



## Geospatial and modeling tools for leishmaniasis studies: a review of publication between 2008-2018

### Ferramentas geoespaciais e de modelagem para estudos de leishmaniose: uma revisão de publicação entre 2008-2018

[RIALA6/1759](#)

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Recebido: 17.09.2018 - Aceito para publicação: 28.12.2018

#### ABSTRACT

Aspects of how geospatial technologies can be used on visceral leishmaniasis (VL) control programs are discussed. We reviewed a number of papers discussing the usage of those technologies, through a PubMed literature review. Additionally, we provided conceptual elements for a development of a hierarchical scale framework on VL for decision making in São Paulo State, using Geographical Information Systems. Supported by Geospatial Techniques, we developed a view of some instruments for helping communities to better manage their risk areas. We used a classification called Strengths of GIS and Spatial Analysis in Epidemiology (SGISSAE). This review identified 50 papers published in the PubMed. With respect to developing the theoretical perspective, this paper can help to identify points of deficiency in shortage in discussions and leishmaniasis control programs, which led us to recommend future to delimitation studies to at community-based level and to define local actions to identify and manage the disease. In the conceptual framework data at community-based level will allow us to understand more broadly the changing spatial distribution of the disease.

**Keywords.** geospatial technologies, visceral leishmaniasis, review, geography, scale, landscape thresholds.

#### RESUMO

Aspectos sobre como as tecnologias geoespaciais podem ser usadas nos programas de controle da leishmaniose visceral (LV) são discutidos. Nós confrontamos uma série de artigos discutindo o uso dessas tecnologias, através de uma revisão da literatura no PudMed. Adicionalmente, fornecemos elementos conceituais para o desenvolvimento de uma estrutura hierárquica sobre a escala na tomada de decisão sobre a leishmaniose no Estado de São Paulo, utilizando Sistemas de Informação Geográfica. Com o apoio das técnicas geoespaciais, desenvolvemos alguns instrumentos para ajudar as comunidades a gerenciar melhor suas áreas de risco. Usamos uma classificação chamada Forças do SIG e da análise espacial em Epidemiologia (SGISSAE). A revisão nos permitiu selecionar 50 artigos publicados no PubMed. Com relação ao desenvolvimento da perspectiva teórica, este artigo pode ajudar a identificar pontos de deficiência em discussões e programas de controle da leishmaniose, o que nos levou a recomendar futuros estudos de delimitação a nível comunitário e a definir ações locais para identificar e gerenciar a doença. No quadro conceptual, os dados ao nível da comunidade permitirão compreender mais amplamente a evolução da distribuição espacial da doença.

**Palavras-chave.** tecnologias geoespaciais, leishmaniose visceral, revisão, geografia, escala, domínios de escala, limiares de paisagem.

## INTRODUCTION

Visceral Leishmaniasis (VL) was considered endemic in 75 countries in 2015, with 23,804 new cases reported worldwide. Over 90% of cases of VL occur in three eco-epidemiological hotspots: the East Africa; the Indian Subcontinent (Bangladesh, India and Nepal) and Brazil<sup>1</sup>. In Brazil, the most important eco-epidemiological hotspot is the region of MATOPIBA<sup>2</sup> composed of the states of Maranhão, Tocantins, Piauí and Bahia. Although the state of São Paulo is not located in the highly endemic area, authorities have reported 2,856 cases of VL in humans from 1999 to 2017. The municipalities of Araçatuba, Bauru and Dracena are well-known endemic foci of VL<sup>3</sup>.

Multiple factors can influence the dynamics of VL transmission, such as demographic, medical-social, biologic and environmental information. Environmental factors in particular, can affect the generation and permanence of leishmaniasis foci either promoting or blocking the life cycle of the sandfly vector<sup>4</sup>. VL is a focal disease and its epidemiology differs according to the nosogeographic regime, which means that certain communities are more vulnerable.

Control programs for many diseases have benefitted from recent advances in geospatial technologies, due to the improvements in identifying and measuring environmental factors and the potential to target interventions in space and time, globally, regionally and locally<sup>5</sup>. Geospatial technology have become much more than a new tool in public health applications. It has provided a great contribution to understanding how environmental factors affect human/animal health and well-being.

Nowadays, such technologies have increasingly been applied into public health research with the development of computer applications and the availability of geocoded information on disease occurrence. Still, little is known about the relationship between VL and the landscape scale process function. The role of the ecological niche and man-made changes to the landscape are essential for the support of the transmission cycle and disease spread<sup>6</sup>. Spatial analysis can help identify priority areas for effective surveillance and control. Predictive modeling of disease epidemiology based on its explanatory and causative variables may identify the origin and direction of expansion to predict new foci areas. This review aims

to provide conceptual elements for a hierarchical scale framework on VL risk for decision making in São Paulo State.

### Geospatial technologies and disease programs

When dealing with environmental sensitive diseases, many authors have pointed out the usefulness of geospatial technologies, which have become increasingly popular on VL studies<sup>6</sup>. A key question for policy makers is to determine which method to use and what spatial question to ask when applying this resource. Geographic Information Systems (GIS) are not to be considered a way of solving problems, as it has advantages and disadvantages, but as an alternative to better understand scenarios with its associated factors in the heterogeneity of the landscape, considering scale dependency or scale sensitivity.

The role of geography is to unravel and interpret data from different scales. In other words, systematically assess the effect of scale in the models and analysis. It also aims to identify the spatial units that best capture the essential characteristics of the geographical phenomenon under investigation. Therefore, generalizations may lead to an inadequate interpretation of a phenomena. Studies that have analyzed different scales have shown that it is possible to identify idiosyncrasies present in the community-based context that can be invisible on a smaller scale, such as countries, for instance; and assign local phenomena to regional levels and subdivisions of the locale itself.

Another problem that is often discussed is the incorporation of the time variable into the models. It has been observed that the current techniques of spatial analysis have not been able to adequately capture the changes that epidemiological studies have demonstrated, suggesting that better methods for identification of risk factors are needed.

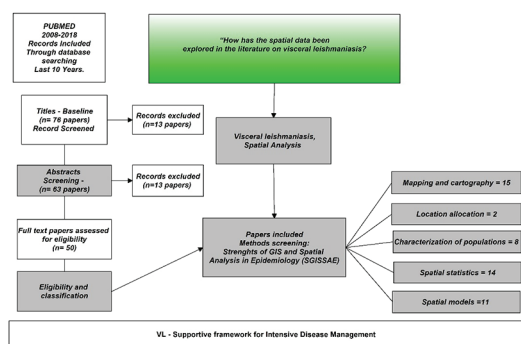
### Multiscale Relationships Between VL and the Environment: A Review

This review identifies recent research reports that have negative and positive interfaces between geospatial methods and occurrence of VL. It summarizes the main international standards that the themes intersect, in order to understand the role of the use of these data, ranging from simple location of cases to complex models based on spatial statistics.

The database was constructed via access to the PubMed website (<https://www.ncbi.nlm.nih.gov/pubmed>) including papers that were published

between 2008 and 2018, by use of the two following descriptors: spatial analysis, visceral leishmaniasis.

The search results returned a total of 76 studies of VL using spatial analysis techniques. However, 26 of these studies were shown to be irrelevant after title and abstract screening (Figure 1).



**Figure 1.** Selection criteria for a systematic review of Geospatial analysis on Visceral Leishmaniasis studies, 2008-2018

This review analyzed a selection of 50 published papers in the databases search (Table).

We used a classification called Strengths of GIS and Spatial Analysis in Epidemiology (SGISSAE)<sup>7</sup>, to identify the techniques applied in the articles analyzed, classifying the papers as follows:

- a) *Mapping and cartography* - the first step in the exploratory analysis of spatial data based on maps of morbidity and mortality;
- b) *Location allocation* - the study of optimal locations for health facilities and services;
- c) *Characterization of populations* - corresponding to identification of risk groups, by indicators like age and weight, for example, but including location of cases, such as in a GIS;
- d) *Spatial statistics* - the analysis of patterns in series of data and group according to similarities, probable combinations between input data (diseases, for example) and explanatory variables and;
- e) *Spatial models* - including techniques of Bayesian smoothing, surface interpolation and Monte Carlo.

## RESULTS

### Mapping and Cartography

Thirty percent (15/50) of the search results listed in this class are taking advantage of widely utilized of elements of cartography, such as proportional circles, colors ramps, point patterns, with the main purpose of location. It allows the reader a quick identification of the elements that make up the space in which the infection is located. Most are thematic maps, with GPS points of the houses, some are cartographic sketches. Most of the studies in this category were described areas in Brazil, India and Middle East. From the studies performed in Brazil, the highest number of studies using geospatial technologies was found in the states of Minas Gerais, São Paulo and Piauí.

### Location allocation

There were a very few number of papers, two total (4%), that used elements of location allocation. It is not clear in the literature that this kind of analysis should be useful as a supportive tool for VL control, due to an also unclear origin of infection or foci. The classic studies of distribution of patients and health facilities identifies the distance of some facilities for the patients to have access, but this may not correspond to the place of infection, but the place used for healthcare. With support on these models of allocation, is possible to identify suitable locations, searching for areas that match the analyzed criteria. Other uses for this category is the possibility of point tracking data, through the analysis of triggered location. The most important tool of this group is to determine the least costly way to go from one location to another. In our case, from a household to a health facility or center for control of zoonosis. This analysis determine the shortest weighted distance between two cells in the raster format<sup>8</sup>.

### Characterization of population

In the literature on leishmaniasis, this kind of analysis addresses elements

that enable, in the range of communities, understanding of vulnerabilities according to the characteristics of the community as a risk factor. In the specific case of VL, we can include either dog or human population as targets, with different approaches. Eight papers (16%) were reviewed in this group, and variables such as household size and yard, and breed of dogs and number of dogs in the household were often seeing.

### Spatial Statistics

Fourteen papers (28%) used spatial statistics, the fastest increasing in number of publications on VL. Examples of analysis seeing in this group are: cluster and outliers, coincidence or overlapping of points of occurrence in a time series, autocorrelation and exploratory regression<sup>8</sup>.

### Spatial Models

In the literature on VL, spatial models address elements that allow, in a range of communities, and understanding of vulnerabilities created by risk factors for the disease. There is a clear relationship between spatial models and cartography. This approach was found in 11 (24%) peer-reviewed papers. Some papers showed association between vector and climatic variables, through the Bayesian, linear or logistic regression, generalized additive mixed models (GAMM); monthly or seasonal trend series; and annual incidence rate. Other papers showed geographically weighted regression, focusing on distance between points or polygons, defined as the Euclidean distance. Examples of other analysis used in the 12 papers reviewed are: maximum likelihood classification, classification Bhattacharya, classification ISOSEG, ecological niche model, spatial overlays and concentration maps, interpolating surfaces, remote sensing indexes.

**Table.** Examples of published studies using Spatial analysis, showing type of research technique and objective

Research Technique	Objective	Citation
Bayesian Models	To correct underreporting of cases in small areas. Correction from the neighborhood areas.	(De Almeida. 2011; Martins-Melo. 2014; Rajabi. 2014; Silva. 2017)
Buffer	To build simulations around a circular area surrounding the vector collection places.	(Khanal. 2010; Santini. 2015; Berrozpe. 2017)
Climate variables	Visualize spatial distribution of rainfall, land surface temperature. To infer driven factors for infection rates.	(De Almeida. 2011; Rajabi. 2014; Yousuf. 2017)
Clusters	To detect unexpected events distributed in time and space.	(Santini. 2015)
Choropleth map	To represent incidences, mortality rates and to plot the autocorrelation.	(Cardim. 2013; Fu. 2013; Naufal-Spir, 2015)
Kernel density.	To explore areas of excessive risk for the disease.	(Khanal. 2010; De Almeida. 2011; Machado da Silva. 2011; Menezes. 2015; Ursine. 2016)
Moran index	To test whether geographically connected areas display greater similarity in terms of the target indicator than would be expected considering a random pattern. The	(Roma Sánchez De Toledo I; Bhunia. 2010; De Almeida. 2011; Barbosa. 2014; Martins-Melo. 2014; Berrozpe. 2017)
NDVI, Land Surface temperature, Land Use Land cover	Normalized Difference Vegetation Index (NDVI) ranges, searching for suitable environmental conditions for reproductive success of the vector	(Aratjo. 2013; D.M. 2014; Yousuf. 2017; Santini. 2018)
Principal components analysis	To examine the correlation between the spatial distribution of sand-fly species and socioeconomic and environmental variables.	(Kahime. 2015)
Kriging	To create an estimated surface of the temperature and rainfall.	(Cardim. 2013)

### Different models fit different problems – proposal of a community-based geospatial model for Visceral Leishmaniasis

It is an accepted aphorism that “all models are wrong but some models are useful”, because they represent assumptions of the real world that we know are partially false<sup>9</sup>. Models, as a generic term, are abstract solutions with computational support aimed at solving complex problems.

According to disease program specialists, the question that often arise is: “Do we pay too much attention to irrelevant precision of measurement in searches that don’t require highly distilled evidence of causality?”<sup>10</sup>. A modeling capability involves a separation of a set of meaningful characteristics of the environment, in the form of variables, aimed at solving a specific problem.

A mathematical model that quantitatively describes VL transmission at the community-scale needs to include the following components:



1) Serum Conversion of Dogs - Combination of diagnostic techniques, efficiency, efficacy, pairwise and specificity of different techniques. This component will impact directly on the time necessary for design of serum surveys, due to the infection rates/ related to the time of serum conversion<sup>11</sup>.

2) Clinical cases in dogs - Analysis of the symptoms of dog, with serum surveys, promoting a critical approach of the laboratory-based surveillance.

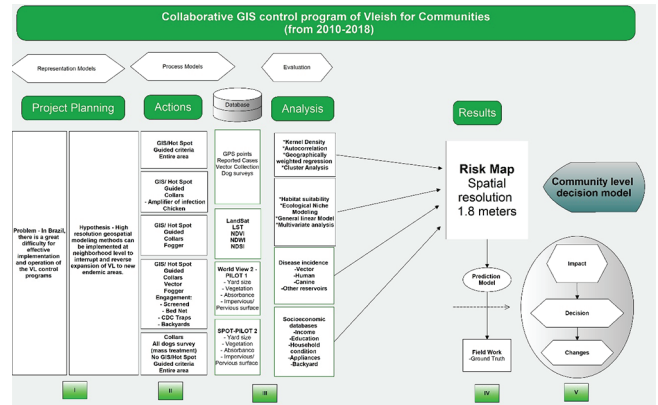
3) Human Archival data - Infected person-years prevented places of residence and hot spot analysis. These components will show the background data necessary for models to define areas to start the serological survey in human or dogs. In Brazil, the individual records of epidemiological investigation for VL have a very detailed databases<sup>12</sup>.

4) Sandfly - Analysis of population dynamics, number and seasonal collections; the infection rate and blood meal.

5) Community features - Evaluation of Knowledge-Attitude and Practice, review protocols of the control programs for human disease and discussion with policy makers.

In this paper, we presented a conceptual and analytical framework for models use at the community-based level. The basic idea is to provide instruments for detection at the microfoci level with all environmental variables related to VL propagation and transmission.

**Figure 2** shows a framework of variables for a collaborative GIS analysis of VL programs at community scale studies. The framework for VL at community level was produced to identify uses of high resolution satellites (2 m<sup>2</sup> resolution).



**Figure 2.** Framework for studies of Visceral Leishmaniasis across community scales. The framework show a project planning composed by the research problem and the hypothesis (I). The second section is composed by the actions, thinking on how technological innovation and new approaches can be incorporated to the current actions of the control programs of VL (II). The sections of the Databases and Analysis allow to use a very complex and diverse group of techniques in Geospatial Analysis to gather the landscape scale process function; additionally the management of databases from different sources and its interoperability (III). After the analysis the framework propose is to delimitate risk maps in high resolution for the disease spread and processes on the environment. The results will triggers different answers for research and assessment for decision makers to reduce the disease vulnerability (IV). As the last section of the framework the evaluation is part of the after elimination/block plan for the disease (V). Prediction could be included in the final model, such as climate suitability and disease spread. Also, the evaluation of the model itself, in which the researchers can include new variables or redesign strategies to access communities.

**Final Comments**

This paper aimed at identifying new approaches to VL control programs, led us to recommend limiting studies to the community level, an approach that has not yet been used for VL, although this has been shown to be promising in studies of schistosomiasis<sup>13</sup>. There is a number of reasons for the absence thus far of a community approach in studies on VL. The lack of financial support for innovative programs; as well as the lack of well-trained public health personnel and information on time series and post elimination strategies for VL are just a few of them.

Visceral leishmaniasis is a complex disease of multiple risk factors, and Geographic Information Systems offer new ways to approach control of the disease. In the conceptual framework, data from the state of São Paulo and study at community-based level will allow us to better understand more broadly the spatial distribution of the disease. In the long term, it will be feasible to incorporate protocols and standards based on mapping and remote sensing as facilitators for scanning foci and environments, providing new tools for surveillance and control programs dealing with VL.

Actions at community-level are important for redesigning the strategies and the generation of normative protocols of spatial analysis for control programs of VL. Near-real time analysis can lead to improved management, community services and research. In other words, contextual solutions for identifying “hotspots” of infection. When public health workers utilize landscape intervention, based on an accurate comprehension of the transmission cycle of VL it may be possible to develop plans that may lead to VL elimination.

This literature review highlights some emerging themes in modeling for public health. Globally, VL has been spreading and changing patterns because of environmental change. In order to promote mitigating actions based on changing climate and health, relevant data on land surface temperature, rain seasonality and dry season that affect propagation and transmission of the vector population, and consequently disease spread, are needed.

The massive increasing production of potentially useful databases from earth observing satellites allow research groups to have multidimensional information, but with all the problems coming from interoperability of data from different sources. The future of epidemiology may be called e-epidemiology. By the use of geospatial technologies, we can also include the term neo-cartography. A new field of cartography related to production and access to the knowledge and print-outs of digital media from internet browsers, by tablets, mobile phones and other devices.

#### ACKNOWLEDGMENTS

**Research funding:** Dissemination of geoepidemiological knowledge for the improvement

of public policies for surveillance and control of leishmaniasis in the Pontal do Paranapanema, São Paulo state, Brazil. Financial Support. Number: 2014/12494-0, São Paulo Research Foundation (FAPESP).

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