-transformed incidence rates better followed a normal distribution (Fig. S2), which would benefit our subsequent analysis. All the explanatory factors (variables of fixed-effects) were determined in the final model by a stepwise backward deletion test. The model, formulated as Eq. (1), was developed for both TL and VL respectively, but each has their specific independent variables, as previously explained, and was based in Dormann et al. (2007) and Guo et al. (2017). The models were implemented by the *MASS* package in R software (R Core Team, 2019), version 3.6.1, and the *glmmPQL* function.

The GLMM model can then be expressed as:

$$Log[E(Y_{it})] = a_i + \beta X_{it} + \alpha^{d_{ij}} \tag{1}$$

Where Y_{it} is the disease incidence (log transformed) in municipalities $i(=1,2,3\ldots n)$ during year t (t = 2007, 2008, …, 2020), and a_i is the random intercept for the municipality i; then pit is the probability of incidence occurrence at each municipality in t; and βX_{it} denote the fixed effects, such as environmental, social and climatic variables, in municipal i during year t. To control for residual spatial autocorrelation we comput α parameter of d_{ij}, that is the distance between centroids of grid of municipalities, i and j; t is the year variable. The spatial correlation structure assumes that the correlation decreases exponentially with increasing spatial distance.

2.2.2. Exploratory spatial data analysis (ESDA)

While GLMM test global associations between the diseases and exposures across the entire study area, ESDA informs local associations and hot/cold spots. Here, we performed univariate Moran's I analyses to identify hot and cold spots of each disease incidence, and bivariate Moran's I analyses to identify local associations between the logarithm incidence of both VL and TL in one municipality with the independent variables in surrounding municipalities. The spatial weight matrix that defined interactions among municipalities was set based on the inversed Euclidean distance between municipal centroids within a threshold of 81.05 km. This threshold distance allowed each municipality to have at least one municipality in its neighborhood. Resulting Moran's indexes were tested through 999 randomizations (empirical pseudo-significance), in order to obtain the significance of the test statistic

(Anselin, 2020). All ESDA were performed using GeoDa 1.14.0.

3. Results

3.1. Descriptive statistics

As shown in Fig. 1A, the average incidence of TL was 2.91 cases/10,000 inhabitants from 2007 to 2020. The annual incidence peaked in 2010 at 5.8 cases per 10,000 inhabitants, declined dramatically to 2.0 in 2014 and oscillated between 1.4 and 2.8 until 2020. The number of municipalities with reported cases varied from 15.4% (64; in 2019) to 23.5% (98; in 2011), with an average of 19.4%. The years 2009 to 2011 and 2014 had the most municipalities with cases (around 23%), while in recent years (from 2018 to 2020) the percentage dropped below the average.

In Fig. 1B, the incidence of VL in the state varied dramatically during the study period, with an average of 0.2 cases per 10,000 inhabitants. In the most recent years (from 2018 to 2020), the incidence declined to 0.1–0.15 cases per 10,000 inhabitants. The percentage of municipalities reporting VL cases was higher than that of TL, with an average of 37.5%. The percentage reached the lowest in 2017 (31.6%), then gradually increased in the following years and remained high in 2019 and 2020. To summarize, the incidence of both TL and VL decreased in recent years, but TL was more geographically spread than VL as more municipalities with reported cases.

The incidence of TL and VL presented distinct distribution over space and time (Fig. 2a and b) in that TL cases were clustered on the east side of the state while VL cases were more likely to occur in the central and west parts of state. The Global Moran's indexes of the correlation between both diseases were negative, as −0.190. Our univariate local Moran's I analysis on all years (Fig. 3) showed that TL cases were mainly concentrated in the central part of eastern coast, South Health Macro-Region (HMR). Different than TL, the hot spot of VL occurred in the north-central region of the state, in Northeast, North-central and Southwest (HMR). The concentration of cases are represented as Q1 (High-High) category in Figure 3, as well as the low or absent concentration of cases are represented as Q2 (Low-Low) category.

On average, 15.6% (65) of municipalities reported at least one case of both diseases in all years, and 32.4% (135) reported no cases of both diseases (Fig. 4). Although these percentages remained relatively stable over the years, there were 310 out of 417 municipalities with at least one case of both diseases and only four municipalities reporting no cases of both diseases.

3.2. Statistical and spatial analysis of tegumentary leishmaniasis (TL)

In the GLMM model, only the area of natural forest cover had significant negative association with the TL incidence (Table 1).

The global bivariate Moran's indexes showed that TL incidence had a positive spatial correlation with natural forest with Moran's I ranging from 0.369 to 0.491 in all years (Supplemental Table 1). Local bivariate Moran's analysis further indicated that municipalities in the north and central-west areas of the state presented a low-low pattern between TL incidence and natural forest coverage (dark blue in Fig. 5a). Municipalities along the lower eastern coast showed a high-high pattern (dark red in Fig. 5a). On the other hand, TL incidence exhibited a negative spatial correlation with savannah landscape, given the global Moran's indexes varying between −0.174 and −0.329 in all years (Supplemental Table 1). Municipalities in the north and central-west area of the state presented a high-low pattern between TL incidence and savannah coverage (light blue in Fig. 5-b), while those in the central-east areas showed a low-high pattern (light red in Fig. 5-b). It is important to cite that the statistical results of all randomizations for TL and VL suggested no spatial randomness of analysis.

3.3. Statistical and spatial analysis of visceral leishmaniasis (VL)

In the GLMM model, only Savanna cover had significant negative association with the VL incidence (Table 2).

The global bivariate Moran's indices showed that VL incidence had negative spatial correlations with the natural forest (−0.186 to −0.262 in all years) and the mean temperature (−0.006 to −0.39 in all years). The incidence also had positive spatial correlations with the savannah (0.1197 to 0.343 in all years) and the deforestation rate (0.154) (Supplemental Table 2). Local bivariate Moran's analysis further identified that municipalities in the central area of the state presented a low-high pattern between VL incidence and natural forest (light red in Fig. 6-a) but a high-high pattern between VL incidence and savannah coverage (dark red in Fig. 6-a). The correlation of VL incidence with savannah coverage was identified by the local Moran's analysis, with a high-high pattern in municipalities of the north and central part of the state (dark red in Fig. 6-b) and low-high pattern in the central coast (dark blue in Fig. 6-b). The deforestation in 2016 was low in areas where VL is most common, mainly in the center and north of the state (dark red in Fig. 6-c), and low in the central and south coast, which was also the area with few or zero cases (dark blue in Fig. 6-c). The VL incidence and the correlation with mean temperature presented a local Moran's analysis with high-low pattern in the municipalities in the center of the state (light red in Fig. 6-d), and low-high in the central and northern coast (light blue in Fig. 6-d).

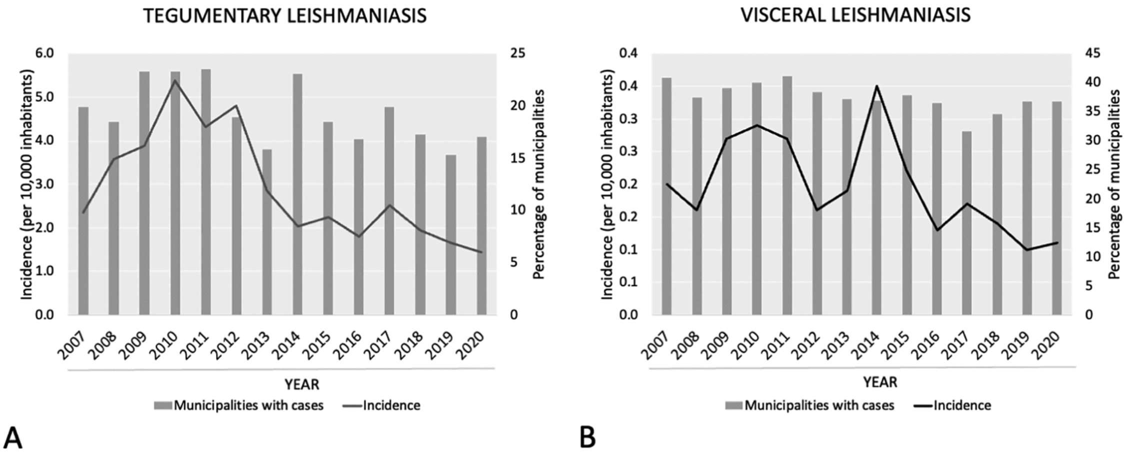
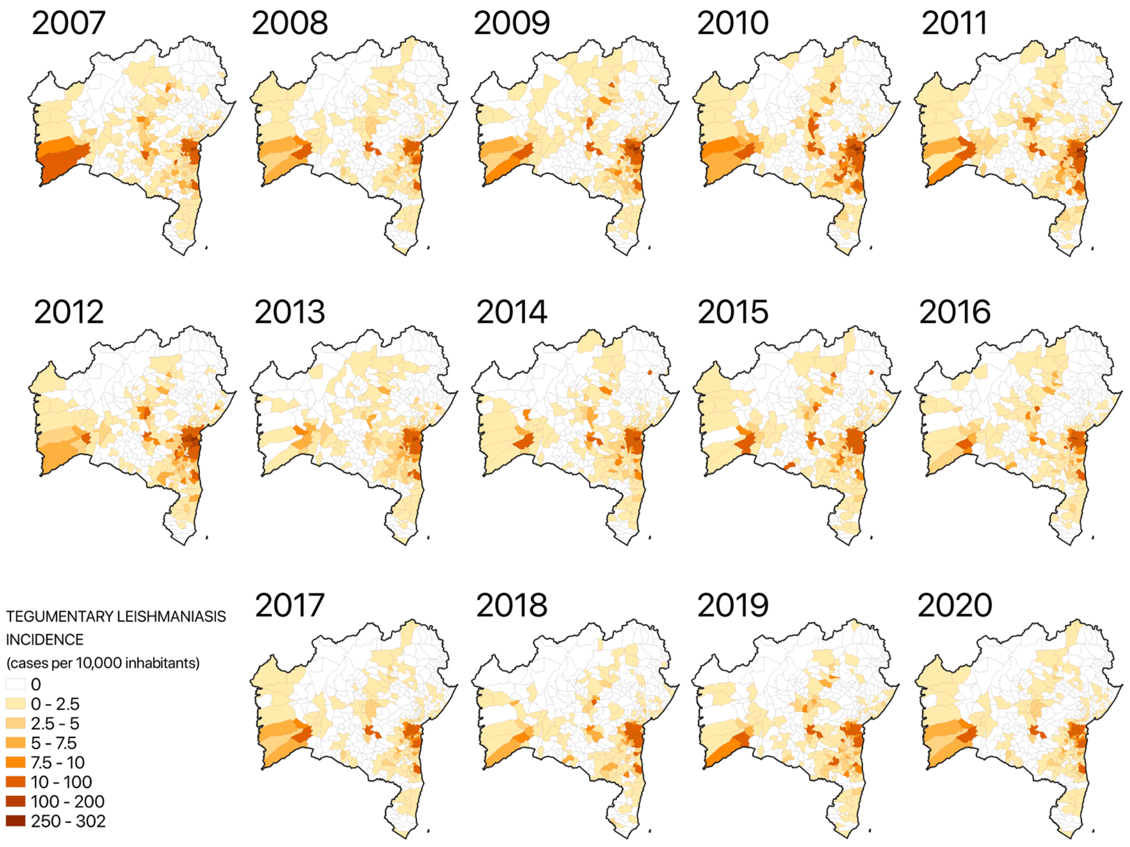


Fig. 1. Incidence of tegumentary leishmaniasis (A) and visceral leishmaniasis (B) and percentage of municipalities in Bahia with at least one case, in the years between 2007 and 2020.



(a)

Fig. 2. Incidence of tegumentary leishmaniasis (A) and visceral leishmaniasis (B) per municipality in Bahia in the years from 2007 to 2020.

4. Discussion

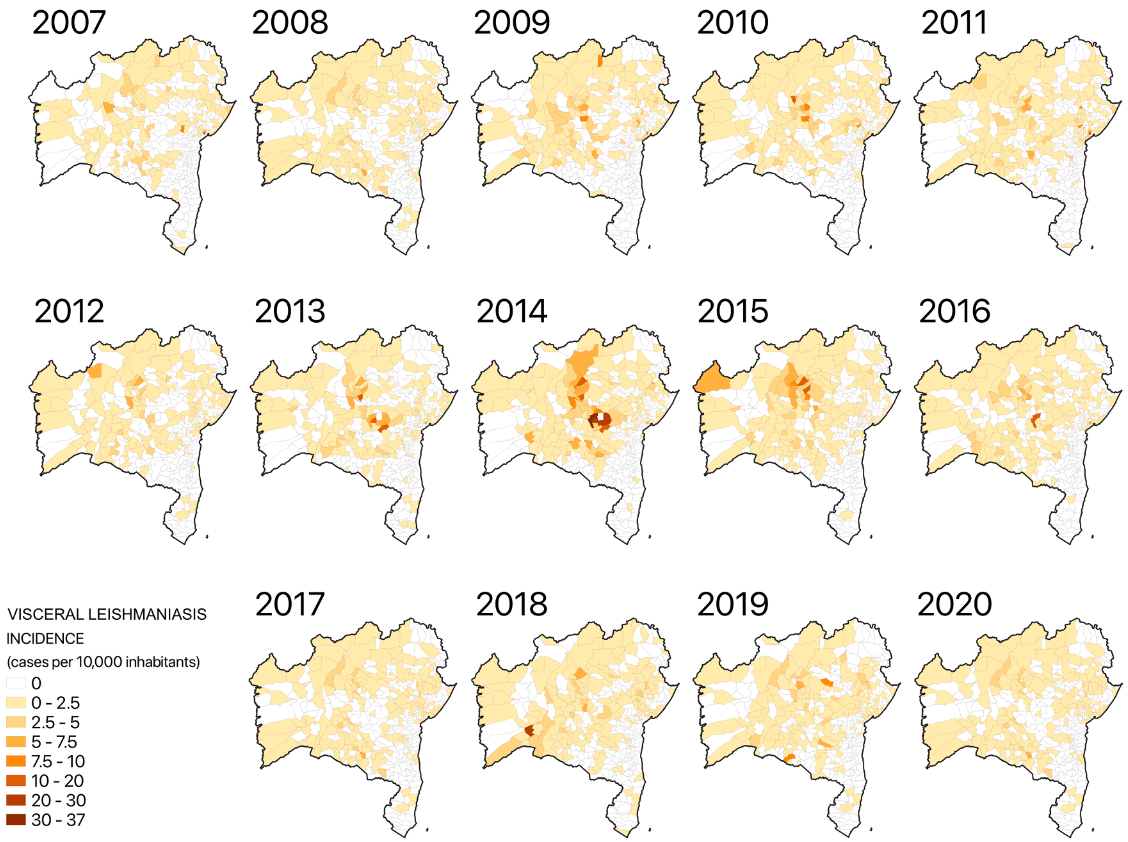
Between 2007 and 2020 in the state of Bahia, the incidence of TL was higher than VL, but the number of municipalities with VL cases was almost twice that of TL cases. Although the incidence of both diseases had decreased over years, the number of municipalities reporting TL had declined while those reporting VL remained relatively constant. Geographically, the northeast and southeast of the state were cold spots for both diseases. The south and north central regions were found to be hot-spot for TL and VL respectively, which should be prioritized for disease control actions (Melo et al., 2023).

Leishmaniases are diseases with complex dynamics, modulated by ecological factors related to vectors, parasites and hosts, all of which interact in a landscape affected by socioeconomic variables (Galvis-Ovallos et al., 2020). We evaluated the correlation of landscape and climatic variables with the incidence of TL and VL and found distinct spatial patterns of associations between the two diseases. Climate conditions are generally important determinants for vector-borne diseases (Cardenas et al., 2006). Sandflies need warm temperatures and sustained precipitation to maintain favorable humidity conditions in breeding sites (Desjeux, 2001; Forattini, 1971). Temperature also plays an important role in the immature stage duration of sandflies (Endris et al., 1984). Furthermore, temperature influences the duration of the gonotrophic cycle and the parasite's extrinsic period (Ovallos et al., 2013). Most studies have not considered the association of vectors with thermal amplitude; instead they only referred to high or low temperature, and reported that high temperatures were not favorable for TL occurrence (Barata et al., 2013; Karagiannis-Voules et al., 2013; Valderrama-Ardila et al., 2010).

Although favorable humidity conditions of breeding sites are necessary for VL vectors (Desjeux, 2001; Forattini, 1971), the VL cases occurred in hot and dry areas of the Northeast region of Brazil (Andrade-Filho et al., 2017; Machado et al., 2020). In the present study, the correlation of VL with mean temperature was significant in bivariate Moran's I analysis. The mean temperature in Bahia varied from 19.6 °C to 26.4 °C, suggesting that temperatures of 26.4 °C or higher is not suitable for vectors in the state. In São Paulo state, located in the Southeast region of Brazil, higher temperatures (annual average between 19 °C and 23 °C) facilitated the spread of VL vectors (Sevá et al., 2017). Other studies have observed the correlation of VL cases or vector presence with high temperature, but they have not specified the degrees (Costa et al., 2013; Michalsky et al., 2009).

Although annual average rainfall was not significantly correlated with TL incidence, it varied from 41 mm to 296 mm, and this range affected the sandfly species carrying the parasite of TL. *Nyssomyia whitmani*, the main vector of *Le. Braziliensis*, had high densities in the dry season (Machado et al., 2017; Pereira et al., 2020), but with high humidity (Machado et al., 2017). However, these studies did not evaluate the amplitude range as we did.

The forest area had a local positive association with TL incidence in the Atlantic Forest fragment in the south and costal region of Bahia and was significant in spatial and spatio-temporal models. The vector *N. whitmani* was found in different dense forest environments, like that in Bahia, by Da Costa et al. (2018a). Other studies have shown that sandflies involved in the transmission of TL agents are closely related to preserved forest fragments surrounding rural and periurban areas (Lainson and Rangel, 2005; Nasser et al., 2009; Pedrosa and Ximenes, 2009), or residual and riparian Atlantic Forest areas remaining after



(b)

Fig. 2. (*continued*).

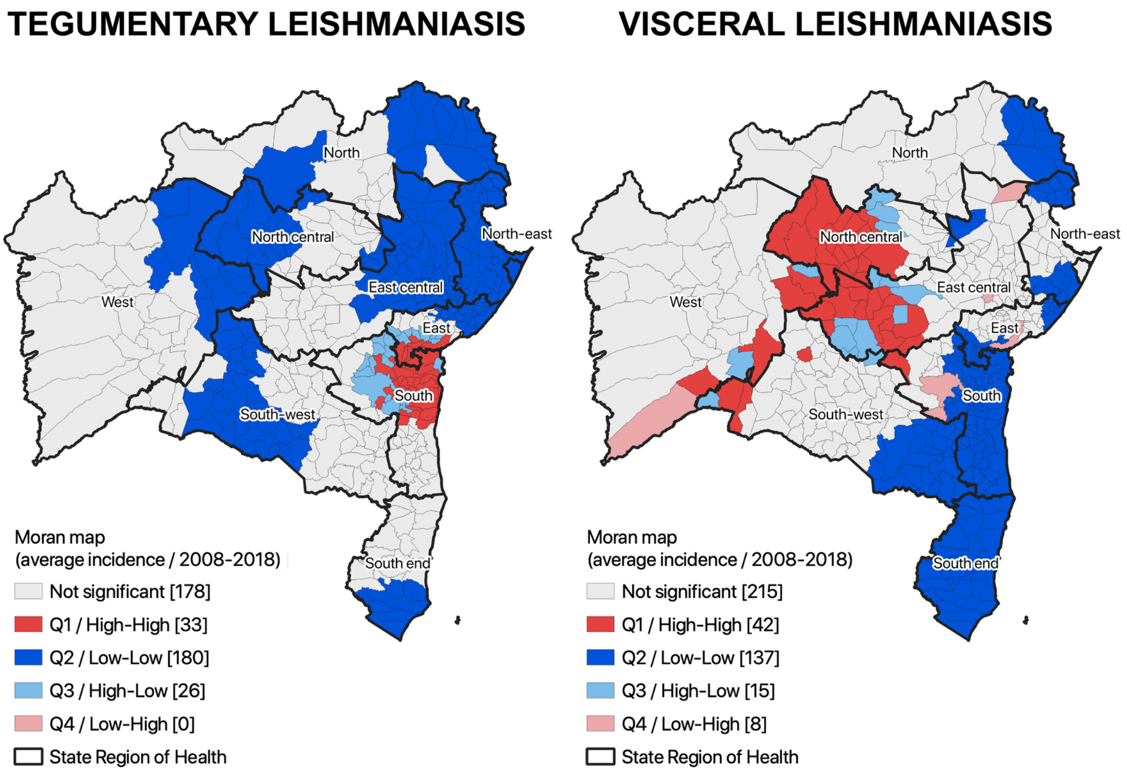


Fig. 3. Local Moran's indices of tegumentary and visceral leishmaniasis.

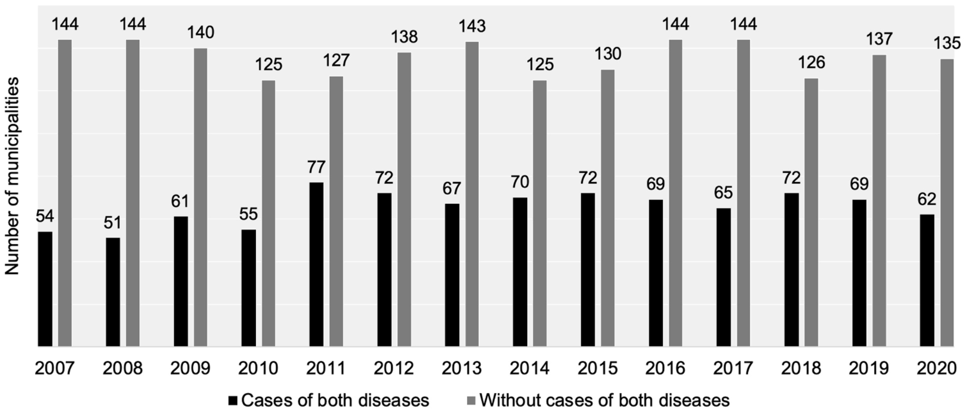


Fig. 4. Number of municipalities with cases of both diseases and with no cases of both diseases.

Table 1
Results of GLMM to test the effects of variables on TL incidence in 2007–2020 in Bahia, Brazil.

Variable	Value	Standard error	t-value	p-value	Incidence Ratio
(Intercept)	−2.357	0.188	−12.49	**<0.001**	0.09
Natural forest	0.043	0.003	13.87	**<0.001**	1.04
Savannah	0.002	0.002	0.798	0.424	1.00
Coffee plantation	−0.067	0.101	−0.668	0.504	0.93
Range of rainfall	0.001	0.001	0.521	0.602	1.00

Legend. Conditional R-squared: 0.698; p-values in bold indicate statistical significance.

deforestation (Nasser et al., 2009; De Oliveira et al., 2016), a common process in Brazil. Deforestation can generate relevant environmental impacts that favor the establishment of outbreaks and endemic areas for TL (Da Costa et al., 2018a). These areas of forests offer a microclimate that also features humid conditions and potential wildlife reservoirs (Ribeiro et al., 2011) that are suitable for sandfly species. Wild and synanthropic animals are frequently related to the TL cycle in Brazil, with prevalence reaching to 23.5% (Brandão-Filho et al., 2003; Cardoso et al., 2015; Marcelino et al., 2011). It is noteworthy that some species, such as *Ny. whitmani,* have increased their range of climatic suitability for potential expansion of TL (Da Costa et al., 2018b). In this circumstance, anthropized areas adjacent to forests should be given priority for surveillance to detect TL foci, such as peri-urban or rural settlements and farms.

For VL, the natural forest presented a negative association. Vector species of VL agents, such as *Lu. longipalpis*, do not need dense vegetation to survive (Salomón et al., 2015) and can be found in specific hot spots where environmental conditions are unfavorable to other species (Galvis-Ovallos et al., 2018). In contrast, other wild sandfly species that are also VL vectors, but with lower frequency, occur mainly in secondary forests and are able to maintain transmission cycles, such as *Migonemyia migonei* (Carvalho et al., 2010) and *Pintomyia fischeri* (Galvis-Ovallos et al., 2020). However, this transmission pattern was found to occur in a

Table 2
Results of GLMM of to test the effects of variables on VL incidence in 2007–2020 in Bahia, Brazil.

Variable	Value	Sttandard error	t-value	p-value	Incidence Ratio
(Intercept)	−2.459	0.088	−28.02	**<0.001**	0.09
Savannah	0.022	0.002	11.16	**<0.001**	1.02
Urban area	0.016	0.016	0.994	0.3205	1.02

Conditional R-squared: 0.494; p-values in bold indicate statistical significance.

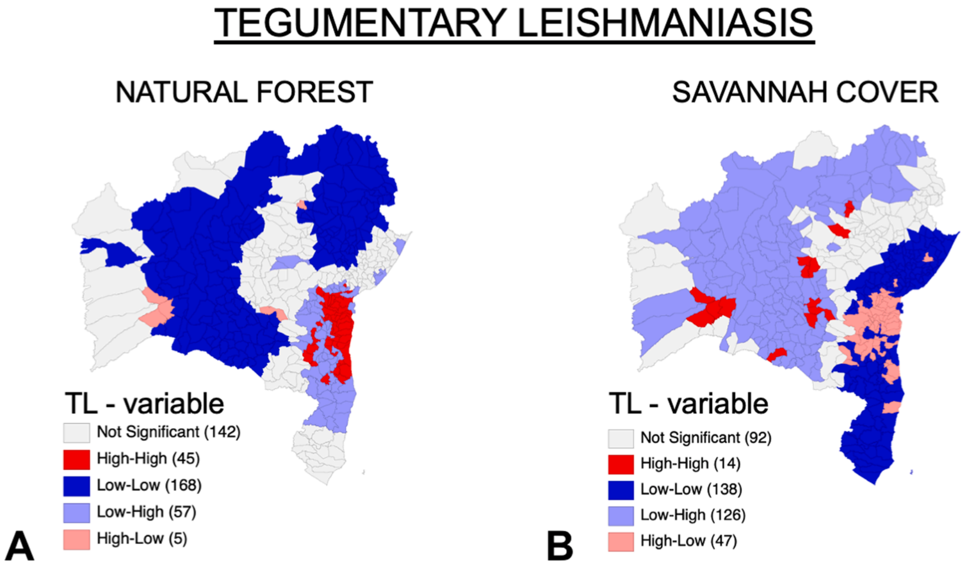


Fig. 5. Local spatial correlation of TL incidence against natural forest (a) and savannah cover (b). The legend represents different categories of spatial patterns and the number in parentheses indicates how many municipalities are in that category.

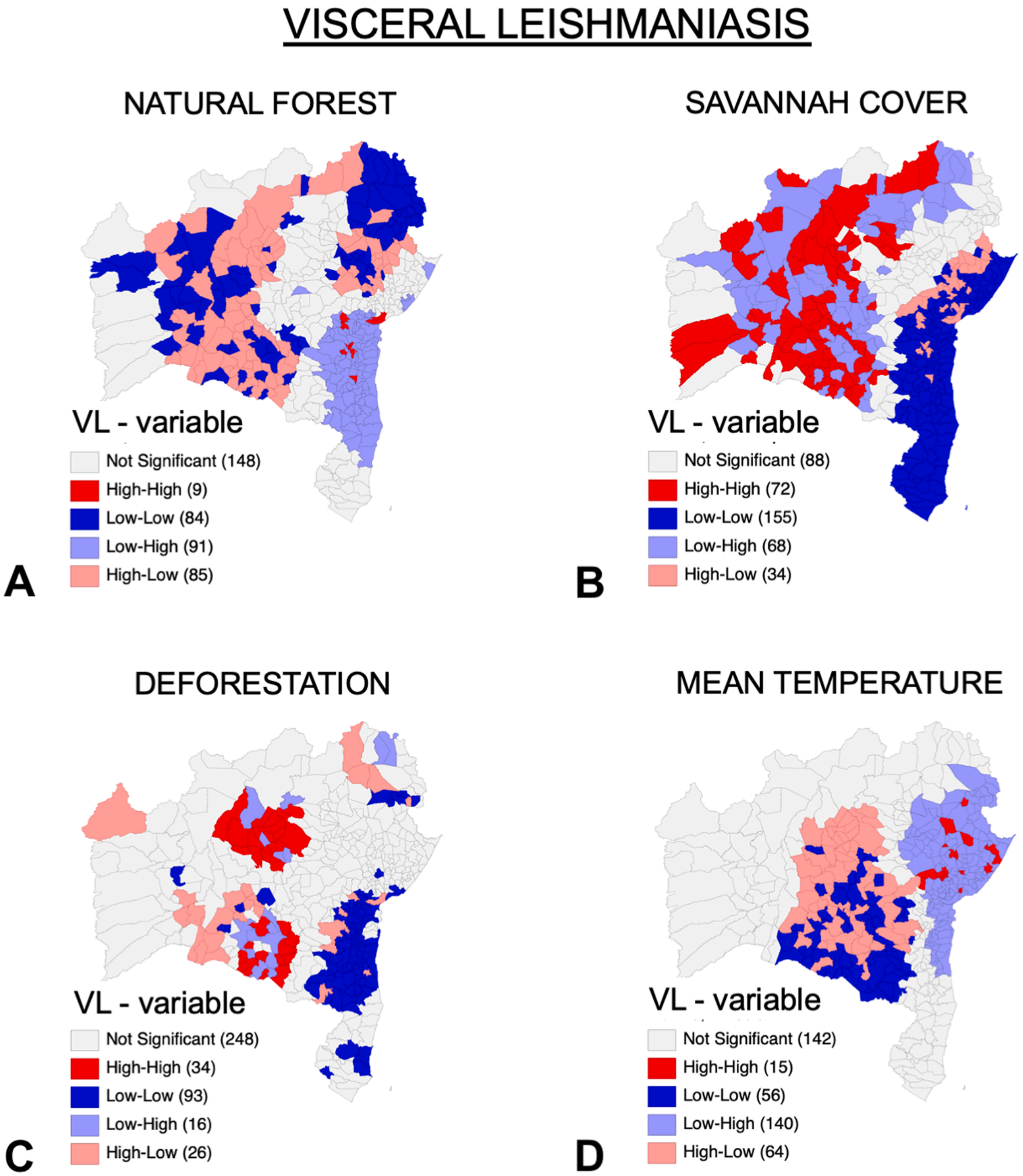


Fig. 6. Local spatial correlation of VL incidence against natural forest (a), savannah cover (b), deforestation (c) and mean temperature (d). The legend represents different categories of spatial patterns and the number in parentheses indicates how many municipalities are in that category.

state far from Bahia. In the same way, the VL cases were positively correlated with savannah cover in specific regions of the state (in the Moran's I analysis), which is related to the areas favorable to the distribution of *Lu. longipalpis*. For instance, in a municipality surrounded by Cerrado (savannah) vegetation, high incidence rates were found in peripheral neighborhoods close to this land use type (Machado et al., 2017; Werneck and Maguire, 2002).

The incidence of neither disease was associated with urban areas. The presence of VL cases has been increasing in recent years (Conti et al., 2016; Harhay et al., 2011; Salomón et al., 2004), and currently the disease is considered as an urban disease spread by the main vector species, *Lu. longipalpis*, which has become well adapted to urban environments (Casanova et al., 2015; Pereira et al., 2020; Salomón et al., 2015). Therefore, more frequent VL cases in urban areas did not necessarily mean that there are in all municipalities of the state with higher extension of urban area. Our results can be justified because the risk factors must also be considered at a micro scale, with possible heterogeneity in the transmission within the same municipality (Galvis-Ovallos et al., 2017a), such as hot and cold spots (Reisen, 2010) that are not identified in analysis of aggregate data (e.g., for a whole municipality, as we considered). In addition, the fact that the vectors are adapted to urban areas does not necessarily mean that a greater proportion of urban area in a municipality will be associated with higher disease incidence. The disease incidence also depends on other characteristics of the area, such as presence of trees, micro-climate conditions, garbage disposal and population density.

TL is broadly distributed in Brazil, showing focal particularities on it transmission cycle because the presence of diverse parasites (Cupolillo et al., 2003) vector and host species (Roque et al., 2014). In Bahia, transmission cycles of TL have been related to the presence of L.

amazonensis and L. *Braziliensis* in some regions of the state (Brasil, 2017), however the high number of cases are caused by L. *Braziliensis,* including in the area where we found the cluster of cases (Schriefer et al., 2004). It is noteworthy that our focus is on investigating the relationship between the occurrence of cases of TL and its explanatory variables, and thus we did not consider the focal differences in the transmission cycles. On the other hand, the only one cluster of TL cases that we found could be related to either L. *brasiliensis* or both of parasite species.

The present study investigated leishmaniasis across municipalities rather than a within-municipality scale. For example, the occurrence of vectors and disease cases might be related to specific conditions, such as inside a forest with different hosts or in peri-domicile areas and sites with organic material from fruit trees (i.e., varying geographically within the municipality). This indicates the need to associate general and local characteristics in each place to design prevention and control measures accordingly.

Based on environmental factors related to the VL and TL cases, it was possible to identify those strongly associated to vector sensitivity. Since data regarding vector abundance and richness are rare for all municipalities of the state in the period studied, a need exists for more data to better understand dynamics of diseases in specific spaces. This will require better surveillance of vectors by the public health authorities to provide open and easily available data to health agents and researchers.

In this study, we identified distinct contributing factors of TL and VL outbreaks along with their respective high-risk areas in the state, based on which we proposed different measures for prevention, control, health assistance and epidemiological surveillance for each disease. For instance, TL incidence was related to natural forest, such as the dense Atlantic Rainfall Forest, implying that the anthroponotic contact with this environment could be risk, while more attention should be paid to health education of population, high surveillance and entomological monitoring. For VL, its preferential areas had different environments than TL, and required better technical capacitation of health professionals, such as fast diagnostic and treatment and adequate reporting, in the target regions. Increases the surveillance of domestic dogs in these regions could be another alternative to prevent human cases, once this host is considered main urban reservoir of VL parasite in endemic areas (Baneth et al., 2008; Brasil, 2014), and infected dogs are identified before the human cases in municipalities that never had cases (Sevá et al., 2017; Werneck et al., 2007).

5. Conclusions

In conclusion, the incidence of TL and VL in humans presented different patterns of spatial dispersion, which were influenced by environmental, climatic, and socioeconomic factors in different ways. Few municipalities in Bahia presented both diseases. TL was positively related to natural forest, but negatively related to savannah cover in the local spatial analysis. On the other hand, VL was positively related to savannah cover in local spatial analysis. The TL incidence increased while VL incidence declined in the period studied. The number of municipalities with reported cases of TL decreased slowly over years, while those with VL remained stable. We identified areas with predominance of TL and VL cases and the factors that influence their incidence, identifying risk areas that could be prioritized for epidemiological surveillance and prevention campaigns.

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Declaration of Competing Interest

The authors declare that they have no known competing personal relationships or financial interests that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sste.2023.100615.

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