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.

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 Icterohaemorrhagiae, Copenhageni, Australis, Autumnalis, Bataviae, Lai and Pyrogenes1,2. 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* *icterohaemorrhagiae*2,3. The main form of
transmission to man is the contact with water, soil and food contaminated by the urine of the reservoirs.

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. 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.

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. 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.

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.

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.

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, areas de risco/risk area and distribuição 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. The statistical package R was used to perform this methodology.

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 place.

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 | 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    | 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    | 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    |
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
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.

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.

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.
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.\textsuperscript{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\textsuperscript{31} and Australia\textsuperscript{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\textsuperscript{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\textsuperscript{35}. 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\textsuperscript{36}. 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 \textit{et al.}\textsuperscript{37}, 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\textsuperscript{38}, 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.

FINANCIAL SUPPORT

From the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), grant Nº 88882.183657/2018-01.

REFERENCES

1. Coura JR, editor. Dinâmica das doenças infecciosas e parasitárias. Rio de Janeiro: Guanabara Koogan; 2005.
2. Oliveira SV, Arsky EP, Caldas EP. Reservatórios animais da leptospirose: uma revisão bibliográfica. Saude (Santa Maria). 2013;39:9-20.
3. Brasil. Ministério da Saúde. Secretaria de Vigilância em Saúde. Coordenação-Geral de Desenvolvimento da Epidemiologia em Serviços. Guia de vigilância em saúde: volume único. 3º ed. Brasília: Ministério da Saúde; 2019. [cited 2020 April 17]. Available from: https://portalquivos2.saude.gov.br/images/pdf/2019/junho/25/guia-vigilancia-saude-volume-unico-3ed.pdf
4. Snow J. Sobre a maneira de transmissão do cólera. São Paulo: Hucitec-Abrasco; 1990.
5. Reis RB, Ribeiro GS, Felzemburgh RD, Santana FS, Mohr S, Melendez AX, et al. Impact of environmental and social gradient on Leptospira infection in urban slums. PloS Negl Trop Dis. 2008;2:e228.
6. Soares TS, Latorre MR, Laporta GZ, Buzzar MR. Spatial and seasonal analysis on leptospirosis in the municipality of São Paulo, Southeastern Brazil, 1998 to 2006. Rev Saude Publica. 2010;44:283-91.
7. Vasconcelos CH, Fonseca FR, Lise ML, Arsky ML. Fatores ambientais e socioeconômicos relacionados à distribuição de casos de leptospirose no Estado de Pernambuco, Brasil, 2001-2009. Cad Saude Colet. 2012;20:49-56.
8. Flauzino RG, Souza-Santos R, Oliveira RS. Dengue, geoprocessamento e indicadores socioeconômicos e ambientais: um estudo de revisão. Rev Panam Salud Publica. 2009;25:456-61.
9. Fitz PR. Geoprocessamento sem complicação. São Paulo: Oficina de Textos; 2008.
10. Zanella JR. Zoonoses emergentes e reemergentes e sua importância para saúde e produção animal Pesq Agropec Bras. 2016;51:510-9.
11. Hu Y, Li R, Bergquist R, Lynn H, Gao F, Wang Q, et al. Spatio-temporal transmission and environmental determinants of Schistosomiasis Japonica in Anhui Province, China. PLoS Negl Trop Dis. 2015;9:e0003470.
12. Tolnai Z, Széll Z, Sréter T. Environmental determinants of the spatial distribution of Angiostrongylus vasorum, Crenosoma vulpis and Eucoleus aerophilus in Hungary. Vet Parasitol. 2015;207:355-8.
13. Himsworth CG, Bidulka J, Feng AY, Tang P, Jardine CM, Kerr T, et al. Ecology of Leptospira interrogans in Norway rats (Rattus norvegicus) in an inner-city neighborhood of Vancouver, Canada. PLoS Negl Trop Dis. 2013;7:e2270.
14. Ghneim GS, Viers JH, Chomel BB, Kass PH, Descollonges DA, Johnson ML. Use of a case-control study and geographic information systems to determine environmental and demographic risk factors for canine leptospirosis. Vet Res. 2007;38:37-50.
15. Raghavan R, Brenner K, Higgins J, Van der Merwe D, Harkin KR. Evaluations of land cover risk factors for canine leptospirosis: 94 cases (2002-2009). Prev Vet Med. 2011;101:241-9.
16. Szakai S, Suzuki H, Igarashi K, Tambatamba B, Mulenga P. Spatial analysis of risk factor of cholera outbreak for 2003-2004 in a peri-urban área of Lusaka, Zambia. Am J Trop Med Hyg. 2008;79:414-21.
17. Barcellos C, Sabroza PC. The place behind the case: leptospirosis risks and associated environmental conditions in a flood-related outbreak in Rio de Janeiro. Cad Saude Publica. 2001;17 Suppl:59-67.
18. Araújo KC, Resendes AP, Souza-Santos R, Júnior JC, Barbosa CS. Análise espacial dos focos de Biomphalaria glabrata e de casos humanos de esquistossomose mansônica em Porto de Galinhas, Pernambuco, Brasil, no ano 2000. Cad Saude Publica. 2007;23:409-17.
19. Hino P, Villa TC, Cunha TN, Santos CB. Distribuição espacial
36. Milaré G, Silva NM, Paranhos Filho AC. Cenário do uso de software livre em sistemas de informações geográficas (SIG) no Brasil. Anu Inst Geocien UFRJ. 2016;39:111-5.
37. Najer AL, Marques EC, organizadores. Saúde e espaço: estudos metodológicos e técnicas de análise. Rio de Janeiro: Editora FIOCRUZ; 1998.
38. Tassiniari WS, Pellegrini DC, Sabroza PC, Carvalho MS. Distribuição espacial da leptospirose no Município do Rio de Janeiro, Brasil, ao longo dos anos de 1996-1999. Cad Saude Publica. 2004;20:1721-9.
39. Littnan CL, Stewart BS, Yochem PK, Braun R. Survey for selected pathogens and evaluation of disease risk factors for endangered Hawaiian Monk Seals in the main Hawaiian Islands. EcoHealth. 2006;3:232-44.
40. Norman SA, DiGiacomo RF, Gulland FM, Meschke JS, Lowry MS. Risk factors for an outbreak of leptospirosis in California sea lions (Zalophus californianus) in California, 2004. J Wildl Dis. 2008;44:837-44.
41. Lerdhusnee K, Ngojo J, Monkanna T, Leepitakrat W, Leepitakrat S, Insuan S, et al. Surveys of rodent-borne disease in Thailand with a focus on scrub typhus assessment. Integr Zool. 2008;3:267-73.
42. Melo CB, Reis RB, Ko AI, Barreto CM, Lima AP, Silva AM. Espacialização da leptospirose em Aracaju, Estado de Sergipe, no período de 2001 a 2007. Rev Soc Bras Med Trop. 2011;44:475-80.
43. Bier D, Martins-Bedê FT, Morikawa VM, Ullmann LS, Kikuti M, Langoni H, et al. Spatial distribution of seropositive dogs for livestock pathogens in free-ranging mule deer (Odocoileus hemionus). PLoS One. 2012;7:e50600.
44. Raghavan RK, Brenner KM, Higgins JJ, Hutchinson JM, Harkin KR. Evaluations of hydrologic risk factors for canine leptospirosis: 94 cases (2002-2009). Prev Vet Med. 2012;107:105-9.
45. Roug A, Swift P, Torres S, Jones K, Johnson CK. Serosurveillance for livestock pathogens in free-ranging mule deer (Odocoileus hemionus). PLoS One. 2012;7:e50600.
46. Lau CL, Skelly C, Smythe LD, Craig SB, Weinstein P. Emergence of new leptosomal serovars American Samoa: ascertainment or ecological change? BMC Infect Dis. 2012;12:19.
47. Fonzar UJ, Langoni H. Geographic analysis on the occurrence of human and canine leptospirosis in the city of Maringá, state of Paraná, Brazil. Rev Soc Bras Med Trop. 2012;45:100-5.
48. Schneider MC, Nájera P, Alldighieri S, Bacallao J, Soto A, Marquiño W, et al. Leptospirosis outbreak in Nicaragua: identifying critical areas and exploring drivers for evidence-based planning. Int J Environ Res Public Health. 2012;9:3883-910.
50. Raghavan RK, Brenner KM, Harrington JA Jr, Higgins JJ, Harkin KR. Spatial scale effects in environmental risk-factor modelling for diseases. Geospat Health. 2013;7:169-82.

51. Himsworth CG, Jardine CM, Parsons KL, Feng AY, Patrick DM. 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. 2014;9:e91654.

52. Felzemburgh RD, Ribeiro GS, Costa F, Reis RB, Hagan JE, Melendez AX, et al. Prospective study of leptospirosis transmission in an urban slum community: role of poor environment in repeated exposures to the Leptospira agent. PloS Negl Trop Dis. 2014;8:e2927.

53. Oliveira Filho RB, Malta KC, Santana VL, Harrop MH, Stipp DT, Brandespim DF, et al. Spatial characterization of Leptospira spp. infection in equids from the Brejo Paraibano micro-region in Brazil. Geospat Health. 2014;8:463-9.

54. Gracie R, Barcellos C, Magalhães M, Souza-Santos R, Barrocas PR. Geographical scale effects on the analysis of leptospirosis determinants. Int J Environ Res Public Health. 2014;11:10366-83.

55. Costa F, Ribeiro GS, Felzemburgh RD, Santos N, Reis RB, Santos AC, et al. Influence of household rat infestation on Leptospira transmission in the urban slum environment. PloS Negl Trop Dis. 2014;8:e3338.

56. Vega-Corredor MC, Opadeyi J. Hydrology and public health: linking human leptospirosis and local hydrological dynamics in Trinidad, West Indies. Earth Perspect. 2014;1:3.

57. Lau CL, Skelly C, Doch M, Smythe LD. The emergency of Leptospira borgpetersenii serovar Arborea in Queensland, Australia, 2001 to 2013. BMC Infect Dis. 2015;15:230.

58. Dutra FR, Valadão RC, Conflonieri UE, Müller GV, Quadro MF. A influência da variabilidade da precipitação no padrão de distribuição dos casos de leptospirose em Minas Gerais, no período de 1998-2012. Hygeia. 2015;11:106-26.

59. Sánchez-Montes S, Espinosa-Martínez DV, Ríos-Muñoz CA, Berzunza-Cruz M, Becker I. Leptospirosis in Mexico: epidemiology and potential distribution of human cases. PLoS One. 2015;10:e0133720.

60. Nia AM, Alimohammadi A, Habibi R, Shirzadi MR. Spatial and statistical analysis of Leptospirosis in Guilan Province, Iran. Int Arch Photogramm Remote Sens Spat Inf Sci. 2015;40:497-502.

61. García-Ramírez LM, Giraldo-Pulgarin JY, Agudelo-Márín N, Holguin-Rivera YA, Gómez-Sierra S, Ortiz-Revelo PV, et al. Geographical and occupational aspects of leptospirosis in the Coffee-Triangle region of Colombia, 2007-2011. Recent Pat Antiinfect Drug Discov. 2015;10:42-50.

62. Hagan JE, Moraga P, Costa F, Capian N, Ribeiro GS, Wunder Jr EA, et al. Spatiotemporal determinants of urban leptospirosis transmission: four-year prospective cohort study of slum residents in Brazil. PloS Negl Trop Dis. 2016;10:e0004275.

63. Lau CL, Watson CH, Lowry JH, David MC, Craig SB, Wynwood SJ, et al. Human leptospirosis infection in Fiji: an ecoepidemiological approach to identifying risk factors and environmental drivers for transmission. PloS Negl Trop Dis. 2016;10:e0004405.

64. Zhao J, Liao J, Huang X, Zhao J, Wang Y, Ren J, et al. Mapping risk of leptospirosis in China using environmental and socioeconomic data. BMC Infect Dis. 2016;16:343.

65. Cook EA, Glanville WA, Thomas LF, Kariuki S, Bronsvoort BM, Fèvre EM. Risk factors for leptospirosis seropositivity in slaughterhouse workers in western Kenya. Occup Environ Med. 2017;74:357-65.

66. Chaiblich JV, Lima ML, Oliveira RF, Monken M, Penna ML. Estudo espacial de riscos à leptospirose no município do Rio de Janeiro (RJ). Saude Debate. 2017;41 N Esp 2:225-40.
### 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<sup>33</sup> | 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<sup>17</sup> | Brazil  | The place behind the case: leptospirosis risks and associated environmental conditions in a flood-related outbreak in Rio de Janeiro. | Cadernos de Saúde Publica. | MapInfo. | Significance analysis using Poisson and map of risk. |
| 2004               | Tassinari et al.<sup>38</sup> | Brazil  | Distribuição espacial da leptospirose no Município do Rio de Janeiro, Brasil, ao longo dos anos de 1996-1999. | Cadernos de Saúde Publica. | TerraView, “R”. | Kernel ratio. |
| 2007               | Littnan et al.<sup>39</sup> | 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.<sup>14</sup> | 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.<sup>5</sup> | Brazil  | Impact of environment and social gradient on Leptospira infection in urban slums. | PLOS Neglected Tropical Diseases. | ArcView, Epilinfo, “R”. | Chi-square correlation and Wilcoxon tests. Kernel density analysis and Spearman's correlation coefficient. |
| 2008               | Norman et al.<sup>40</sup> | 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.<sup>41</sup> | Thailand | Surveys of rodent-borne disease in Thailand with a focus on scrub typhus assessment. | Integrative Zoology. | ArcGIS. | Kernel density. |
| 2010               | Soares et al.<sup>6</sup> | Brazil  | Spatial and seasonal analysis of leptospirosis in the city of São Paulo, SP, 1998 to 2006 | Revista de Saúde Publica. | ArcGIS, MapInfo | Global and local Moran indices and the Spearman's correlation coefficient. |
| 2011               | Raghavan et al.<sup>15</sup> | 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.<sup>42</sup> | 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.<sup>43</sup> | 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. | 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. | 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. | 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. | Samoa | Leptospirosis in American Samoa - estimating and mapping risk using environmental data. | PLOS Neglected Tropical Diseases. | ArcMap, SaTScan, STATA, "R". | Logistic regression model and thematic map. |
| 2012                | Lau et al. | 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 | 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. | 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. | 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. | 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. | Canada | Ecology of Leptospira interrogans in Norway rats (Rattus norvegicus) 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. | 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. | 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. | 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. | 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. | 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 | 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. | 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. | Australia | The emergency of Leptospira 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. | 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 Médica e da Saúde | ArcGIS. | Spatialization of cases by ArcGIS. |
| 2015                | Sánchez-Montes et al. | 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. | 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                | Garcia-Ramirez et al. | 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. | Brazil | Distribuição espaço-temporal da leptospirose e fatores de risco em Belém, Pará, Brasil | Ciencia & Saúde Coletiva. | TerraView, Epinfo and Biosat. | Moran's estimation technique to measure spatial autocorrelation. |
| 2016                | Hagan et al. | 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. | 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. | 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. | 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. | Brazil | Estudo espacial de riscos à leptospirose no município do Rio de Janeiro (RJ). | Saude em Debate. | ArcGIS | Empirical Bayesian estimator and Kernel density. |