

## MODELOS ESTATÍSTICOS E ESPACIAIS IMPULSIONAM REDES DE PESQUISA SOBRE LEISHMANIOSE CUTÂNEA E ALTERAÇÕES AMBIENTAIS (1999–2024)

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### RESUMO

A Leishmaniose Cutânea é uma doença tropical negligenciada, de ampla distribuição geográfica, que tem despertado crescente interesse da comunidade científica em diferentes regiões do mundo. Esta revisão bibliométrica teve como objetivo identificar as principais tendências de pesquisa relacionadas à Leishmaniose Cutânea e às alterações ambientais, sintetizando a produção científica e mapeando redes colaborativas com base em estudos indexados na base Scopus (Elsevier). A seleção dos artigos foi realizada por três revisores independentes utilizando a plataforma Rayyan, enquanto a análise e visualização das redes de coautoria e da coocorrência de palavras-chave foram conduzidas por meio das ferramentas Bibliometrix, VOSviewer<sup>®</sup> e Microsoft Excel 2010<sup>®</sup>. Os resultados evidenciam um crescimento consistente das publicações desde o final da década de 1990, com predominância do idioma inglês e destaque para o periódico *Acta Tropica*. As redes colaborativas mais robustas são lideradas por pesquisadores e instituições do Brasil e dos Estados Unidos. A análise semântica da coocorrência de palavras-chave, aliada à síntese dos artigos mais citados, indica uma expansão de estudos epidemiológicos, impulsionada pela incorporação de abordagens estatísticas e espaciais e pela ampliação da disponibilidade de dados. Conclui-se que a pesquisa sobre Leishmaniose Cutânea vem se consolidando como um campo interdisciplinar, contribuindo para a compreensão da dinâmica contemporânea da doença e antecipação de cenários futuros.

**Palavras-chave:** *Leishmania*; Doenças Tropicais Negligenciadas; Determinantes Ambientais Bibliometria; Colaboração em Pesquisa.

### STATISTICAL AND SPATIAL MODELS DRIVE RESEARCH NETWORKS ON CUTANEOUS LEISHMANIASIS AND ENVIRONMENTAL CHANGES (1999–2024)

### ABSTRACT

Cutaneous Leishmaniasis is a neglected tropical disease with a wide geographic distribution that has attracted increasing attention from the scientific community across different regions of the world. This bibliometric review aimed to identify the main research trends related to Cutaneous Leishmaniasis and environmental changes, synthesizing the scientific production and mapping collaborative networks based on studies indexed in the Scopus (Elsevier) database. Article selection was conducted by three independent reviewers using the Rayyan platform, while co-authorship networks and keyword co-occurrence were analyzed and

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visualized using Bibliometrix, VOSviewer, and Microsoft Excel 2010. The results demonstrate a consistent increase in publications since the late 1990s, with English as the predominant language and *Acta Tropica* as the most frequent journal. The most robust collaborative networks are led by researchers and institutions from Brazil and the United States. Semantic analysis of keyword co-occurrence, combined with a synthesis of the most cited articles, indicates an expansion of epidemiological studies driven by the integration of statistical and spatial approaches and the increasing availability of data. Research on Cutaneous Leishmaniasis has become increasingly interdisciplinary, contributing to a better understanding of the current dynamics of the disease and supporting the anticipation of future scenarios.

**Keywords:** *Leishmania*; Neglected Tropical Diseases; Environmental Determinants; Bibliometrics; Research Collaboration.

## LOS MODELOS ESTADÍSTICOS Y ESPACIALES IMPULSAN REDES DE INVESTIGACIÓN SOBRE LEISHMANIASIS CUTÁNEA Y CAMBIOS AMBIENTALES (1999–2024)

### RESUMEN

La Leishmaniasis Cutánea es una enfermedad tropical desatendida, de amplia distribución geográfica, que ha despertado un creciente interés en la comunidad científica en diferentes regiones del mundo. Esta revisión bibliométrica tuvo como objetivo identificar las principales tendencias de investigación relacionadas con la Leishmaniasis Cutánea y los cambios ambientales, sintetizando la producción científica y mapeando redes de colaboración a partir de estudios indexados en la base de datos Scopus (Elsevier). La selección de los artículos fue realizada por tres revisores independientes utilizando la plataforma Rayyan, mientras que el análisis y la visualización de las redes de coautoría y de la coocurrencia de palabras clave se llevaron a cabo mediante Bibliometrix, VOSviewer y Microsoft Excel 2010. Los resultados evidencian un crecimiento sostenido de las publicaciones desde finales de la década de 1990, con predominio del idioma inglés y destacándose la revista *Acta Tropica*. Las redes de colaboración más robustas están lideradas por investigadores e instituciones de Brasil y Estados Unidos. El análisis semántico de la coocurrencia de palabras clave, junto con la síntesis de los artículos más citados, indica una expansión de los estudios epidemiológicos, impulsada por la integración de enfoques estadísticos y espaciales y por la creciente disponibilidad de datos. La investigación sobre la Leishmaniasis Cutánea se ha consolidado como un campo interdisciplinario, contribuyendo a la comprensión de la dinámica actual de la enfermedad y a la anticipación de escenarios futuros.

**Palabras clave:** *Leishmania*; Enfermedades Tropicales Desatendidas; Determinantes Ambientales; Bibliometria; Colaboración en Investigación.

### INTRODUCTION

Leishmaniasis is a group of infectious disease that affecting humans and other mammals, and is present in several countries worldwide. It's most common form, Cutaneous Leishmaniasis (CL), is endemic in approximately 90 countries across the Americas, Africa, Southeast Asia, the Eastern Mediterranean, and parts of Europe. According to the World Health Organization <sup>(1)</sup>, it is estimated that between 700,000 and one million people are at risk of contracting the disease each year.

CL is transmitted by the bite of infected female phlebotomine sandflies, which serve as

vectors of protozoa from the genus *Leishmania*, the etiological agent responsible for skin lesions or ulcers and, in some cases, spread throughout the body in infected hosts. The complexity of the CL transmission cycle stems from the diversity of parasites, vectors, reservoirs, and hosts involved<sup>(2,3)</sup>. Currently, around 20 species of *Leishmania* are recognized as responsible for human infections on a global scale<sup>(4)</sup>. This complexity is further compounded by social, economic, and environmental factors, making eradication a major challenge<sup>(5)</sup>. Nevertheless, CL mobilizes one of the most consolidated research networks in Brazil<sup>(6)</sup> and has been drawing increasing attention within the field of international tropical medicine.

Leishmaniasis have been studied by the Western medical-scientific community since the early 20th century. The first documented cases of cutaneous and mucocutaneous leishmaniasis in the Americas date back to 1909, when Latin American physicians described typical clinical manifestations in forested regions, referring to them as "Bauru ulcers." Since then, researchers in different parts of the world have contributed to the identification of new *Leishmania* species, a deeper understanding of the disease's biological and epidemiological cycles, and the development of therapies and control strategies<sup>(6,7)</sup>.

In recent years, several studies have conducted bibliometric analyses of scientific production on leishmaniasis using international databases<sup>(8-10)</sup>. These studies reveal a strong presence of topics such as immunology, molecular biology, and public health, as well as the expansion of scientific collaboration networks in endemic countries. However, an important gap remains: the lack of focus on the interactions between CL and EC, particularly in light of the current climate change scenario and its impact on the distribution of vector insects and disease incidence.

Given this context, it is essential to identify the state of scientific research at this intersection, understanding how the academic community has addressed the influence of environmental factors, such as climate, land use, and land cover (LULC), on the dynamics of CL. In this regard, bibliometrics emerges as a valuable tool to map, describe, and analyze the global scientific output related to CL and its associations with EC. According to Passas, bibliometrics approach enables a structured and comprehensive analysis of the scientific literature, synthesizing large volumes of information through both quantitative and qualitative metrics that assess publication volume, collaboration patterns among authors, institutions, and countries, and the overall relevance and impact of research in the field<sup>(11)</sup>.

Considering the complexity of the disease and the growing concern over the effects of environmental changes on its epidemiology, bibliometric analysis can provide crucial insights for understanding the evolution of knowledge, identifying gaps, mapping emerging areas, and guiding future research in a strategic and evidence-based manner.

In this context, the present study aimed to identify the main research trends on CL in association with EC. The bibliometric review was conducted through the analysis of scientific publications indexed in the Scopus database (Elsevier), focusing on the characterization of collaboration networks and the mapping of scientific evidence. The guiding research questions were: What are the main findings in the literature on the links between CL, climate change, and land use and cover? Who are the leading researchers, countries, and institutions in this field? Are there temporal trends in publications on this topic? What methodologies have been employed by research groups?

## METHODOLOGY

### Data Collection

Figure 1 presents the Methodological Flowchart of Bibliometric Analysis. Data

collection for this review was carried out using the Scopus database (Elsevier), which is recognized as one of the most comprehensive scientific bibliographic repositories, covering areas such as medical sciences, engineering, and the social sciences. The choice of Scopus was based on its international coverage, the rigor in selecting academic sources, and its integration with specialized databases such as Embase, Compendex, World Textile Index, Fluidex, Geobase, Biobase, and Medline, making it a reliable tool for bibliometric analysis<sup>(12)</sup>.



Figure 1. Methodological Flowchart of Bibliometric Analysis. Image taken in <https://www.canva.com/>The image outlines the protocol for data collection, processing, and analysis of records retrieved from Scopus between 1999 and September 2024.

To formulate the search strategies, the Health Sciences Descriptors/Medical Subject Headings (DeCS/MeSH) terms “Cutaneous Leishmaniasis”, “Diffuse Cutaneous Leishmaniasis”, “Mucocutaneous Leishmaniasis”, and “Leishmaniasis” were used in combination with the following keywords: *Leishmania*, “climate change”, “global warming”, “environmental change”, “soil use”, and “land use”. Searches were conducted within the title, abstract, and keyword fields using the following combinations:

1. "Cutaneous Leishmaniasis" OR "Diffuse Cutaneous Leishmaniasis" OR

"Mucocutaneous Leishmaniasis" AND "soil use" OR "land use"

2. "Cutaneous Leishmaniasis" OR "Diffuse Cutaneous Leishmaniasis" OR "Mucocutaneous Leishmaniasis" AND "climate change" OR "environmental change"

Only primary research articles published up to the year 2024, indexed in the Scopus database, were included in this review. No temporal restrictions were applied, and publications in English, Spanish, or Portuguese were considered.

### Selection Criteria and Data Extraction

Title and abstract screening were conducted using the Rayyan platform<sup>(13)</sup>, which facilitates collaborative review among authors. Initially, duplicate records were removed. Then, two researchers independently screened titles and abstracts in a blinded manner, with any conflicts resolved by a third reviewer. Review articles, brief communications, clinical trials, conference papers, and studies falling outside the thematic scope of this review were excluded. Only primary studies addressing, directly or indirectly, climatic and LULC factors in the context of CL were included.

### Data Analysis

Data analysis was conducted using a combination of network visualization, mapping, and graphical tools, as proposed by Passas<sup>(11)</sup>. The selected articles were exported in .csv format for bibliometric analysis using VOSviewer<sup>®</sup> (version 1.6.20)<sup>(14)</sup> which enables the construction and visualization of co-authorship networks, keyword co-occurrence, and institutional collaborations, and the *Bibliometrix R package* (version 4.1.3)<sup>(15)</sup>, which supports the analysis of research trends, author productivity, and citation and collaboration structures.

Key metrics extracted included keyword co-occurrence, co-authorship among authors, countries, and institutions, and cluster analysis. Visualizations generated in VOSviewer<sup>®</sup> were exported and used to compose figures in this review. Metadata were organized in Microsoft Excel 2010<sup>®</sup> spreadsheets and supplemented with maps and graphs produced in *ggplot<sup>2</sup> R package*<sup>(16)</sup>, including the h-index and the relevance of the most cited sources.

In the networks generated, nodes represent authors, institutions, countries, or keywords; edges (or links) indicate the strength of connections, such as co-authorship or keyword co-occurrence. The thickness of the edges reflects the intensity of relationships, and the proximity between nodes indicates a higher degree of association. Node size corresponds to the frequency of element occurrence, while colors denote different thematic clusters<sup>(14,17)</sup>.

In the co-authorship analysis, we aimed to identify the leading researchers, institutions, and countries contributing to studies on CL and EC, as well as to understand the structure and density of their collaborative networks. The full counting method in VOSviewer<sup>®</sup> was used, with a minimum of one publication per analyzed category. A thesaurus file was applied to standardize author and institutional name variations and prevent duplication. The influence of authors and institutions was measured by the number of publications and citations, as proposed by Donthu et al.<sup>(17)</sup>, and the ten most influential authors, countries, and institutions were highlighted.

In the keyword co-occurrence analysis, the unit of analysis was set as "author keyword," using full counting, with a minimum of one occurrence per term. Redundancy was minimized using a synonym thesaurus file. This analysis enabled the identification of key topics and recurring methodological approaches in studies linking CL and EC.

Finally, a sample corresponding to the top 20% most-cited articles from the period 1999 to 2024 was selected for full-text reading and qualitative synthesis. Data extraction included: title, authors, journal, year of publication, number of citations, geographic area of study,

analytical method, institutional affiliation, and main findings reported in the studies.

## RESULTS

### Number of Publications, Metrics, and Collaborative Networks in the Literature on Cutaneous Leishmaniasis and Environmental Change (1999–2024)

The data retrieval process identified 190 articles indexed in the Scopus database between 1999 and September 2024. After the removal of duplicate records and blind screening of titles and abstracts, 111 articles were included in the bibliometric analysis. However, six of these articles were excluded from the statistical analysis and evidence synthesis due to insufficient metadata. The authors cited in the following sessions correspond to the corpus analyzed and are presented as results of the bibliometric analysis.

Figure 2 shows the distribution curve of publications addressing CL and EC over the 1999–2024 period. A consistent increase in publication output is observed starting in 2014, with notable peaks in 2016, 2017, 2021, and 2022.

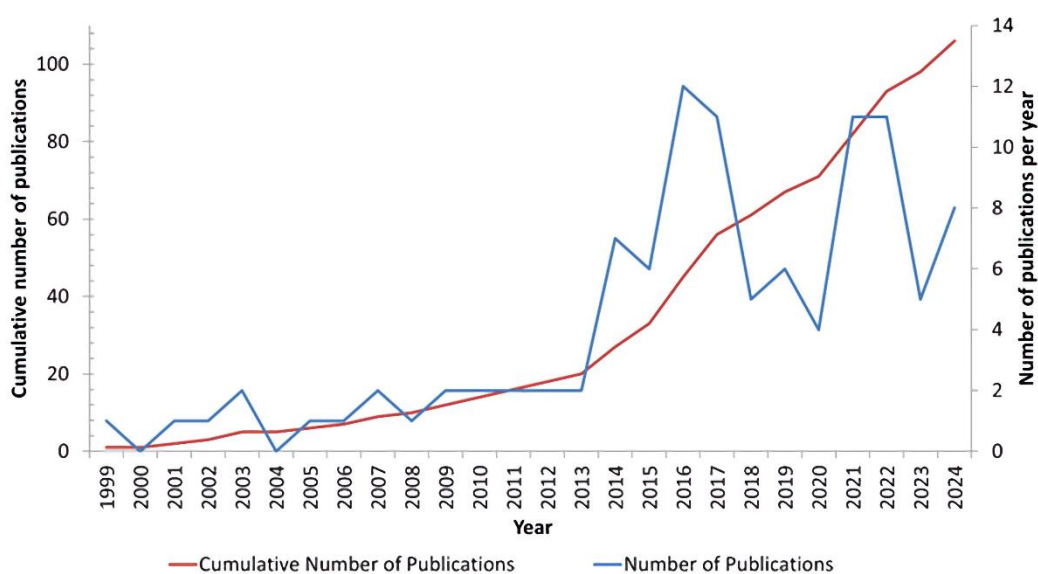


Figure 2. Annual distribution curve of the number of publications ( $n = 105$ ) on Cutaneous Leishmaniasis and environmental changes (1999–2024).

The bibliometric analysis revealed that *Acta Tropica* stands out as the most locally cited journal (315 citations), in addition to being the most prolific source, with 16 published documents in the analyzed dataset. It also ranks second in local impact, with an h-index of eight. These findings underscore its relevance to the field of CL and EC, making it a strategic choice for future publications on the topic.

*PLOS Neglected Tropical Diseases* also shows notable prominence, ranking second in the number of documents (10), while leading in local impact ( $h = 9$ ), indicating the greatest influence in the studied domain. Although *PLOS ONE* has a lower number of documents (6), it demonstrates moderate relevance in terms of both local citations and impact ( $h = 5$ ).

Among Brazilian journals, the *Revista da Sociedade Brasileira de Medicina Tropical* is noteworthy for its consistent presence, with four documents included in the sample and a local h-index of four, reflecting a relevant level of production and moderate internal citation impact within the analyzed set (Figure 3, a, b, and c).

The majority of the documents were published in English (98/92.4%), followed by

Portuguese (6/5.7%), Spanish (1/0.9%), and bilingual Portuguese/English publications (1/0.9%).

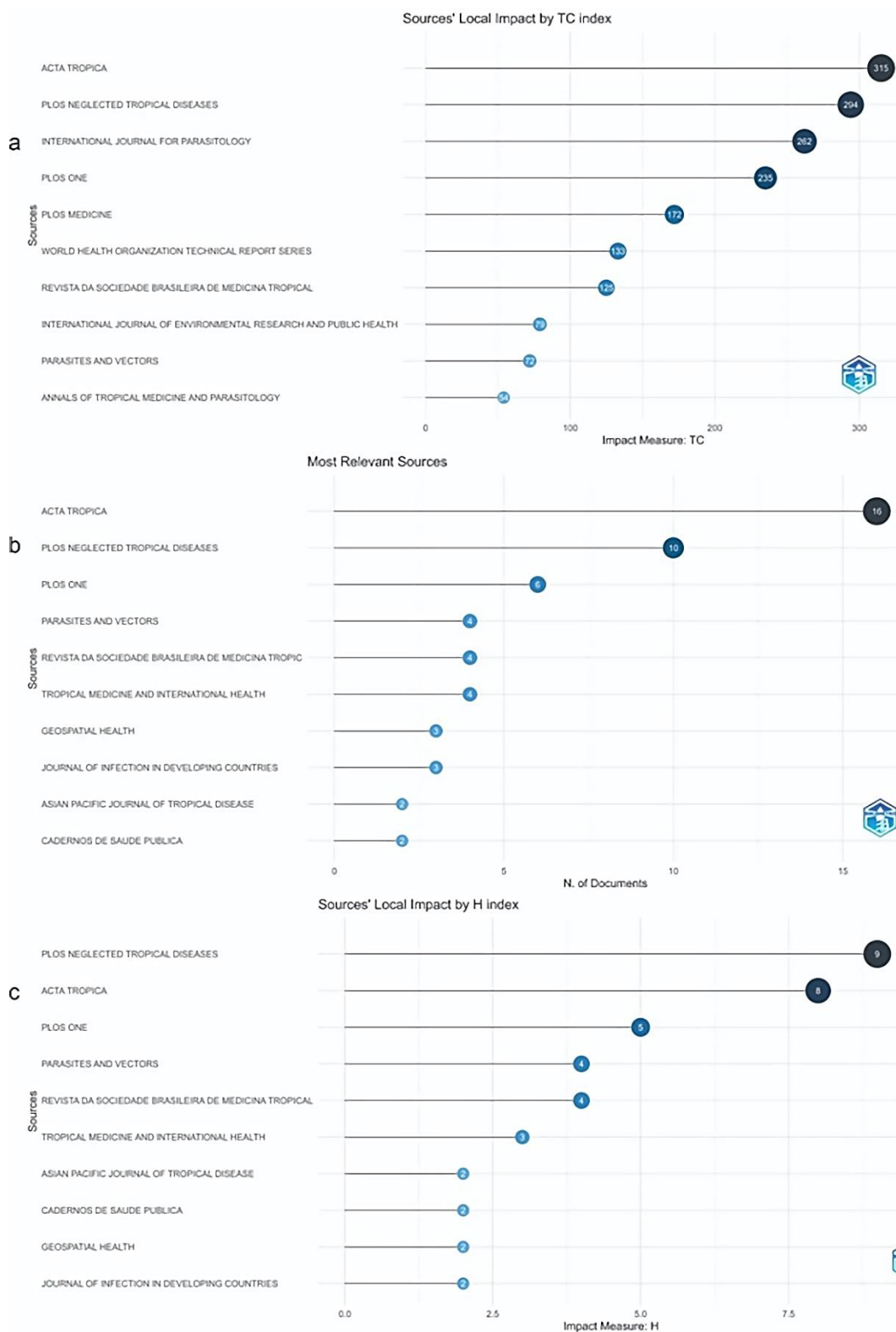


Figure 3. Analysis of the scientific sources that published the most on CL and EC, 1999-2024. (a) Sources' Local Impact by TC index, considering the number of times each journal was referenced within the set of articles analyzed. (b) Most relevant sources, based on the number of published articles present in the sample. (c) Local impact of sources, measured by the H-index, which reflects the frequency with

which articles from the same journal were cited among themselves in Scopus. Image taken in Bibliometrix package, version 4.1.3.

Figure 4 presents the co-authorship networks, while Table 1 details the most influential authors, countries, and institutions in the field. During the analyzed period, 497 researchers were identified as co-authors of at least one of the 111 included articles, distributed across 61 co-authorship clusters. Among these, 58 authors (11.0%) are connected within five interlinked clusters, collaborating on at least one publication (Figure 4a). Hanafi-Bojd, A. A. leads in the number of publications (six) and occupies a central position in the network, with strong connections to multiple researchers. Chaves, L. F., with five publications and 314 citations, is one of the most influential authors, followed by Peterson, A. T. and Shaw, J., who co-authored a highly cited paper referenced by 262 documents.

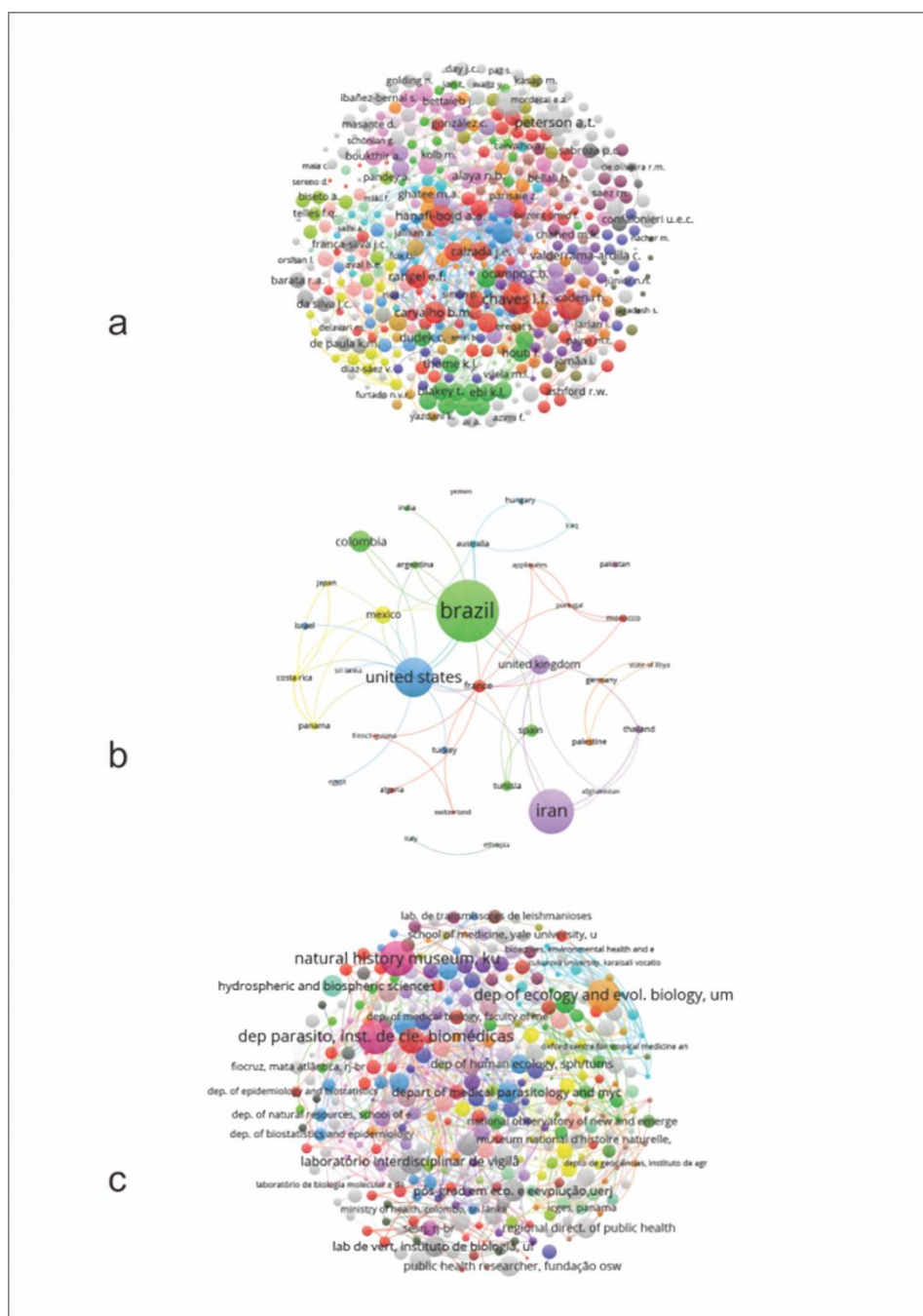


Figure 4. Authors (a), countries (b) and organizations (c) co-authorship network in all the 111 scientific articles selected in Scopus (1999-2024). The network nodes represent authors, countries and organizations, and the lines between the nodes the collaboration of these. Image taken in VOSviewer® version 1.6.20.

Table 1. Most influential authors, countries and institutions in research on CL and EC, selected from the Scopus database (1999-2024)<sup>a</sup>

Author	Docs	Cit by	Link strength	Pais	Docs	Cit by	Link strength	Institutions	Docs	Cit by	Link strength
CHAVES L.F.	5	314	19	United States	18	880	22	Departamento de Parasitologia, Inst. Cie. Biomédicas, USP, São Paulo, Brazil	1	262	1
PETERSON A.T.	1	262	1	Brazil	30	840	9	Natural History Museum, University of Kansas, USA	1	262	1
SHAW J.	1	262	1	Iran	21	332	8	Department of Ecology And Evolutionary Biology, University Of Michigan, USA	2	230	0
PASCUAL M.	2	230	2	United Kingdom	8	230	15	Department of Medical Entomology And Vector Control, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran	5	125	17
RANGEL E.F.	5	165	15	Tunisia	4	181	3	Laboratório Interdisciplinar de Vigilância Entomológica em Díptera e Hemiptera, Instituto Oswaldo Cruz, Rio De Janeiro, Brazil	2	107	4
HANAFI-BOJID A.A.	6	149	40	Colombia	9	179	2	Zoonoses Research Center, Tehran University Of Medical Sciences, Tehran, Iran	2	89	10
CARVALHO B.M.	3	135	9	France	5	118	10	Department of Disease Control, Faculty Of Infectious And Tropical Diseases, London School of Hygiene And Tropical Medicine, London, United Kingdom	1	81	3
SHIRZADI M.R.	5	131	49	Spain	5	85	2	Laboratório de Vertebrados, Instituto De Biologia, Universidade Federal Do Rio De Janeiro, Brazil	1	81	3
FERRO C.	2	119	12	Costa Rica	3	84	8	Pós-Graduação em Ecologia e Evolução, Universidade do Estado do Rio de Janeiro, Brazil	1	81	3
READY P.D.	2	107	6	Panamá	3	84	8	Department of Medical Parasitology and Mycology, School of Public Health, Tehran University of Medical Sciences, Iran	2	80	9

<sup>a</sup> Data obtained in VOSviewer® version 1.6.20.

A total of 36 countries contributed to research on CL and EC between 1999 and 2024. All are represented in the co-authorship network (Figure 4b), which comprises 16 clusters, of which 23 countries are interconnected. Brazil stands out with 30 publications and 840 Correia JE, Dias-Lima AG, Cruz LA, Nascimento PMVO, Silva AV. Modelos estatísticos e espaciais impulsionam redes de pesquisa sobre leishmaniose cutânea e alterações ambientais (1999–2024). Vet. e Zootec. 2026; v33: 1-31.

citations and is part of the same cluster as Colombia (nine publications, 179 citations) and India (two publications, 58 citations). This cluster connects with countries such as the United States, United Kingdom, Spain, and Argentina. Iran was the second most productive country, with 21 publications and 332 citations; however, the United States, with 18 articles and 880 citations, was the most influential, showing a strong presence across nearly all network clusters.

The institutional network identified 362 institutions contributing to the field. Although only 59 are connected in seven main clusters, the full network visualized (Figure 4c) comprises 83 clusters and their respective connections. Among the most influential research centers are the Department of Parasitology at the Institute of Biomedical Sciences, University of São Paulo – USP, and the Natural History Museum of the University of Kansas, which collaborated on a paper cited 262 times. The third most influential institution is the Department of Ecology and Evolutionary Biology at the University of Michigan, with two publications and 230 citations.

Among Brazilian institutions, notable contributors include the Interdisciplinary Laboratory of Entomological Surveillance in Diptera and Hemiptera, Oswaldo Cruz Institute, Oswaldo Cruz Foundation (Fiocruz), Rio de Janeiro (two publications, 107 citations); the Laboratory of Vertebrates, Institute of Biology, Federal University of Rio de Janeiro (UFRJ); and the Graduate Program in Ecology and Evolution at the State University of Rio de Janeiro (UERJ), each with one publication and 81 citations. These institutions are part of the same cluster and are connected with the Department of Disease Control, Faculty of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, United Kingdom.

Iranian institutions form the largest national collaborative network, comprising six clusters exclusively connected to each other. The Cellular and Molecular Research Center at Yasuj University of Medical Sciences is also linked to international institutions such as the University of Oxford (United Kingdom), the Technical University of Applied Sciences Wildau (Germany), and the Mahidol Oxford Tropical Medicine Research Unit (Thailand).

### **Thematic Relationships and Scientific Evidence on Cutaneous Leishmaniasis and Environmental Change: A Critical Analysis**

This section discusses the main findings identified in the scientific literature on LC and EC, with emphasis on emerging thematic relationships, collaboration patterns, and predominant methodological approaches. Based on the bibliometric analysis, the goal is to interpret how these elements structure the research field and guide scientific agendas aimed at understanding the epidemiological dynamics of the disease in contexts of environmental transformation.

The keyword co-occurrence network (Figure 5) reveals 199 terms used across the 111 analyzed articles, grouped into 18 thematic and methodological clusters (Table 2). The term Cutaneous Leishmaniasis stands out in terms of frequency (43 occurrences) and total link strength (163), and is associated with terms such as climate change (14/55), leishmaniasis (14/60), ecological niche model (12/47), sand fly (12/47), GIS (10/39), epidemiology (7/24), LCLU (land cover and land use, 7/31), phlebotominae (7/27), and spatial analysis (7/21). These associations reflect the growing incorporation of EC - understood as alterations in climate patterns (e.g., temperature, precipitation, and humidity) and LULC dynamics (e.g., deforestation, urban expansion, and agricultural intensification) - into the analysis of the bioecology, spatial distribution, and control of leishmaniasis vectors, particularly those associated with CL. In parallel, statistical and spatial modeling approaches have been increasingly integrated into epidemiological analyses, enabling a more comprehensive understanding of disease dynamics.

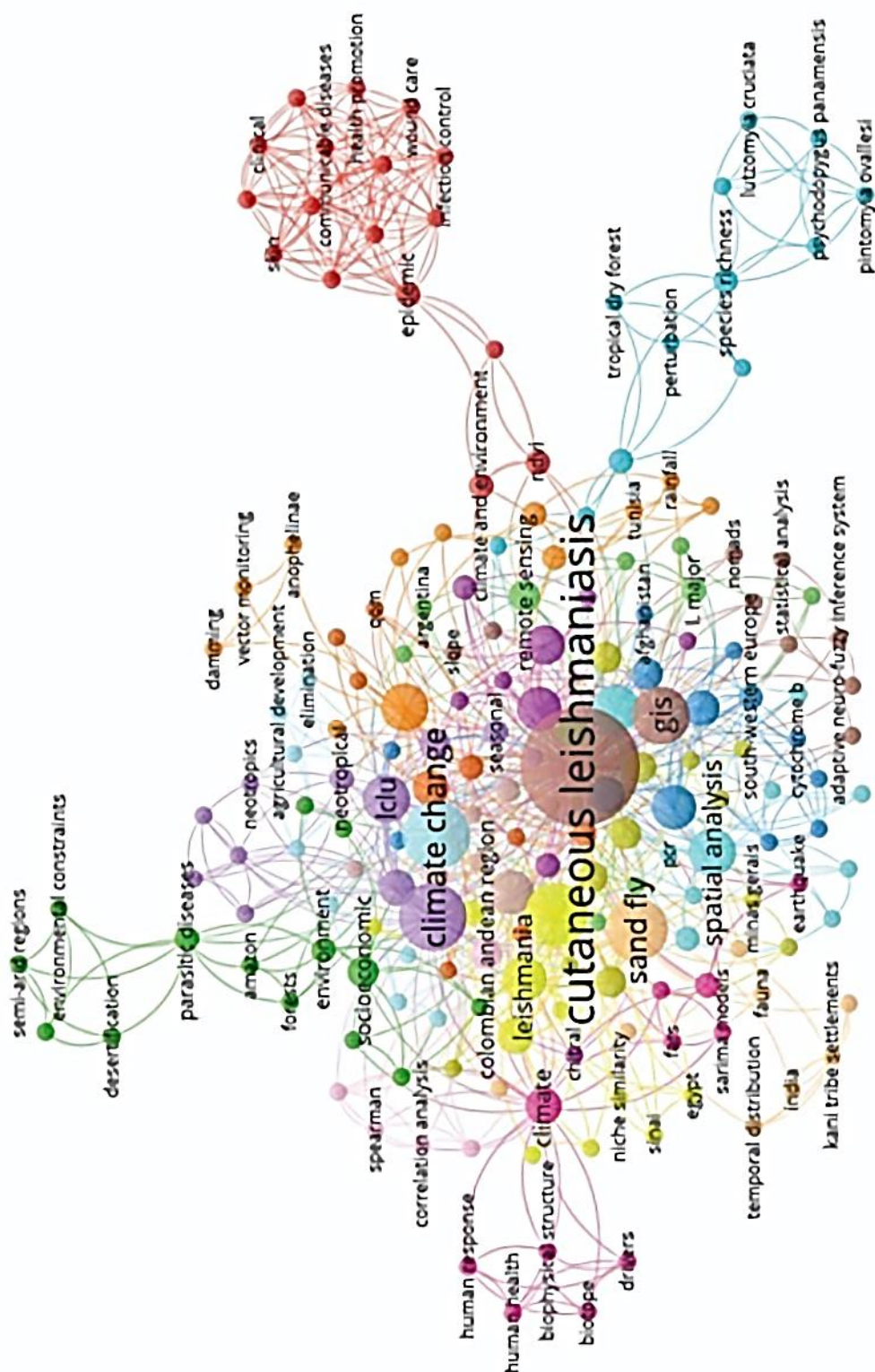


Figure 5. Word co-occurrence network presented in titles, abstracts and of keywords in all the 111 scientific articles about CL and EC selected in Scopus (1999-2024). Image taken in VOSviewer® version 1.6.20.9.

Table 2 Scientific production on CL and EC worldwide. Classification of keywords presented in titles, abstracts and keywords obtained from the word co-occurrence network in all 105 scientific articles selected in Scopus (1999-2024).  
(continues...)

Cluster	Keywords <sup>a</sup>	Research focus	Methodology approach
01	Climate and environment, Clinical, Communicable disease, Epidemic, Health promotion, Infection, Infection control, Infection prevention, NDVI, Patients, Prevention, Psychological care, Public health, Skin, Southernmost South America, Wound care, Wound management.	Influence of environmental and climatic aspects on public health, especially on infectious and skin diseases and care management in South America.	Epidemiological surveys, intervention studies, and assessment of environmental factors.
02	Amazon, Desertification, Environment, Environmental constraints, Forest geography infectious diseases transmission, Landscape epidemiology, Levant, Parasitic disease, Semi-arid regions, Socioeconomic, Vegetation cover. Negative binomial regression model	Association between socioeconomic and environmental conditions in the transmission of infectious and parasitic diseases in the Amazon.	Analysis of environmental data, landscape epidemiology, and spatial modeling.
03	Afghanistan, Anthroponotic cutaneous leishmaniasis, Cytochrome b, Ecological traits, Environmental variable, <i>L. Tropica</i> , Mitochondrial lineages, PCR-RFLP, <i>Phlebotomus arabicus</i> , <i>Phlebotomus sergenti</i> , Predictive distribution, Rocky hyrax, South-western europe.	Study of LC, with emphasis on the ecology and distribution of <i>Phlebotomus</i> , genetics of the parasite ( <i>Leishmania tropica</i> ), in association with environmental variables.	Predictive vector distribution model.
04	Alpha and beta diversity, Biodiversity, Ethiopia, Geographic distribution, <i>Lutzomyia cruciata</i> , Neglected Tropical Diseases, Perturbation, <i>Phitomyia ovallesi</i> , <i>Psychodopygus paraensis</i> , Species richness, Tropical dry forest, Vector borne disease.	Biodiversity of Neglected Tropical Diseases transmitted by vectors.	Analysis of biological diversity and ecology of vectors, geographic distribution modeling.
05	Biting rate, Diversity, Inoculation, LCLU, Leishmaniasis, Neotropical, Neotropics, Panama, Prevalence, Seasonal, Tropical forest.	Eco-epidemiology of leishmaniasis in tropical and neotropical regions associated with changes in vegetation cover, climate and impacts on human health.	Analysis of vector bite rates. Disease prevalence. Ecological diversity of vectors
06	America, Animal reservoir host, Deforestation, El Niño, Genetic algorithm for-rule set prediction, <i>Leishmania (Viannia) braziliensis</i> , Lutsomia, Marginalization, Minas Gerais, Molecular epidemiology, Potential distribution, Varzelandia.	Ecology of vectors, etiological agents and reservoirs. A association of environmental, climatic and social factors in the distribution and epidemiology of the disease.	Molecular epidemiology, predictive distribution modeling, and the use of genetic algorithms to predict disease-related patterns.

Table 2 Scientific production on CL and EC worldwide. Classification of keywords presented in titles, abstracts and keywords obtained from the word co-occurrence network in all 105 scientific articles selected in Scopus (1999-2024).  
(continues ...)

What is the focus of research on CL and EC? What methodological approaches were used by the studies?		
Cluster	Keywords <sup>a</sup>	Methodology approach
07	Ambient temperature, Anophelinae, Control, Dummy, Ecological forecast, Incidence, Phlebotominae, Rainfall, Rodent density, Temporal association, Tunisia, Vector monitoring.	Temporal analysis of disease incidence and its association with climate variables and vector propagation control strategies.
08	Biophysical structure, Biotope, Climate, Drivers, Earthquake, Fars, Forecasting, Human health, Human response, Sarima models, Times setting analysis.	Analysis of the biological and physical structure of the environment. Time series analysis (SARIMA).
09	Adana, ArcOgis, Ecological niche model, Egypt, Leishmania, Maxtent, Nich similarity, <i>Phlebotomus tobbi</i> , Stane, Turkey, Yazd province.	Ecological niche models (Maxtent) to predict potential distribution based on environmental data.
10	Adaptive neuro-fuzzy Inference system, American cutaneous leishmaniasis (ATL), Elevation emerging focus, Geoclimatic determinants, Geoclimatic factors, GIS, Nomads, Principal component analysis, Slope statistical analysis.	Spatial and geo-climatic analysis models using tools such as: Adaptive neuro-fuzzy inference system GIS, Statistical analysis. Principal component analysis.
11	Bayes theorem, Environment health, Epidemiology, Fuzzy logic, LUR, PCR, Protected areas, Social determinants of health, Spatial analysis, Wildlife.	Statistical modeling, spatial analysis: Bayes theorem, fuzzy logic, LUR, PCR.
12	Argentina, Diseases ecology, Ectoparasitas, Indian gerbil, Jericho, L. Major, Leishmania Killicki, Palestine, Remote sense, Species distribute model.	Statistical modeling of species distribution.
13	Agricultural development, Climate change, Elimination, <i>Lutzomyia</i> (n.) <i>Withmany</i> , <i>Lutzomyia intermedia</i> , <i>Lutzomyia nevai</i> , Migration, Population displacement, South America.	Analysis of environmental and climatic impacts on the distribution and control of vectors ( <i>Lutzomyia</i> ).

Table 2 Scientific production on CL and EC worldwide. Classification of keywords presented in titles, abstracts and keywords obtained from the word co-occurrence network in all 105 scientific articles selected in Scopus (1999-2024).

Cluster	Keywords <sup>a</sup>	Research focus	Methodology approach
14	Fauna, Hourly frequency, India, Canny tribby statement, Monthly frequency, Sand fly, São Vicente Ferrer, Temporal distribution, Western ghats.	Temporal distribution of phlebotomine sand fly fauna in Saint Vincent Ferrer, India..	Mapping the distribution of sandflies.
15	AHP, Children, Citral, Decision model, Iran, Khuzestan, Khyber Pakhtunkhwa, Pakistan, Risk factors.	Child health risks	AHP, decision model. Predictive models of species distribution.
16	Bioclimate, Ecology, Entomological survey, Morocco, <i>Phlebotomus papatasi</i> , <i>Pisammou obesus</i> , <i>Rhombomys opimus</i> , QOM, RCP scenario.	Ecology of diseases and vector studies.	Development and application of surveillance systems.
17	Biogeography, health surveillance, Infectious disease, One health, Parasitology, Public health surveillance, Under-estimation, Zoonosis.	Health surveillance, Biogeography, Zoonoses and One Health.	Biogeographic analysis of the distribution of pathogens and vectors.
18	Climate variables, Colombia andean region, Correlation analysis, correlation coefficient, Spearman.	Assessment of local epidemiological scenarios.	Statistical analysis and spatial correlation.

<sup>a</sup> Keywords taken in VOSviewer® version 1.6.20.

The term Cutaneous Leishmaniasis belongs to Cluster 10, which includes keywords such as Adaptive Neuro-Fuzzy Inference System, GIS, statistical analyses, and principal component analysis - geo-climatic methodological tools applied to the spatial distribution of vector-borne diseases. Most of the geographical terms indicate a concentration of studies in South America, Asia, and Africa (Figure 6), corroborating the findings from the country-level cluster analysis (Figure 4b).

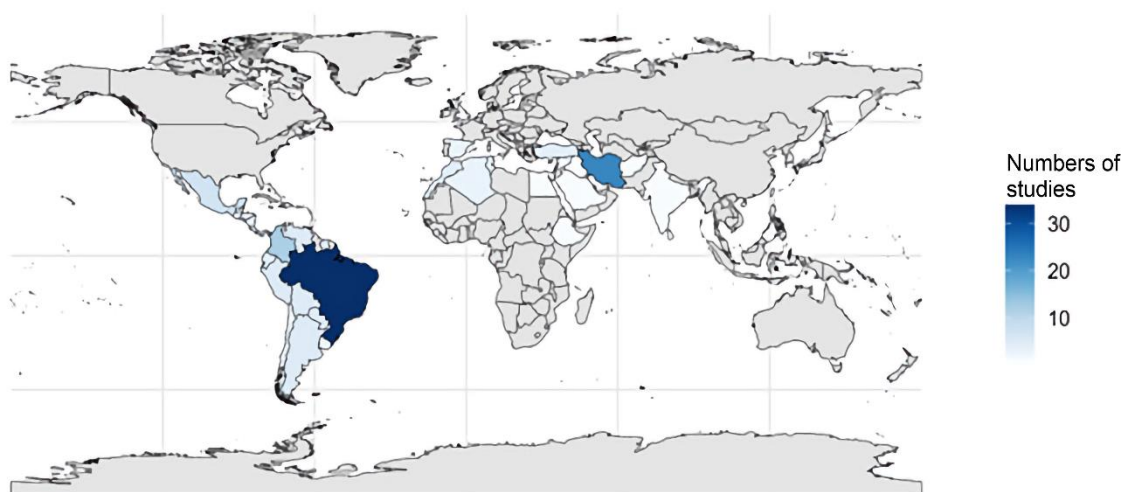


Figure 6. Geographic distribution of studies on CL and EC (1999–2024). Image taken in Bibliometrix package, version 4.1.3.

### Scientific Evidence and Thematic Trends in Studies on Cutaneous Leishmaniasis and Environmental Change

The articles indexed in Scopus span the period from 1999 to 2024. A sample comprising the top 20% most-cited publications was synthesized and is presented in Table 3. The article by (18) leads with 262 citations, followed by Chaves (2006, PLOS Medicine). Most of the highly cited articles were published in high-impact journals such as PLOS ONE, PLOS Neglected Tropical Diseases, and Acta Tropica, highlighting the centrality of these outlets in disseminating research on the topic. Notably, interdisciplinary studies published in journals such as Environmental Research Letters and International Journal of Environmental Research and Public Health reflect the growing integration of public health, geotechnologies, and environmental sciences in the highest-impact research on the subject.

Most studies were conducted in South America, particularly in Brazil<sup>(18–22)</sup>. The most commonly employed tools for assessing vector occurrence and distribution were Ecological Niche Models, including GARP<sup>(18)</sup>, MaxEnt<sup>(23–25)</sup>, BIOCLIM, DOMAIN, logistic regression, and Random Forest—all of which were applied using climatic biovariables<sup>(19)</sup>.

Generalized Additive Models (GAM, GAMM), linear forecasting models (SAR, BSM), and time series analyses<sup>(26)</sup> were also used. The most frequently analyzed variables were climatic variables (11 out of 21 studies), followed by LULC (9/21), socioeconomic factors (4/21), and urbanization (3/21). Climatic variables were associated with vector distribution<sup>(18–22)</sup> vector density<sup>(19,21,27–29)</sup>, case numbers<sup>(30)</sup>, disease incidence<sup>(26,28,31,32)</sup>, and host infection prevalence<sup>(33)</sup>.

Environmental changes such as urbanization<sup>(22,34)</sup> and agricultural expansion<sup>(20)</sup> were addressed through spatial modeling and epidemiological surveys. Associations between CL and climatic or LULC variables were identified in relation to case numbers<sup>(31)</sup>, disease incidence<sup>(29,32,35,36)</sup>, epidemiological zones<sup>(37)</sup>, spatial distribution<sup>(24,25)</sup>, and vector diversity<sup>(23)</sup>. Only one of the most cited articles employed a continental-scale predictive model integrating

Correia JE, Dias-Lima AG, Cruz LA, Nascimento PMVO, Silva AV. Modelos estatísticos e espaciais impulsionam redes de pesquisa sobre leishmaniose cutânea e alterações ambientais (1999–2024). *Vet. e Zootec.* 2026; v33: 1-31.

socioeconomic factors, climate change, and land use across South and Mesoamerica<sup>(38)</sup>.

The analysis of keyword clusters and synthesis of the most-cited studies confirms “Cutaneous Leishmaniasis” as the central focus of research connecting the disease to climate change and land use and land cover. The keyword network also reveals strong methodological terms, reflecting advances in epidemiological modeling, public health surveillance, and care management strategies. Most studies feature robust statistical and spatial analyses, using tools that enable associations between disease incidence, vector distribution, and environmental changes.

Since 1999, the topic “Cutaneous Leishmaniasis associated with environmental changes” has been developed by an international research network with significant contributions to entomological and epidemiological studies. Alptekin et al.,<sup>(27)</sup> through the capture and identification of sand fly species in Turkey, suggested that controlling *Phlebotomus sergenti* and *Phlebotomus papatasi* could eliminate disease transmission in the region - an insight that influenced subsequent research.

Between 2001 and 2005, epidemiological studies identified correlations between CL incidence and EC. In Israel, Anis et al.,<sup>(34)</sup> observed morbidity peaks from 1961–2000, attributed to migration into endemic areas, frontier urbanization, agro-industrial projects, and global warming. In Brazil, Kawa and Sabroza<sup>(42)</sup> documented increased incidence of Leishmaniose Cutânea in endemic areas undergoing urbanization during the 1980s, particularly in zones of urban expansion within the Atlantic Forest biome in Rio de Janeiro, highlighting the role of anthropogenic landscape transformation in reshaping transmission patterns. In Paraná, between 1993 and 2003, agricultural activity in the Ribeira Valley was linked to CL incidence due to deforestation of primary forests<sup>(20)</sup>.

Several studies have applied ecological niche modeling to project the future distribution of CL vectors<sup>(18,19,23,24)</sup> and reservoirs<sup>(25)</sup>. Under potential climate change scenarios, these models offer insights into the ecological basis for geographic variation in *Lutzomyia* species distributions, including expansion across southeastern Brazil and into neighboring countries<sup>(18)</sup>; projections of *Lutzomyia (Nyssomyia) flaviscutellata* expansion by 2050 in the Amazon, driven by EC and urbanization<sup>(19)</sup>; identification of high vector richness areas in modified ecosystems in Colombia, indicating potential for vector domiciliation<sup>(24)</sup>; and increased transmission risk in Iran’s Qom province due to higher *Phlebotomus papatasi* diversity<sup>(23)</sup>.

Gholamrezaei et al.,<sup>(25)</sup> also identified ecological niches of three rodent hosts (*Rhombomys optimus*, *Meriones libycus*, and *Tatera indica*), emphasizing the role of seasonal precipitation, mean annual temperature, and slope in their distribution. Host age was also shown to influence transmission, according to regression models<sup>(33)</sup>. Other studies reported that temperature, humidity, and rainfall affect sandfly populations differently depending on the region<sup>(21)</sup>, and that climatic events such as El Niño–Southern Oscillation (ENSO) may increase vector abundance and outbreak risk in Panama<sup>(28)</sup>.

Climatic variables, ENSO, and seasonality were widely used as predictors, with models demonstrating strong predictive power - up to one year for human cases<sup>(26)</sup> and through 2050 for vectors in increasingly urbanized areas<sup>(19)</sup>. Generalized Additive Models (GAM/GAMM) proved effective for predicting transmission<sup>(29)</sup>, and suggested that sandfly population peaks could trigger epidemics<sup>(28)</sup>. Logistic regression models indicated that CL distribution in southwestern Iran results from a combination of climatic, ecological, and environmental changes<sup>(35)</sup>. Meanwhile, continental-scale predictive models that incorporated socioeconomic variables, climate change, and LULC showed weak associations with future seasonality, temperature, and precipitation<sup>(38)</sup>. Valderrama-Aardila et al.,<sup>(36)</sup> applied a conditional autoregressive Poisson model to demonstrate spatial correlation between CL incidence, climate, and vegetation cover, highlighting the environmental drivers of transmission, while

also acknowledging the unexplained spatial variation.

Table 3. Summary of data extracted from the most influential articles (n=105) that related CL to EC. Selected from Scopus (1999-2024)

		What evidence has been presented in publications on CL and EC over the years?				
Title	Authors	Cit by	Source title	Affiliations	Geographic area/method/driver	Finding
Lutzomyia vectors for cutaneous leishmaniasis in Southern Brazil: Ecological niche models, predicted geographic distributions, and climate change effects	Peterson, A.T.; Shaw, J. 2003	262	Int. Parasitol.	J. Natural History Museum, University of Kansas, Lawrence, United States; Dep. de Parasitologia, Inst. de Cie. Biomédicas, Universidade de São Paulo, Brasil.	<b>Area:</b> Southeastern Brazil. <b>Method:</b> Ecological niche modeling using Genetic Algorithm for Rule-set Prediction (GARP). <b>Driver:</b> Climate change.	“Projections of potential geographic distributions under global climate change scenarios suggest that only <i>Lutzomyia whitmani</i> is likely to experience dramatic improvements in habitat suitability in southeastern Brazil, where cutaneous leishmaniasis appears to be re-emerging; <i>Lutzomyia intermedia</i> and <i>Lutzomyia migonei</i> may be facing more subtle improvements in climatic conditions, but the implications are not straightforward.”.
Climate cycles and forecasts of cutaneous leishmaniasis, a nonstationary vector-borne disease	Chaves L.F.; Pascual M., 2006	172	PLoS Medicine	Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor, MI, United States.	<b>Area:</b> Costa Rica. <b>Method:</b> Non-stationary time series analysis: description of interannual disease cycles associated with oceanic and atmospheric variables. <b>Driver:</b> Oceanic and atmospheric variables.	“Linear models using temperature and the Multivariate ENSO Index can satisfactorily predict ATL incidence dynamics up to 12 months ahead (with an accuracy of 72% to 77%, depending on the forecasting horizon). Gaps: Comparing the predictive capacity of nonlinear models and more mechanistic formulations.”.
Ecological niche modeling predicts southward expansion of <i>Lutzomyia (Nyssomyia) flaviscutellata</i> (Diptera: Psychodidae), vector of Leishmania (Leishmania) amazonensis in South America, under climate change	Carvalho, B.M. et al, 2015	81	PLoS ONE	Laboratório de Vertebrados, Instituto de Biologia, Universidade Federal do Rio de Janeiro, Brazil; Lab. Interdisciplinar de Vigilância Entomológica em Díptera e Hemiptera, Instituto Oswaldo Cruz FIOCRUZ, Rio de Janeiro, Brazil; Department of Disease Control, Faculty of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, London, United Kingdom; Pós-Graduação em Ecologia e Evolução, Universidade do Estado do Rio de Janeiro, Brazil.	<b>Area:</b> Amazon region (South America). <b>Method:</b> Ecological niche modeling to predict vector occurrence vs. predictive bioclimatic variables using niche modeling algorithms (BIOCCLIM, DOMAIN, MaxEnt, GARP, logistic regression, and Random Forest). <b>Driver:</b> Climate change.	“ <i>Lutzomyia flaviscutellata</i> is likely to encounter increasingly suitable conditions for its expansion into areas where human population size and density are much greater than in its current range. If environmental conditions change as projected, the vector’s range is likely to expand into southeastern and south-central Brazil, eastern Paraguay, and further into the Amazonian regions of Bolivia, Peru, Ecuador, Colombia, and Venezuela.”

(continues)

Table 3. Summary of data extracted from the most influential articles (n=105) that related CL to EC. Selected from Scopus (1999-2024)

Title	Authors	Cit by	Source title	Affiliations	Geographic area/ method/ driver	Finding
Linking climate to incidence of zoonotic cutaneous leishmaniasis (L. major) in pre-Saharan North Africa.	Bounoua, L. <i>et al.</i> , 2013	79	Int Environ Res Public Health	Hydrospheric and Biospheric Sciences Laboratory, NASA's Goddard Space Flight Center, Maryland, MD 20771, USA., United States.	Area: Northwestern Algeria (Saïda Province) and northeastern Morocco (Errachidia Province). Method: Variations in temperature, humidity, precipitation, and the Normalized Difference Vegetation Index (NDVI) were analyzed in relation to the number of ZCL cases. Driver: Vegetation cover and climatic variability.	"The annual cycle of zoonotic cutaneous leishmaniasis (ZCL) is influenced by extreme temperatures and humidity, particularly during the transmission period. Regional climate and vegetation changes may be promoting the northward expansion of ZCL into pre-Saharan regions."
Temporal dynamics and impact of climate factors on the incidence of Zoonotic Cutaneous Leishmaniasis in central Tunisia	Tounni A. <i>et al.</i> , 2012	73	PLoS Neglected Tropical Diseases	Laboratory of Medical Epidemiology, Pasteur Institute of Tunis, Tunis, Tunisia; Regional Directorate of Public Health, Sidi Bouzid, Tunisia	Area: Central Tunisia. Method: The impact of precipitation, humidity, and temperature—adjusted for trend and seasonality of the disease—was evaluated using Generalized Additive Models (GAM) and Generalized Estimating Equations (GEE). Driver: Climatic variables.	"Humidity is a more important predictor of ZCL incidence than precipitation. Higher rainfall levels may increase rodent density by enhancing food availability."
Spatial distribution of sand fly vectors and ecology of zoonotic cutaneous leishmaniasis transmission in Colombia	Ferro C. <i>et al.</i> , 2015	67	PLoS ONE	Lab. de Entomología, Subdirección Red Nacional de Laboratorios, Instituto Nacional de Salud, Bogotá, Colombia; Centro de Investigaciones en Microbiología y Parasitología Tropical, Facultad de Ciencias, Universidad de los Andes, Bogotá, Colombia; Biomac, Facultad de Ingeniería, Universidad de los Andes, Bogotá, Colombia	Area: Colombia. Method: Ecological niche modeling (MaxEnt) was performed to explore the potential distribution of medically important vector species in Colombia, using bioclimatic variables, topographic variables, and principal components derived from NDVI. Driver: Climatic variables and vegetation cover.	"Areas of highest vector richness are associated with areas of high cutaneous leishmaniasis (CL) prevalence; these same sites also coincide with transformed ecosystems, which support the possibility of a domestication process."
Ecological Modeling of reservoir zoonotic leishmaniasis in Iran	Gholamrezaei <i>et al.</i> , 2016	65	Acta Tropica	Depart of Medical Parasitology and Mycology, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran; Center for Research of Endemic Parasites of Iran, Tehran; University of Medical Sciences,	Area: Iran. Method: Maximum entropy method (MaxEnt) was used to find the most suitable ecological niches for each rodent species. Driver: NDVI and climatic variables.	"climatological and topographic variables such as seasonal precipitation, mean annual temperature and slope had high contributions to predicting the potential distribution of the three main local reservoir species".

Table 3. Summary of data extracted from the most influential articles (n=105) that related CL to EC. Selected from Scopus (1999-2024)

Title	Authors	Cit by	Source title	Affiliations	Geographic area/ method/ driver	Finding
				Tehran, Iran; Depart of Medical Entomology and Vector Control, School of Public Health, Tehran; University of Medical Sciences, Tehran, Iran; Depart of Human Ecology, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran; Zoonotic Depart, Center for Communicable Diseases Management, Ministry of Health and Medical Education, Tehran, Iran; Zoonoses Research Center, Tehran University of Medical Sciences, Tehran, Iran.		
Comparing models for early warning systems of neglected tropical diseases	Chaves L.F., Pascual M., 2007	58	PLOS Neglected Tropical Diseases	Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor, MI, United States.	<b>Area:</b> Costa Rica. <b>Method:</b> Monthly mean temperature and multivariate ENSO index were used as predictors to model the LCA. The linear models used were SAR and BSM, and the nonlinear models were NLF, generalized additive models (GAM) and feed-forward neural networks (FNN). <b>Driver:</b> Climate variables.	"EWS are a viable ecological application for neglected tropical diseases, as illustrated for ACL. The models show good levels of predictability up to one year in advance for the number of cases. Predictability depends heavily on the use of an appropriate framework for the different components of the model, including seasonality and exogenous factors such as climate variables."
Sandflies (Diptera: Psychodidae) in an outbreak of cutaneous leishmaniasis in the State of Minas Gerais	Dias E.S. et al, 2007	56	Revista da Sociedade Brasileira de Medicina Tropical	Centro de Pesquisas René Rachou, Fiocruz, Belo Horizonte, MG, Brazil; Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil; Secretaria de Vigilância em Saúde, Belo Horizonte, MG, Brazil; Laboratório de Leishmanioses, CPqRR, FIOCRUZ, Belo Horizonte, MG, Brazil	<b>Area:</b> Brejo do Mutambal, Varzelândia (MG). <b>Method:</b> Temperature, humidity and rainfall on the number of captured sandflies were assessed by the Pearson correlation test and when the normality assumptions were not satisfactory, the Spearman correlation test was used through the Prism Version 3 software. <b>Driver:</b> climatic variables.	"the Pearson or Spearman coefficient applied to the independent variables and the density of sand flies did not observe a positive correlation between these variables. The existence of an environment favorable to the reproduction of sand flies associated with the presence of domestic animals may represent factors that explain the large number of insects in this environment".

Table 3. Summary of data extracted from the most influential articles (n=105) that related CL to EC. Selected from Scopus (1999-2024)

Title	Authors	Cited by	Source title	Affiliations	Geographic area/ method/ driver	Finding
Leishmania major infection in the fat sand rat <i>Psammomys obesus</i> in Tunisia: Interaction of host and parasite populations	Fichet-Calvet, et al, 2003.	54	Annals of Tropical Medicine and Parasitology	Liverpool Sch. of Tropical Medicine, Pembroke Place, Liverpool L3 5QA, United Kingdom; Lab. Epidemiol./Ecologie Parasitaire, Institut Pasteur de Tunis, B.P. 74, 1002 Tunis Belvédère, Tunisia; Museum National d'Histoire Naturelle, Lab. Mammifères et Oiseaux, 55 rue de Buffon, 75 005 Paris, France.	Area: Tunisia. Method: Prevalence study using logistic regression. Driver: Climatic variation (seasonality).	"Factors such as season, climatic variations, and host age have a combined effect. Prevalence was highly dependent on the age of <i>Psammomys obesus</i> , with season and age acting synergistically, resulting in high infection rates in rodents at the end of summer and in autumn."
Environmental risk factors for the incidence of American cutaneous leishmaniasis in a sub-andean zone of Colombia (Chaparral, Tolima)	Valderram a-Aardila et al, 2010.	52	American Journal of Tropical Medicine and Hygiene	Department of Biology, Universidad Icesi, Cali, Valle del Cauca, Colombia; Centro Internacional de Entrenamiento e Investigaciones Médicas, Carrera, Cali, Colombia; Laboratorio de Entomología, Instituto Nacional de Salud, Bogotá, Colombia; School of Medicine, Yale University, New Haven, CT, United States	Area: Chaparral, Tolima, Colombia. Method: Spatial analysis was conducted at the rural municipal level using a conditional autoregressive Poisson model to account for spatial correlation. Driver: Climate change and land use/land cover.	"Spatial analysis showed that the incidence of tegumentary leishmaniasis was higher in municipalities with intermediate mean temperatures along the municipality's mountainous region. Incidence was independently associated with greater forest or shrub cover and lower population density."
Cutaneous Leishmaniasis and Sand Fly Fluctuations Are Associated with El Niño in Panamá	Chaves, L.F. et al, 2014	50	PLOS Neglected Tropical Diseases	Institute of Tropical Medicine, Nagasaki University, Sakamoto, Nagasaki, Japan; Programa de Investigación en Enfermedades Tropicales, Escuela de Medicina Veterinaria, Universidad Nacional, Heredia, Costa Rica; Instituto Comemorativo Gorgas de Estudios de la Salud, Panamá	Area: Panamá. Method: Association between monthly time series (January 2000 to December 2010) of CL cases, precipitation, and temperature in Panamá, and an ENSO index, using autoregressive models, cross-wavelet coherence, and GLMM (Poisson). Driver: Climate change.	"In Panamá, the occurrence of cutaneous leishmaniasis (CL) appears to be influenced by ENSO and by local climatic factors such as temperature and precipitation. Sudden changes in vector abundance during the cold phase of ENSO may increase the risk of CL epidemic outbreaks."

Table 3. Summary of data extracted from the most influential articles (n=105) that related CL to EC. Selected from Scopus (1999-2024)

Title	Authors	Cited by	Source title	Affiliations	Geographic area/method/driver	Finding
Modeling zoonotic cutaneous leishmaniasis incidence in central Tunisia from 2009-2015: Forecasting models using climate variables as predictors	Talmoudi, K. et al, 2017	46	PLoS Neglected Tropical Diseases	Tunis National School of Engineering, Tunis El Manar University, Tunisia. Research Unit in Modeling, Statistics and Economic Analysis, Higher School of Statistics and Information Analysis, University of Carthage, Tunisia. Department of Epidemiology and Statistics, Abderrahman Mami Hospital, Ariana, Tunisia. Research Unit on the Effects of Environmental and Climate Change on Health, Department of Epidemiology and Statistics, Abderrahman Mami Hospital, Ariana, Tunisia. Department of Epidemiology and Public Health, Faculty of Medicine of Tunis, Tunis El Manar University, Tunisia. Observatorio Nacional de Doenças Novas e Emergentes, Tunis, Tunisia.	<b>Area:</b> Three districts of Sidi Bouzid, Central Tunisia. <b>Method:</b> Generalized Additive Model (GAM) and Generalized Additive Mixed Model (GAMM) with natural cubic splines. <b>Driver:</b> Rodent density and environmental changes.	“The ZCL outbreak was more strongly associated with local environmental diversity than with climatic factors, although both can be used to predict ZCL transmission. Additive models provide flexible modeling tools for regression problems.”
How will climate change pathways and mitigation options alter incidence of vector-borne diseases? A framework for leishmaniasis in South and Meso-America	Purse B.V., et al, 2017	39	PLoS ONE	NERC Centre for Ecology and Hydrology, Crownmarsh Gifford, Oxfordshire and the Environment Centre Wales, Bangor, UK; the School of BioSciences, University of Melbourne, Victoria, Australia; the Institute for Health Metrics and Evaluation, University of Washington, Seattle, USA; the Instituto de Ecología, A.C., Red Ambiente y Sustentabilidad, Xalapa, Veracruz, Mexico; and the Institute of Geography, National Autonomous University of Mexico, Mexico City, Mexico.	<b>Area:</b> South America and Mesoamerica. <b>Method:</b> Predictive modeling. <b>Driver:</b> Socioeconomic factors, climate change, and land use.	“LC was associated with low seasonality in temperature and precipitation. Both LC and LV were predicted to be geographically extensive by 2050.”
Spatial distribution of tegumentary leishmaniasis in the city of Rio de Janeiro: Espacialização da leishmaniose tegumentar na cidade do Rio de Janeiro.	Kawa H., Sabroza P.C., 2002	39	Cadernos de saúde pública/MS, Fiocruz, Escola Nacional de Saúde Pública	Secretaria Estadual de Saúde do Rio de Janeiro, RJ, Brasil.	<b>Area:</b> Rio de Janeiro, RJ, Brazil. <b>Method:</b> Data analysis: articulate the occurrence of LT with the historical and social processes of urban occupation, land appreciation and population dynamics. <b>Driver:</b> Urbanization.	“The spatiotemporal dynamics of cutaneous leishmaniasis (TL) transmission in Rio de Janeiro resulted from the interaction between population mobility and environmental conservation. These movements, mediated by land values, favored the reproduction of TL and the emergence of a new endemic region in the West Zone of the city.”

Table 3. Summary of data extracted from the most influential articles (n=105) that related CL to EC. Selected from Scopus (1999-2024).

Title	Authors	Cit by	Source title	Affiliations	Geographic area/ method/ driver	Finding
Eco-epidemiological survey of Leishmania (Vianna) braziliensis American cutaneous and mucocutaneous leishmaniasis in Ribeira Valley River, Paraná State, Brazil	De Castro et al., 2005	38	Acta Tropica	Univ. Federal Do Paraná, Setor de Ciê. Biol., Depto. Patol. Básica, Ctro. Curitiba, Paraná, Brasil; Secretaria Estadual Saúde Do E., Parana, Brazil; Hospital de Clínicas, Univ. Federal do Paraná, Curitiba, Paraná, Brazil; Biotechnology Division, Regional Research Laboratory, CSIR, Trivandrum, India; Univ. Federal do Paraná, Setor de Ciê. Biol., Departamento de Genética, Paraná, Brazil	<b>Area:</b> Adrianópolis - Ribeira Valley - Paraná. <b>Method:</b> Epidemiological surveys: humans, vectors and hosts. <b>Driver:</b> environmental changes (deforestation).	"In Adrianópolis, cutaneous leishmaniasis (CL) presented low parasite pressure and irregular distribution, mainly affecting people exposed to forest areas. The replacement of forest by agricultural crops may have increased the risk of exposure to the disease."
Role of environmental, climatic risk factors and livestock animals on the occurrence of cutaneous leishmaniasis in newly emerging focus in Iran	Ghatee M.A., et al, 2018	37	Journal of Infection and Public Health	Cellular and Molecular Research Center, Yasuj University of Medical Sciences, Yasuj, Iran; Department of Medical Parasitology and Mycology, School of Medicine, University of Medical Sciences, Yasuj, Iran; Research Center for Modeling in Health, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran; Department of Immunology, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran; Province Health Center, Yasuj University of Medical Sciences, Yasuj, Iran; Infectious Diseases Research Center, Birjand University of Medical Sciences, Birjand, Iran	<b>Area:</b> Southwest Iran. <b>Method:</b> Univariate and multivariate logistic regression model. <b>Driver:</b> annual climatic factors and environmental factors (presence of livestock and land cover, slope and elevation).	"Regions with urban coverage, dry farms and thin pastures with lower slope and altitude, close to cattle stables, appear to be areas potentially at greater risk, reflecting that the combination of climatic, environmental and ecological factors influence the distribution of CL in the region."
'Spatio-temporal variability of NDVI over southernmost South America: Possible linkages between climate signals and epidemics	Tourre et al, 2008	35	Environmental Research Letters	METEO-France, Metropole, France; Lamont Doherty Earth Observatory, Columbia University, Palisades, NY, United States; Centre d'Etudes Spatiales de la Biosphere, Université Paul Sabatier, Observatoire Midi Pyrénées, France; Instituto de Altos Estudios Espaciales 'Mario Gulich', Comisión Nacional de Actividades Espaciales, Universidad Nacional de Córdoba, Argentina; CNES, DSP/ARP/AV, France.	<b>Area:</b> Southern South America <b>Method:</b> Climate, environment, epidemic modeling: Mapping of NDVI and precipitation variability and comparison with areas of preliminary epidemiological reports. <b>Driver:</b> climate change and vegetation.	Advanced knowledge of the phases of climate signals (for high and low frequencies, such as the QB and IA/QQ signals, which will modulate local seasonal variability, such as the South American Monsoon System. Working in collaboration with entomologists and virologists to delineate some mechanisms that contribute to epidemic outbreaks also becomes a necessity.

Table 3. Summary of data extracted from the most influential articles (n=105) that related CL to EC. Selected from Scopus (1999-2024).

Title	Authors	Cit by	Source title	Affiliations	Geographic area/ method/ driver	Finding
"Cutaneous leishmaniasis in Israel in the era of changing environment"	Anis et al, 2001.	33	Public Health Reviews	Department Infectious Diseases, Ministry of Health, Israel.	<b>Area:</b> Israel (Middle East). <b>Method:</b> Epidemiological survey: prevalence and morbidity. <b>Driver:</b> Urban expansion, ecological changes (global warming).	"Two peaks of LC, between 1967-1969 and 1980-1982, are clearly seen. These peaks reflect environmental changes caused by the introduction of non-immune people into the area of endemic foci, enhanced urbanization by the expansion of settlements bordering this area, agricultural/industrial projects and, most likely, the effect of global warming."
Species diversity of sand flies and ecological niche model of <i>Phlebotomus papatasi</i> in central Iran	Abedi-Astaneh F. et al, 2015	32	Acta Tropica	Department of Medical Entomology and Vector Control, School of Public Health, Tehran Univ. of Medical Sciences, Tehran, Iran; Deputy for Health, Qom University of Medical Sciences, Qom, Iran; Zoonotic Depart, Center of Disease Control (CDC), Ministry of Health and Medical Education, Tehran, Iran.	<b>Area:</b> Iran (Qom province). <b>Method:</b> Eco-epidemiology of CL. Ecological niche modeling in seasonal distribution of vectors. <b>Driver:</b> Climatic and geographic variables.	"Diversity in the mountains is greater than in the plains. Maxent revealed that the monthly mean of maximum temperature-minimum temperature had greater gains. The plains provide good niches for <i>P. papatasi</i> offering greater transmission potential."
Sandflies (Diptera: Psychodidae) associated with epidemic cutaneous leishmaniasis in Saniurfa, Turkey	Alptekine t al., 1999	31	Journal of Medical Entomology	Department of Medical Biology, Faculty of Medicine, Cukurova University, Balcali, Adana, Turkey; Dept. of Epidemiol. and Pub. Health, Yale University School of Medicine, United States; Depts. of Biology and Epidemiology, University of Michigan, US.	<b>Area:</b> Saniurfa, Turkey <b>Method:</b> capture, identification of sand flies <b>Driver:</b> Climatic variables (humidity, teture)	"The results indicated that <i>P. sergenti</i> or <i>P. papatasi</i> were the likely vectors of cutaneous leishmaniasis during this outbreak and that control of these sand flies could eliminate transmission."

## DISCUSSION

Studies indexed in the Scopus database on CL and EC date back to 1999, although earlier records associated with the MeSH descriptors “leishmaniasis” or “*Leishmania*” date from as early as 1945<sup>(39-41)</sup>. Growing international political interest over the years fostered the development of medical research networks supported by institutions such as the World Health Organization (WHO), Pan American Health Organization (PAHO), and the Wellcome Trust. These initiatives prioritized training in tropical diseases and strengthening control strategies<sup>(6,7)</sup>. In Brazil, this was reflected in the expansion of educational institutions, increased public research funding, and a growing number of trained researchers<sup>(9)</sup>, resulting in a notable increase in scientific publications on leishmaniasis over the past decades, spanning 145 countries or regions<sup>(8)</sup>, with Brazil as a leading contributor.

The epidemic expansion of mucocutaneous leishmaniasis during the 1960s in Brazil coincided with intense anthropogenic activities such as deforestation to establish settlements and farms, road construction, and population displacement due to war or revolution. These events spurred research that later enabled the development of strategies such as epidemiological surveys, control and surveillance programs, data analysis, active case finding, and improved access to diagnosis and treatment<sup>(7)</sup>.

Between 2007 and 2019, key global meetings established strategies and targets for the control and potential elimination of leishmaniasis by 2030. Notable milestones included WHO’s first report on Neglected Tropical Diseases (NTDs) and the official classification of leishmaniasis as part of this group<sup>(1,42,43)</sup>. Meanwhile, the WHO Global Leishmaniasis Surveillance Report (1998-2020) noted a rise in CL cases between 2013 and 2019 - especially in the Eastern Mediterranean region - followed by a decrease in 2020, attributed to the COVID-19 pandemic<sup>(44)</sup>. These patterns align with the observed increase in publications from 2016 onward and may have contributed to expanded interdisciplinary collaboration in global research efforts.

The visibility of high-impact, open-access journals suggests a shift in publication preferences beginning in 2005, favoring outlets focused on public health and neglected infectious tropical diseases, such as *Acta Tropica* and *PLOS Neglected Tropical Diseases*. These journals not only published the greatest volume of literature on CL and EC but also demonstrated strong influence within the citation network, positioning them as key sources of scientific advancement. *PLOS Neglected Tropical Diseases*, in particular, is highlighted for its major impact on tropical medicine<sup>(8-10)</sup>.

The *Revista da Sociedade Brasileira de Medicina Tropical* stands out as the preferred Brazilian journal<sup>(8,9)</sup>. Founded in 1967, it is a major reference in health sciences and tropical medicine, ranking among the top 10 journals in the field and playing a central role in South American collaboration networks<sup>(45)</sup>. Its high Scimago Journal Rank (SJR) reflects strong citation metrics and international relevance<sup>(9)</sup>, reaffirming the importance of national journals in consolidating scientific knowledge on CL and its environmental determinants in the Brazilian context.

English remains the predominant language in high-impact journals<sup>(46)</sup>, though the geographic distribution of leishmaniasis, especially in endemic Latin American countries like Brazil, may influence preferences for national journals publishing in local languages. This leads to shared prevalence between English, Portuguese, Spanish, and French<sup>(41)</sup>.

The co-authorship network reveals a substantial number of researchers engaged in studies on CL and environmental change. This network structure presents in two primary forms: isolated clusters (SCP – Single Country Publications) and interconnected clusters (MCP – Multiple Country Publications). Isolated clusters may represent institution-specific groups or narrowly focused research themes<sup>(41)</sup>, but they can also reflect resource limitations

or lack of awareness of the value of collaboration in public health research networks<sup>(47)</sup>. Conversely, isolation may also be linked to increased productivity through individual effort<sup>(39)</sup>. Nevertheless, strong, self-sustaining scientific output was observed in Brazilian and Iranian clusters, which emerged as the most prolific in the bibliometric analysis by<sup>(40)</sup> on the expansion of leishmaniasis in urban areas. Greater density is observed among five interconnected author clusters, contributing to a more productive and integrated research landscape.

This interconnectedness promotes shared interests, strengthens collaboration in research ideas and methods, and facilitates resource sharing<sup>(48)</sup>, indicating a high level of international cooperation in global research networks.

Al-Mutawakel et al.,<sup>(39)</sup> demonstrated broad global interest in leishmaniasis research, with participation from 140 countries, 95.7% of which were involved in collaborative networks, most notably in North and South America and Western Europe. In the present study, 36 countries were found to be interconnected in co-authorship networks. Brazil, Iran, and the United States lead in publication output. As in the findings of Al-Mutawakel et al.,<sup>(39)</sup>, strong collaboration was observed between grouped countries, with the United States occupying a central position in the collaborative network, suggesting a concentration of coordinated research clusters within its territory.

Brazil, an endemic country for American Tegumentary Leishmaniasis, recorded the highest number of cases in the Americas in 2022, with 12,878 notifications - equivalent to 12.97 cases per 100,000 inhabitants<sup>(49)</sup>. The results of this analysis indicate an extensive national co-authorship network and multiple international connections. Alongside the United States, Brazil forms one of the most influential networks in the field<sup>(8-10,39)</sup>, concentrating major scientific collaborations on CL and EC.

Brazil's research output in this field is supported by factors that reduce dependence on external collaboration, including the high disease burden, significant public research funding, an active interinstitutional network in South America<sup>(45)</sup>, a large number of involved researchers, and the country's leadership in the regional scientific landscape<sup>(6,41)</sup>. Additionally, Brazil is home to centers of excellence in public health and tropical medicine, such as the Evandro Chagas Institute, the Oswaldo Cruz Foundation (Fiocruz), the Tropical Medicine and Nutrition Center at the University of Brasília, and maintains collaborative networks with researchers from Europe and North America who have played essential roles in disseminating leishmaniasis research across Latin America<sup>(6)</sup>. Our data highlight the strong contributions of federal and state public universities, as well as Fiocruz, in advancing this field<sup>(8,9)</sup>.

The high prevalence of CL in Iran - particularly in the provinces of Isfahan, Shiraz, Khorasan, Khuzestan, Kerman, and Azerbaijan<sup>(46)</sup>, combined with scientific expansion in Asia and the growth of regional journals<sup>(41)</sup>, may explain Iran's increasing independent research efforts. In this study, Iran surpassed India in publication output within the Asian context<sup>(40)</sup>.

The strong participation of North American and European countries in leishmaniasis research, despite the disease not being a major public health concern in those regions, stems from the need to prevent the introduction of tropical diseases<sup>(39)</sup>. These countries - leaders in scientific excellence - should expand collaborative publication efforts with developing countries, especially in North Africa and the Middle East<sup>(41)</sup>. Both the U.S. and Europe have longstanding institutions and agencies that support research in health, tropical medicine, and parasitology, maintaining networks of scientists who collaborate with endemic countries.

Based on the analysis of the articles and supporting evidence, there is growing consensus in the literature about the close relationship between CL and EC - particularly those related to climate change and LULC. The term "Cutaneous Leishmaniasis" appears as the central axis of research, highlighting the development of an interdisciplinary field that

integrates epidemiology, entomology, geoprocessing, and health surveillance. Numerous studies have demonstrated, through sophisticated statistical and spatial models, that factors such as deforestation, unplanned urban expansion, intensive agriculture, and extreme climatic events (e.g., El Niño) directly influence disease transmission dynamics by altering the habitats of vectors and reservoirs<sup>(40)</sup>. Ecological niche modeling<sup>(50)</sup> and predictive models<sup>(51)</sup> are increasingly used to forecast the future distribution of CL and its vectors under global warming and land-use change scenarios. Although these models have revealed significant patterns, such as the potential expansion of vectors into non-endemic areas, studies also acknowledge that environmental changes alone do not fully explain the complexity of CL transmission, underscoring the need to integrate socioeconomic, ecological, and environmental factors<sup>(52,53)</sup>. This emphasizes the importance of integrated, interdisciplinary approaches to understanding and addressing CL dissemination in rapidly changing environments and reinforces the relevance of environmental surveillance and urban planning strategies aligned with the Sustainable Development Goals (SDGs) by addressing the ecological determinants of health.

## FINAL CONSIDERATIONS

Although the number of publications addressing CL and its relationship with EC has increased in recent years, solutions for the clinical challenges posed by the disease remain limited. This paper reveals a growing trend of incorporating environmental variables, such as LULC and climate factors, into research on CL, influenced by global meetings and their resulting reports.

Both endemic countries, like Brazil and Iran, and non-endemic ones, such as the United States, have invested in studies addressing CL and EC, with a particular focus on vector control. Brazil stands out in this study as a prolific and influential Latin American country with a robust research landscape in tropical diseases, supported by universities and international collaborative networks.

Indeed, the control of many vector-borne infectious diseases is hindered by gaps in knowledge of vector ecobiology, ecosystem diversity, and environmental, climatic, and socioeconomic factors that influence transmission chains. These gaps can be addressed through globalization and interdisciplinarity, fostering collaborative research networks driven by a One Health approach that contributes to a deeper understanding of the links between these changes and Cutaneous Leishmaniasis.

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