UNIVERSIDADE DE BRASÍLIA
INSTITUTO DE GEOCIÊNCIAS
CURSO DE ESPECIALIZAÇÃO EM GEOPROCESSAMENTO AMBIENTAL

MODELAGEM DE ÁREAS SUSCETÍVEIS À TRANSMISSÃO E A DINÂMICA DA LEISHMANIOSE VISCERAL NO DISTRITO FEDERAL, BRASIL

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Monografia de especialização em Geoprocessamento Ambiental apresentada à banca examinadora do Instituto de Geociências como exigência para a obtenção do título de especialista em Geoprocessamento

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RESUMO

Introdução: A leishmaniose visceral (LV) é uma zoonose parasitária negligenciada que está se espalhando rapidamente em áreas urbanas, principalmente devido a fatores socioambientais. O objetivo deste estudo foi identificar áreas com risco de transmissão da doença no Distrito Federal, caracterizando também as condições ambientais e socioeconômicas adequadas às ocorrências.

Métodos: Um banco de dados com 1641 casos mistos da doença de humanos e canídeos, assim como dados de amostragens dos vetores, foi coletado de 2014 a 2017. Mapas temáticos do modelo de distribuição espaço-temporal foram produzidos usando a abordagem de modelagem de nicho ecológico Maxent. O modelo utilizou 24 variáveis ambientais e duas socioeconômicas, um dado epidemiológico (razão de proporção de incidência) e um índice de vulnerabilidade socioeconômica, confeccionado para essa análise.

Resultados: Nossa estimativa sugere que 53% da população do Distrito Federal reside em áreas com alta suscetibilidade de transmissão da LV. De acordo com o mapa de risco de transmissão da doença, as áreas mais suscetíveis são: Fercal, Lago Norte, Lago Sul, Jardim Botânico, Sobradinho I, Sobradinho II, e Taguatinga. Curiosamente, as três variáveis que mais influenciaram do modelo foram a densidade populacional humana (41,9%), uso e ocupação da terra (25,2%), e o índice de proporção de incidência (VLIP, 11,7%).

Conclusão: A identificação de áreas suscetíveis à transmissão de doenças, por meio da modelagem da distribuição potencial, é crucial para o entendimento da dinâmica da LV e na orientação para a implementação de estratégias efetivas de vigilância e controle.

Palavras-chave: MODELAGEM DE NICHO ECOLÓGICO, EPIDEMIOLOGIA, GEOPROCESSAMENTO EM SAÚDE, MAXENT, DOENÇAS TRANSMITIDAS POR VETORES, AVALIAÇÃO DE RISCO A SAÚDE.

ABSTRACT

Background: Visceral leishmaniasis (VL) is a neglected parasitic zoonosis which is spreading fast in urban areas owing to socio-environmental factors. The aim of this study was to identify areas with disease-transmission risk of VL infection in the Brazilian Federal District, also characterizing the environmental and socio-economic conditions suitable for the occurrences.

Methods: A database of 1641 mixed VL cases from humans and canids, also the vectors samples, were collected from 2014 to 2017. Thematic maps on the spatiotemporal distribution model were produced using the Maxent ecological niche modeling approach. The model used 24 environmental and two socio-economic variables, an incidence proportion ratio, and a socioeconomic vulnerability index.

Results: Our estimate suggests that 53% of the Brazilian Federal District population is currently living at high susceptibility to VL transmission areas. According to the disease-transmission risk map, the riskiest are Fercal, Lago Norte, Lago Sul, Jardim Botânico, Sobradinho I, Sobradinho II and Taguatinga. Interestingly, the three most influencing model variables were human population density (41.5%), land use (25.6%), and visceral leishmaniasis incidence proportion (VLIP, 11.7%).

Conclusion: Modeling the disease distribution to identify susceptible transmission areas is crucial to understand the VL dynamics, and guide the implementation of effective surveillance and control strategies.

Keywords: ECOLOGICAL NICHE MODELING, EPIDEMIOLOGY, GEOPROCESSING IN HEALTH, MAXENT, VECTOR-BORNE DISEASE, HEALTH RISK ASSESSMENT

SUMÁRIO

CAPÍTULO 1: CONTEXTUALIZAÇÃO

Introdução

As leishmanioses estão entre as mais importantes endemias mundiais, com registro em mais de 65 países, os quais reportam anualmente mais de 400.000 casos, sendo 90% deles de origem latino americana (WHO, 2018). Causa uma infecção sistêmica podendo levar ao óbito em 90% dos casos se não tratada (WHO, 2018). Os agentes etiológicos são protozoários flagelados de ciclo heteroxênico do gênero Leishmania Ross 1903, para o Brasil é a espécie *Leishmania* (*L.*) *infantum* (*syn. chagasi*) (Nicolle, 1908) (Ministério da Saúde, 2014). A Leishmaniose visceral se apresenta como uma típica doença tropical negligenciada por parte dos governos e indústrias farmacêuticas, (WHO, 2018). Suas principais sintomatologias são febre de longa duração, aumento do fígado e baço, perda de peso, fraqueza, redução da força muscular, anemia e outras manifestações (Ministério da Saúde, 2014; 2017).

No Brasil as leishmanioses são principalmente transmitidas pela picada de flebotomíneos fêmeas infectados do gênero *Lutzomya* (WHO, 2018), os quais são conhecidos popularmente como mosquito palha, tatuquira, birigui, entre outros. As principais espécies de flebotomíneos envolvidas na transmissão da Leishmaniose são *Lutzomyia longipalpis* e *Lutzomyia cruzi* (Marques, 2017; WHO, 2018). Para a proliferação do vetor é necessário uma junção de fatores ambientais como a temperatura, vegetação e umidade, podendo ser encontrados em áreas rurais, urbanas e periurbanas (Andrade et al., 2014).

Inicialmente classificada como uma endemia rural, as leishmanioses adentraram as cidades brasileiras principalmente em decorrência das elevadas taxas de urbanização, marginalização e ocupação desordenada das cidades, associadas a aspectos sócio-culturais e a degradação ambiental, o que tornou os centros urbanos um excelente local para a propagação dessas doenças (Werneck, 2008). No Distrito Federal a doença vem se espalhando ao longo dos anos principalmente na população canina, mas também em humanos. Em 2017, o Brasil registrou 4.511 casos de leishmaniose visceral, dos quais 21 casos referem-se a registros de residentes do Distrito Federal (SINAN, 2018).

O controle de vetores é a melhor ferramenta para proteger a população de doenças que não possuem vacina (WHO, 2018). Partindo dessa premissa, as modelagens preditivas de distribuição de doenças e o geoprocessamento se tornam importantes instrumentos de auxílio para os gestores (Werneck, 2002). Essas modelagens fundamentam-se inicialmente no estabelecimento de um modelo multivariado que indica a probabilidade da ocorrência da espécie, os quais incorporam os conceitos de nicho ecológico fundamental e realizado (Marco Jr. e Siqueira, 2009; Giannini et al., 2012). Já o geoprocessamento pode permitir a exibição transversal do problema, assim como a pesquisa em múltiplos bancos de dados, determinando relações causais e gerando conclusões que facilitam as tomadas de decisão (Mott et al., 1995).

Hipótese e Justificativa

Anualmente, a leishmaniose visceral gera um alto impacto social e econômico. Para o aprimoramento das ações de prevenção, controle e erradicação no Distrito Federal faz-se necessário determinar as distribuições espaço-temporais dos casos e dos vetores. Considerando o custo-benefício, a abrangência, e a eficácia em relacionar diferentes tipos de informação, o geoprocessamento à serviço da saúde se coloca como uma excelente ferramenta de auxílio nas tomadas de decisão pelos gestores da saúde.

Nesse contexto, a hipótese adotada é de que a distribuição potencial dos vetores pode ser modelada por meio de análises geoestatísticas dos parâmetros socioeconômicos e ambientais locais, buscando a determinação de áreas sem o registro da doença, mas com risco potencial de proliferação.

Objetivo Geral

Modelar a distribuição potencial da leishmaniose visceral e identificar áreas com risco de transmissão da doença no Distrito Federal, Brasil, no período de 2014 a 2017.

Objetivos Específicos

1. Georreferenciar os casos registrados para o Distrito Federal;

2. Modelar a distribuição preditiva e a dinâmica da leishmaniose visceral no Distrito Federal;
3. Analisar a influência dos aspectos socioeconômicos e ambientais na distribuição da doença, como: vulnerabilidade socioeconômica, densidade urbana, renda, fatores climáticos, Modelo Digital de Terreno e ocupação do solo;
4. Definir áreas de risco e vulnerabilidade.

Estrutura da Monografia

A monografia compreende dois capítulos. Esse primeiro capítulo tratou de uma contextualização sobre o tema, apresentando as justificativas e objetivos do estudo, assim como a estruturação desse manuscrito. O segundo traz as metodologias utilizadas, as análises realizadas, os resultados obtidos e uma discussão geral sobre o tema, em formato de artigo científico, o qual seguiu o modelo proposto pela revista "Transactions of the Royal Society of Tropical Medicine and Hygiene" (Online ISSN 1878-3503/Print ISSN 0035-9203).

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CAPÍTULO 2: ARTIGO CIENTÍFICO

Title page

Modeling the transmission susceptible areas and visceral leishmaniasis dynamics in the Federal District, Brazil

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Abstract

Background: Visceral leishmaniasis (VL) is a neglected parasitic zoonosis which is spreading fast in urban areas owing to socio-environmental factors. The aim of this study was to identify areas with disease-transmission risk of VL infection in the Brazilian Federal District, also characterizing the environmental and socio-economic conditions suitable for the occurrences.

Methods: A database of 1641 mixed VL cases from humans and canids, also the vectors samples, were collected from 2014 to 2017. Thematic maps on the spatiotemporal distribution model were produced using the Maxent ecological niche modeling approach. The model used 24 environmental and two socio-economic variables, an incidence proportion ratio, and a socioeconomic vulnerability index.

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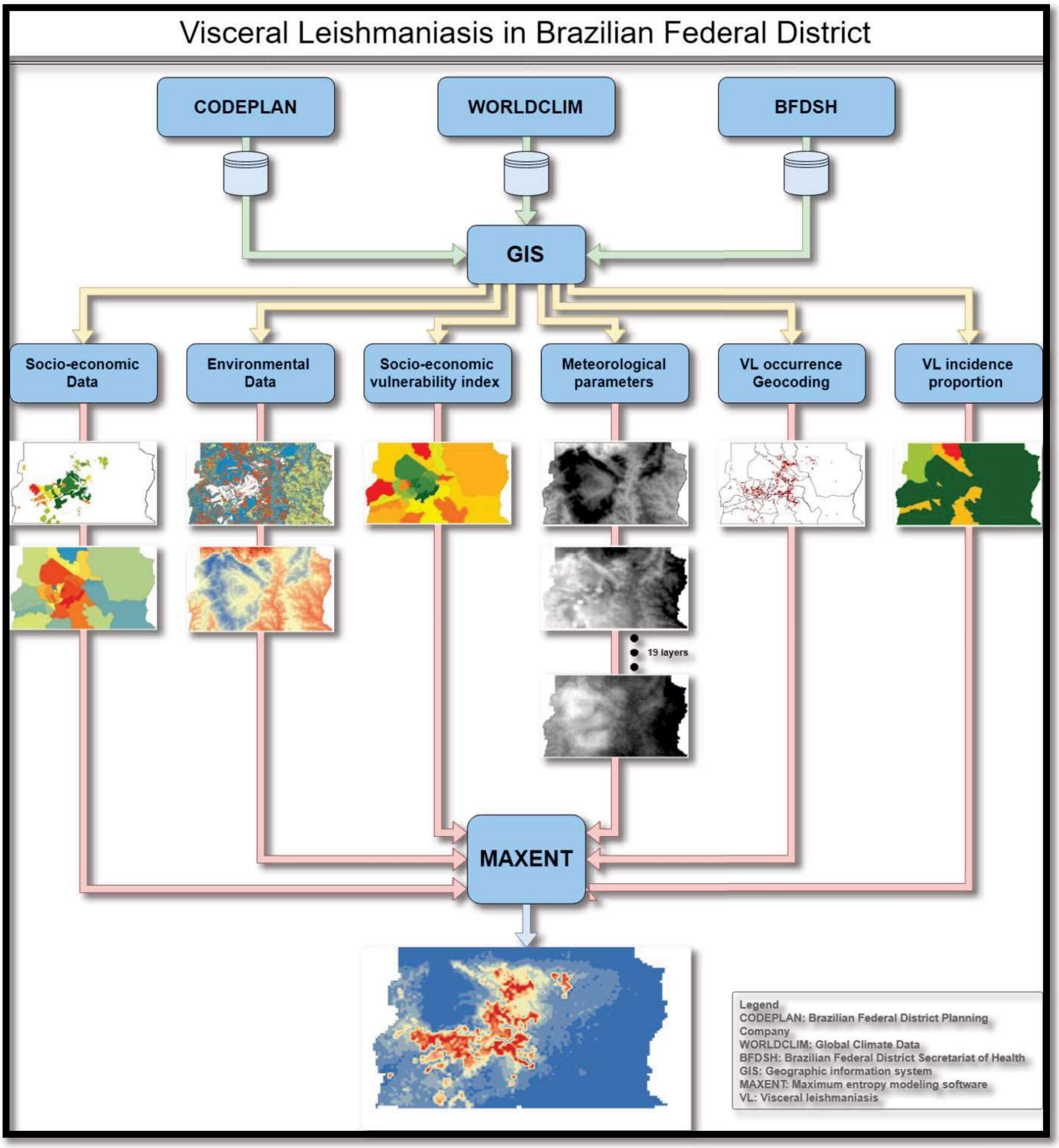
Graphical Abstract



Introduction

Visceral Leishmaniasis (VL) is among the most important endemic diseases in the world, which if untreated lead to a chronic systemic involvement resulting in death in over 90% of cases [1]. Neglected by governments and the pharmaceutical industry, this typically tropical widespread vector-borne disease is recognized as a parasitic zoonosis, having different species of *Leishmania* genus as the etiological agent, to Latin America, it is *Leishmania* (*L.*) *infantum* (*syn. chagasi*) Nicolle, 1908 [2].

In Brazil, the transmission to humans occurs by the bite of infected female sandfly vectors of the genus *Lutzomyia*, mostly by the species *Lutzomyia longipalpis* Lutz & Neiva, 1912, in enzootic areas with dogs (*Canis familiaris*) being an important source of infection [3].

Originally classified as a rural endemic disease, it has been spreading fast in the urban areas, being reported in 21 Brazilian states and affecting manly low-income populations [1]. The urbanization of VL results from a combination of deforestation, climatic factors, environmental alteration, high rates of disordered urbanization and poor sanitation [4, 5, 6]. In the Brazilian Federal District (BFD), the disease has been spreading over the years mostly in the canids population, but also in humans that recorded more than 20 cases in 2017 [7].

Understanding the presence, biology and ecology of all organisms involved in the chain of infection, also the influence of each socio-environmental feature may contribute to identifying priority areas of susceptibility and to promote actions to mitigate the effects of the disease burden by health managers [8].

Considering vector-borne diseases, some approaches represent an effective spreading evaluation, for example, monitoring the local environment and predicting the spatial dynamics of vectors [9, 10]. In this context, studies have reported the importance of ecological niche modeling in the geographical spread prediction for vector-borne diseases, also the significance of Maxent as a powerful tool for these analyses [11, 12]. The software uses the principle of maximum entropy and presence-only data associated with predicting variables to generate suitability risk maps, which result in a prediction of current or future distributions of a species [13].

In this study, we used Maxent modeling approach to identify areas with disease-transmission risk of VL in the BFD, using a multi-temporal spatial pattern of the organisms involved in the disease cycle, also characterizing the environmental and socio-economic conditions suitable for the occurrences.

Materials and methods

Study design

We conducted a cross-sectional analysis. The study was performed in three stages: i) data collection; ii) processing data; and iii) modeling analyses (Figure 1).

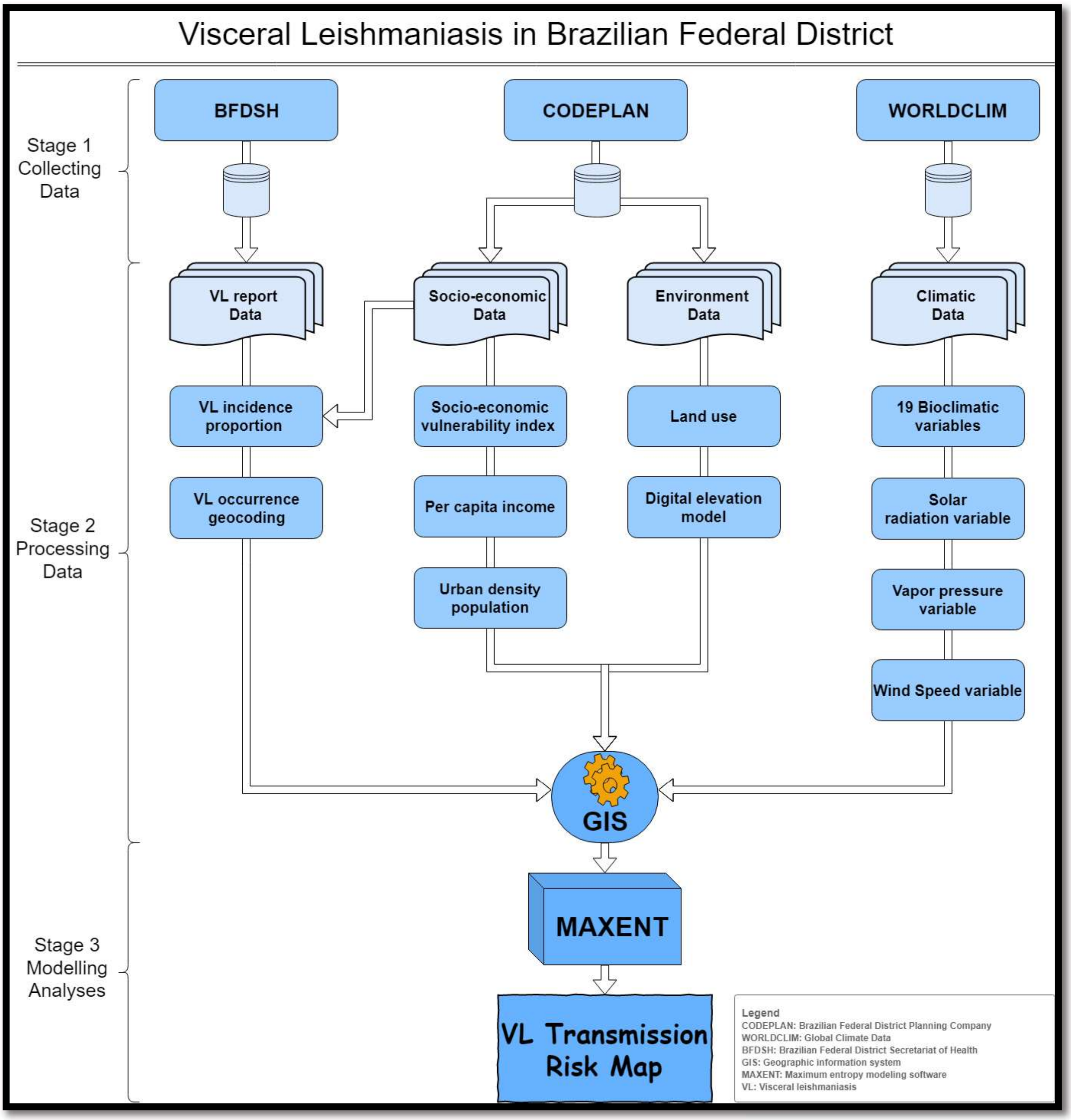


Figure 1. Flowchart of the activity. Source: The authors, 2019.

Study area

The BFD has a total area of 5,789.16 km², which is comprised of 31 administrative regions, with a total population of approximately 3 million inhabitants [14]. The BFD is totally inserted in the domain of the Cerrado biome. According to Köppen climate classification systems, the predominant climate for the studied area fits between "Aw" (tropical savanna climate) and “Cwb” (subtropical highland climate) with precipitations around 1,600 mm annually and concentration of rainfall in the summer [15]. The BFD has had a very rapid process of urban expansion since the foundation of the capital Brasília.

Initially the area of BFD was designated to hold the Brazilian capital city and rural areas, however the development brought a disordered urbanization. Nowadays, BFD has three main distinct realities, the rural environs, areas based on the original project of Brasília, and the satellite cities. Brasília is an icon of the modernist architecture associated to guidelines of the Athens Charter, where the project aimed to keep the relationship between built spaces and open spaces, respecting the daily living and maintain the bucolic environment [16]. On the other hand, the satellite cities expanded fast and disorderedly, illustrating the same urbanization pattern as other Brazilians cities. Brasília and each satellite city represent one of the 31 BFD administrative regions.

Occurrence data

We used a multi-temporal dataset of 1642 records, which were based on the combination of vector surveys, and infection reports in humans and dogs (*Canis familiaris*). All occurrence data carry out from 2014 to 2017, and were provided by different departments of the Brazilian Federal District Secretariat of Health. Reports on human VL infection were obtained from the Notifiable Diseases Information System (SINAN), which is overseen by the Epidemiological Surveillance Department (DIVEP). Information on seropositive reservoir hosts (*Canis familiaris*) and vectors survey (*Lu. longipalpis*) were acquired from the Department of Environmental Surveillance in Health (DIVAL).

The vectors survey and canine diagnosis followed the Brazilian Ministry of Health protocol [1] except the sandflies samples were performed using exclusively the CDC light trap, and the captured sandflies were taken to the DIVAL entomology central laboratory for submission to the identification process. The reservoir hosts diagnosis were performed in dogs, using the Dual Path Platform (DPP) rapid test for the first animal triage, if reagent the animals had the serum analyzed by means of the ELISA (Enzyme-Linked Immunosorbent Assay). If both tests were reactive, the animals were considered seroreactive.

The occurrence records were geocoded using the batchgeo engine (available at https://batchgeo.com) to convert addresses into geographic coordinates.

Model variables

We selected an assembly of 28 variable layers (Table 1) to determine the potential distribution of VL, of which 24 environmental variables, two socio-economic variables, one constructed socio-economic vulnerability index and another built epidemiological index. For each model variables a standardized maps were built with the spatial resolution of approximately 1 km^2 and converted to ASCII raster format through software ESRI® ArcMap 10.6.1 for the following analysis in Maxent model.

The data came from two different sources. Meteorological parameters were downloaded from WorldClim - Global Climate Data, website (http://www.worldclim.org), and the Brazilian Federal District environmental and socio-economic data were provided by Brazilian Federal District Planning Company (CODEPLAN) available online (http://www.codeplan.df.gov.br).

Environmental variables

The environmental data included 22 climatic parameters, and two variables derived from remotely sensed data.

Meteorological variables: We retrieved 19 bioclimatic variables representing annual trends, seasonality, also three climatic variables related to the vectors behavior and dispersion (solar radiation, wind speed, and water vapor pressure), all obtained in a 30 arc second spatial resolution.

Digital Elevation Model (DEM): DEM has been created from the Global Shuttle Radar Topographic Mission (SRTM).

Land use: A land use map was derived from remotely sensed classification. The namely categories used were, agropastoral, grassland, forest formation, savanna formation, others, irrigation center pivot, reforestation area, water and built area.

Table 1. Utilized model variables by type and their source.

Model variables	Variables type	Variables source
Annual Mean Temperature	*Climatic*	*WorldClim*
Mean Diurnal Range	*Climatic*	*WorldClim*
Isothermality	*Climatic*	*WorldClim*
Temperature Seasonality	*Climatic*	*WorldClim*
Max Temperature of Warmest Month	*Climatic*	*WorldClim*
Min Temperature of Coldest Month	*Climatic*	*WorldClim*
Temperature Annual Range	*Climatic*	*WorldClim*
Mean Temperature of Wettest Quarter	*Climatic*	*WorldClim*
Mean Temperature of Driest Quarter	*Climatic*	*WorldClim*
Mean Temperature of Warmest Quarter	*Climatic*	*WorldClim*
Mean Temperature of Coldest Quarter	*Climatic*	*WorldClim*
Annual Precipitation	*Climatic*	*WorldClim*
Precipitation of Wettest Month	*Climatic*	*WorldClim*
Precipitation of Driest Month	*Climatic*	*WorldClim*
Precipitation Seasonality	*Climatic*	*WorldClim*
Precipitation of Wettest Quarter	*Climatic*	*WorldClim*
Precipitation of Driest Quarter	*Climatic*	*WorldClim*
Precipitation of Warmest Quarter	*Climatic*	*WorldClim*
Precipitation of Coldest Quarter	*Climatic*	*WorldClim*
Solar Radiation	*Climatic*	*WorldClim*
Wind Speed	*Climatic*	*WorldClim*
Water Vapor Pressure	*Climatic*	*WorldClim*
Digital Elevation Model	*Environmental*	*CODEPLAN*
Land Use	*Environmental*	*CODEPLAN*
Urban density	*Socio-economic*	*CODEPLAN*
Per capita income	*Socio-economic*	*CODEPLAN*
Socio-economic vulnerability index	*Socio-economic Index*	*CODEPLAN*
VL incidence proportion	*Epidemiologic Index*	*CODEPLAN*

Socio-economic data

Demographic and socio-economic variables relating to urban density and per capita income were included in the final model. These data originally came from the biennial population census performed by CODEPLAN in 2015.

Urban density: only urban areas were considered for the production of this layer.

Per capita income: for this layer production was weighed the average per capita income of each administrative region, which was choropleth mapped and convert to Maxent acceptable format.

Socio-economic vulnerability index (SEVI)

The SEVI aimed to identify the factors associated to the social susceptibility and vulnerability areas in the studied territory, combining information from various socio-economic indicators into a synthetic index, and was used as a layer for Maxent software analysis.

The SEVI was constructed based on the adapted methodology from Tiburcio and Corrêa [17] and Rocha et al. [18], using data of each administrative region from the demographic census of 2015 available online at the CODEPLAN website. Although, the concept of vulnerability employed aimed to assemble and correlate socio-economic characteristics related to the vectors biology, also to human and dog vulnerability, trying to analyze the problem from the overall view perspective. Illustrating, we use the presence of heaps of wastes and rubble in the households surroundings as an example of a primary indicator, these conditions offered maintenance of shelter and nourishment for vectors and stray dog near the residences, also represent the absence of public services to human. Such conditions favor the disease tripod (human host, canid reservoir, and the vector).

The used primary indicators of each administrative region were classified into positive (T1) or negative (T2) indicators, which were standardized as the formula:

$$T1:\ I_p = \frac{Maximum_I - I_{Observed}}{Maximum_I - Minimum_I}$$

$$T2:\ I_p = \frac{I_{Observed} - Minimum_I}{Maximum_I - Minimum_I}$$

Where I_p depicts the primary indicators; I_{Observed} defines the observed value for each administrative region of every primary indicator; and among the administrative regions of the primary indicator, the highest and the minimum value are describe as $Maximum_I$ and $Minimum_I$, respectively.

We categorized the primary indicators by affinity on three synthetic indicators, namely, household structure vulnerability indicator (HSVI), urban infrastructure vulnerability indicator (UIVI) and social structure vulnerability indicator (SSVI). Each synthetic indicators was calculated based on the arithmetic mean of affiliated standardized primary indicators (Table 2).

The SEVI was constructed from the arithmetic mean of the three synthetic indicators (HSVI, UIVI and SSVI). The high values of SEVI represent situations of higher vulnerability and low values represent situations of less vulnerability. Every administrative region had an associated index of vulnerability, which was choropleth mapped and convert to Maxent acceptable format.

Table 2. Socio-economic vulnerability index constructed from the three synthetic indicators.

Socioeconomic vulnerability index	Vulnerability indicators	Socioeconomic Indicators
SEVI	HSVI	Proportion of PPD with absent garbage collection service (T2)
		Proportion of PPD with electricity from distributing company (T1)
		Proportion of PPD with general water supply (T1)
		Proportion of shanty domiciles (T2)
		Proportion of PPD with health and sanitation from the sewer network (T1)
	UIVI	Proportion of PPD with open sewage in the surroundings (T2)
		Proportion of PPD with flooded areas in the surroundings (T2)
		Proportion of PPD with risk of erosion in the surroundings (T2)
		Proportion of PPD with heaps of wastes and rubble in the surroundings (T2)
		Proportion of PPD in dangerous slopes (T2)
	SSVI	Proportion of persons responsible for the household with less than 9 years of study (T2)
		Average incoming of persons responsible for the household (T1)
		Infant mortality rate (T2)

PPD: Permanent private domiciles; HSVI, household structure vulnerability indicator; SSVI, social structure vulnerability indicator; UIVI, urban infrastructure vulnerability indicator.
Source: Adapted from Rocha et al, 2018.

VL incidence proportion (VLIP)

The VLIP was constructed from the sum of identified cases of human and canids of each administrative region, divided by the sum of the human population size and the estimation of canids population of that administrative regions, as the formula:

VLIP = [(human cases + seroreactive canids) / (human population + estimation of canids population*)] x 100000 inhabitants

**Estimation of canids population:* was calculated from the arithmetic mean of three human/dog ratios provided from previous studies of different city scales in Brazil, one of each city size (small [19], medium [20], and large [21]). The human/dog ratio used was 3.84. The VLIP was calculated for each administrative region, choropleth mapped and convert to Maxent acceptable format.

Modeling VL distribution

We analyzed the VL distribution occurrence as if it was a species, considering the records of the pathogen and the main organisms involved in the transmission cycle.

The machine learning algorithm, based in presence-only data that applies principles of maximum entropy implemented in Maxent software [22] was used to modeling the potential distribution of VL across BFD. The analysis was conducted with the default Maxent model parameter settings as suggested by Phillips et al.[13] (auto features, convergence threshold of 0.00001, maximum number of background points = 10000, regularization multiplier = 1, and 500 as the maximum numbers of iterations). In order to evaluate the percentage contribution of every single variable we used the Jackknife statistical technique. The resulting distribution map is in ASCII raster format and was exported to ArcMap.

Model evaluation. The records of VL were divided into two groups, in order to evaluate the model. The first group were randomly selected 75% points, and was used to run the models; the second group the remaining 25% evaluated the model accuracy. The results are visualized as an AUC (area under the curve), that indicates the test global accuracy, by predicting the model performance by comparison of the model predictiveness ability to a random prediction [13]. Higher AUC values correspond to a better model, and the scale varies from 0 to 1, where 0.5 denotes random prediction [13].

Results

For the period of 2014-2017, were reported 77 cases of human BFD residents (Table 3), 1657 seroreactive canids (Figure 2), and 48 *Lu. longipalpis* captures (Table 3). However, only 1642 of the mixed reports could be efficiently geocoded (91.5%: 72 humans, 1522 canids and 48 vectors) and used. The cases with addresses inconsistencies were excluded from the analyses. It is noteworthy that the entomological collection survey of *Lu. longipalpis* was homogeneous during the sampled period, nevertheless an exception occurs in 2016, which none was sampled.

Our findings showed a relatively stable epidemiologic situation of the VL in BFD population, without unpredictable fluctuations in the total number of cases (canids and humans).

However, in 2014 occurred an increment of infected canids in some areas, such as Jardim Botânico, Lago Norte, Lago Sul, Sobradinho e Sobradino II, all other areas showing a low incidence reports (Figure 2). On the other hand, during the analyzed years, it is interestingly to note a pattern of distribution the cases over the year for the canids which varying only on the number of cases, in general presenting a similar trend in the infection distribution for canids (Figure 2). Considering the human cases, some fluctuation could be observed since 2014, which had an accentuated increment in 2016 reaching a peak of 27 cases, them occurs a slight decrease in 2017 with 21 cases (Table 3). Comparing the relation between the reported cases in humans and canids it is possible to observe a trend, usually when are cases in canids there are cases in human too, and vice-versa. However, this relation is not proportional (Figure 2).

Table 3. Numbers of human cases and captured vectors for each Administrative Region per year.

	Human Cases				Vectors surveys			
Administrative Regions	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**
Águas Claras	-	-	1	1	-	-	-	-
Brasília	1	3	4	3	-	-	-	9
Brazlândia	1	2	-	1	-	14	-	-
Candangolândia	1	-	1	-	-	-	-	-
Ceilândia	-	1	-	5	-	-	-	-
Cruzeiro	-	-	-	-	-	-	-	-
Fercal	-	1	-	-	-	-	-	-
Gama	1	-	-	1	-	-	-	-
Guará	2	-	1	-	-	-	-	-
Itapoã	-	-	1	-	3	-	-	-
Jardim Botânico	1	2	-	-	5	-	-	-
Lago Norte	-	-	2	-	2	-	-	-
Lago Sul	-	-	1	2	5	-	-	-
Núcleo Bandeirante	-	1	-	-	-	-	-	-
Paranoá	-	-	-	-	-	-	-	-
Park Way	-	-	-	2	-	-	-	-
Planaltina	-	-	1	1	2	-	-	1
Recanto das Emas	-	-	-	1	-	-	-	-
Riacho Fundo	-	2	-	-	-	-	-	-
Riacho Fundo II	-	-	1	-	-	-	-	-
Samambaia	-	-	3	-	-	-	-	-
Santa Maria	-	-	-	-	-	-	-	-
São Sebastião	2	-	3	1	-	-	-	1
SCIA	-	-	-	-	-	-	-	-
SIA	-	1	-	-	-	-	-	-
Sobradinho	-	1	2	-	-	-	-	-
Sobradinho II	1	-	3	-	2	4	-	-
Sudoeste/Octogonal	-	-	-	-	-	-	-	-
Taguatinga	-	-	2	1	-	-	-	-
Varjão	-	-	-	-	-	-	-	-
Vicente Pires	-	-	1	2	-	-	-	-
Total	10	14	27	21	19	18	0	11

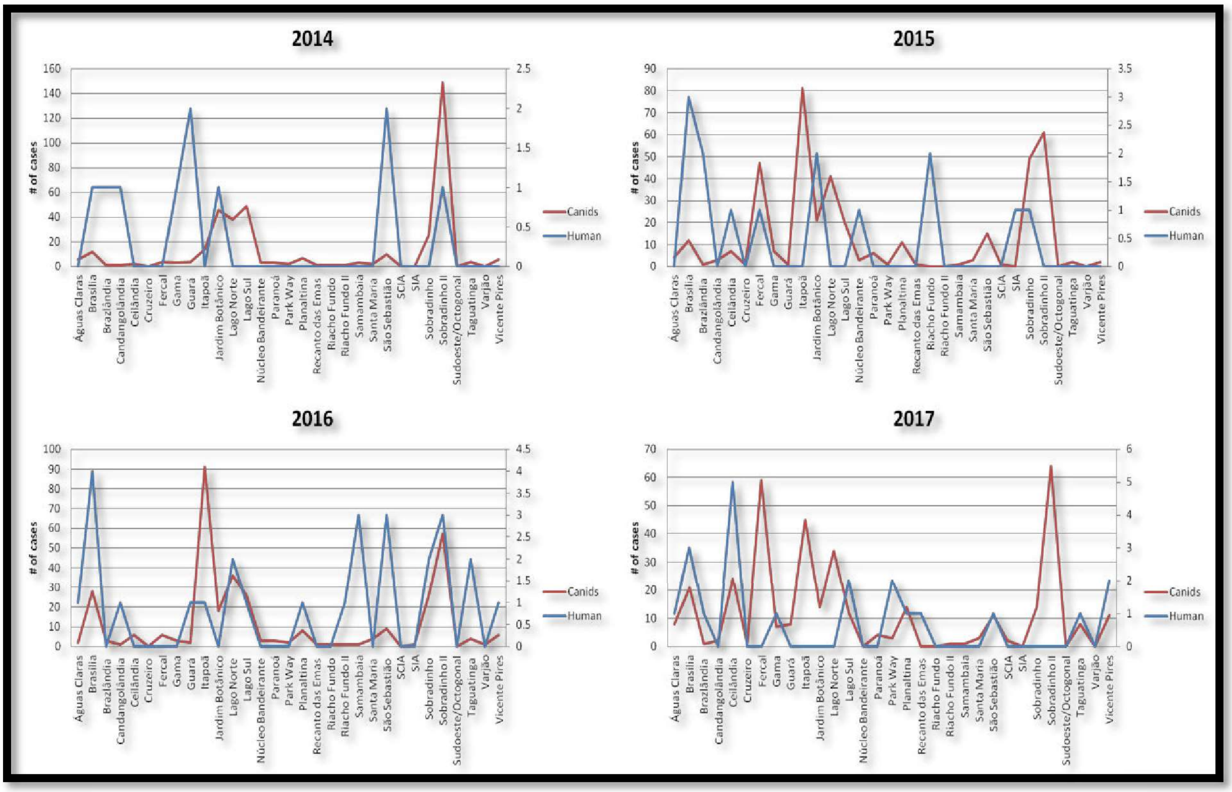


Figure 2. Comparison the number of cases in canids and human for each Administrative Region per year.

Disease-transmission risk map

The occurrences of VL were verified in 30 of 31 administrative regions. There was an absence of VL cases in Sudoeste/Octogonal AR.

Notably, our estimate suggests that 53% of the total BFD population is currently at high susceptibility to VL transmission. The suitable areas for the occurrence of the parasite, vector, and reservoir were especially noteworthy for Fercal, Lago Norte, Lago Sul, Jardim Botânico, Sobradinho I, Sobradinho II and Taguatinga (Figure 3).

The modeling results revealed a high distribution of VL in almost all urbanized areas with human density > of 6 pop./km^2 (Figure 4).

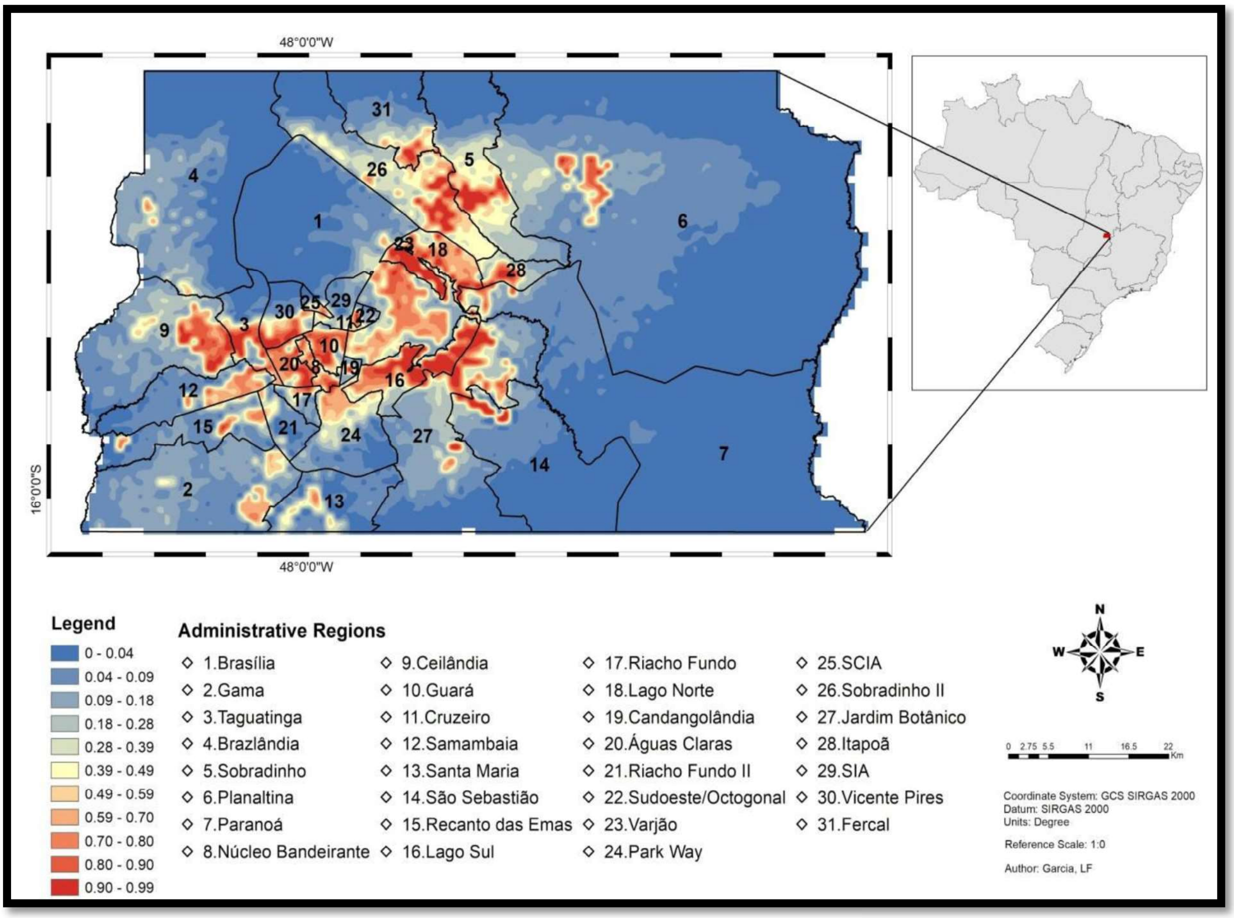


Figure 3. Disease-transmission risk map. Values close to one (red) indicate the most suitable areas for VL transmission.

Evaluating the spatial patterns of the reported cases it could be observable a diffuse distribution in almost all large populated areas, except for the Sobradinho II and Lago Sul, which showed a slight agglomeration (Figure 5). Few reports occurred outside of urbanized areas.

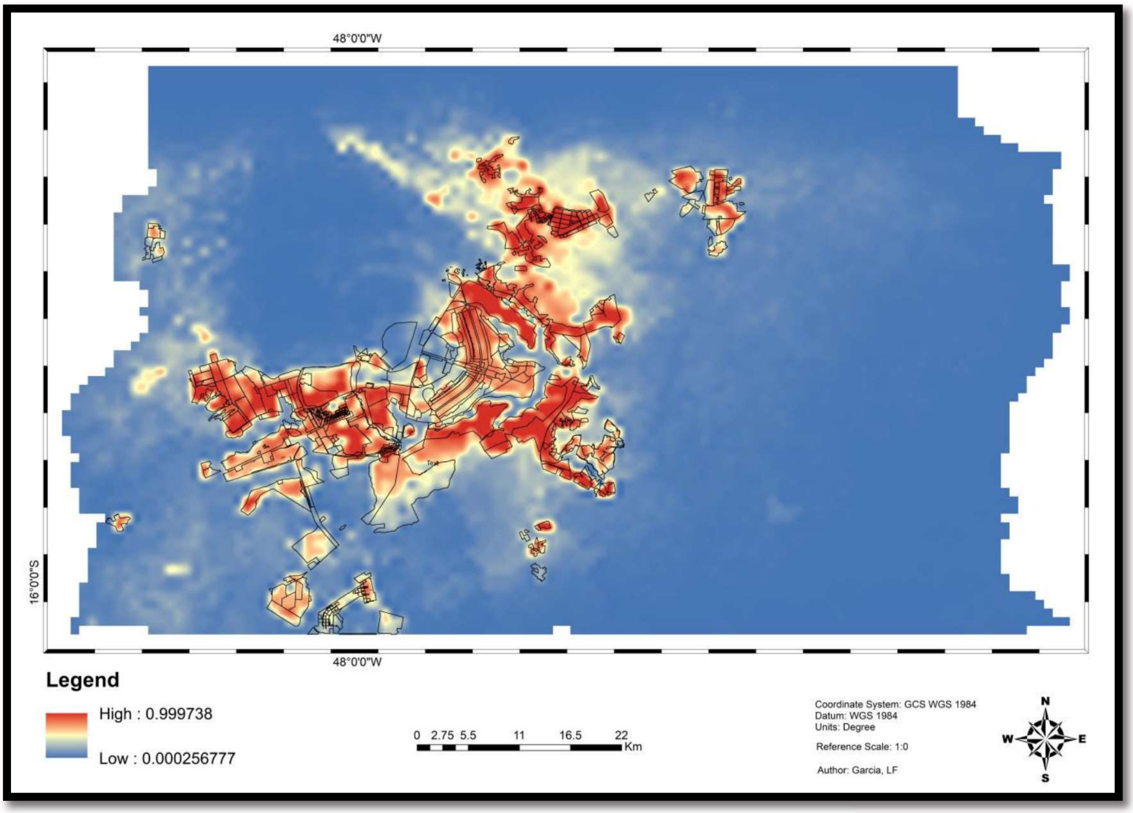


Figure 4. Disease-transmission risk map overlapping the urban areas. Values close to one (red) indicate the most suitable areas for VL transmission.

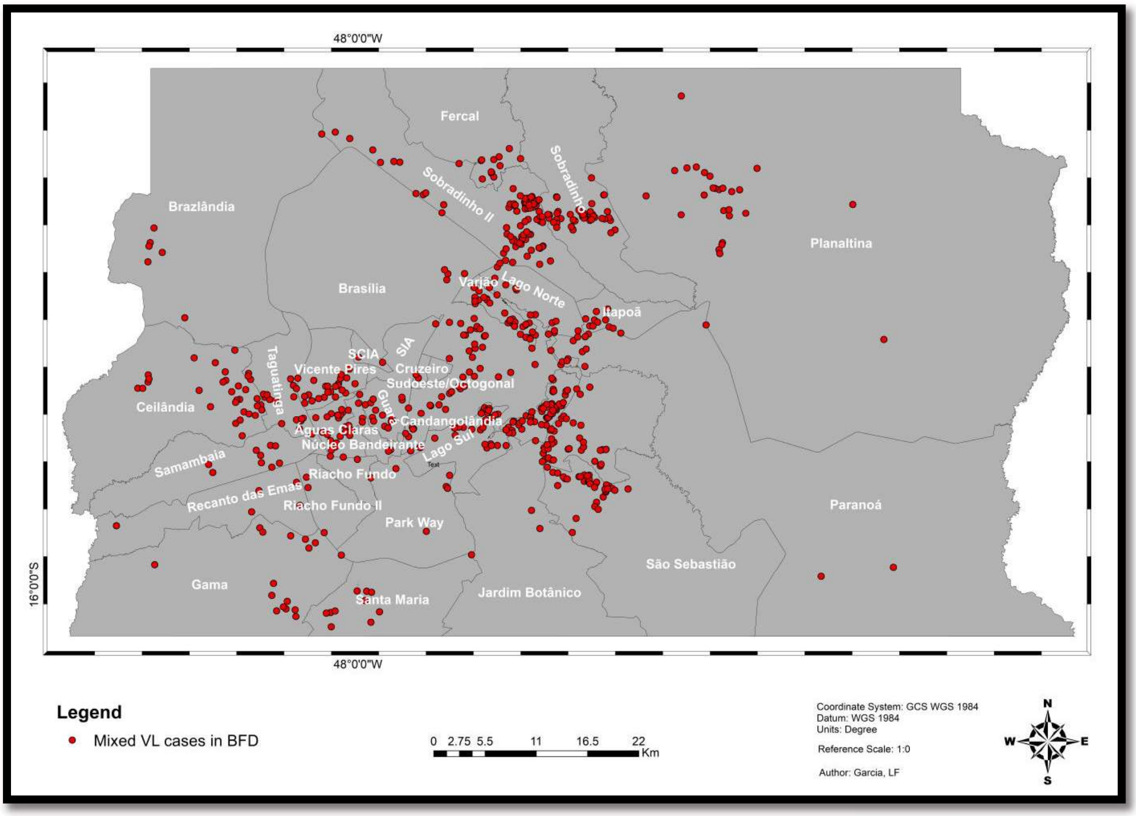


Figure 5. Spatial distribution of VL reported cases in Brazilian Federal District. Dots in red indicate the reported cases.

With regard to the model evaluation, both test AUC (0.886) and training AUC (0.915) was considered good. The Jackknife tests (Figure 6) suggest that among all analyzed variables, the human population density was the most influencing (41.9%), followed by land use (25.2%), VLIP (11.7%), and precipitation seasonality (6.4%). all other parameters reached below 4%.

Variable	Percent contribution	Permutation importance
Human_population_density	41.9	6.2
Land_use	25.2	7.1
VLIP	11.7	8.8
Precipitation_seasonality	6.4	11.5
Min_temperature_coldest_month	3.4	4.3
Solar_radiation	3.1	12.6
Precipitation_wettest_month	2.1	11
Precipitation_driest_quarter	1.1	4.8
Annual_precipitation	1.1	0.1
Isothermality	1	12.5
Max_temperature_warmest_month	0.8	0.4
Income_percapta	0.5	6.1
Precipitation_driest_month	0.4	7.7
Water_vapor_pressure	0.3	1.6
Mean_temperature_coldest_quarter	0.2	0.3
Mean_diurnal_range	0.2	0
SEVI	0.1	2.3
DEM	0.1	1.1
Temperature_seasonality	0.1	0.3
Precipitation_wettest_quarter	0.1	0.2
Precipitation_coldest_quarter	0.1	0.6
Wind_speed	0.1	0.2
Mean_temperature_driest_quarter	0	0.1
Precipitation_warmest_quarter	0	0.1
Temperature_annual_range	0	0
Mean_temperature_wettest_quarter	0	0
Mean_temperature_warmest_quarter	0	0
Annual_mean_temperature	0	0

Figure 6. Contribution and importance for each variable from the Jackknife results.

SEVI and VLIP

Among the SEVI analysis, the worst scores were obtained for Fercal (0.69), followed by Ceilândia (0.63) and SCIA - Estrutural (0.58). The best score were obtained for Lago Sul (0.06) and Sudoeste/Octogonal (0.09) (Figure 7A).

Considering the VLIP, the worst ratio scores were obtained for the Fercal with 11 cases per 100000 inhab for the period, followed by Lago Norte (3,4 cases per 100000 inhab for the period), and Lago Sul (3,2 cases per 100000 inhab for the period). There was no VL report for Sudoeste/Octogonal, and Recanto das Emas had the best ratio scores for VLIP indice (0.027 cases per 100000 inhab for the period) (Figure 7B).

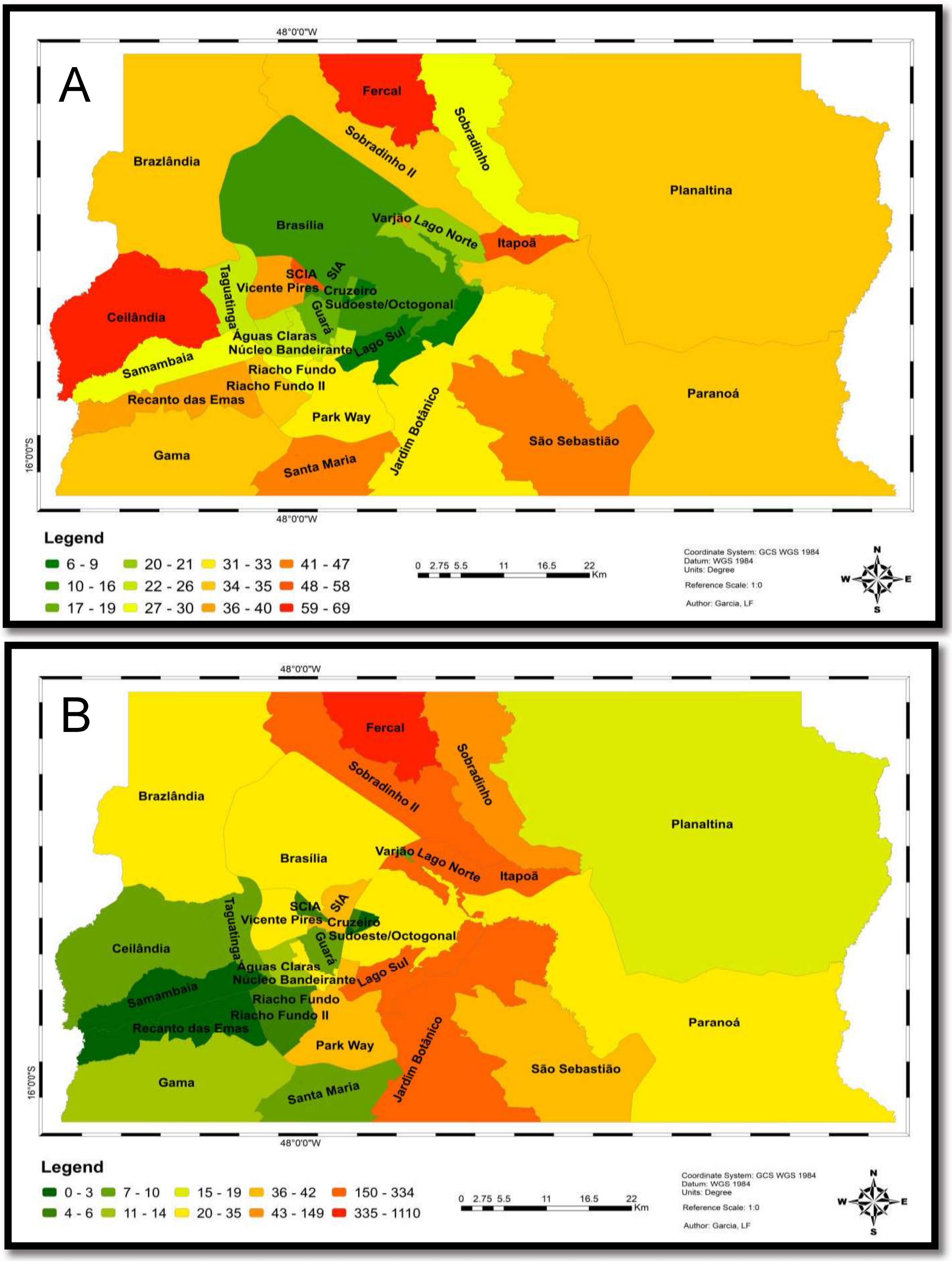


Figure 7. SEVI and VLIP choropleth map results. Warm colors indicate the most vulnerable areas. (A) SEVI. (B) VLIP.

Discussion

Visceral leishmaniasis distribution was modeled to predict susceptible areas of transmission in BFD. We consider that the effective control programs which aim to interrupt the disease cycle should apply integrated strategies of spread constrain. Because of this, our approach was trying to create a comprehensive model that links and analyze the most important aspects of VL cycle, which encompasses the geographical, biological and social aspects.

Based on our results, it is noteworthy that for a specific case of Lago Sul, which showed a low human density (6 pop./km^2), and the SEVI topmost socio-economic standards. Meanwhile, it was presented as the highest transmission susceptibility area, according to the disease-transmission risk map, depicting the importance of VLIP index. We consider of high concerning the score of 53% of the BFD population living in transmission susceptibility areas, principally in area such as Fercal that is considered highly vulnerable by the SEVI and VLIP.

Jackknife tests reveal that human population density is the most crucial factor that boundary VL distribution and influential the spreading. Thus, human populations mean more nourishment (human and consequently dogs, as the main reservoir in urban environments), procreation sites, and hideouts to hematophagous sandflies females.

Another important variable high ranked in jackknife analyses was the land use. Often associated with sylvatic habitats [23] the near environment alteration could dangerously influence the fast disease urbanization. Therefore, we are convinced of the more areas will become increasingly suitable for species spread and distribution as the habitat alteration and disordered urbanization continuing.

The influence of poverty, malnutrition, poor sanitary infrastructure, limited healthcare services, illiteracy and other socioeconomic problems in the proliferation of visceral leishmaniasis is undeniable [24,25,26,27,28]. However, our study demonstrate that the disease in the Federal District is strongly related to the peri-urban environment influence, being the socio-economic influence not a main cause, notwithstanding an aggravating factor or secondary in nature.

As previously mentioned about the BFD urban conformation, where some peri-urban areas obeyed the strict the plan of Brasília design (usually with high socioeconomic standards) others followed the general pattern Brazillian pattern. Some of these high socioeconomic standards areas are considered one of the most susceptible regions for VL transmission, and are illustrated by the administrative regions such as Lago Sul or Lago Norte. Such occurrence is probably related to their urban structure, which present houses with large lots even so with a maximum construction rate limit of 40% of the land. Consequently create green corridors which would facilitate the dispersal of the vectors. Dogs as guard animals are also associated with this kind of urban organization, which by default are kept outside homes and susceptible to attack by the vectors.

It is noteworthy that the importance of the canids infection in our analysis, corresponding to more than 90% of the reported case. This could amplify the transmission to humans living in marginalized areas. In general, the Brazilian situation of low-income influence the VL spread due to the difficult to properly take care of dogs, such as, buying mosquito repellent leashes, veterinarian treatment or even the animal food. On the other hand, the exposition during the guard role, adopted by dogs in houses of middle and upper class could have contributed to the VL spread on theses social stratus.

Although previous studies [29, 30] suggest the impact of high wind speed, thermophily and the high temperatures dependency for the sandflies development, survival, and spread. Our results displayed the precipitation seasonality as the most climatic influencing feature for the species in the Brazilian Federal District, which suffer from a very dry and long season, with humidity reaching less than 20% for almost half of the year.

This study had several limitations that should be mentioned. A considerable amount of canids address reports were imprecise or inexistent, hindering the analysis of our model, which depends on the accuracy of reports. Moreover, we could not measure the impact of asymptomatic cases. Detailed information about canids dynamic population and health (mainly stray dogs) surveys is absent. Please note that the concerning knowledge about the ecology, biotic interactions and previous study focusing on the spatial distribution of the *Lu. longipalpis* is missing too. Additionally, operational difficulties with CDC Light Trap were reported during the attempt of the vectors survey, compromising the sample. Finally, the almost impeditive bureaucracy to acquire the data, and the lack of specific public health programs and investments for VL, create a lacuna in the disease data.

Despite the financial and logistical scarcity of the under-resourced countries, most of them are located on tropical regions from different continents, presenting the perfect socio-economic and environmental conditions for VL spread, such as Brazil. In this context, our analysis and results could provide crucial data to improve the surveillance design and resources allocation for VL control. Helping the detection of establishment infested areas, zones with early stages of infection or potential risk.

Conclusion

In this study, we mapped the transmission susceptible areas of VL in the BFD. We based on the Maxent ecological niche modeling approach, using the spatial VL occurrence and a set of socio-economic and environmental variables.

Our estimate suggests that 53% of the total BFD population is currently at high susceptibility to VL transmission areas. According to the disease-transmission risk map, the riskiest are Fercal, Lago Norte, Lago Sul, Jardim Botânico, Sobradinho I, Sobradinho II and Taguatinga. The occurrence of VL was strongly associated with human population density (41.9%) and land use (25.2%).

Our findings along with the disease-transmission risk map produced could help health authorities to understand the VL dynamics and guide the implementation of effective surveillance and control strategies.

Authors' disclaimers

Authors' contributions

LFG drafted the manuscript, conceived the study design, implemented the study, analyzed and interpreted the data; LAB and HLR contributed to the study design and implementation, also the manuscript revision; CM contributed to the study implementation, and the manuscript revision. All authors contributed, read and approved the final manuscript.

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