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REVIEW

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Geoprocessing and spatial analysis for identifying leptospirosis risk areas: a systematic review

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ABSTRACT

Leptospirosis is a reemerging zoonosis caused by bacteria of the genus *Leptospira sp.* with global importance in the medical and veterinary fields, being responsible for about 59 thousand deaths each year in the world. The use of Geographic Information Systems (GIS) in the health sector is propitious and has been adopted by human and animal health professionals as an important tool in spatial analyses of health. The objective of this study was to conduct a systematic review on the geoprocessing and spatial analysis techniques adopted for mapping risk areas of human and animal leptospirosis. The articles were collected on scientific platforms by entering the following terms: SIG/GIS, leptospirose/leptospirosis, area de risco/risk area and distribuicao espacial/spatial distribution, and included in the study if they met the following criteria: a) publication in the period from 1998 to 2017; b) identification of risk areas and/or spatial distribution of leptospirosis as one of the research topics; and c) application of GIS in the methodology. As a result, we found 40 articles, published by 15 different countries, which adopted GIS for the spatial analysis and identification of risk areas of leptospirosis. Among these, only 45% (18) conducted an spatial statistical analysis. Brazil and USA had the highest numbers of publications, 16 and 7 articles, respectively. From 2007, the use of GIS and spatial analysis techniques, applied to the theme of this study, have been intensified and diversified, and 93% of the articles elected for this review were published from 2007 to 2017. The results point to a progressive interest of health professionals in applying these techniques for monitoring and conducting epidemiological analyses of leptospirosis, besides indicating a greater need for intersectoral integration between health professionals and others, in the use of spatial analysis and GIS techniques.

KEYWORDS: Leptospirosis. Geoprocessing. Risk areas. Spatial analysis.

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INTRODUCTION

Leptospirosis is a bacterial zoonosis caused by invasive spirochetes belonging to the genus *Leptospira sp*. The disease may present with mild symptoms of fever, headache and myalgia, or in a severe form with jaundice, renal insufficiency and hemorrhages, and these symptoms are mainly associated with serovars Icterohaemrhagiae, Copenhageni, Australis, Autumnalis, Bataviae, Lai and Pyrogenes[1,2].

In Brazil, the main reservoir is constituted by the synanthropic rodents of the species *Rattus norvegicus* (brown rat or sewer rat), *Rattus rattus* (black rat or roof rat) and *Mus musculus* (house mouse). *R. norvegicus* is often associated with the peridomicile of houses that provide food, such as exposed garbage, and refuge, being the main carrier of *L. interrogans icterohaemorraghiae*[2,3]. The main form of transmission to man is the contact with water, soil and food contaminated by the urine of the reservoirs[3].

Currently, much is discussed in the public health field about the use of geoprocessing and spatial statistical techniques in the study of infectious diseases. These techniques today have become of mandatory use for health surveillance services, collaborating in daily work of health managers and professionals. The application of such techniques in epidemiological research began in the 19th century with Dr. John Snow. Thanks to the use of georeferencing techniques, he demonstrated that there was a spatial association between cholera deaths and the supply of water by different public supply pumps. From this finding, it was possible to control the cholera epidemic in the city of London[4]. Dr. Snow's classic study continues as a permanent source of inspiration to health professionals who seek interdisciplinarity in understanding the health-disease process.

The establishment, evolution, propagation and perpetuation of infectious diseases of humans and animals are closely related to hygienic-sanitary, socioeconomical and demographic factors, and the occurrence of these vector-borne diseases is characterized by spatial and temporal patterns due to the context of residences of individuals and animals, and the aspects of the environment are associated with the proliferation of populations of reservoirs, vectors and infectious agents[5-7].

Therefore, the use of Geographic Information Systems (GIS) and spatial statistical analysis in the health field generate an important recovery of the role of the socio-environmental atmosphere in the production and reproduction of leptospirosis, since it is closely related to the ecological characteristics of the environment, enabling a more complete analysis of the disease and the identification of spatial heterogeneity in the studied localities, besides generating advances in the notion of interdisciplinarity, because the participation of professionals from different areas of knowledge becomes necessary for a good result of the surveys carried out[8,9]. Therefore, research involving techniques capable of identifying and directing the attention of scholars to the dynamism and evolutionary nuances of leptospirosis is essential in the continuous and updated promotion of scientific and technological knowledge on health, promoting the formation of a network of cooperation between human and animal health experts[10].

The effectiveness of using GIS, combined with spatial analysis, in studies that specifically deal with spatial and temporal outbreaks of leptospirosis, and other diseases, can be found in several scientific articles that have been already published around the world in different countries, such as: China, Hungary, Canada, USA, Zambia and Brazil[11-21].

Considering the etiological agent of leptospirosis as an inherent structure of the space-climate relationship, and since the space is the means by which the infectious agent circulates, it can be concluded that the epidemiological structure of the disease is modified by the transformation of space and climate over the years, hence requiring continuous technological innovations of surveillance models in a diverse and complex social context, such as the current urban life[22,23].

This study aims to conduct a systematic review, through the election of national and international articles, of the main techniques of GIS and spatial analysis used in scientific studies on the identification of risk areas of leptospirosis in the period from 1998 to 2017, as well as to create a ranking table that points out the frequency of publications with this theme in countries that have already used these tools over time, in order to provide a detailed and updated source on the advances in the use of these technologies in the fields of human and animal health in a global context.

MATERIALS AND METHODS

The systematic literature review focused on articles that included GIS as a tool and whose theme was the identification of risk areas of leptospirosis. To this end, searches were carried out on the following platforms: CAPES, PubMed, Medline and Google Scholar journals. The articles were searched by entering the following combinations of terms in the search fields of these platforms: SIG/GIS, leptospirose/leptospirosis, area de risco/risk area and distribuicao espacial/spatial distribution.

The inclusion/exclusion criteria were applied in two stages. In the first stage, duplicate documents, newspaper articles and all abstracts for which it was not possible to retrieve the full article were excluded. In the second stage, the full articles retrieved were evaluated individually and included in the study, provided that they met the following inclusion criteria: a) publication in the last 20 years; b) identification of risk areas and/or spatial distribution of leptospirosis as one of the research topics; and c) application of GIS in the methodology.

To visualize the global progress in the application of GIS and spatial analysis techniques, a ranking table with the countries of origin of all the articles included in this review was created.

To provide a detailed description of the articles selected in this review, a table containing the year of publication, authors, country of origin, title, scientific publication journal, software and spatial analysis technique was created.

Multidisciplinary extension was checked by surveying the most cited terms in these articles that pointed out GIS and spatial analysis techniques for identifying risk areas of leptospirosis. To this end, we used the word cloud method, which groups words graphically according to their frequency. The larger the font, the higher the frequency of use of the word[24]. The statistical package R was used to perform this methodology[25].

From the flowchart (Figure 1), containing the flowchart of the systematic review, it can be observed that among 301 articles identified during the bibliographic survey, 220 were retrieved and evaluated individually, according to the inclusion criteria. After applying the second stage of inclusion, we obtained a total of 40 scientific articles that met the previously established inclusion criteria.

According to the results shown in Table 1, it is possible to note that from 2007, the use of GIS techniques, applied to the theme of this article, intensified and diversified over the years, and the eight softwares listed were employed with different regularities during the total period of the study. However, 37 of the 40 articles elected, which corresponds to approximately 93% of all articles, were found in the period from 2007 to 2017.

Prior to 2007, that is, between 1998 and 2006, there were only three publications, all of which from Brazil, related to the Oswaldo Cruz Foundation, a research institute on public health, representing 7% of the total.

The ArcGIS software had the highest number of users in the last 20 years, being employed in 21 of the 40 articles, which corresponds to approximately 53% of the total.

The year 2012 stands out in the study period for the largest production of scientific articles, involving the theme of identification of risk areas of leptospirosis coupled with GIS techniques, with a total of nine scientific articles. In these nine articles, the authors elected the following softwares as the data processing tool: ArcMap (4), ArcGIS (3) and ArcView (2). The USA was responsible for producing three of these articles involving the States of Kansas, Nebraska and California, while American Samoa and Brazil produced two articles each, and Nicaragua and Taiwan produced one article each.

In the last 20 years, the 40 articles have been published by 15 different countries (Figure 2) led by Brazil, which ranked first in the world ranking of scientific publications that used GIS techniques applied to the analysis of risk of leptospirosis (Table 2), being responsible for the production of 16 of the 40 articles. These publications of Brazilian origin did not follow a pattern in the choice of softwares, with great diversity over the years, but despite the presence of such variation, many of the objectives common to the studies, such as the construction of a risk map and distribution of cases, have been achieved.

The USA produced a total of seven scientific papers during the study period, being the second country with the largest publication focused on the theme of this review. The third and fourth places were not occupied by a single country; three of the 15 countries were in third place, with two articles published, and 10 countries were in fourth

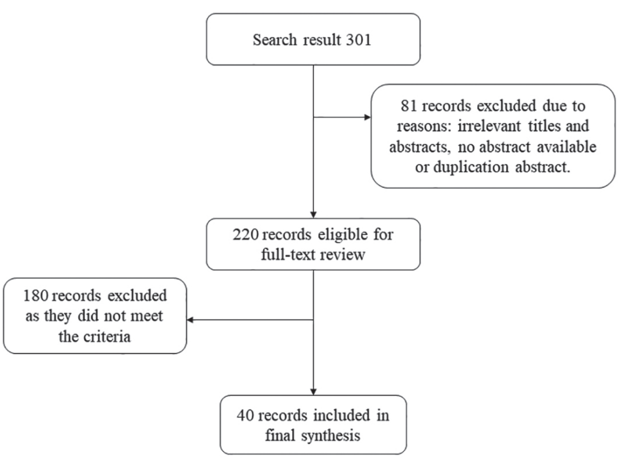

Figure 1 - Flowchart of the procedure for including articles in the study.

Table 1 - Temporal distribution of the softwares used in studies on risk areas of leptospirosis in the last 20 years worldwide.

	Years of the publications																				
Software	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	TOTAL
ArcGIS										2	2		1		3	1	4	3	4	1	21
ArcMap														1	4			1			6
ArcView											1				2		1				4
QGIS																		1			1
MapInfo			1	1									1								3
TerraView							1							1			1		1		4
ArcSDE																1					1
Kosmo																		1			1
Total	0	0	1	1	0	0	1	0	0	2	3	0	2	2	9	2	6	6	5	1	41

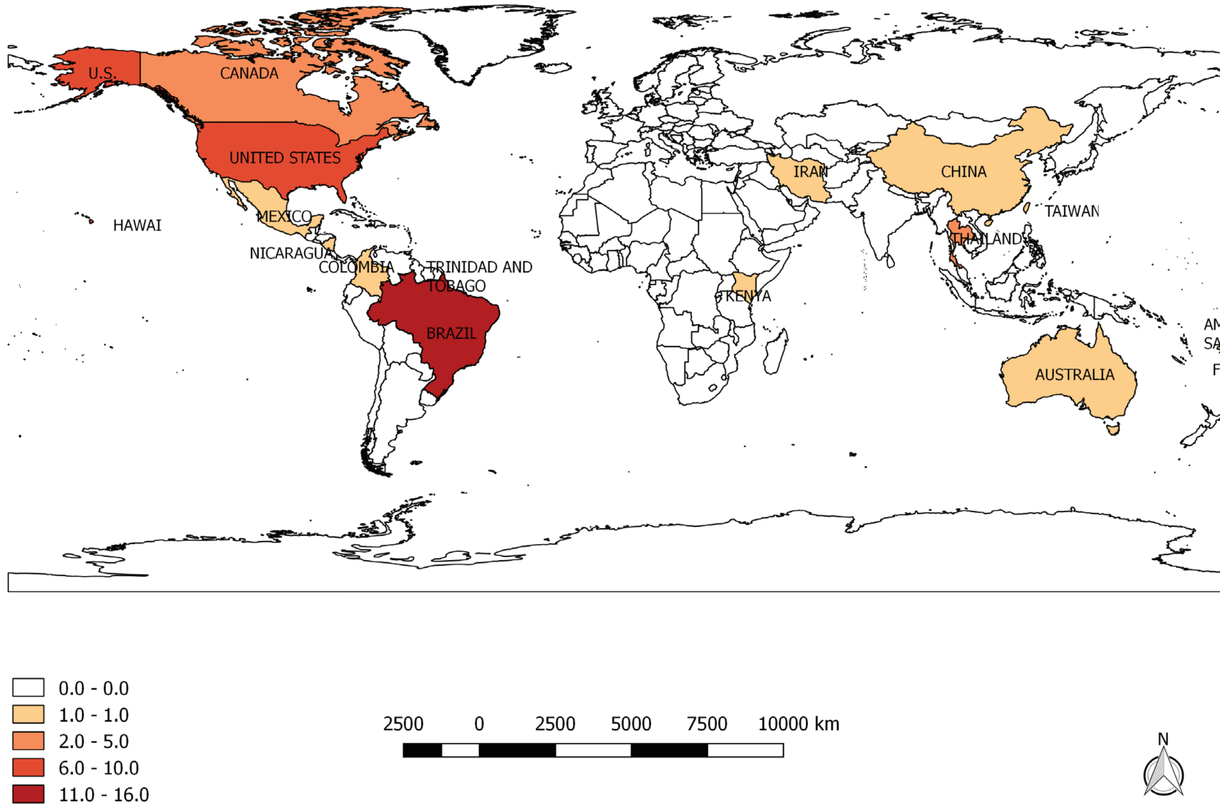

Figure 2 - Map of the global distribution in number of articles published by countries from 1998 to 2017.

Table 2 - Ranking of countries of origin of the scientific articles elected for this study.

Ranking	Country	Number of articles published (1998-2017)	Year(s) of publication
1st	Brazil	16 Articles	2000, 2001, 2004, 2008, 2010, 2011, 2012, 2014, 2015, 2016, 2017.
2nd	Usa	7 Articles	2007, 2008, 2011, 2012 and 2013.
3rd	Canada	2 Articles	2013 and 2014.
3rd	American Samoa	2 Articles	2012
3rd	Thailand	2 Articles	2008 and 2015.
4th	Kenya	1 Articles	2017
4th	China	1 Article	2016
4th	Fiji	1 Article	2016
4th	Iran	1 Article	2015
4th	Mexico	1 Article	2015
4th	Nicaragua	1 Article	2012
4th	Trinidad And Tobago	1 Article	2014
4th	Usa (Hawai)	1 Article	2007
4th	Australia	1 Article	2015
4th	Taiwan	1 Article	2012
4th	Colombia	1 Article	2015

place, with only one article published in the last 20 years. It was observed that 34 articles were in the human field and six were in the animal field.

Among the 40 articles, only 18 performed spatial statistical analysis, and nine of them used the Kernel density technique. In 22 articles, the authors only performed spatial analysis by constructing thematic maps and distributing cases on these maps to visualize the spatial pattern of

Figure 3 - Cloud of words representing the distribution of their frequencies in the abstracts of the analyzed articles.

leptospirosis distribution, as shown in the Supplementary Table. Despite this variation of complexity in the methodologies adopted, all studies achieved the objectives initially proposed by the authors.

Applying the word cloud technique (Figure 3) to the abstracts of the articles in this systematic review, it was possible to observe the frequent use of the following terms: "leptospirosis", "environmental", "spatial", "epidemiology", "*leptospira*", "GIS", "regression", "zoonotic", "dogs", "geographic", "health", "socioeconomical", "maps" and "ecological". This result shows that this type of study has a strong multidisciplinary character, i.e., the participation of professionals from various fields of human knowledge was essential for the elaboration of these studies.

DISCUSSION

In this study, through the analysis of the publications, we could observe that the origin of most articles coincides with the areas considered endemic for leptospirosis in the world, being located mainly in the Caribbean, Central and South Americas, South-Western Asia and Oceania, and that all countries cited in the ranking, except for Canada and the USA, are part of endemic regions, which leads us to conclude that, despite the small number of publications from some countries, albeit to a lesser extent, they are interested in the interdisciplinary integration arising from the application of GIS in the spatial analysis of leptospirosis[26,27].

According to previous studies, the highest morbidity and mortality rates related to leptospirosis occurs in the South and Southeast regions of Asia, Oceania, the Caribbean, Andean, Central and Tropical regions of Latin America, Africa and the Sub-Saharan East, and Brazil is in 17th place among the 28 countries with the highest annual incidence of human leptospirosis, while Seychelles and Trinidad and Tobago are in the 1st and 2nd places, respectively.

Although these studies point out Trinidad and Tobago as a country with a very high annual incidence of leptospirosis, this country has published only one article on leptospirosis incorporating GIS techniques into its methodology in the last 20 years, while Brazil, with an annual incidence of 12.8 per million, led the ranking of publications as shown in the present study. The authors have also found that the USA had an annual incidence of 0.1 per million, hence not being considered an endemic country. In contrast to this epidemiological reality, in the present study the USA ranked 2nd in number of publications on leptospirosis supported by GIS.

Brazil and the United States, over the years, have been working hard to combat human leptospirosis and animal leptospirosis, respectively, an effort evidenced by the partnership between the two countries, which have sought since 2002 to manufacture an effective vaccine that promotes human immunization and reduction in economic losses[28,29].

It should be pointed out that the urban occurrence of this disease was not restricted to only humans and that the broadening of the view on the state and control of the animal population health can occur due to the demographic and epidemiological transition phenomena, since the displacement of people from rural to urban areas has contributed to increasing the number of domestic animals in large cities and that they have also begun to show different patterns of prevalence of diseases, so the epidemiological transition occurs not only for humans, but also for animals. Therefore, the search for immunization, also for animals, is not only to reduce economic losses, but it is also a fair action that promotes protection and well-being for animals, besides being considered a health action measure[29].

The revised literature showed a contribution of the GIS in the identification of ecological characteristics favorable to the transmission of leptospirosis from the perspective of the production of different forms of data aggregation, building epidemiological indicators in different spatial units, according to the research interest, as well as in the verification of the existence of a spatial pattern and the performance of socio-environmental risk factors, culminating in the delimitation of critical areas.

Lau *et al*.[30], for example, by using the GIS, have punctually represented the cases and suggested that the strength of the impact of environmental and climate changes on American Samoa[31] and Australia[32] acted as a precursor in the transmission of private leptospirosis serovars, formerly absent in the region, reinforcing environmental changes as an important risk factor. These studies showed that regardless of the study area, the dynamics of the disease has a direct relationship with the environmental and climate changes in the environment, are contributing to the epidemiological understanding of the disease. Through the use of GIS, it was also possible to overlay maps of topographic characteristics, such as elevation and climate characteristics, such as rainfall indexes with case maps represented punctually or in the form of clusters that highly contributed to the understanding of the emergency, reemergence and distribution of leptospirosis over the years[33,34].

The absence of integration of human leptospirosis data with animal leptospirosis data in the studies of this review points to the lack of connection between the areas of health science and calls for a greater need to promote intersectoral actions among health professionals, such as physicians, veterinarians, geographers, cartographic engineers, statisticians, animal scientists, biologists, among others, with strategic actions in surveillance, research, communication and training[10]. This vision of integrated public health is at the heart of the One Health concept, which according to the One Health Commission is a collaborative, multisectoral, and trans-disciplinary approach - working at local, regional, national, and global levels - to achieve optimal health and well-being outcomes recognizing the interconnections between people, animals, plants and their shared environment[35]. In the context of leptospirosis, the results of one study may become a proxy for another study, even if one uses human data and the other uses animal data.

In addition, the survey of the main terms used in the articles of this review points to the great need for a multidisciplinary approach in research on spatial analysis of infectious diseases, and it is evident that health professional researchers today cannot be limited only to their area of knowledge, making it necessary to seek interdisciplinarity.

In terms of interdisciplinarity, it was found that over the last 20 years there has been a growing interest of human and animal health professionals in exploring GIS as a technique of spatial representation of leptospirosis data. This growing interest was not restricted to only free softwares because, as we noted, ArcGIS, a non-free software, was the most used tool in the studies of this review. According to Milaré *et al*.[36], the use of free softwares reached an average of 32% (2,128) of the 6,778 articles analyzed between 1978 and 2013, and the authors signaled a trend of an increasing use from the 1990s, corroborating the results of this study.

Although we have observed the growing interest in GIS, this review has also pointed out the need for greater incorporation of spatial statistics in human and animal health fields within the theme of this study, because less than half of the researchers employed geostatistics (45%). In addition, there was an underutilization of GIS potential, which were mostly used to create maps aiming only at visualizing the spatial pattern of leptospirosis, possibly due to the lack of technical preparation of researchers, who as software users should resort to specific training before data management. According to Najar and Marques[37], geoprocessing users who receive adequate training are able to conduct valid and free of inconsistency analyses in the procedures adopted.

A quick search of the Medline database using the terms 'GIS and infectious diseases' showed an evolution in the use of geoprocessing in general, in infectious diseases. However, from the total of 266 studies that used geoprocessing techniques, only four studies were on leptospirosis, reflecting its neglected disease condition.

The authors suggest that these types of studies are carried out more frequently in urban territories due to the availability of the data necessary for a greater efficiency of geoprocessing techniques, which explains the discrepancy in the number of studies concentrated in urban and rural areas in this review. Finally, we observed the publication of several studies using spatial analysis and leptospirosis, but the articles that deal with the use of geoprocessing tools in the identification of risk areas for leptospirosis (animal and human) are still scarce.

CONCLUSION

The results of this review suggest a positive trend in the use of GIS and spatial analysis by scientific professionals working with health environment for the control and surveillance of leptospirosis. The use of spatial statistical analysis techniques, combined with the use of GIS tools, can enable a more detailed view of the questions to be answered and will consequently favor a faster and more reliable decision-making by governments and institutes working in public health. Thus, the incentive to use such techniques should begin in the period of academic training of health professionals and thereafter with promotion of their continuing education in this area by the organizations and institutes that promote health, so that this technique will be seen as a tool that can be mastered by health professionals.

In this study, Brazil had the highest number of articles published, showing its potential for acting in the monitoring and epidemiological analyses of leptospirosis and, consequently, of other infectious diseases.

Finally, we emphasize that countries that promote interdisciplinary integration will advance and have greater chances for controlling diseases with a health surveillance system based on the integration of various areas of human knowledge using spatial analysis and GIS techniques.

AUTHORS' CONTRIBUTIONS

IPO designed the study, wrote the protocol, collected data, conducted the analysis and drafted the manuscript; WST designed the study, wrote the protocol and conducted the analysis; MSU was responsible for reviewing the manuscript.

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Supplementary Table - List of the elected articles with their respective descriptions regarding the year of publication, authors, country of origin, title, scientific journal, software and method of analysis in the 2007-2017 period

Year of Publication	Authors	Country	Title	Scientific Journal	Software	Method of Analysis
2000	Barcellos and Sabroza[33]	Brazil	Socio-environmental determinants of the leptospirosis outbreak of 1996 in western Rio de Janeiro: a geographical approach.	International Journal of Environmental Health Research.	MapInfo and SPSS	Statistical analysis to verify the correlation and significance by using the Pearson's coefficient and ANOVA, respectively. Spatial operations of variables distribution were performed with thematic maps entered in MapInfo.
2001	Barcellos and Sabroza[17]	Brazil	The place behind the case: leptospirosis risks and associated environmental conditions in a flood-related outbreak in Rio de Janeiro.	Cadernos de Saude Publica.	MapInfo.	Significance analysis using Poisson and map of risk.
2004	Tassinari et al.[38]	Brazil	Distribuição espacial da leptospirose no Município do Rio de Janeiro, Brasil, ao longo dos anos de 1996-1999.	Cadernos de Saude Publica.	TerraView, "R".	Kernel ratio.
2007	Littnan et al.[39]	USA (Hawai)	Survey for selected pathogens and evaluation of disease risk factors for endangered Hawaiian Monk Seals in the main Hawaiian Islands.	EcoHealth.	ArcGIS.	Kernel density
2007	Ghneim et al.[14]	USA	Use of a case-control study and geographic information systems to determine environmental and demographic risk factors for canine leptospirosis.	EDP Sciences, Veterinary Research.	EGRET, ArcGIS and JMP.	Bivariate and multivariate logistic regression models.
2008	Reis et al.[5]	Brazil	Impact of environment and social gradient on Leptospira infection in urban slums.	PLOS Neglected Tropical Diseases.	ArcView, EpiInfo, "R".	Chi-square correlation and Wilcoxon tests. Kernel density analysis and Spearman's correlation coefficient.
2008	Norman et al.[40]	USA	Risk factors for an outbreak of leptospirosis in California sea lions (Zalophus californianus) in California, 2004.	Journal of Wildlife Diseases.	ArcGIS, STATA.	Regression model and thematic maps.
2008	Lerdthusnee et al.[41]	Thailand	Surveys of rodent-borne disease in Thailand with a focus on scrub typhus assessment.	Integrative Zoology.	ArcGIS.	Kernel density.
2010	Soares et al.[6]	Brazil	Spatial and seasonal analysis of leptospirosis in the city of São Paulo, SP, 1998 to 2006	Revista de Saude Publica.	ArcGIS, MapInfo	Global and local Moran indices and the Spearman's correlation coefficient.
2011	Raghavan et al.[15]	USA	Evaluations of land cover risk factors for canine leptospirosis: 94 cases (2002-2009).	Preventive Veterinary Medicine.	ArcMap, Google Earth, "R"	Logistic regression model and distribution map.
2011	Melo et al.[42]	Brazil	Espacialização da leptospirose em Aracaju, Estado de Sergipe, no período de 2001 a 2007.	Revista da Sociedade Brasileira de Medicina Tropical.	TerraView.	Kernel density.
2012	Bier et al.[43]	Brazil	Spatial distribution of seropositive dogs to Leptospira spp. and evaluation of leptospirosis risk factors using a decision tree.	Acta Scientiae Veterinariae.	ArcView.	Matrix and decision tree.

Supplementary Table - List of the elected articles with their respective descriptions regarding the year of publication, authors, country of origin, title, scientific journal, software and method of analysis in the 2007-2017 period (cont.)

Year of Publication	Authors	Country	Title	Scientific Journal	Software	Method of Analysis
2012	Raghavan et al.[44]	USA	Evaluations of hydrologic risk factors for canine leptospirosis: 94 cases (2002-2009).	Preventive Veterinary Medicine.	ArcGis	Logistic regression model and map of distribution of cases.
2012	Roug et al.[45]	USA	Serosurveillance for livestock pathogens in free-ranging mule deer (Odocoileus hemionus).	PLOS One.	STATA and ArcMap	Logistic regression model and thematic map.
2012	Raghavan et al.[31]	USA	Neighborhood -level socioeconomic and urban land use risk factors of canine leptospirosis: 94 cases (2002-2009).	Preventive Veterinary Medicine.	ArcMap, TIGER, SAS and “R”.	Logistic regression model and spatial autocorrelation by geoR.
2012	Lau et al.[43]	Samoa	Leptospirosis in American Samoa - estimating and mapping risk using environmental data.	PLOS Neglected Tropical Diseases.	ArcMap, SaTScan, STATA, “R”.	Logistic regression model. Kulldorff’s scan statistic and SaTScan were used to identify clusters. Construction of thematic map.
2012	Lau et al.[46]	Samoa	Emergence of new leptospiral serovars American Samoa - ascertainment or ecological change?	BMC Infectious Diseases.	ArcMap, STATA.	Logistic regression model and thematic map.
2012	Fonzar and Langoni[47]	Brazil	Geographic analysis on the occurrence of human and canine leptospirosis in the city of Maringá, state of Paraná, Brazil.	Revista da Sociedade Brasileira de Medicina Tropical.	ArcView.	Risk areas were determined by the construction of thematic maps.
2012	Schneider et al.[48]	Nicaragua	Leptospirosis outbreak in Nicaragua: identifying critical areas and exploring drivers for evidence-based planning.	International Journal of Environmental Research and Public Health.	ArcGIS, SAS.	Logistic regression model and thematic map.
2012	Chen et al.[49]	Taiwan	Effects of extreme precipitation to the distribution of infectious diseases in Taiwan, 1994-2008.	PLOS One	ArcGIS.	Geospatial Kriging method.
2013	Raghavan et al.[50]	USA	Spatial scale effects in environmental risk-factor modelling for diseases.	Geospatial Health.	ArcSDE , ArcMap, “R”.	Construction of buffers by NLCD
2013	Himsworth et al.[13]	Canada	Ecology of Leptospira interrogans in Norway rats (Rattus novergicus) in an Inner-city neighborhood of Vancouver, Canada.	PLOS Neglected Tropical Diseases.	“R”, ArcGIS and SaTScan.	Logistic regression model. Identification of clusters by SaTScan.
2014	Himsworth et al.[51]	Canada	The characteristics of wild rat (Rattus spp.) populations from an Inner-city neighborhood with a focus on factors critical to the understanding of rat-associated zoonoses.	PLOS One.	ArcGIS and “R”.	Logistic regression model and map of distribution.
2014	Felzemburgh et al.[52]	Brazil	Prospective study of leptospirosis transmission in an urban slum community: role of poor environment in repeated exposures to the Leptospira agent.	PLOS Neglected Tropical Diseases.	ArcView	Logistic regression model and thematic map.

Supplementary Table - List of the elected articles with their respective descriptions regarding the year of publication, authors, country of origin, title, scientific journal, software and method of analysis in the 2007-2017 period (cont.)

Year of Publication	Authors	Country	Title	Scientific Journal	Software	Method of Analysis
2014	Oliveira Filho et al.[53]	Brazil	Spatial characterization of Leptospira spp. Infection in equids from the Brejo Paraibano micro-region in Brazil.	Geospatial Health	TerraView	Spatial statistical analysis with application of Kernel density.
2014	Gracie et al.[54]	Brazil	Geographical scale effects on the analysis of leptospirosis determinants.	International Journal of Environmental Research and Public Health.	ArcGIS, SPSS and ArcInfo.	Moran's index to test autocorrelation between data.
2014	Costa et al.[55]	Brazil	Influence of household rat infestation on Leptospira transmission in the urban slum environment.	PLOS Neglected Tropical Diseases.	ArcGIS and Epi-Info.	Logistic regression model and spatial analysis by ArcGIS.
2014	Vega-Corredor and Opadeyi[56]	Trinidad and Tobago	Hydrology and public health: linking human leptospirosis and local hydrological dynamics in Trinidad, West Indies.	Earth Perspectives.	ArcGIS.	Kernel density.
2015	Suwanpakdee et al.[32]	Thailand	Spatio-temporal patterns of leptospirosis in Thailand: is flooding a risk factor?	Epidemiology & Infection.	ArcGIS and Stata.	Logistic regression model and spatial analysis using ArcGIS.
2015	Lau et al.[57]	Australia	The emergency of Leptospirosa borgpetersenii serovar Arborea in Queensland, Australia, 2001 to 2013.	BMC Infectious Diseases.	ArcMap and Stata.	Logistic regression model and map of incidence of cases.
2015	Dutra et al.[58]	Brazil	A influência da variabilidade da precipitação no padrão de distribuição dos casos de leptospirose em Minas Gerais, no período de 1998-2012.	Revista Brasileira de Geografia Medica e da Saude	ArcGIS.	Spatialization of cases by ArcGIS.
2015	Sánches-Montes et al.[59]	Mexico	Leptospirosis in Mexico: epidemiology and potential distribution of human cases.	PLOS One.	QGIS, GARP and SPSS.	Creation of potential distribution model by GARP and map of distribution of cases.
2015	Nia et al.[60]	Iran	Spatial and statistical analysis of Leptospirosis in Guilan Province, Iran.	Remote Sensing and Spatial Information Sciences.	ArcGIS,	Use of Moran technique to identify clusters and spatial autocorrelation.
2015	García-Ramirez et al.[61]	Colombia	Geographical and occupational aspects of Leptospirosis in the Coffee-Triangle region of Colombia, 2007-2011.	Recent Patents on Anti-Infective Drug Discovery.	Kosmo	Construction of regional and epidemiological map with rate of annual incidence of cases.
2016	Gonçalves et al.[34]	Brazil	Distribuição espaço-temporal da leptospirose e fatores de risco em Belém, Pará, Brasil	Ciencia & Saude Coletiva.	TerraView, EpiInfo and Biostat.	Moran's estimation technique to measure spatial autocorrelation.
2016	Hagan et al.[62]	Brazil	Spatiotemporal determinants of urban leptospirosis transmission: four-year prospective cohort study of slum residents in Brazil.	PLOS Neglected Tropical Diseases.	ArcGIS.	Construction of choropleth map of risk distribution.
2016	Lau et al.[63]	Fiji	Human leptospirosis infection in Fiji: an ecoepidemiological approach to identifying risk factors and environmental drivers for transmission.	PLOS Neglected Tropical Diseases.	ArcGIS and STATA	Production of risk map through analysis of risk factors by regression model.

Supplementary Table - List of the elected articles with their respective descriptions regarding the year of publication, authors, country of origin, title, scientific journal, software and method of analysis in the 2007-2017 period (cont.)

Year of Publication	Authors	Country	Title	Scientific Journal	Software	Method of Analysis
2016	Zhao et al.[64]	China	Mapping risk of leptospirosis in China using environmental and socioeconomic data.	BMC Infectious Diseases.	ArcGIS and "R".	Identification of risk areas by ecological niche model.
2017	Cook et al.[65]	Kenya	Risk factors for leptospirosis seropositivity in slaughterhouse workers in western Kenya.	Occupational and Environmental Medicine.	ArcGIS and "R".	Application of Kernel technique by R and Moran.
2017	Chaiblich et al.[66]	Brazil	Estudo espacial de riscos à leptospirose no município do Rio de Janeiro (RJ).	Saude em Debate.	ArcGIS	Empirical Bayesian estimator and Kernel density.