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Papers

Geoepidemiological Profile of Venomous Animal Incidents in Indigenous and Non-Indigenous Populations in Brazil

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Abstract
This study analyzes venomous animal incidents between 2012 and 2023 using data from the Notifiable Diseases Information System (SINAN), focusing on differences between Indigenous and non-Indigenous populations. It uses a cross-sectional and ecological methodology, incorporating descriptive statistical analyses and Moran's spatial autocorrelation to examine geographic patterns and identify prevalence clusters. The results reveal a concentration of notifications in the Southeast region. Among the groups analyzed, the Indigenous population had the highest prevalence rate, with 2,654 cases per 100,000 inhabitants, demonstrating significant vulnerability to venomous animal incidents. Regarding age groups, Indigenous children and adolescents were particularly susceptible. Scorpions were the main causative agent among non-Indigenous individuals (57.3%), while snakes were more prevalent among Indigenous groups (56.6%). The study underscores the need for public policies and prevention strategies that consider the cultural and environmental specificities of vulnerable populations, emphasizing the importance of educational and public health actions adapted to local realities.

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INTRODUCTION

In recent years, accidents involving venomous animals have become a relevant topic in public health, reflecting the complex connections between human health and environmental factors, including, but not limited to, climate change. It is anticipated that climate change, alongside other factors (e.g., habitat loss), will lead to increased migration of venomous animals such as snakes, spiders, and insects like bees and ants (Needleman *et al.*, 2018a). The destruction of natural habitats, often driven by unregulated urban expansion and the conversion of natural areas into agricultural land, forces these animals to migrate to new territories, raising the risk of interactions with humans. These transformations are not restricted to terrestrial animals and include marine species and venomous amphibians, such as jellyfish, poisonous fish, and toxic frogs, which are also affected by environmental changes (Needleman *et al.*, 2018b). It is important to distinguish that venomous animals possess specialized structures for injecting venom, such as fangs or stingers, while poisonous animals release toxins through their skin or other body parts when touched or ingested. Transformations in climate patterns, including global warming and changes in rainfall regimes, directly impact both venomous and poisonous animals, increasing risks to human and animal health, particularly for historically vulnerable populations, and bringing significant implications for industries, trade, and tourism.

Changes in global climate patterns, characterized by global warming and altered rainfall regimes, directly affect the behavior and geographic distribution of venomous animals (Needleman *et al.*, 2018a). Global warming causes changes in the behavioral patterns of these animals, such as periods of activity, reproduction, and hibernation (Moreno-Rueda *et al.*, 2009). That, in turn, can lead to an increase in the frequency of interactions between these animals and humans, especially in rural and peri-urban areas where human expansion encroaches on natural habitats (Zacarias, Loyola, 2018). As global temperatures rise, the activity season for many venomous animals may lengthen, leading to a more extended yearly period during which the risk of envenomation is elevated. That is particularly relevant for regions experiencing a significant increase in average and minimum temperatures (Martínez *et al.*, 2022), especially in Global South countries like Brazil.

In this context, this study describes and analyzes accidents involving venomous animals reported in the Sistema de Informação de Agravos de Notificação (SINAN, national SUS system that records notifications of health issues) between 2013 and 2022, focusing on Indigenous populations. It also identifies geographic distribution patterns and highlights differences in how vulnerable these populations are to these risks.

The relevance of this study lies in the need to understand the factors reshaping the risks associated with venomous animal accidents. Indigenous peoples, who maintain a deep connection to their traditional territories, are disproportionately affected, facing not only an elevated risk of accidents but also the associated complications that affect their lives at a community level, resulting in the loss of livelihood and culture (Green; Raygorodetsky, 2010). Therefore, it is imperative to investigate these dynamics to develop effective prevention and mitigation strategies, safeguarding public health and Indigenous populations' cultural and environmental integrity.

With this in mind, this study conducts a comparative analysis of the epidemiological profile and spatial distribution of accidents involving venomous animals, distinguishing between Indigenous and non-Indigenous populations. It seeks to identify geographic distribution patterns and highlight how Indigenous peoples are more vulnerable to these risks. This analysis will advance our understanding of the impacts of these accidents on public health and inform the development of effective responses to the challenges posed by venomous animals.

METHODOLOGY

This cross-sectional and ecological study aimed to investigate the prevalence of venomous animal accidents in Brazil from 2013 to 2022, using records from the SINAN. Following the guidelines of the Brazilian Ministry of Health (2024), a confirmed case was characterized by clinical signs of envenomation specific to the animal category involved without the need to identify the causative animal.

Data included individuals of all age groups, genders, and other sociodemographic variables as available in SINAN. The variables analyzed included individual notification data, such as age, gender, pregnancy status, race/color, and education level; residential data, such as municipality of residence; epidemiological background, such as the interval between the bite and medical attention and the location of the bite; and clinical data, including local and systemic manifestations, type of accident, case classification, and outcome. Non-Indigenous individuals were classified as those reported under white, black, brown, and yellow (Asian) race/ethnicity categories, while Indigenous individuals were those reported as Indigenous. Rates were calculated per 100,000 inhabitants. Missing data referred to records in which information about race/ethnicity was not adequately filled out in the system, leading to absent or inconsistent data that could not be accurately classified.

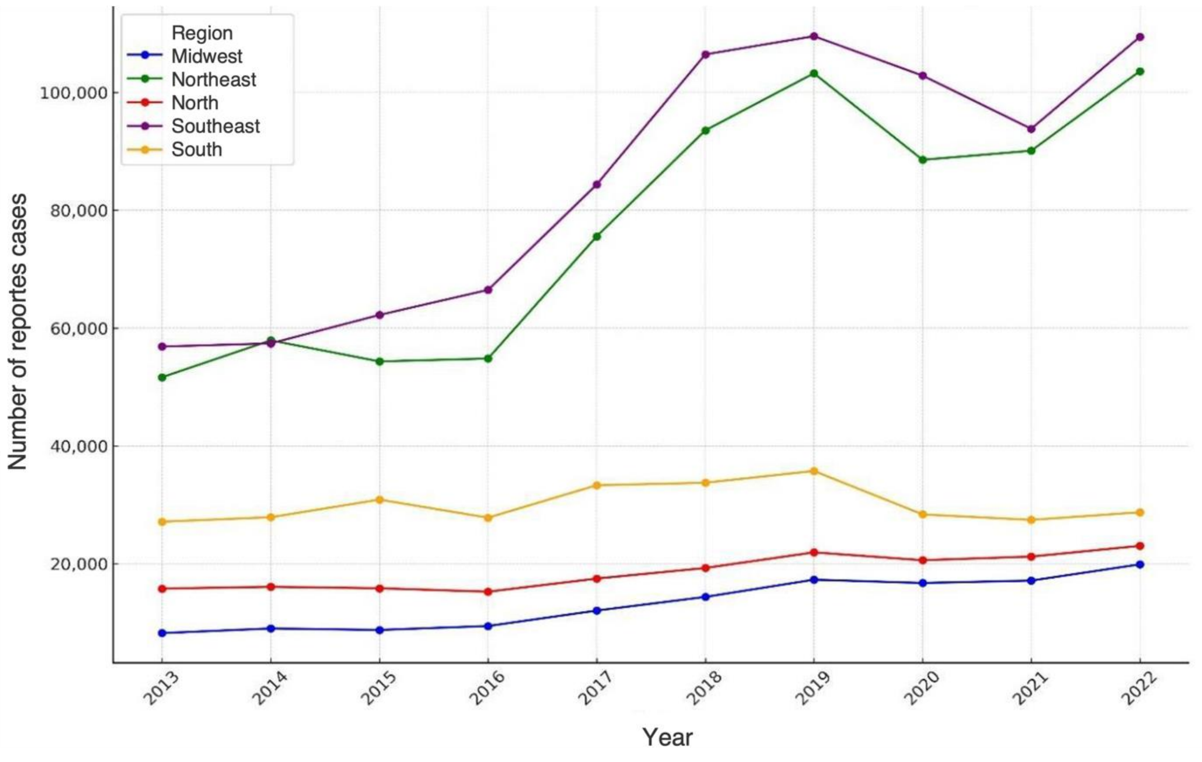
Data was collected via the DATASUS file transfer system, supplemented by demographic and socioeconomic information from the 2010 Census (Instituto Brasileiro de Geografia e Estatística - IBGE, the Brazilian Institute of Geography and Statistics). Data processing was performed using the R statistical software, where descriptive statistics and Pearson's Chi-square test were conducted to assess differences between populations. Spatial analysis was integrated using Anselin Moran I's spatial autocorrelation index, categorizing the spatial distribution of events into four types of spatial association: High-High and Low-Low Clusters, and High-Low and Low-High Outliers (where clusters represent geographically proximate areas with similar values of a specific variable, and outliers represent areas with discrepant values compared to their surroundings). To generate the maps, the shapefile resulting from the LISA spatial analysis was processed using the ArcGIS software, licensed by the Universidade Federal do Rio Grande do Sul (Federal University of Rio Grande do Sul in English).

The study adhered to the ethical principles outlined by the General Data Protection Law (Law No. 13,709/2018) and the Resolution of the National Health Council No. 466/2012. Since it utilized anonymized secondary data, ethical approval by a Research Ethics Committee was waived.

RESULTS

In the analysis of notifications of venomous animal accidents (Figure 1), the Southeast region leads from 2013 to 2022, followed by the Northeast region. The South, North, and Central-West regions rank third, fourth, and fifth, respectively. The peak in notifications across all regions occurred in 2019.

Figure 1 – Evolution of reported cases of venomous animal accidents, Major Regions, Brazil, 2013 to 2022



Source: The authors (2023) based on SINAN (c2024).

The results presented in Table 1 show that the majority of reported cases involve individuals identified as brown (*pardos*), representing 46.6% of the total, followed by white individuals (34.0%) and black individuals (5.6%). The lowest prevalence was observed among individuals of Asian descent (0.7%). Notably, the highest prevalence rate was recorded among Indigenous peoples, with 2,654.0 cases per 100,000 inhabitants, suggesting a heightened vulnerability of this group to venomous animal accidents. On the other hand, cases categorized as "Ignored" and "Invalid Data" represent 10.3% and 1.9% of the total, respectively, indicating gaps in the recording of racial data in health systems.

Table 1 – Race/Color of Reported Cases of Venomous Animal Accidents, Brazil, 2013 to 2022

Race/Color	N	%	Rate*
White	762.505	34,0	837,4
Black	124.746	5,6	859,3
Yellow (Asian	16.300	0,7	782,0
Brown (*pardo*)	1.045.742	46,6	1.271,0
Indigenous	21.709	1,0	2.654,0
Ignored	230.999	10,3	-
Invalid Data (missing)	42.039	1,9	-
Total	2.244.040	100,0	-

Source: The authors (2023) based on SINAN (c2024) and IBGE (2010).
*per 100,000 inhabitants

Table 2 presents information on the non-Indigenous and Indigenous populations by sex and age group. A predominance of cases is observed among males in the non-Indigenous population (55.2% of cases, at a rate of 1,325.5 per 100,000 inhabitants) and the Indigenous population (61.6%, at a rate of 3,260.5). For females, the numbers are slightly lower among non-Indigenous individuals (44.8%, rate of 1,032.8) compared to Indigenous individuals (38.4%, rate of 2,044.1), indicating a statistically significant ($p<0.0001$) discrepancy in the incidence rate per 100,000 inhabitants between sexes and between Indigenous and non-Indigenous populations.

Regarding age groups, the data reveal that the prevalence of accidents varies considerably, with the highest rates observed among younger and older groups in the Indigenous population, highlighting greater vulnerability or exposure to venomous animals. Specifically, Indigenous infants under 1 year and adolescents aged 15 to 17 show elevated prevalence rates (2,488.5 and 3,229.7 per 100,000 inhabitants, respectively). In contrast, among non-Indigenous individuals, the age distribution of accidents shows a different pattern, with higher rates observed between the 18 to 29 and 50 to 59 age groups.

Table 2 – Total, percentage, and rate per 100,000 inhabitants of sex and age group of reported venomous animal accidents, non-Indigenous and Indigenous populations, Brazil, 2013 to 2022

Sex	Non-Indigenous			Indigenous			p-value
	N	%	Rate	N	%	Rate	
Male	1.238.101	55,2	1.325,5	13.365,0	61,6	3.260,5	< 0,001
Female	1.005.420	44,8	1.032,8	8.341,0	38,4	2.044,1	
Ignored	519	0,02	-	3	0,01	-	-
Age Group	**N**	**%**	**Rate**	**N**	**%**	**Rate**	
Under 1	31.426	1,4	1.158,2	493	2,3	2.488,5	< 0,001
1 to 4	80.472	3,6	726,1	844	3,9	1.037,1	
5 to 9	127.933	5,7	854,6	2.043	9,4	2.046,3	
10 to 14	134.603	6,0	784,1	2.552	11,8	2.691,2	
15 to 17	91.719	4,1	885,5	1.659	7,6	3.229,7	
18 to 29	453.456	20,2	1.106,5	5.333	24,6	3.144,0	
30 to 39	350.621	15,6	1.183,2	3.113	14,3	2.979,1	
40 to 49	323.202	14,4	1.301,0	2.346	10,8	3.058,9	
50 to 59	295.919	13,2	2.918,2	1.610	7,4	2.983,9	
60 and over	354.681	15,8	1.394,7	1.716	7,9	2.091,4	
Invalid Data (missing)	8	-	-	-	0,0	-	-
Total	2.244.040	100,0	-	21.709	100,0	-	-

Source: The authors (2023) based on SINAN (c2024) and IBGE (2010).

Regarding education level (Table 3), it is notable that there were no recorded cases among illiterate individuals in either group, suggesting potential gaps in data collection or accessibility to the notification system for all segments of the population. Among non-Indigenous individuals, the majority of cases are concentrated among people with some primary education, representing 25.6% of the total, followed by individuals with complete secondary education and some secondary education. In the Indigenous population, there is also a significant presence of cases among people with some primary education, as well as a notable percentage of records categorized as "Ignored" or "Invalid Data (missing)," indicating issues with data accuracy and the integrity of the reported information.

As for pregnancy status, a relatively low number of cases were reported among pregnant individuals, distributed fairly evenly across the three trimesters in both populations. However, the vast majority of records indicate that most individuals were not pregnant at the time of the accident or that this information was not applicable, which may include male individuals or non-pregnant women.

Tabela 3 – Education level and pregnancy status of reported venomous animal accidents, non-Indigenous and Indigenous populations, Brazil, 2013 to 2022

Education Level	Non-Indigenous		Indigenous		p-value
	N	%	N	%	
Illiterate	0	0	0	0	
Some Primary Education	574.026	25,6	6.807	31,4	
Complete Primary Education	115.719	5,2	1.029	4,7	
Some Secondary Education	138.662	6,2	1.178	5,4	< 0,001
Complete Secondary Education	281.211	12,5	1.202	5,5	
Some Higher Education	26.425	1,2	102	0,5	
Complete Higher Education	53.155	2,4	114	0,5	
Ignored	579.098	25,8	3.481	16,0	-
Not applicable	188.517	8,4	2.464	11,4	-
Invalid Data (missing)	287.227	12,8	5.332	24,6	-
Pregnancy Status	**N**	**%**	**N**	**%**	**p-value**
1st Trimester	4.808	0,2	88	0,4	
2nd Trimester	6.927	0,3	120	0,6	
3rd Trimester	4.940	0,2	83	0,4	< 0,001
Gestational Age Ignored	3.069	0,1	73	0,3	
Not pregnant	567.706	25,3	4.293	19,8	
Not applicable	1.513.105	67,4	16.620	76,6	-
Ignored	143.416	6,4	431	2,0	-
Invalid Data (missing)	69	0,0	1	0,0	-
Total	2.244.040	100,0	21.709	100,0	-

Source: The authors (2023) based on SINAN (c2024).

In the identified accidents (Table 4), scorpions are the primary cause of venomous animal accidents among non-Indigenous individuals, representing 57.3% of cases, followed by spiders (14.1%) and snakes (12.9%). In contrast, among the Indigenous population, snake accidents are the most predominant, accounting for 56.6% of cases.

Regarding the location of the bite, both groups show a tendency for bites on the feet as the most common, especially among Indigenous individuals, where 44% of accidents affect this part of the body. That suggests greater exposure of the feet to environments where such animals are prevalent, likely due to differences in daily activities or footwear use.

The time to receive medical care is critical in managing venomous animal accidents, with most cases receiving care within 1 to 3 hours after the bite. However, a significant proportion of notifications, both among non-Indigenous and Indigenous individuals, report seeking care over 24 hours after the accident.

Table 4 – Type of accident, bite location, and time elapsed from accident to health care for reported venomous animal accidents, non-Indigenous and Indigenous populations, Brazil, 2013 to 2022

Type of Accident	Non-Indigenous		Indigenous		p-value
	N	%	N	%	
Snake	288.474	12,9	12.278	56,6	< 0,001
Spider	315.534	14,1	1.872	8,6	
Scorpion	1.286.801	57,3	5.668	26,1	
Caterpillar	45.824	2,0	242	1,1	
Bee	173.550	7,7	745	3,4	
Others	93.383	4,2	738	3,4	
Ignored	40.367	1,8	164	0,8	-
Bite Location	**N**	**%**	**N**	**%**	**p-value**
Head	140.868	6,3	760	3,5	< 0,001
Arm	123.145	5,5	730	3,4	
Forearm	64.052	2,9	408	1,9	
Hand	369.478	16,5	2.474	11,4	
Finger	369.590	16,5	1.891	8,7	
Torso	120.986	5,4	583	2,7	
Thigh	87.781	3,9	536	2,5	
Leg	182.125	8,1	2.909	13,4	
Foot	532.288	23,7	9.557	44,0	
Toe	166.919	7,4	1.541	7,1	
Ignored	86.701	3,9	318	1,5	-
Invalid Data (missing)	107	0,0	2	0,0	-
Time Elapsed to Care	**N**	**%**	**N**	**%**	**p-value**
0 to hour	1.084.890	48,3	5.881	27,1	< 0,001
1 to 3 hours	504.527	22,5	5.570	25,7	
3 to 6 hours	166.709	7,4	3.532	16,3	
6 to 12 hours	77.266	3,4	2.006	9,2	
12 to 24 hours	79.610	3,5	1.634	7,5	
More than 24 hours	134.575	6,0	1.703	7,8	
Ignored	141.055	6,3	936	4,3	-
Invalid Data (missing)	55.408	2,5	447	2,1	-
Total	2.244.040	100,0	21.709	100,0	-

Source: The authors (2023) based on SINAN (c2024).

Regarding case classification, most cases in both populations are classified as mild, with 82.5% among non-Indigenous individuals and 62.2% among Indigenous individuals, indicating that a significant portion of the accidents result in less severe symptoms. However, the proportion of moderate and severe cases is significantly higher among Indigenous people (27.8% and 5.6%, respectively) compared to non-Indigenous people (11.3% and 1.6%).

The prevalence of local complications is also higher among Indigenous individuals, with 4% of cases reporting complications, in contrast to only 1.1% among non-Indigenous individuals. This stark difference may reflect not only the nature of the accidents but also disparities in access to immediate medical care and effective treatment, highlighting a critical public health issue.

Secondary infection and extensive necrosis are the most common among the specified local complications. Notably, the proportion of cases resulting in amputation, though low, is significantly higher when local complications are reported, indicating the potential severity of these accidents. Systemic complications, though less frequent, also show a discrepancy, being more prevalent among Indigenous people.

Most cases result in recovery, precisely 91.4% for non-Indigenous individuals and 89.4% for Indigenous individuals. However, the mortality rate due to venomous animal accidents is higher among Indigenous people (0.6% compared to 0.1% among non-Indigenous people), a statistically significant difference that underscores the inequalities in the impact of these accidents between the populations.

Table 5 – Case classification, local complications, and outcomes of reported venomous animal accidents, non-Indigenous and Indigenous populations, Brazil, 2013 to 2022

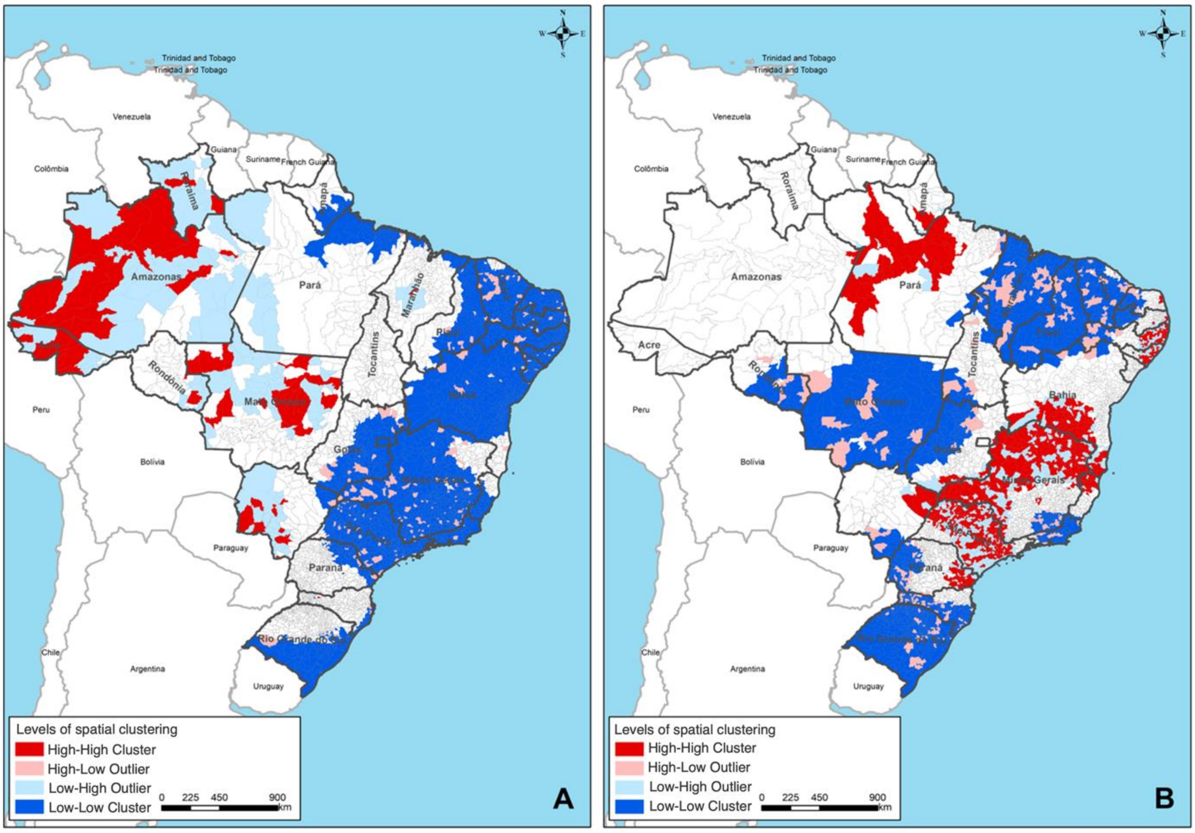
Case Classification	**Non-Indigenous**		**Indigenous**		**p-value**
	N	**%**	**N**	**%**	
Mild	1.851.315	82,5	13.511	62,2	
Moderate	253.361	11,3	6.035	27,8	
Severe	35.413	1,6	1.221	5,6	< 0,001
Unknown	53.716	2,4	417	1,9	
Invalid Data (missing)	50.955	2,3	525	2,4	
Total	2.244.040	100,0	21.709	100,0	-
Local Complications	**N**	**%**	**N**	**%**	**p-value**
Yes	25.649	1,1	858	4,0	
No	1.991.079	88,7	18.570	85,5	< 0,001
Ignored	90.599	4,0	872	4,0	
Invalid Data (missing)	136.713	6,1	1.409	6,5	-
Total	2.244.040	100,0	21.709	100,0	-
Specification of Local Complications	**N**	**%**	**N**	**%**	**p-value**
Amputation*	323	1,2	23	2,6	
Secondary Infection*	19.692	76,5	660	76,6	
Extensive Necrosis*	4.654	18,1	121	14	< 0,001
Behavioral Syndrome*	1.953	7,5	101	11,7	
Functional Deficit*	2.870	11,1	143	16,6	
Systemic Complications	8.020	0,3	241	1,2	
Case Outcome	**N**	**%**	**N**	**%**	**p-value**
Recovered	2.049.974	91,4	19.402	89,4	
Death by venomous animal accident	2.812	0,1	124	0,6	< 0,001
Death by other causes	362	0,0	14	0,1	
Ignored	63.494	2,8	644	3,0	-
Invalid Data (missing)	127.398	5,7	1.525	7,0	-
Total	2.244.040	100,0	21.709	100,0	-

*Information for cases with "yes" for local complications.
Source: The author (2023) based on SINAN (c2024).

Regarding the distribution of spatial clustering levels, as illustrated in Figure 1, there is a predominant concentration of High-High clusters among the Indigenous population in the states of Amazonas, Acre, and Mato Grosso, regions with a higher proportion of Indigenous residents. Notably, there is a continuous sequence of Low-Low clusters extending from the northeast of Paraná to the northeastern coast of Brazil, also encompassing parts of the northern region. In the extreme south of the country, specifically in the south-central region of Rio Grande do Sul, approximately half of the territory is also influenced by a Low-Low cluster.

For the non-Indigenous population, a High-High cluster is observed along the coast of Paraná and, in a more dispersed manner, in the state of São Paulo, Pará, as well as in the southwestern and northwestern regions of Minas Gerais and southern Bahia. The states of Mato Grosso and Rio Grande do Sul are notable for their almost complete coverage by Low-Low clusters, with some High-Low outliers.

Figure 1 – Level of spatial clustering for reported venomous animal accidents, Indigenous (A) and non-Indigenous (B), Brazil, 2013 to 2022



Source: IBGE (2022). Elaborated by the authors (2024).

DISCUSSION

Our results highlight a differentiated vulnerability to venomous animal accidents between Indigenous and non-Indigenous populations. Research indicates that unregulated urban expansion, lack of pest control, and inadequate waste management significantly contribute to the proliferation of scorpions in urban and peri-urban areas (Zanetta *et al*., 2020; Cruz *et al*., 1995; Guerra-Duarte *et al*., 2023). These factors create favorable environments for the survival and reproduction of these arachnids, increasing the incidence of scorpion accidents, especially in densely populated regions (Olivero *et al*., 2021).

The higher prevalence of snakebite accidents among Indigenous peoples reflects the more frequent contact of these communities with natural habitats. A study conducted in the Western Brazilian Amazon showed that people living in rural or forested areas are more likely to be affected by snakebites due to the presence of snakes and activities such as extractivism and agriculture (Silva; Colombini Moura-da-Silva; Souza; Monteiro; Bernarde, 2020; Silva; Fonseca; Silva, Amaral; Ortega; Oliveira; Correa; Oliveira; Monteiro; Bernarde, 2020). Schneider *et al*. (2021) demonstrated that Indigenous people have the highest rates of exposure to snakebites (194.3 per 100,000 inhabitants), significantly higher compared to other population groups.

The tendency for snakebites to occur on the feet, particularly among Indigenous people, reflects cultural practices and outdoor activities often carried out by this population without proper protection and adequate lighting (Pierini *et. al.,* 1996). In many cases, Indigenous and other rural populations engage in subsistence activities such as hunting, gathering, or farming while barefoot or using minimal footwear, which significantly increases their exposure to snakes (Leite *et al*., 2013; Jayawardana *et al*., 2020; Venugopalan *et al*., 2021). Moreover, these activities typically occur in environments with a high presence of snakes, such as forests, fields, and riverbanks, which are natural habitats for these animals (Eniang *et. al*., 2012*;* Silva; Fonseca; Silva; Amaral; Ortega; Oliveira; Correa; Oliveira; Monteiro; Bernarde, 2020).

The time to access healthcare is a crucial factor in preventing severe complications, particularly for Indigenous populations who face significant geographical and logistical barriers. Studies indicate that distance and the lack of adequate infrastructure delay access to treatment, substantially increasing health risks (Nguyen *et al.*, 2020). Additionally, cultural issues and discrimination in healthcare further hinder admittance and care continuity (Nelson; Wilson, 2018). Decentralizing, improving infrastructure in remote areas, and developing intercultural strategies in healthcare services are essential to mitigate these risks and ensure that care reaches vulnerable populations efficiently (Juárez-Ramírez *et al.*, 2019). Community initiatives like building healthcare infrastructure adapted to local needs have also shown positive results in expanding access to primary care (Dutta, 2020).

The classification of venomous animal accident cases, with increased severity among Indigenous populations, underscores the urgent need for culturally appropriate and effective public health interventions (Farias *et al.*, 2023). The high prevalence of complications, such as secondary infections and extensive necrosis in these populations, highlights the need for immediate and adequate healthcare, along with continuous follow-up to treat complications (Murta *et al.*, 2023). Studies demonstrate that decentralizing antivenom treatment to local healthcare units within Indigenous territories can reduce the time between diagnosis and treatment, improving the prognosis of envenomation and reducing severe sequelae (Monteiro *et al.*, 2020).

Although this study does not explore the effects of climate change on the reporting of venomous animal accidents, it is worth considering that changes in temperature and precipitation regimes may influence the geographic distribution and behavior of some venomous species (Needleman, 2018a; 2018b; Bouazza *et al.*, 2019; Martinez *et. al.*, 2018; Martinez *et. al.*, 2022; Martinez *et. al.*, 2024; Zacarias, Loyola., 2018). Future studies could explore these hypotheses using predictive models to assess how climate change may alter risk patterns.

The gap in data completeness in the healthcare sector, combined with the need for interoperability with environmental data, highlights the urgency for more robust and integrated reporting systems. Effective integration is crucial to ensure accessible health information to support evidence-based decision-making (Ying *et al.*, 2007).

Scientific literature suggests that integrating data from various sources can significantly improve the completeness of records, contributing to more efficient healthcare management (Emran *et. al.*, 2017). Furthermore, interoperability between healthcare systems enables not only the secure exchange of information but also enhances the quality of available data for epidemiological analysis (Dixon *et al.*, 2011).

CONCLUSION

This study highlighted the heightened vulnerability of Indigenous populations to venomous animal accidents, particularly the high prevalence of snakebites within this group. The results demonstrated that the geographic distribution of accidents is influenced by factors such as proximity to natural habitats and the cultural practices of Indigenous populations, who are often exposed to greater risks. Additionally, the spatial analysis underscored the importance of targeted, territory-based strategies for allocating healthcare resources, especially in remote regions with a high concentration of accidents.

Public policies must account for these vulnerabilities when planning interventions to ensure rapid and effective access to treatment, such as the decentralization of healthcare units equipped with antivenom in Indigenous areas. The findings of this research emphasize the need to improve healthcare infrastructure and data collection to optimize the response to these accidents and mitigate disparities between Indigenous and non-Indigenous populations.

To further comprehend the dynamics underlying this context, future research should adopt analyses of socio-environmental factors and the implications of climate change. Given that variations in temperature and precipitation patterns have the potential to alter the geographic distribution and behavior of venomous animals, it is crucial to explore how climate change may increase risks for vulnerable populations. Such studies could contribute to establishing a solid scientific foundation to support the development of effective and interculturally based interventions, as well as health policies that not only anticipate but also mitigate the impacts of climate change on human health, with particular attention to Indigenous communities.

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