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SPATIAL AUTOCORRELATION OF SNAKEBITES IN THE MUNICIPALITY OF RIO DE JANEIRO, BRAZIL

AUTOCORRELACIÓN ESPACIAL DE PICADAS DE COBRA EN EL MUNICIPIO DE RÍO DE JANEIRO, BRASIL

AUTOCORRELAÇÃO ESPACIAL DE PICADAS DE COBRA NO MUNICÍPIO DO RIO DE JANEIRO, BRASIL

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ABSTRACT

Snake bites are a global public health problem, with approximately 2.7 million cases annually. In Brazil, reporting snake bites is mandatory, with around 29,000 cases recorded each year, and antivenom is available free of charge in the public health system. In the city of Rio de Janeiro, there are around 150 reports annually. Knowing the spatial distribution of these accidents is essential for the efficient planning and allocation of antivenom. This study aimed to analyze the spatial autocorrelation of snake bites in the city of Rio de Janeiro between 2007 and 2017. This is an observational, cross-sectional study with data from SINAN. The highest prevalence rates were concentrated in the West Zone, an area where the two reference units for treating poisoning are located. The Moran index was 0.46, with high statistical significance ($p < 0.001$), indicating positive spatial autocorrelation and dependence between neighborhoods. The Moran's Local Index (LISA) confirmed the West Zone as the area with the highest risk of incidence. The most affected neighborhoods showed population growth and an increase in occupied households, suggesting intense territorial expansion. The genus Bothrops spp was responsible for most cases of poisoning. About half of the victims received care within the ideal time frame for treatment, demonstrating that, although access

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to specialized care exists, there are still challenges in reducing response time and preventing cases.

Keywords: Poisoning. Neglected Tropical Disease. Risk. Prevalence. Moran's Index.

RESUMEN
Las mordeduras de serpiente constituyen un problema de salud pública mundial, con aproximadamente 2,7 millones de casos/año. En Brasil, su notificación es obligatoria, registrándose 29 000 casos/año, y el antídoto se proporciona gratuitamente en la red pública de salud. En el municipio de Río de Janeiro se registran alrededor de 150 notificaciones/año. Conocer la distribución espacial de estos accidentes es fundamental para la planificación y asignación eficiente de antidotos. El objetivo de este estudio fue analizar la autocorrelación espacial de las mordeduras de serpiente en el municipio de Río de Janeiro entre 2007-2017. Se trata de un estudio observacional transversal, con datos procedentes del SINAN. Las mayores tasas de prevalencia se concentraron en la Zona Oeste, área donde se encuentran las das unidades de referencia en la atención de envenenamientos. El índice de Moran fue de 0,46, con una significación estadística elevada (p < 0,001), lo que indica una autocorrelación espacial positiva y una dependencia entre barrios. El índice de Moran local (LISA) confirmó que la zona oeste es el área con mayor riesgo de incidencia. Los barrios más afectados mostraron un crecimiento demográfico y aumento de los hogares ocupados, lo que sugiere intensa expansión territorial. *Bothrops spp* fue responsable de la mayoría de los casos de envenenamiento. Aproximadamente la mitad de las víctimas recibieron atención dentro del tiempo considerado ideal para el tratamiento, lo que demuestra que, aunque existe acceso a la atención especializada, aún hay desafíos en la reducción del tiempo de respuesta y la prevención de casos.

Palabras clave: Envenenamiento. Enfermedad Tropical Desatendida. Riesgo. Prevalencia. Índice de Moran.

RESUMO
A picada de cobra constitui um problema de saúde pública global, com aproximadamente 2,7 milhões de casos anuais. No Brasil, sua notificação é compulsória, registrando-se cerca de 29.000 casos por ano, e o antiveneno é disponibilizado gratuitamente na rede pública de saúde. No município do Rio de Janeiro, observam-se cerca de 150 notificações anuais. Conhecer a distribuição espacial desses acidentes é fundamental para o planejamento e a alocação eficiente de soros antiofídicos. Este estudo teve como objetivo analisar a autocorrelação espacial das picadas de cobra no município do Rio de Janeiro entre 2007 e 2017. Trata-se de um estudo observacional, transversal, com dados provenientes do SINAN. As maiores taxas de prevalência concentraram-se na Zona Oeste, área onde estão localizadas as duas unidades de referência no atendimento a envenenamentos. O índice de Moran foi de 0,46, com significância estatística elevada (p < 0,001), indicando autocorrelação espacial positiva e dependência entre bairros. O Índice de Moran Local (LISA) confirmou a Zona Oeste como área de maior risco de incidência. Os bairros mais afetados mostraram crescimento populacional e aumento de domicílios ocupados, sugerindo intensa expansão territorial. O gênero *Bothrops spp.* foi responsável pela maioria dos casos de envenenamento. Cerca de metade das vítimas recebeu atendimento dentro do tempo considerado ideal para tratamento, demonstrando que, embora o acesso ao cuidado especializado exista, ainda há desafios na redução do tempo de resposta e na prevenção de casos.

Palavras-chave: Envenenamento. Doença Tropical Negligenciada. Risco. Prevalência. Indice de Moran.

1 INTRODUCTION

Snakebite poisoning is a global concern[1–4], considered a medical emergency requiring immediate attention [5,6]. It occurs mainly in tropical and subtropical countries in Africa, Asia, and Latin America [7–9]. It mainly affects rural and socioeconomically vulnerable communities in these regions [10].

It is estimated that around 2.7 million people worldwide are victims of snake bite poisoning every year [1,11,12], and approximately 100,000 to 138,000 people die annually and another 400,000 are disabled due to this condition [8,13–15]. Most of the world's population, around 5.8 billion people, is at risk of suffering from this condition[3,16]. In 2017, the World Health Organization (WHO) designated snake bite envenomation (SBE) as a priority Neglected Tropical Disease (NTD), recognizing its impact on the world's most vulnerable populations. More than 95% of SBE cases occur in tropical environments, mainly in South Asia, Sub-Saharan Africa (SSA), and South America, with the greatest burden falling on low-income rural populations [17].

Snakebite poisoning represents a major challenge in the field of public health in Brazil [10] which stands out as one of the countries most affected by snakebite poisoning, with snakes of the genus *Bothrops spp.* responsible for most bites because they are spread throughout the national territory [2,10,18].

In Brazil, reporting snakebites is mandatory. Approximately 29,000 cases are reported annually to the Ministry of Health's National Disease Surveillance System. (acronym in Portuguese, SINAN) [19,20] and the antidote has been available for 120 years, being highly effective and distributed free of charge in the public health system through the Unified Health System (SUS),) and is directly related to the reporting of new cases [2,21].

Brazil stands out as one of the countries most affected by snakebite poisoning, with snakes of the genus *Bothrops spp.* responsible for most bites due to their widespread distribution throughout the country [2,10,18]. Brazil has a wide variety of wild animals and the greatest diversity of reptiles in the world, so there are also many cases of poisoning [22]. Knowing the profile of snakebites is relevant to public health, both for the adoption of strategies to prevent new poisonings and for the identification of populations vulnerable to this type of health hazard. It can also guide policies on the distribution of and access to antivenoms, which are currently the only effective treatment available to victims [23].

Identifying the snake that bite, and its habitat is essential to understanding the ecoepidemiology of snakebites and optimizing clinical treatment. To prevent and combat the neglected disease of snakebites, improving the identification of venomous snake species, better defining their geographical distribution, and characterizing their morphology can be great allies in understanding the dynamics of the conflict between humans and snakes and devising health actions for prevention and control, as well as providing adequate health facilities [24].

Whether due to deforestation forcing these animals to seek new habitats, or due to the search for food or mating, encounters between humans and snakes seem to be increasingly common. This, coupled with limited knowledge rooted in myths and legends, triggers prejudice and harmful attitudes towards them [25]. Previous studies have demonstrated the association between deforestation and snakebites in Brazil [2].

The municipality of Rio de Janeiro reported around 150 cases between 2007 and 2022, but in the last three years, there have been more than twice as many reports, reaching over 470 cases of snakebites annually (SINAN-DATASUS) [26]. A better understanding of the distribution of cases would help managers in the distribution of antivenom and in accident prevention strategies.

The objective of this study is to analyze the spatial autocorrelation of snakebites in the municipality of Rio de Janeiro, Brazil, from 2008 to 2017.

2 METHODOLOGY

This is an observational, cross-sectional epidemiological study on the spatial correlation of snake bites conducted in the municipality of Rio de Janeiro from 2008 to 2017.

2.1 STUDY AREA

The municipality of Rio de Janeiro has a population of 6,211,223 inhabitants and an area of 1,200.330 square kilometers, according to the 2022 census [27]. It is divided into administrative regions (RA) and planning areas (AP). The administrative region is an administrative division of the municipality of Rio de Janeiro that aims to bring public management closer to the population, making services more accessible; currently, there are 34. The Planning Area, on the other hand, is the territorial division that groups neighborhoods according to environmental, historical, and land use criteria, with the objective of supporting urban planning and management and promoting local development. Rio de Janeiro is divided into five main Planning Areas (PA-1 to PA-5), which are managed by the Local Planning Management Offices (GPLs) of the Municipal Secretariat of Urbanism [28,29].

2.2 VARIABLES

These variables were obtained from the following sources:

a) The data on snake bites that happened and were reported in the city of Rio de Janeiro between 2008 and 2017, through the Notifiable Diseases Information System (SINAN)[19]. The data was provided through the Access to Information System, protocol number 25820.001698/2019, from 2019.

b) Sociodemographic data: Brazilian Institute of Geography and Statistics (IBGE)[27], Open Data Portal of the City of Rio de Janeiro (DATA.RIO)[28], Municipal Secretariat for Social Assistance and Human Rights (SMASDH)[29].

2.3 GEOSPATIAL ANALYSIS

For the spatial autocorrelation analysis, we first considered the prevalence rate of snakebites by neighborhood reported in the municipality of Rio de Janeiro during the study period. To calculate this, we used the following formula:

$$\text{Prevalence Rate} = \frac{Total\ snakebite}{Total\ population\ at\ risk\ in\ the\ municipality\ of\ RJ}\ X\ 1\ 000\ 000 \quad (1)$$

The total population at risk during the period was selected as the inhabitants of the municipality of Rio de Janeiro in 2010, extracted from the 2010 Brazilian census conducted by the Brazilian Institute of Geography and Statistics (IBGE)[27]. This was estimated at 6,320,446 inhabitants. Initially, the distribution of prevalence rates for the period by neighborhood was compared visually using a spatial distribution map.

For spatial autocorrelation analyses, the calculation of the Moran's Global Index and its graphical representation (scatter plot) were integrated, as well as the calculation of the Moran's Local Index (LISA) and its representation on a map of clusters or agglomerations. The Moran's Global Index defines the differences between the prevalence rates for the period, associated with the neighborhoods of the municipality of Rio de Janeiro, using a correlation coefficient for the relationship between the spatial values of the rates and their mean value, considering the first neighbor, i.e., using a first-order neighborhood matrix, regardless of the criterion chosen for the composition of the matrix [W] [30]. In this sense, the following expression is used:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\,(Z_i - \mu_z)(Z_i - \mu_z)}{\sum_{i=1}^{n}(Zi - \mu_z)^2} \quad (2)$$

Where:

I = Moran's index; n = number of areas;

Zi = value of the rate considered in area (i);

μz = average value of the attribute in the study region;

Wij = element (ij) of the normalized neighborhood matrix.

The result of equation (I) is analogous to that obtained for a non-spatial correlation coefficient: if there is a positive correlation, most neighboring polygons will have values on the same side of the mean and the index will be positive [I > 0], indicating direct spatial correlation; if there is a negative correlation [I < 0], then the spatial relationship is negative or inverse. When I = 0, there is no spatial correlation [30].

The Moran's Global Index (I) can be subjected to a statistical test whose null hypothesis represents spatial independence, a condition given by [I = 0]. Therefore, the null hypothesis can only be rejected if (I) is statistically different from zero, for a pre-established significance level. This index can also be represented in a two-dimensional scatter plot of (Z) (normalized values) by (Wz) (neighborhood average), divided into four quadrants (Q1, Q2, Q3, Q4), whose purpose is to provide the necessary elements for comparing the normalized values of the prevalence rate in each area with the average of its neighbors [30,31].

The Moran's Local Index (Ii) was designed as a statistical tool to test local autocorrelation and detect spatial objects that influence the Moran's Global Index (I). It can be expressed for each neighborhood (i) based on the normalized values (Zi) of the prevalence rate using the following equation:

$$\mathrm{I}_i = \frac{Z_1 \sum_{i=1}^{n} \sum_{j=1}^{n} \; W_{ij}\, Zj}{\sum_{i=1}^{n} Zj^2} \quad (3)$$

In which: [zi] = [(Zi - μz) / δz] is the standardized prevalence rate.

From the Ii equation, positive results are obtained where there are concentrations of low or high values of the rate, while negative results arise from the proximity between low and high values in the same area. Thus, Moran's Local Index (Ii) provides an indication of the homogeneity and diversity in the distribution of rates [30].

The Moran's Local Index (Ii) is also represented in a scatter diagram on the dispersion graph, which becomes an analytical tool where each point representing each neighborhood takes on its own meaning, unlike the Moran's Global Index (I). Here, quadrants Q_1 and Q_2 represent the neighborhoods that contribute to positive autocorrelation, indicating clusters or agglomerations of neighborhoods with high and low values, respectively, to be represented on a map. Quadrants Q_3 and Q_4 represent areas that contribute to negative autocorrelation, indicating transition neighborhoods, with high prevalence rates surrounded by low values, and vice versa. The Moran's Local Index (Ii) also explores the concept of local pockets of statistically significant correlation by allowing the identification of clusters of neighborhoods with similar and dissimilar or anomalous rate values [30,31].

In this study, a significance level of 5% was established for all statistical tests performed. The *softwares Microsoft 365 Excel* (version 2311) helped with downloading and organizing the statistical databases. The *software R* (versão 4.0.5 [*packages: dplyr; ggplot; geobr; sf; rio; readr; tidyverse; pacman; ggspatial; spdep; ape; ggstats; rgeoda; ggiraph*]) was used in statistical analyses and graphical representations.

3 RESULTS AND DISCUSSION

3.1 DISTRIBUTION OF SNAKEBITES IN THE MUNICIPALITY OF RIO DE JANEIRO

We can observe in this study that most bites were caused by snakes of the genus *Bothrops spp.* (**Table 1**), corresponding to approximately 89% of recorded cases. Similar results have been described in different regions of Brazil, where species of this genus (**Figure 1**) also stand out as the main cause of snakebites. This predominance is related to the wide geographical distribution of this genus throughout virtually the entire national territory and the high diversity of the group, which comprises 29 described species [2,18,26,32–37].

Table 1

Type of accident occurring in the city of Rio de Janeiro, Brazil, 2008 to 2017

Type of Accident	Snakebite	%
Botropic	**441**	**89,10%**
Elapidic	6	1,20%
Lacetic	2	0,40%
Non-Venemous	18	3,60%
IGN	28	5,70%

Source: SINAN[19]. Adapted by the authors, 2025.

In Brazil, reporting snakebites is mandatory. Approximately 29,000 cases are reported annually to the Ministry of Health's National Disease Surveillance System (acronym in Portuguese, SINAN) [19,20].

Figura 1

Bothrops jararaca, municipality of Rio de Janeiro, Brazil, 2024.

Photo: Moana F Santos, 2024.

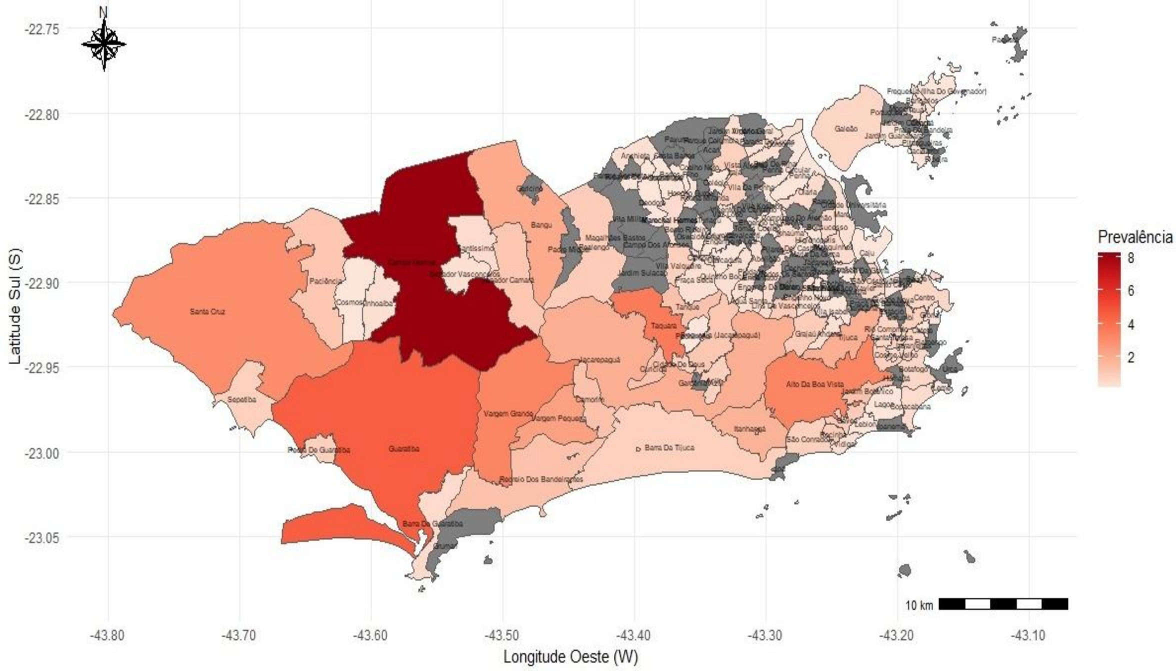
3.2 SPATIAL AUTOCORRELATION ANALYSIS

As for spatial distribution, shown in **Figure 2**, snakebite cases were reported in 102 of the 161 neighborhoods, representing 62.7% of the neighborhoods in the municipality of Rio de Janeiro in 2010. Fifty-nine neighborhoods had no records or no occurrences and were classified as unknown. The highest prevalence rates, although generally low, were concentrated in the West Zone, constituting the zone with the highest risk of bites. The neighborhoods with the highest rates were: Campo Grande (8,23 by 1 000 000 inhabitants), Guaratiba (4,59 by1 000 000 inhabitants) and Taquara (3,64 by 1 000 000 inhabitants), followed by Vargem Grande (3,32 by 1 000 000 inhabitants) and, Alto de Boa Vista (3,32 by 1 000 000 inhabitants), the latter in the Northern Zone.

The lowest prevalence (0,16 by 1 000 000 inhabitants) it was distributed across 35 neighborhoods, mainly located in the North Zone, and, together with the neighborhoods with no reported cases, those with the lowest risk of snakebites: Bancários, Barros Filho, Benfica, Cacuia, Caju, Cascadura, Catete, Cocota, Colégio, Cosmos, Del Castillo, Deodoro, Engenho da Rainha, Freguesia (Ilha do Governador), Guadalupe, Higienópolis, Honório Gurgel, Jardim Guanabara, Lagoa, Leblon, Leme, Madureira, Oswaldo Cruz, Pechincha, Penha, Penha Circular, Praça da Bandeira, Riachuelo, Ricardo Alburquerque, Sampaio, Santo Cristo, Saúde, Tomas Coelho, Vaz Lobo e Vila Isabel **(Table 2**).

Figura 2

Spatial distribution of snakebite prevalence rates in neighborhoods in the municipality of Rio de Janeiro (Brazil). Period from 2008 to 2017



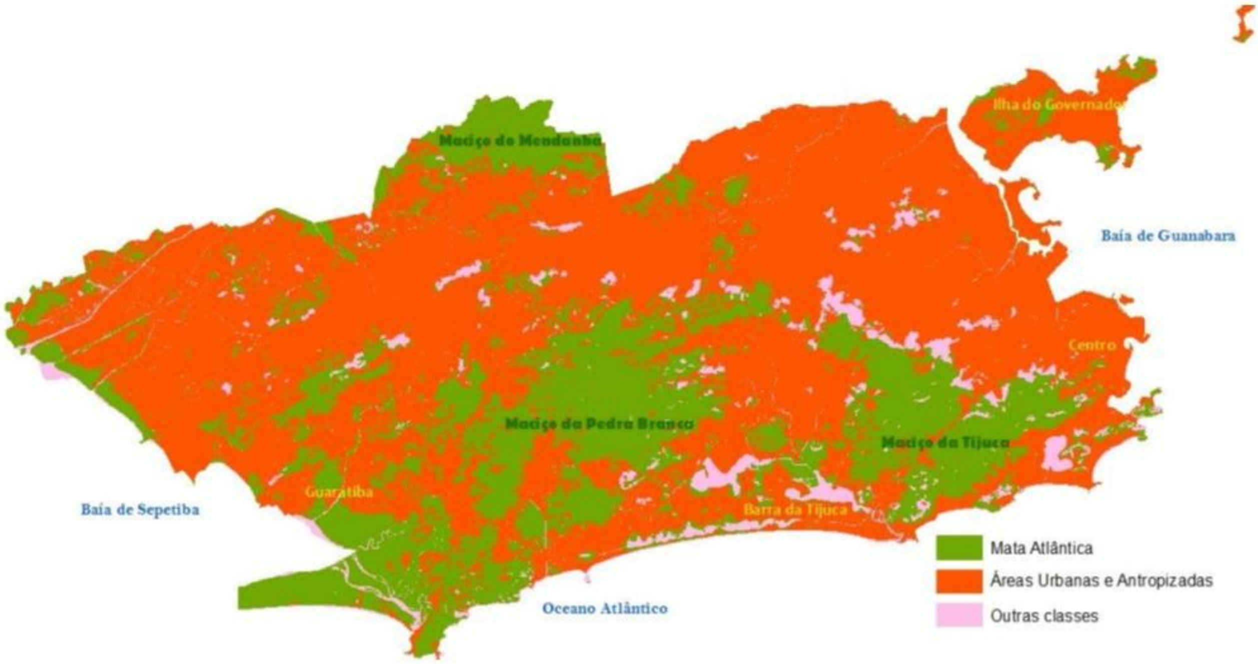
Gray = neighborhoods with no reported cases of snakebites. Source: Produced by the authors, 2025

Figure 3 shows an extensive urban network, represented by the red coloring, which expands over the green corridors, promoting intense fragmentation, especially in areas with a higher prevalence of snakebites, notably in Planning Areas 4 and 5. Although the municipality of Rio de Janeiro has a higher forest cover than the average of the other capitals located in the Atlantic Forest Biome, the spatial configuration resulting from urban expansion has given the remaining forests a fragmented character, comparable to “islands.” This process of advancing urbanization is a potential additional risk factor for snakebites, due to the greater proximity between residences and the natural habitat of these animals. In addition, the presence of peri-urban areas can attract these animals, either by providing shelter or by facilitating access to food, thus increasing the likelihood of unwanted interactions with humans.

From an environmental and public health perspective, habitat fragmentation and urban sprawl create socio-ecological vulnerabilities, as they increase the exposure of peripheral populations to risk. Areas dominated by mosaics of forest fragments interspersed with urban areas require integrated monitoring, combining environmental surveillance and community education to mitigate the occurrence of bites[38,39].

Figure 3

Vegetation cover and land use in the municipality of Rio de Janeiro, 2014



Source: GT Corredores Verdes, 2012 [40].

Table 2

Neighborhoods that reported snakebites, municipality of Rio de Janeiro, 2008–2017

Neighborhood	PA	N	POP	Prev. Rate
Campo Grande	5	52	6320446	8,23
Guaratiba	5	26	6320446	4,59
Taquara	4	23	6320446	3,64
Alto da Boa Vista	4	21	6320446	3,32
Vargem Grande	2	21	6320446	3,32
Santa Cruz	5	19	6320446	3,01
Vargem Pequena	4	15	6320446	2,37
Bangu	5	13	6320446	2,06
Jacarepagua	4	12	6320446	1,90
Tijuca	2	12	6320446	1,90
Itanhangá	4	11	6320446	1,74
Camorim, Curicica, Tanque, Recreio Bandeirantes	4	8	6320446	1,27
Jardim Botânico	2	8	6320446	1,27
Freguesia - jpga	4	7	6320446	1,11
Paciencia, Senador Camará	5	7	6320446	1,11
Gávea, Grajaú, Rocinha	2	6	6320446	0,95
Lins de Vasconcelos	3	6	6320446	0,95
Realengo	5	6	6320446	0,95
Anil, Barra da Tijuca, Cidade de Deus	4	5	6320446	0,79

Iraja, Santa Teresa, Vila Valqueire	3	5	6320446	0,79
Pedra de Guaratiba, Sepetiba	5	5	6320446	0,79
São Conrado	2	5	6320446	0,79
Botafogo, Laranjeiras	2	4	6320446	0,63
Centro, São Cristóvão	1	4	6320446	0,63
Galeão, Rio Comprido	3	4	6320446	0,63
Bonsucesso, Engenho de Dentro, Inhaúma, Manguinhos, Marechal Hermes, Olaria	3	3	6320446	0,47
Copacabana, Cosme Velho	2	3	6320446	0,47
Barra de Guaratiba, Santíssimo	5	3	6320446	0,47
Água Santa, Anchieta, Campinho, Cordovil, Engenho Novo, Jardim América, Maré, Parada de Lucas, Piedade, Quintino Bocaiuva, Tauá	3	2	6320446	0,32
Andaraí, Gloria, Vidigal	2	2	6320446	0,32
Inhoaíba	5	2	6320446	0,32
Praça Seca	4	2	6320446	0,32
Senador Vasconcelos	5	2	6320446	0,32
Benfica, Caju, Santo Cristo, Saúde	1	1	6320446	0,16
Cacuia, Barros Filho, Bancários, Cascadura, Cocotá, Colégio, Del Castilho, Engenho da Rainha, Freguesia (ilha), Madureira, Guadalupe, Higienópolis, Honório Gurgel, Jardim Guanabara, Osvaldo Cruz, Riachuelo, Tomas Coelho, Sampaio, Ricardo Albuquerque, Vaz Lobo, Penha, Penha Circular	3	1	6320446	0,16
Catete, Lagoa, Leblon, Leme, Praça da Bandeira, Vila Isabel	2	1	6320446	0,16
Cosmos, Deodoro	5	1	6320446	0,16
Pechincha	4	1	6320446	0,16
Ignored (59 Neighborhood)	NH	0	6320446	0

PA – Planning Area; **N** – number of snakebites in the study period; **POP** – population of the municipality of Rio de Janeiro; **Prev. Rate** – Prevalence Rate per 1,000,000. Source: DATASUS[26]. Adapted by the authors, 2025.

Although several factors are strongly associated with risk in different geographic regions, further studies are needed to elucidate the pattern of association between important climatic and environmental variables and risk in various contexts. Increasing and improving mandatory reporting of snakebite incidents can substantially help generate the data needed to perform these analyses [17].

Spatial analysis can be a powerful tool for associating environmental, socioeconomic, and health factors. This analytical approach provides a set of information that facilitates the visualization of patterns of health conditions, often exhibiting a significant correlation with the analyzed space [41].

Spatial correlation analyses of snakebite prevalence initially showed that the average neighborhood between neighborhoods in the municipality of Rio de Janeiro where bites occurred was 4.09. **Figure 4** shows that the calculated Moran's index was 0.46, with high

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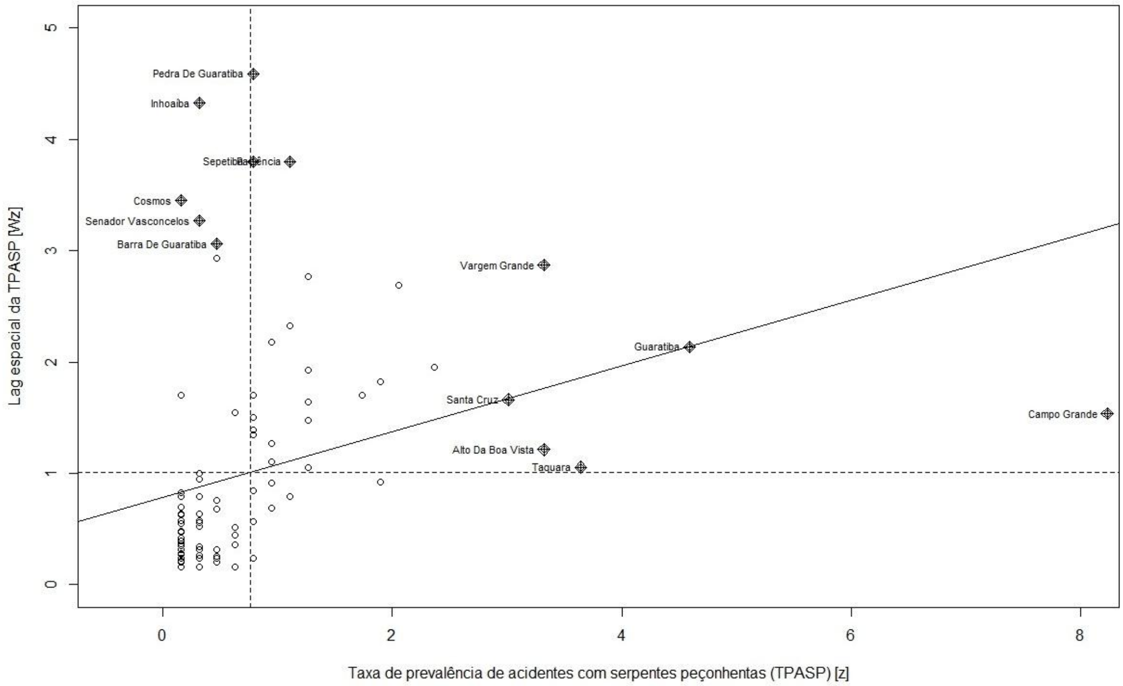
statistical significance (p-value < 0.001), demonstrating positive spatial autocorrelation in the distribution of snakebites and spatial dependence between neighborhoods in the study period. In this figure, the scatter plot also shows the patterns of spatial variability behavior, with the highest number of points in quadrants Q_1 and Q_2, confirming the positivity of spatial autocorrelation. In this regard, neighborhoods with a High-High (**HH**) pattern (upper right quadrant) stand out: Campo Grande, Guaratiba, Taquara, Vargem Grande, Alto de Boa Vista, Santa Cruz and, and Paciência, além de Jacarepaguá, Senador Camará, Sepetiba, Curicica, Realengo, Pedra de Guaratiba, all located in the West Zone of the municipality of Rio de Janeiro. These results showed that the prevalence rate for each neighborhood and the average rate for neighboring neighborhoods were higher than the overall average.

The Low-Low pattern (**LL**; lower left quadrant), where the prevalence rate of snakebites in each neighborhood and the average rate in neighboring neighborhoods were lower than the overall average, was represented by the following neighborhoods: Olaria, São Cristóvão, Manguinhos, Madureira, Guadalupe and, Inhaúma; all located in the North Zone, except for São Cristóvão, located in the central zone of the municipality. The Low-High pattern (**LH**; upper left quadrant), characterized by a prevalence rate for each neighborhood below the overall average, while the average rate in neighboring neighborhoods was above average, was represented by the following neighborhoods: Santíssimo, Senador Vasconcelos, Cosmos, Inhoaíba e Barra de Guaratiba, all also located in the West Zone.

Figure 4

Moran's index = 0.46; p<0.001. Overall statistics on the spatial variability of snakebites in neighborhoods in the municipality of Rio de Janeiro (Brazil). Period from 2008 to 2017

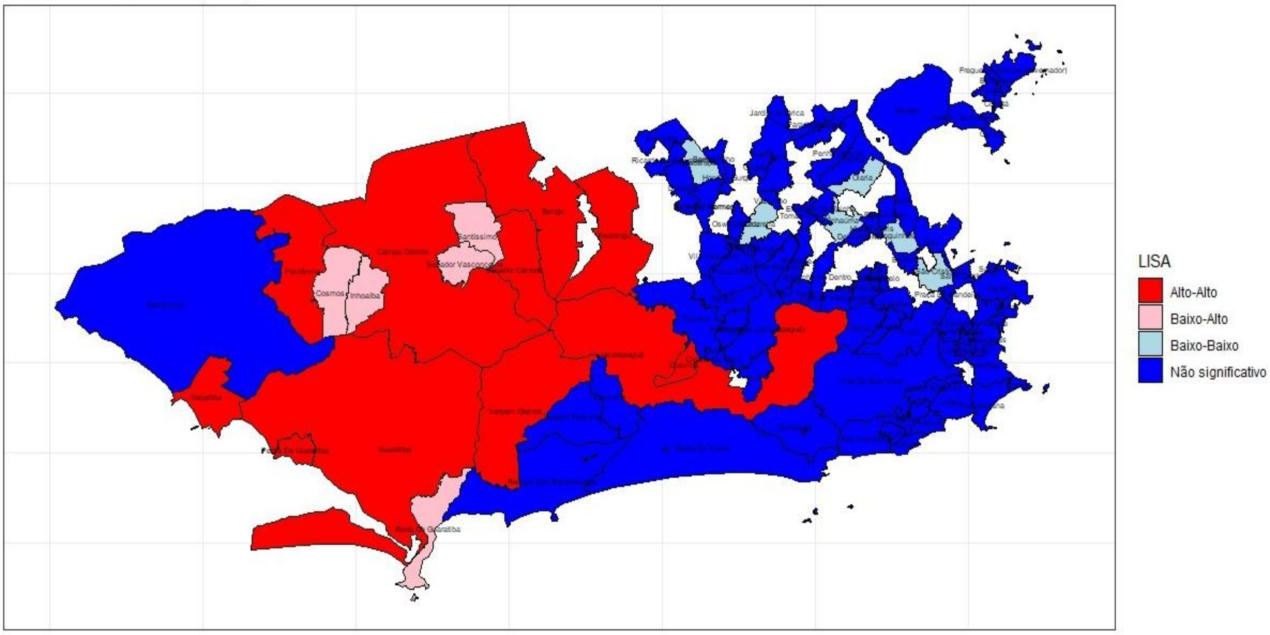


Standards: High-High [**HH**] = Q_1 (upper right quadrant); Low-Low [**LL**] = Q_2 (lower left quadrant); Low-High [**LH**] = Q_3 (upper left quadrant); High-Low [**HL**] = (lower right quadrant). Source: Produced by the authors, 2025.

From another perspective, Moran's Local Index (LISA), shown in **Figure 5** identified clusters or conglomerates of statistically significant and insignificant behaviors, based on the calculation of this index at the local level, homogeneously grouping neighborhoods with similar prevalence rates. Thus, this result confirms that the West Zone has the highest concentration of neighborhoods with high and low statistically significant values, which contributed to positive autocorrelation. Therefore, from a geospatial point of view, this was the area with the highest risk of snakebites during the study period. Unlike the rest of the zones, considered transition areas, where neighborhoods with high prevalence rates were surrounded by neighborhoods with low prevalence rates, and vice versa.

Figure 5

Moran's Local Index (LISA). Clusters for venomous snakebites in neighborhoods in the municipality of Rio de Janeiro (Brazil) - Period 2008 to 2017



Source: Produced by the authors, 2025

Determining the geographic variation of snakebites provides useful information for identifying high-risk areas. This helps policymakers target preventive measures and allocate resources efficiently at the local level [42].

The generation of high spatial resolution knowledge is a pressing need for future actions in education, prevention, access to treatment, resource allocation, community training, and strengthening of health systems in countries where snakebites are endemic. In addition, it is necessary to estimate the risk of snakes to humans using variables that attract these animals, such as factors related to poverty and rural work, food storage, straw storage, the habit of sleeping on the floor, vegetation index, and distance to water sources [43].

A study conducted in Costa Rica suggests that the spatial distribution of snake bites may be primarily driven by a combination of environmental factors that affect the distribution of venomous snakes and their association with the size of the exposed human population [44]. The presence of snakes in forest remnants located in urban areas or in forests adjacent to urbanized areas has also encouraged encounters between humans and these animals and may contribute to an increase in snakebites[32].

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With the increasing availability of climate and environmental data and the resolution required for spatial modeling, there is great potential for spatial techniques to leverage the limited incidence data available to better understand the variation in the risk of snakebites [17].

The implementation of environmental awareness programs is essential to reinforce the need for the conservation of biological resources [45]. According to Oliveira *et al*. (2022), a large part of the human population is ignorant about snakes, and this may be due to society's aversion to these animals, mainly because of the fear that some species can produce and inject lethal venom [22].

3.3 OCCUPATION OF THE TERRITORY

Regarding the occupation and mobilization of the territory of the eleven neighborhoods, we observed that there has been gradual population growth in 2000, 2010, and 2022 censuses [27,28]. Over the last decade, nine of these neighborhoods have also seen an increase in the number of occupied private residences, which requires greater movement of people in this territory (**Table 3**).

Table 3

Data on population growth and the total number of occupied private residences in the neighborhoods most affected by snake bites in the city of Rio de Janeiro, extracted from the 2000, 2010, and 2022 demographic censuses

Neighborhood	**TP 2000 (a)**	**TP 2010 (b)**	**TP 2022 (c)**	**DP-% b- a**	**DP-% c- b**	**TDPO 2010**	**TDPO 2022(b)**	**DDPO-% b - a**
Campo Grande	297.494	328.370	352.704	10,38	7,41	104.871	129.987	23,95
Guaratiba	87.132	107.369	154.125	23,23	43,55	32.282	55.404	71,63
Taquara	93.741	102.126	107.188	8,94	4,96	33.850	41.530	22,69
Vargem Grande	9.306	14.039	20.663	50,86	47,18	4.469	7.727	72,90
Alto da Boa Vista	8.254	9.343	9.831	13,19	5,22	2.974	3.785	27,27
Santa Cruz	191.836	217.333	249.130	13,29	14,63	66.156	89.387	35,00
Vargem Pequena	11.536	27.250	31.115	136,22	14,18	8.431	11.671	38,00
Bangu	244.518	218.089	211.912	-10,81	2,80	69.016	76.572	11,00
Tijuca	163.636	163.805	142.326	0,10	13,11	61.923	60.892	-2,00
Itanhangá	21.813	38.415	67.969	76,11	76,93	12.790	26.886	110
Jacarepaguá	100.822	143.440	175.943	42,27	-22,66	47.904	69.078	44,00

TP – Total Population; **DP (%)** – Difference in Population in numbers and percentage: **TDPO** – Total Occupied Private Households; **DDPO (%)** – Difference in Occupied Private Households in numbers and percentage. Source: DATA.RIO [28]; IBGE[27]; SMASDH[29]. Adapted by the authors, 2025.

While it is true that snakes often migrate in search of more suitable habitats, including areas with greater vegetation cover, recent research suggests that urban environments are becoming increasingly attractive to some snake species. This can be observed in regions where natural habitats are being destroyed or degraded due to urbanization. Urban areas can provide suitable shelter and food sources, such as rodents, which thrive in human settlements [10]. High levels of human activity in regions where snakes are present result in a greater likelihood of encounters with humans, consequently increasing the risk of these poisonings [32].

We should note that snake populations can be affected by multiple factors, such as habitat destruction, behavior, spatial ecology, activity patterns, decrease or increase in prey populations, changes in climatic variables, and the use of pesticides and household poisons [24,46].

3.4 TIME ELAPSED FROM POISONING TO TREATMENT

The results of the study showed that 52.30% of accident victims were rescued within the time frame that offers the best prognosis for recovery, i.e., between 0 and 3 hours. If we extend this period to 6 hours, we have 63.30% of accident victims treated within a time frame that provides a better prognosis for poisoning. However, despite this effort to ensure care, we still observe a significant portion that is treated after a prolonged period, i.e., 33.50% of the total number of accident victims (**Table 4**).

Table 4

Time elapsed from poisoning to treatment in hours, in the municipality of Rio de Janeiro, Brazil, 2008 to 2017

Time	Snakebite	%
0-1h	46	9,90%
1-3h	**197**	**42,40%**
3-6h	51	11,00%
6-12h	15	3,20%
12-24h	19	4,10%
24+	39	8,40%
IGN	98	21,00%

Source: SINAN [19]. Adapted by the authors, 2025.

Antivenom is the ideal and recommended treatment for snakebites, considered by many experts to be the only treatment [21,44,47]. The time between the bite and the administration of antivenom serum is decisive in the evolution of the victim's health condition [2,37,48]. Ideally, it should be administered within 3 to 6 hours after poisoning to offer better results and lower risk of surgical interventions, myotoxicity, neurotoxicity, disability, and death. They are specific, and to be effective, they must be administered according to the type of accident and the severity of the case [49–51]. Patients who seek care in the first few hours after being bitten have significantly lower morbidity and mortality rates [52]. On the contrary, delayed care increases the risk of injury and acute renal failure, as well as the severity of poisoning [53]. However, there is a lack of availability in medical centers located in rural areas. In addition, the number of snakebite cases is generally unknown and underestimated in many tropical countries. As a result, the distribution of antivenom and management of the disease are difficult to optimize, so estimating the incidence of snake bites has been proposed as a key factor in improving the management of snakebites [44].

In Brazil, antivenom has been available for 120 years and is highly effective. It is distributed free of charge in the public health system through the Unified Health System (SUS) and is directly linked to the reporting of new cases [2,21].

It should be noted that the two units that treat snakebite poisoning in the municipality are in the western part of the city: Lourenço Jorge Municipal Hospital in the Barra da Tijuca neighborhood (AP – 4) and Pedro II Municipal Hospital in the Santa Cruz neighborhood (AP - 5). However, the time elapsed between the snakebite and arrival at one of these units exceeds the ideal time frame for a better outcome in approximately half of the victims, resulting in fewer sequelae for these victims.

4 CONCLUSION

Although all planning areas (AP) in the municipality reported cases of snakebites, the study revealed that the neighborhoods with the highest number of occurrences are in the western part of the municipality of Rio de Janeiro, distributed between planning areas 4 and 5. These neighborhoods also showed population growth observed in the demographic censuses of 2000, 2010, and 2022. In addition, over the last decade, there has also been an increase in the number of occupied private residences, suggesting greater mobilization and occupation of the territory in question. It is also in the western zone that some of the most important remnants of the Atlantic Forest biome are located, which are part of the Rio de Janeiro mosaic and which, due to this increase in land occupation, have been fragmented, offering an increased risk of snakebites.

Knowledge of the areas of greatest risk for snakebites in the municipality of Rio de Janeiro is essential for establishing healthcare strategies, both in terms of treating poisoning and preventive measures that can be based on environmental and health education activities. The municipality's two snakebite poisoning treatment centers are in the western zone, which is an important finding of this study. It should be noted that antivenom is free under the Brazilian Unified Health System (SUS). However, the time elapsed between the accident and arrival at one of these units exceeds the ideal time for a better outcome in approximately half of the victims, resulting in fewer sequelae for these victims. Perhaps greater guidance for the population on the risk of accidents and the importance of seeking care as soon as possible is needed in these regions.

Epidemiological studies, in addition to being socially relevant, contribute to public health and the combat of snakebites. It can be a starting point for developing strategies to mitigate the problem, as the implementation of preventive measures is crucial, and spatial analysis can be an ally, standing out as a valuable methodology for investigating spatial patterns associated with snakebites.

Snakes of the genus *Bothrops spp*. are highly adaptable to different Brazilian environments and biomes, including forest, rural, and even peri-urban areas. The diversity of species in the genus, currently around 29 in Brazil, contributes to their presence in virtually all regions. This wide distribution, combined with abundance and ecological diversity, makes this genus the main cause of snakebites in the country. Their predominantly terrestrial behavior and crepuscular or nocturnal habits may be factors that facilitate contact with humans in various activities. These factors may explain why this genus is the leading cause of bites in the municipality during the study period.

INSTITUTIONAL REVIEW BOARD STATEMENT

This doctoral project in the Postgraduate Program in Infectious and Parasitic Diseases at the School of Medicine of the Federal University of Rio de Janeiro, entitled "Epidemiological aspects of accidents by venomous snakes reported in the municipality of Rio de Janeiro between 2008 and 2017", was submitted, evaluated and approved by the Human Research Ethics Committee of the Clementino Fraga Filho University Hospital of the Federal University of Rio de Janeiro (CEP/HUCFF/FM/UFRJ), Brazil. It is registered under the protocol CAAE: 70667423.9.0000.5257.

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CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

REFERENCES

1. Chippaux, J. P., Massougbodji, A., & Habib, A. G. (2019). The WHO strategy for prevention and control of snakebite envenoming: A sub-Saharan Africa plan. Journal of Venomous Animals and Toxins Including Tropical Diseases, 25.

2. Schneider, M. C., [et al.]. (2021). Overview of snakebite in Brazil: Possible drivers and a tool for risk mapping. PLoS Neglected Tropical Diseases, 15, 1–18.

3. Minghui, R., Malecela, M. N., Cooke, E., & Abela-Ridder, B. (2019). WHO's snakebite envenoming strategy for prevention and control. The Lancet Global Health, 7, e837–e838. https://doi.org/10.1016/S2214-109X(19)30225-6

4. da Silva, W. R. G. B., [et al.]. (2023). Who are the most affected by Bothrops snakebite envenoming in Brazil? A clinical-epidemiological profile study among the regions of the country. PLoS Neglected Tropical Diseases, 17, e0011708.

5. Harrison, R. A., Casewell, N. R., Ainsworth, S. A., & Lalloo, D. G. (2019). The time is now: A call for action to translate recent momentum on tackling tropical snakebite into sustained benefit for victims. Transactions of the Royal Society of Tropical Medicine and Hygiene, 113, 834–837. https://doi.org/10.1093/trstmh/try134

6. Qamruddin, R. M., [et al.]. (2023). Frequency, geographical distribution and outcomes of pit viper bites in Malaysia consulted to Remote Envenomation Consultancy Services (RECS) from 2017 to 2020. PLoS Neglected Tropical Diseases, 17.

7. Castro-Pinheiro, C., [et al.]. (2024). Effect of seaweed-derived fucoidans from Undaria pinnatifida and Fucus vesiculosus on coagulant, proteolytic, and phospholipase A2 activities of snake Bothrops jararaca, B. jararacussu, and B. neuwiedi venom. Toxins, 16.

8. World Health Organization. (2025). Snakebite. https://www.who.int/health-topics/snakebite#tab=tab_1

9. Dossou, A. J., Fandohan, A. B., Omara, T., & Chippaux, J. P. (2024). Comprehensive review of epidemiology and treatment of snakebite envenomation in West Africa: Case of Benin. Journal of Tropical Medicine, 2024, 10 pages.

10. da Silva, F. F. B., Moura, T. de A., Siqueira-Silva, T., Gutiérrez, J. M., & Martinez, P. A. (2024). Predicting the drivers of Bothrops snakebite incidence across Brazil: A spatial analysis. Toxicon, 250, 108107.

11. Gutiérrez, J. M. (2020). Snakebite envenoming from an Ecohealth perspective. Toxicon X, 7.

12. World Health Assembly. (2018). Addressing the burden of snakebite envenoming. 17, 24–26.
13. Takayasu, B. S., Rodrigues, S. S., Madureira Trufen, C. E., Machado-Santelli, G. M., & Onuki, J. (2023). Effects on cell cycle progression and cytoskeleton organization of five Bothrops spp. venoms in cell culture-based assays. Heliyon, 9, 2405–8440.

14. Mise, Y. F., Lira-da-Silva, R. M., & Carvalho, F. M. (2019). Fatal snakebite envenoming and agricultural work in Brazil: A case–control study. American Journal of Tropical Medicine and Hygiene, 100, 150–154.

15. World Health Organization. (2019). Snakebite: WHO targets 50% reduction in deaths and disabilities. https://www.who.int/news/item/06-05-2019-snakebite-who-targets-50-reduction-in-deaths-and-disabilities

16. Longbottom, J., [et al.]. (2018). Vulnerability to snakebite envenoming: A global mapping of hotspots. The Lancet, 392, 673–684.

17. Collinson, S., Lamb, T., Cardoso, I. A., Diggle, P. J., & Lalloo, D. G. (2025). A systematic review of variables associated with snakebite risk in spatial and temporal analyses. Transactions of the Royal Society of Tropical Medicine and Hygiene, 119, 1084–1099.

18. Schneider, M. C., [et al.]. (2021). Snakebites in rural areas of Brazil by race: Indigenous the most exposed group. International Journal of Environmental Research and Public Health, 18.

19. Ministério da Saúde. (2025). Portal SINAN. https://portalsinan.saude.gov.br/

20. Russell, J. J., Schoenbrunner, A., & Janis, J. E. (2021). Snake bite management: A scoping review of the literature. Plastic and Reconstructive Surgery - Global Open, 9, e3506. https://doi.org/10.1097/GOX.0000000000003506

21. Isbister, G. K. (2023). Antivenom availability, delays and use in Australia. Toxicon X, 17, 100145.

22. Oliveira, I. C. da S. de, [et al.]. (2022). Biodiversidade de serpentes: Ferramentas educativas para a conservação das espécies. Research, Society and Development, 11, e67111334892.

23. Amorim, A. P. da C. F. de, & Santos, M. F. dos. (2023). Animais terrestres peçonhentos de importância médica no Brasil. In G. M. da Costa & IMEA (Eds.), Saúde: Pesquisa, tecnologia e aplicabilidade (Vol. 1). João Pessoa.

24. Duque, B. R., [et al.]. (2023). Venomous snakes of medical importance in the Brazilian state of Rio de Janeiro: Habitat and taxonomy against ophidism. Brazilian Journal of Biology, 83, e272811.

25. Amorim, A. P. da C. F. de, Santos, M. F. dos, & Amorim, J. F. de. (2025). Acidentes com animais peçonhentos e a importância das medidas protetivas: Um estudo no município de Três Rios de 2014 a 2023. Revista Foco, 18, e7586.

26. Ministério da Saúde. (2021). DATASUS - Ministério da Saúde. https://datasus.saude.gov.br/

27. Instituto Brasileiro de Geografia e Estatística. (2025). IBGE | Cidades@ | Rio de Janeiro | Rio de Janeiro | Panorama. https://cidades.ibge.gov.br/brasil/rj/rio-de-janeiro/panorama

28. DATARIO. (2025). Censo 2022: População e domicílios por bairros (dados preliminares). https://www.data.rio/datasets/fd354740f1934bf5bf8e9b0e2b509aa9_2/explore?showTable=true

29. Secretaria Municipal de Assistência Social e Direitos Humanos. (2025). Secretaria Municipal de Assistência Social e Direitos Humanos - R.J. https://desenvolvimentourbano.prefeitura.rio/estrutura-da-secretaria/subsecretaria-planejamento-urbano/coordenadoria-de-planejamento-local/

30. Luzardo, A. J. R., Filho, R. M. C., & Rubim, I. B. (2017). Análise espacial exploratória com o emprego do índice de Moran. GEOgraphia. https://www.periodicos.uff.br/geographia/article/view/13807/9007

31. Buzai, G. D., & Galbán, E. M. (2012). Estadística espacial: Fundamentos y aplicación con sistemas de información geográfica.

32. Fundação Nacional de Saúde. (2001). Manual de diagnóstico e tratamento de acidentes por animais peçonhentos. Ministério da Saúde. https://doi.org/10.22278/2318-2660.1996.v1.n2.a1256

33. Filho, G. A. P., Vieira, W. L. S., & França, F. G. R. (2020). Serpentes de importância médica no Brasil.

34. Costa, M., Freire, E. M. X., & Campos, R. (2020). Serpentes da Caatinga: Prevenir. Sim; matar, não! (pp. 15–38). https://labherpeto.cb.ufrn.br/pdf/manual.pdf

35. Ministério da Saúde. (2022). Guia de vigilância em saúde (pp. 1019–1024). https://bvsms.saude.gov.br/bvs/publicacoes/guia_vigilancia_saude_5ed_rev_atual.pdf

36. Isaacson, J. E., [et al.]. (2023). Antivenom access impacts severity of Brazilian snakebite envenoming: A geographic information system analysis. PLoS Neglected Tropical Diseases, 17, 1/19.

37. Bravo-Vega, C., Santos-Vega, M., & Cordovez, J. M. (2022). Disentangling snakebite dynamics in Colombia: How does rainfall and temperature drive snakebite temporal patterns? PLoS Neglected Tropical Diseases, 16.

38. Wegermann, K., & Kettermann, B. J. (2020). O desmatamento da floresta amazônica e as consequências da fragmentação de habitats naturais: Como a degradação ambiental impulsiona o surgimento de zoonoses. https://doi.org/10.51162/brc.dev2020-00055

39. Garcia, L. C., Viana, J. N. L., & Lima, C. M. S. (2023). Gestão de risco, vulnerabilidade ambiental e a questão climática na gestão metropolitana. Cadernos Metrópole, 25, 875–897.

40. Prefeitura do Município do Rio de Janeiro. (2012). Corredores verdes. Relatório do Grupo de Trabalho (Resolução SMAC P no183 de 07.11.2011).

41. Kono, I. S., Pandolfi, V. C. F., Marchi, M. N. A. de, Freitas, N., & Freire, R. L. (2024). Unveiling the secrets of snakes: Analysis of environmental, socioeconomic, and spatial factors associated with snakebite risk in Paraná, Southern Brazil. Toxicon, 237, 107552.

42. Ediriweera, D. S., De Silva, T., Kasturiratne, A., De Silva, H. J., & Diggle, P. (2022). Geographically regulated designs of incidence surveys can match the precision of classical survey designs whilst requiring smaller sample sizes: The case of snakebite envenoming in Sri Lanka. BMJ Global Health, 7, 9500.

43. Ochoa, C., [et al.]. (2021). Estimating and predicting snakebite risk in the Terai region of Nepal through a high-resolution geospatial and One Health approach. Scientific Reports, 11, 23868.

44. Castro-Amorim, J., [et al.]. (2023). Catalytically active snake venom PLA2 enzymes: An overview of its elusive mechanisms of reaction. Journal of Medicinal Chemistry, 66, 5364–5376.

45. Fortes, I. de B., & Dias, J. M. de M. (2023). A importância da educação ambiental para a conscientização das populações no entorno de unidades de conservação: O caso do Parque Nacional da Restinga de Jurubatiba. Revista Brasileira de Educação Ambiental (RevBEA), 18, 148–170.

46. Oliveira, L. P. de, [et al.]. (2020). Snakebites in Rio Branco and surrounding region, Acre, western Brazilian Amazon. Revista da Sociedade Brasileira de Medicina Tropical, 53, 1–8.

47. Matos, R. R., & Ignotti, E. (2020). Incidence of venomous snakebite accidents by snake species in Brazilian biomes. Ciência & Saúde Coletiva, 25, 2837–2846.

48. Oliveira, N. da R., Silva, T. M., Sousa, A. C. da R., & Ferreira, K. K. da S. (2022). Epidemiologia de acidentes ofídicos no Brasil (2000–2018). https://editorarealize.com.br/editora/anais/conapesc/2022/TRABALHO_COMPLETO_EV177_MD1_ID1089_TB433_10082022145016.pdf

49. Souza, L. A. de, Silva, A. D., Chavaglia, S. R. R., Dutra, C. M., & Ferreira, L. A. (2021). Profile of snakebite victims reported in a public teaching hospital: A cross-sectional study. Revista da Escola de Enfermagem, 55, 1–7.

50. Tednes, M., & Slesinger, T. L. (2021). Evaluation and treatment of snake envenomations. StatPearls. https://www.ncbi.nlm.nih.gov/books/NBK553151/

51. Knudsen, C., [et al.]. (2021). Snakebite envenoming diagnosis and diagnostics. Frontiers in Immunology, 12. https://doi.org/10.3389/fimmu.2021.661457

52. Lee, S., Lee, J., & Min, K. D. (2025). Association between deforestation and the incidence of snakebites in South Korea. Animals, 15, 198.

53. Malhotra, A., [et al.]. (2021). Promoting co-existence between humans and venomous snakes through increasing the herpetological knowledge base. Toxicon X, 12, 100081.