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SEASONALITY OF SNAKEBITES: STUDY FROM 2008 TO 2017 IN THE MUNICIPALITY OF RIO DE JANEIRO, BRAZIL

SAZONALIDADE DAS PICADAS DE COBRAS: ESTUDO NO PERIODO 2008 A 2017 NO MUNICIPIO DO RIO DE JANEIRO – BRASIL

ESTACIONALIDAD DE LAS MORDEDURAS DE SERPIENTE: ESTUDIO DE 2008 A 2017 EN EL MUNICIPIO DE RÍO DE JANEIRO, BRASIL

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ABSTRACT
This study addresses the phenomenon of snakebite seasonality in the municipality of Rio de Janeiro during the period 2008–2017. During the analyzed period, 498 snakebite cases were reported in Rio de Janeiro, with a predominance of the *Bothrops* genus. Most bites occurred in urban areas of the West Zone, regions still characterized by forest remnants. The victim profile shows male predominance (about twice as frequent compared to females), mainly in the 20–59 age group (mean ages: 36 years for women / 37 years for men). A seasonal pattern was observed, with an increase in cases during the warm and humid months (November to April) and a decrease during the colder months (May to October), suggesting the influence of climatic factors—primarily temperature and humidity—but also the role of land use and occupation. The annual seasonality of snakebites is evident, with alternating periods of higher and lower incidence throughout the year. It was also observed that the increase in cases followed the rise in temperature. Unlike other regions of Brazil, such as the North and

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Northeast, Rio de Janeiro showed a trend of decreasing cases over time. The objective of this study is to present data on the seasonality of snakebites in Rio de Janeiro during the period 2008 to 2017.

Keywords: Neglected Tropical Disease. Seasonal Effect. Envenomation. Heat Islands. Trend.

RESUMO
Esse estudo aborda o fenômeno da sazonalidade de picadas de cobra no município do Rio de Janeiro, em um período de 2008-2017. Durante o período analisado, foram notificados 498 casos de picadas de cobra no município do Rio de Janeiro, com predominância do gênero *Bothrops.* A maioria das picadas ocorreu em áreas urbanas da Zona Oeste, locais ainda marcados por remanescentes florestais. O perfil das vítimas mostra predominância masculina (cerca do dobro em relação às mulheres), principalmente na faixa 20–59 anos (idades médias: 36 anos mulheres / 37 anos homens). Houve um padrão sazonal com aumento nos meses quentes e úmidos (novembro a abril) e redução nos meses frios (maio a outubro), sugerindo uma influência de fatores climáticos principalmente temperatura e umidade, mas também sugere ocupação do território. A sazonalidade anual das picadas de cobra é clara, com períodos de maior e menor incidência ao longo do ano. Foi possível observar que o aumento dos casos acompanhou o aumento da temperatura. Diferente de outras regiões do Brasil como Norte e Nordeste, o Rio de Janeiro apresentou uma tendência à diminuição dos casos ao longo do tempo. O objetivo deste trabalho é apresentar dados sobre a sazonalidade das picadas de cobra no município do Rio de Janeiro, no período de 2008 a 2017.

Palavras-chave: Doença Tropical Negligenciada. Efeito Sazonal. Envenenamento. Ilhas De Calor. Tendência

RESUMEN
Este estudio aborda el fenómeno de la estacionalidad de las mordeduras de serpiente en el municipio de Río de Janeiro durante el período 2008-2017. Durante el período analizado, se notificaron 498 casos de mordeduras de serpiente en Río de Janeiro, con predominio del género *Bothrops*. La mayoría de las mordeduras se produjeron en zonas urbanas de la Zona Oeste, regiones que aún se caracterizan por la presencia de remanentes forestales. El perfil de las víctimas muestra un predominio masculino (aproximadamente el doble que las mujeres), principalmente en el grupo de edad de 20 a 59 años (edad media: 36 años para las mujeres y 37 años para los hombres). Se observó un patrón estacional, con un aumento de los casos durante los meses cálidos y húmedos (noviembre a abril) y una disminución durante los meses más fríos (mayo a octubre), lo que sugiere la influencia de factores climáticos —principalmente la temperatura y la humedad— pero también el papel del uso y la ocupación del suelo. La estacionalidad anual de las mordeduras de serpiente es evidente, con períodos alternos de mayor y menor incidencia a lo largo del año. También se observó que el aumento de los casos seguía al aumento de la temperatura. A diferencia de otras regiones de Brasil, como el norte y el noreste, Río de Janeiro mostró una tendencia a la disminución de los casos a lo largo del tiempo. El objetivo de este estudio es presentar datos sobre la estacionalidad de las mordeduras de serpiente en Río de Janeiro durante el período 2008-2017.

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Palabras clave: Enfermedad Tropical Desatendida. Efecto Estacional. Envenenamiento. Islas de Calor. Tendencia.

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1 INTRODUCTION

Snakebite is one of the leading causes of mortality and morbidity in many rural regions of the tropics. It is a serious global public health problem, including in Brazil, and a life-threatening medical emergency that requires immediate attention and treatment [1–5]. In addition to the clinical impact, it imposes significant economic burdens on the victims, arising from treatment costs and loss of work productivity. Snakebite envenomation is considered a neglected tropical disease (NTD) by the World Health Organization (WHO), affecting poor and vulnerable rural populations in tropical and subtropical regions, perpetuating the cycle of poverty [2,3,6–13]. In May 2019, the World Health Organization (WHO) launched a program to prevent and control snakebite incidents, and one of the strategies is to improve access to effective and safe treatment for the most affected communities, aiming to reduce snakebite mortality and morbidity by 50% by 2030 [14,15].

The WHO has identified snakebite envenoming (SBE) as a high-priority neglected tropical disease, but there is a shortage of epidemiological research on environmental risk factors. Among the environmental factors that influence the epidemiology of snakebite envenoming, the role of external temperature stands out, as it affects snake behavior due to their ectothermic nature. This climatic aspect, combined with factors such as population density, land use, habitat characteristics, and the degree of social vulnerability of populations exposed to the risk of snakebite, is part of the WHO's strategic plan for the prevention and control of these incidents [16,17]. Temperature can affect snakebites through either human or snake behavior. Snakes are ectothermic, meaning that external temperatures influence their internal body temperature and, consequently, their behavior [7,18].

For many people, the prospect of being bitten by a venomous snake may seem remote, but a large part of the world's population, according to the World Health Organization (WHO), About 5.8 billion people are at risk of encountering one of these animals and suffering an accident. It is estimated that 7,400 people are bitten by snakes every day and, as a result, 81,000 to 138,000 die annually. In addition to deaths, around 400,000 victims may develop permanent physical or psychological disabilities, including blindness, amputation, and post-traumatic stress disorder [2,17,19].

Mortality associated with snakebite is underestimated due to the lack of immediate access to hospitals, and often patients seek alternative treatments instead of conventional medicine, delaying proper care [10,11,16,20,21]. Notification systems, when they exist, are fragile, deficient, and incomplete[16,17] Mortality data do not quantify the morbidity associated with the

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physical and mental disabilities caused by snakebites[21]. Estimating actual load is crucial for understanding the ecological characteristics that modulate encounters between humans and snakes, where climate may play an important role in driving the ecology of venomous snakes[10].

Knowing the number of people affected by this DTN is essential to ensure that effective and accessible treatments are available. The availability of antivenoms is essential to prevent the victim's condition from worsening, but there is still much room for innovation[5]. In addition, prevention through community education provided by qualified health professionals can be a very effective and economically viable strategy for reducing the risk of accidents and poisoning[8].

Snakebites are a public health concern in several areas of Brazil. Official data suggests around 27,000 to 30,000 snake bites each year [4,6,22], with the highest number of cases and rates in the Legal Amazon region [6]. Ophidism is part of the Ministry of Health's surveillance system, and cases receive antivenom free of charge. In Brazil, antivenom serum is part of the Unified Health System (SUS) and is free to the population. However, with a vast territory and limited antivenom production, it is necessary to identify areas of greatest risk for its distribution and develop preventive actions [6]. However, this number is underestimated due to inadequacies in data collection and the large number of unreported cases. Difficulties in accessing health services may also contribute to the underreporting of these accidents [4].

The WHO strategic plan for the prevention and control of SBE proposes a better understanding of the epidemiology and ecology of snake-human interactions. The plan highlights several factors that warrant investigation, including climate, human population density, land use, and habitat[18,19,23].

The objective of this study is to present data on the seasonality of snakebites in the city of Rio de Janeiro from 2008 to 2017.

2 METHODOLOGY

This is an observational, cross-sectional epidemiological study on snakebites conducted in the city of Rio de Janeiro from 2008 to 2017.

This research was 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, and is registered under protocol CAAE: 70667423.9.0000.5257.

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2.1 PLACE OF STUDY

Municipality of Rio de Janeiro, located in southeastern Brazil, in the state of the same name, at latitude 22°54'10"S and longitude 43°12'28" W. It has an area of 1,200.330 km² and a population of 6,211,223 according to the 2022 census [24].

To obtain information about the study area, the official websites of the Rio de Janeiro City Hall were used[25], the IBGE[24], and DATARIO[26]. These sources provided information on forest cover, land use, population, and sanitation data, and administrative characteristics of the municipality.

The municipality of Rio de Janeiro, located in the southeastern region of the country, has an area of 1,200.330 km² and a population of 6,211,223 people according to the 2022 census. The municipality of Rio de Janeiro is located approximately at latitude 22°54'10"S and longitude 43°12'28" W. The average altitude of the municipality is approximately 2 meters above sea level. It is the capital of the state of the same name, bordered by the Atlantic Ocean to the south, Guanabara Bay to the east, and Sepetiba Bay to the west. Its maritime borders are more extensive than its land borders. The relief of Rio de Janeiro is affiliated with the Serra do Mar Mountain range, covered by the Atlantic Forest, its predominant biome, characterized by striking contrasts, mountains and sea, forests and beaches, rocky cliffs rising abruptly from extensive lowlands. It is tropical, hot, and humid, with local variations due to differences in altitude, vegetation, and proximity to the ocean. The average annual temperature is 22°C, with high daily averages in the summer (30°C to 32°C). Rainfall varies from 1,200 to 1,800 mm per year [25]. It has extensive green areas, such as Tijuca National Park and Pedra Branca Massif, which are important spaces for leisure and environmental preservation [27].

The urbanized area of the municipality of Rio de Janeiro is 640.34 km², according to the IBGE. This area corresponds to approximately 53.3% of the municipality's total territory, which is 1,200.33 km². The term "urbanized area" refers to areas with infrastructure and characteristics typical of cities, such as buildings, commerce, paved roads, transportation systems, and access to public services. In Rio de Janeiro, this area is almost entirely occupied by buildings, with more significant wooded areas in parks and squares. According to the municipality's Master Plan, the entire territory of the municipality of Rio de Janeiro is considered urban, with no rural areas in the normative sense[27]. It has 94.55% of households with adequate sanitation, 66.17% of urban households on public roads with trees, and 78.4% of urban households on public roads with adequate urbanization: presence of storm drains,

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sidewalks, paving, and curbs [24]. It has 164 neighborhoods divided into 5 planning areas and 4 geographical zones: west zone, south zone, north zone, and center, with the west zone being the most populous and the south zone having the highest HDI [26].

2.2 STATISTICAL ANALYSES

2.2.1 Cross-correlation

Cross-correlation, which expresses the degree of linear association between the two processes X(n) and Y(n), was used to verify the presence of lagged values between both data series (monthly accident occurrences and monthly average temperature), identifying the possibility of one of the series being predictive, quantified by a cross-correlation coefficient, which in turn corresponds to Pearson's bivariate correlation coefficient at lag 0 [28,29]. Linear regression models were also used as a predictive model of the significance of the correlation (linear correlation coefficient) between both series. This modeling was used to evaluate the proportions of the results explained by the model, the fit, through the standard error and R^2. Linear regression is a modeling method for determining the “best fit” linear equation formed between two sets of continuous paired data, one dependent and the other independent. It is a type of analysis used to describe the probability of an outcome occurring, based on the relationship between two or more independent random continuous variables [30,31].

2.2.2 Trend

To estimate the trend in annual snakebite rates in the 163 neighborhoods of the municipality of Rio de Janeiro, the joint point regression model was used. This method selects the best fit from the simplest continuous log-linear regression model that best fits the data and identifies the year(s) in which a trend change occurs, calculates the annual percentage change (APC) between the inflection points of the trend by segments, and estimates the annual average percentage change (AAPC) over the entire study period, estimating statistical significance. The model assumes that changes in the trend are constant throughout each segment. The number of junction points is obtained using the Monte Carlo permutation test (4499 random permutations, significance level of 0.05). Once the number K of junction points is obtained, the different models are compared using the Bayesian Information Criterion (BIC) [32].

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2.2.3 Seasonality

For the seasonal analysis of the number of reported snakebites, after visual analysis of the behavior of the original series, a preliminary seasonal adjustment was performed using the X11 method to identify the presence of cyclical behavior. According to the United States Census Bureau [33], The X11 method uses moving averages to estimate the main components of a series, based on an iterative algorithm principle. The series is broken down into a trend-cycle component (Tt), a seasonal component (St), and an irregular component (It), according to an additive scheme: Yt=Tt+St+It, based on the following algorithms:

1. Estimation of the trend-cycle by moving average: Tt=M0(Yt);
2. Estimation of the seasonal-irregular component: Yt-Tt'=St+It;
3. Estimation of the seasonal component using moving averages for each month: S1t=M1(St+It) and I1t=(St+It) -S1t;
4. Estimation of the seasonally adjusted series: At=Yt-S1t;
5. Estimation of the trend-cycle using a 13-term Henderson moving average;
6. Estimation of the seasonal-irregular component: Yt-Tt" = (St+It)";
7. Estimation of the seasonal component using a 3X5 moving average for each month;
8. Estimation of the seasonally adjusted series: A"t =Yt-Š"t

Based on the algorithms described, moving averages are carefully chosen and refine the estimates of the components through iterations of the algorithm, reproducing the trend-cycle component as accurately as possible, while eliminating the seasonal component and reducing the irregular component as much as possible. Further information on seasonal adjustment using the X11 method [34].

2.2.4 Seasonal effect

To determine the seasonal effect of the series of snakebites, the average of the differences between the observed value and the trend in all months of the year was calculated, using a moving average, whose representative formula, for example, for December is:

$$S_{dez} = S_{12} = S_{24} = \cdots = \frac{1}{N}\sum_{J=0}^{N-1}(X_{12J+12} - T_{12J+12})$$

Where S represents the periodic or seasonal effect of the month, N the number of years, X the values observed in that month, and T the trend for that month [35].

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2.3 VARIABLES STUDIED AND DATA SOURCES

The variables were obtained from the following sources:

a) Data on snakebites in the municipality of Rio de Janeiro between 2008 and 2017, obtained through the Notifiable Diseases Information System (SINAN, https://portalsinan.saude.gov.br, 2025)26. The data were provided through the Access to Information System, protocol number 25820.001698/2019, from 2019.

b) National Institute of Meteorology (INMET)[36,37]: The average monthly temperature for the municipality of Rio de Janeiro was obtained because of the average temperature readings from the following weather stations: Forte de Copacabana (code: A652), Marambaia (code: A602), and Vila Militar (code: A621) between 2008 and 2017.

3 RESULTS AND DISCUSSION

3.1 OVERVIEW OF SNAKEBITES IN THE MUNICIPALITY OF RIO DE JANEIRO

The municipality of Rio de Janeiro has 164 neighborhoods, and during this period, 498 snakebites were reported, although there may have been unreported cases. The neighborhoods with the highest incidence were, in order of importance, Campo Grande (10.50%), Guaratiba (5.30%), Taquara (4.60%), Alto da Boa Vista and Vargem Grande (4.20% each), and Santa Cruz (3.80%), all located in the western part of the city, except for Alto da Boa Vista. It can be observed that the neighborhoods in the western part of the municipality were the most affected by snakebites (**Figure 1**). The study showed that 96.30% of the accidents occurred in the urban area of the city. Of the total number of victims of these bites, 337 (68.10%) were men and 158 (31.90%) were women. Most victims of both sexes were between 20 and 59 years of age, 108 cases among women and 243 among men, an important productive age, which reflects the socioeconomic impact of the injury. The average age among women was around 36 years, and among men was 37 years.

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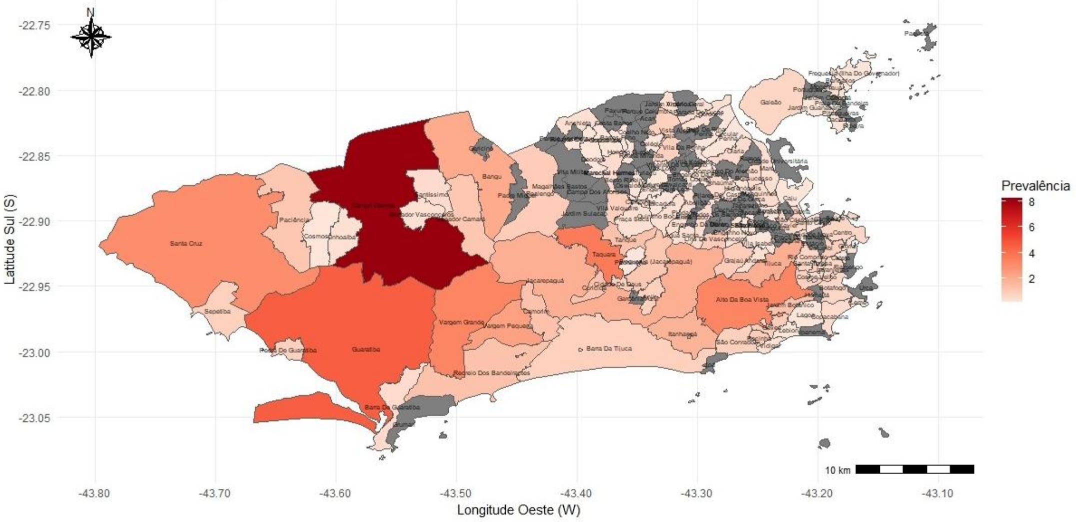
Figure 1

Prevalence of snakebites, neighborhoods in the city of Rio de Janeiro, 2008–2017



Source: produced by the authors, 2025.

Considering the reports during the period, in the table (**Table 1**), which compares the median differences between variables grouped into two independent samples using the Wilcoxon-Mann-Whitney U test, it was found that there was a statistically significant difference between the compared groups. The male gender, which was predominantly affected, had a monthly accident average of 3.33 (Md = 3), which was proportionally double the number of cases when compared to the female gender, i.e., for every 2 cases of accidents in men, there was 1 accident in women. This difference was remarkably significant (p-value < 0.001), but with a small effect size (r = 0.138) from a statistical point of view, being related to the probability that a value in the male group is greater than the probability of a value in the female group. In short, men have accidents more than women at a ratio of 2:1; the difference is statistically significant (p < 0.001), but the practical impact is small (r = 0.138), albeit consistent.

Several studies have shown a significant difference between men and women bitten by snakes in a study conducted between 2008 and 2013, with more men injured than women[14,38–41].

Similarly, age groups also showed significant differences when comparing the adult group, which had the highest average number of monthly snakebites, corresponding to 3.33 (Md = 3), with the other age groups, childhood and adolescence, with 1.51 (Md = 1), and the elderly (60 years or older) with 1.37 (Md = 1).

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Table 1

Difference in median values of variables grouped into two independent samples (Wilcoxon-Mann-Whitney U test) of the monthly occurrence of snakebites, according to gender and age group. Rio de Janeiro – RJ, 2008-2017

Variable		Average / Median	Reason	W / *p-value*	Effect size *r* (95% CI)
Gender	**Male**	3,33 / 3	2,1	5768 / < 0,001*	0,138 (-0,74;0,315)
	Female	1,98 / 2			
Age group	**Childhood and Adolescence**	1, 51 / 1	4,2	4490 / < 0,001*	-0,003 (-0,199;0,184)
	Adult	3,33 / 3	5,6	3867 / < 0,001*	-0,006 (-0,182;0,167)
	Elderly	1,37 / 1			

W= Wilcoxon-Mann-Whitney U test value; * = statistical significance; **CI** = confidence interval.
Source: produced by the authors, 2025

Most poisonings were caused by the genus *Bothrops spp.* (89.29%), in areas considered urban (96.30%). The year 2013 had the highest number of accidents, and 2008 had the lowest (**Table 2**). Studies conducted in several Brazilian states have shown that the genus *Bothrops spp.* is the leading cause of snakebites in Brazil [37,42–47]. There are 29 species of snakes in the *Bothrops* genus [48] known to date and are distributed throughout the national territory, which is why bothropic accidents are the most common [NO_PRINTED_FORM] and that includes the state of Rio de Janeiro [47].

Table 2

Classification of accidents by year of notification and attacking animal, Rio de Janeiro - RJ, 2008-2017

Accident Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	%
Botropic	28	52	63	42	43	58	35	45	40	36	442	89,29
Elapidic	1	0	0	0	1	0	1	0	0	3	6	1,21
Lacetic	0	0	1	0	0	0	0	1	0	0	2	0,40
Non-venomous	1	4	4	1	1	3	3	0	0	2	19	3,85
Unknown	4	4	3	5	3	4	3	1	0	2	26	5,25

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Total	34	60	71	48	48	65	42	47	40	43	495	100,00

Source: SINAN – DATASUS. Modified by the authors, 2025.

3.2 TEMPERATURE

Here we identify that temperature stands out as an important factor in the life cycle of snakes, as they are ectothermic (cold-blooded) animals. According to the physiology of these animals, external heat helps regulate various functions such as reproduction, locomotion, digestion, and ecdysis. During the study period, the average monthly temperature in the municipality was moderately warm (23.5°C [P25=21.8°C; P75=25.5°C]), with a narrow temperature range of 8.7°C between the maximum (28.5°C) and minimum (19.8°C). **Figure 2A** shows, in general, how the increase in cases accompanies the increase in temperatures, and vice versa, over time. This is also confirmed in the cross-correlation analysis, which shows the existence of temporal synchronism of the series signals through the cross-correlation coefficient (0.55), which was positive and statistically significant, with lag 0 having the highest cross-autocorrelation. This ACF at lag 0 also corresponds to Pearson's correlation coefficient, pointing to a high and positive correlation between the occurrence of snakebites and temperature (**Figure 2B**)

The climate appears to drive the population dynamics of zoonotic diseases and has been addressed through retrospective analyses of incidence records. It is important to highlight the role of precipitation and temperature in the dynamics of snakebites. Snakebites are greatly affected by temperature [49].

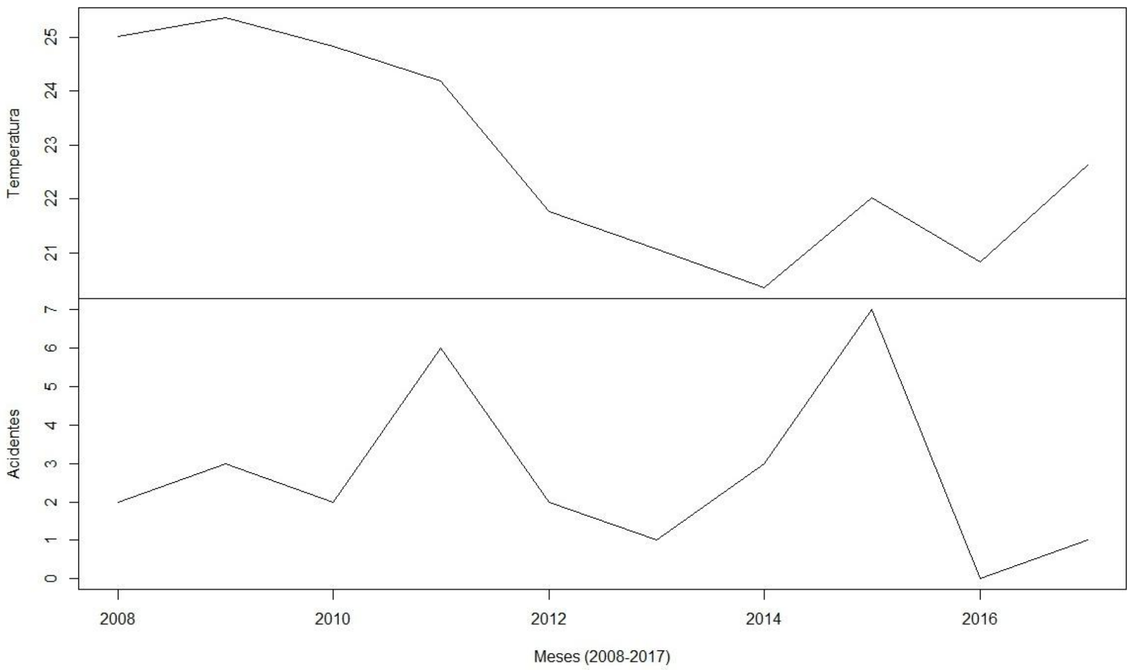
A retrospective study of snakebites in Saudi Arabia from 2015 to 2018, reported by the General Administration of Statistics and Information, Ministry of Health, Kingdom of Saudi Arabia, showed that the rate of snakebite poisoning was higher during the summer months compared to other seasons, and lower in the winter months. This may be because snakes remain inactive in hibernation due to low ambient temperatures [21]. In other words, the onset and end of the hot and rainy seasons of the year may be associated with an increase in the frequency of snakebites and a consequent higher occurrence of these accidents, characterizing seasonal variation[3].

The results describe a linear regression analysis that investigated the relationship between temperature and the number of snakebites in neighborhoods in Rio de Janeiro. Based on the results presented, we can say that for every average increase of 0.68°C in temperature, there was an average increase of one snakebite. This increase was considered statistically significant, indicating that temperature has a relevant effect on the number of poisonings. The standard error of the model is low (0.09), which indicates that the model's fit to the observed data is good and reliable. The coefficient of determination R² is 29%, indicating that 29% of the variation in the number of snakebites can be explained by the variation in temperature. This value shows temperature as an important factor, but not the only one, related to the occurrence of these accidents.

In summary, linear regression suggests that temperature is associated with the number of snakebites and that the model is adequately adjusted to explain part of this relationship.

Figure 2. A

Behavior of the monthly average temperature and the number of monthly snakebites in neighborhoods in the city of Rio de Janeiro (Brazil), from January 2008 to December 2017. ***B:*** *Summary of cross-correlation and linear regression analyses between the monthly data series for snake bites and average temperature*



Series	ACF [*Lag*]	Linear Regression		
		Intercept / Linear correlation coefficient	Standard error	R^2
snakebites + temperature	0,55* [*Lag* 0']	-11,82* / 0,68*	0,09	0,29*

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A – Monthly temperature and snakebite behavior. Neighborhoods of Rio de Janeiro, 2008–2017; **B** – Linear regression. **ACF**=autocorrelation function at *lag* 0; ***Lag***=signal lag; = lag with highest cross-autocorrelation between series; **R2**=linear regression equation fit; *=statistical significance. Source: produced by the authors, 2025.

In this study of snakebites, hourly data on air temperature and humidity (**Table 3**) were obtained from three rain gauge stations located in the municipality of Rio de Janeiro: Copacabana Fort Station, in the southern zone; Marambaia Station and Vila Militar Station, both in the western part of the municipality (**Figure 3**), controlled by the National Institute of Meteorology (INMET) [37]. These stations were chosen because, at the time of the study, they were the active stations in the municipality; the other stations were in neighboring municipalities.

Environmental variables, such as temperature and precipitation, are central elements in geospatial analyses related to snakebites. These variables are often recognized as the main modulators of the incidence or risk of snakebites, although their relative relevance depends on the geographical and methodological specificities of each study. In the context of an Iranian study conducted between 2002 and 2011, precipitation seasonality was identified as the most decisive climatic covariate, directly influencing habitat suitability and, consequently, the risk of poisoning [50].

Table 3

Land-based weather stations of the National Institute of Meteorology (INMET) [37]*. Municipality of Rio de Janeiro, 2008-2017*

Station	Code	Type	Latitude	Longitude	Altitude
Forte de Copacabana	A652	Automatic	-22.98833333	-43.19055555	25,59 m
Marambaia	A602	Automatic	-23.05027777	-43.59555555	12 m
Vila Militar	A621	Automatic	-22.86138888	-43.41138888	30,43 m

Source: National Institute of Meteorology – INMET, 2024. Adapted by the authors, 2025.

Table 4 shows the annual average temperatures and humidity levels in the municipality of Rio de Janeiro, which were collected from weather stations that were active in the municipality at the time of the study. We can see that the temperature varied between 22 and 27°C. The Vila Militar station had the slightly highest temperature, with an overall average of 23.97°C, followed by Forte de Copacabana with an overall average of 23.88°C. As for relative

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humidity, the Copacabana Fort station had the highest overall average relative humidity at 77.78%, followed by the Marambaia station with a slight difference and an overall average of 77.64%. Although the Vila Militar station had higher temperatures, it had much lower humidity, with an overall average of 72.08%.

Table 4

Annual averages of temperature and humidity at weather stations in the city of Rio de Janeiro, 2008 to 2017

Year	Forte de Copacapana				Marambaia				Vila Militar			
	Max.T	Min.T	Max.Hu	Min.Hu	Max.T	Min.T	Max.Hu	Min.Hu	Max.T	Min.T	Max.Hu	Min.Hu
2008	23,27	22,31	81,92	77,31	22,65	21,67	84,19	79,74	23,75	22,55	81,14	75,35
2009	24,49	23,49	80,76	75,90	24,05	23,01	81,08	76,57	24,37	23,36	83,20	76,22
2010	24,50	23,48	81,00	74,17	24,01	22,87	78,94	74,01	24,31	23,08	77,03	70,50
2011	23,00	22,50	81,33	76,58	23,42	22,24	79,94	75,11	23,91	22,63	73,33	67,50
2012	27,70	26,70	81,31	76,32	23,61	22,33	77,64	76,47	25,13	23,80	71,81	65,92
2013	23,87	22,86	80,66	76,06	23,53	22,41	79,91	75,94	24,30	23,04	73,88	68,13
2014	24,02	22,80	78,69	73,21	24,04	22,68	77,19	71,73	25,14	23,72	69,47	63,22
2015	24,82	23,69	79,45	74,27	24,42	23,24	78,97	74,01	25,45	24,16	72,67	66,63
2016	24,34	23,31	79,07	74,83	24,12	23,04	80,23	75,91	24,92	23,66	74,62	69,08
2017	23,86	22,72	78,71	74,10	23,73	22,53	79,92	75,30	24,79	23,48	74,03	67,82

Source: INMET, 2025. **Max.T** - maximum temperature (°C); **Min.T** - minimum temperature (°C); **Max.Hu** - maximum humidity (%); **Min.Hu** - minimum humidity (%). Adapted by the authors, 2025.

3.3 TEMPERATURE VARIATIONS AND HEAT ISLANDS

In Brazil, there is little research on the various consequences of the formation and increase of urban heat islands [51]. The urban heat island (UHI) is defined as the difference between the air temperature in urban and rural areas. Factors contributing to the development of the urban heat island include: geographical location (latitude and proximity to the ocean), the size of the urban area, the predominant function of society, whether industrial, commercial, or residential, the spatial configuration of the city, and the most recurrent weather conditions. The formation of this phenomenon is directly related to the availability of solar radiation [52].

The Heat Island is the main manifestation of the urban climate and one of the main environmental problems of the 21st century. It can be considered a type of climate change, caused by human factors and generated on a local scale, which requires investigation for its detection and understanding. It is an urban environmental phenomenon associated with changes in surface cover [53]. They can be studied on various spatial scales, ranging from global to local, and may vary throughout the day and night, and according to the seasons

[54,55]. One of the main consequences of heat islands is the modification of local atmospheric circulation and, as a result, higher concentrations of pollutants are observed within them, as well as higher temperatures, leading to thermal discomfort [56–59] damage to health, and increased mortality rates [57]. Areas with vegetation cover tend to have cooler temperatures. The presence of vegetation can reduce heat islands in two ways. The first is through the shade produced by trees, which keeps surfaces cooler. The second is that, in the process of evapotranspiration, plants use solar energy to evaporate water, so this energy would not be used to heat the city [56.] Therefore, changes resulting from the urbanization process, such as the replacement of vegetation with various types of materials that waterproof the soil surface, contribute to changes in thermal patterns and air quality, causing the urban environment to become heat concentration centers [59].

As for temperature variations, the topography of the municipality of Rio de Janeiro, with its mountains and coastal areas, allows for milder temperatures. However, disorderly urbanization between the mountains, without urban planning, hinders air circulation and impairs the natural cooling system, leading to the formation of heat islands [60], can be defined as the difference observed between the ambient temperature in urban and peripheral environments [61]. For this reason, they are also known as reverse oases [62].

A study conducted in the municipality of Rio de Janeiro in 2017 showed that the Continental Surface Temperature (CST) registers its highest values in the most urbanized area of the municipality, on the eastern shore of Guanabara Bay, and in the flat areas between the three coastal massifs (Tijuca, Pedra Branca, and Gericinó-Mendanha). These areas define the most intense urban heat island cores[63]. Therefore, the combination of high building density and reduced tree cover appears to be responsible for higher temperatures and the consequent formation of heat islands[53].

The municipality of Rio de Janeiro is vulnerable to environmental disasters associated with climate change, which are intensified by anthropogenic actions, as changes in the physical space, alterations to rivers and streams, deforestation of hillsides, and irregular occupation of coastal regions alter ecosystems, impact biodiversity, and facilitate the occurrence of natural disasters affecting the most vulnerable populations [60]

3.4 SEASONALITY

Studies conducted in Brazil in 2021 showed an association between snakebites and environmental, climatic, and socioeconomic factors. The environmental factors considered

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were primary habitat (tropical or non-tropical), temperature, precipitation, elevation, and the relationship with forest loss due to deforestation or fires, as well as the abundance of venomous snakes. Environmental factors include climate, humidity, temperature, and precipitation. Socioeconomic factors include lower urbanization rates and lower GDP per capita, increased human activity in rural areas, especially during periods of high precipitation [6,41,64–66]. Seasonality tends to be positive during hot and rainy periods [67,68].

The results presented describe the analysis and seasonal behavior of snakebites in the municipality of Rio de Janeiro, based on the information shown in **Figures 4A** and **4B**. **Figure 4A** (black line) shows the initial findings, which indicate the existence of an annual cyclical occurrence of snake bites. The initial seasonal adjustment (red line) more accurately differentiated the occurrence of an annual cyclical periodicity of snakebites in the municipality of Rio de Janeiro. In **Figure 4B** (monthly summary), we can see that in the colder months, from May to October, the average number of accidents is lower, around 2.85 per month. In the warmer months, from November to April, the average rises to 5.84 accidents per month. The annual average was approximately 4.12 bites per month. The months with the highest absolute numbers of cases were January, followed by December.

In summary, snakebites in the municipality of Rio de Janeiro during the study period showed a well-defined seasonal pattern, with a higher incidence in the warmer months, especially January and December, probably reflecting environmental and human activity factors related to climate.

Once the seasonal component of the snakebite series, defined in **Figure 4C**, has been exposed, it can be concluded that there is an Annual Periodic Oscillation, which shows a clear and regular variation throughout the year, with peaks and troughs that repeat annually. Specifically, there is a decline in the number of cases in the middle of the year (possibly between June and August) and an increase in both the early months (January to March), and the late months (November and December) of the year. We can also observe a Positive Average Monthly Seasonal Effect (**Figure 4D**), which shows us that all months have positive effects, indicating that the number of cases is always above the base average in each month, but with variations in intensity. In other words, the highest seasonal effect values occur in the first half of the year (January to June), peaking at around 0.33, and in the second half of the year (July to December), the effect is slightly lower, at around 0.30.

The mention that the temperature does not vary greatly throughout the year indicates that climatic variations are not a relevant factor in explaining this seasonality in these cases.

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Therefore, other factors—possibly behavioral, social, exposure, or economic activity—may be influencing the periodic fluctuation observed.

In summary, the annual seasonality of snakebites is clear, with periods of higher and lower incidence throughout the year, but it is not related to significant variations in the average annual temperature, which suggests that other determinants should be investigated to explain this pattern, such as increased mobilization and occupation of the territory with population growth and an increase in the number of permanent residences, mainly involving deforestation in regions where the incidence rate is higher.

Another factor that can also increase the incidence of snakebites is the occurrence of increased rainfall, the rainy season. This is related to the behavior of the animal, which tends to seek dry places, increasing the risk of encounters with humans [38,41].

A study conducted in Ethiopia in 2022 identified that the transition periods between rainy seasons are correlated with an increase in the incidence of snakebites. The higher frequency of these events coincides with intense agricultural activities that require more labor, such as soil preparation, planting, and weeding, and exposes a growing number of rural workers, increasing their vulnerability to snakebites [69]. In addition, similar seasonal phenomena were documented in investigations conducted in Costa Rica in 2020 [70] and in Mozambique in 2021 [50], corroborating the influence of the climate cycle on the dynamics of snake accidents in different geographical contexts.

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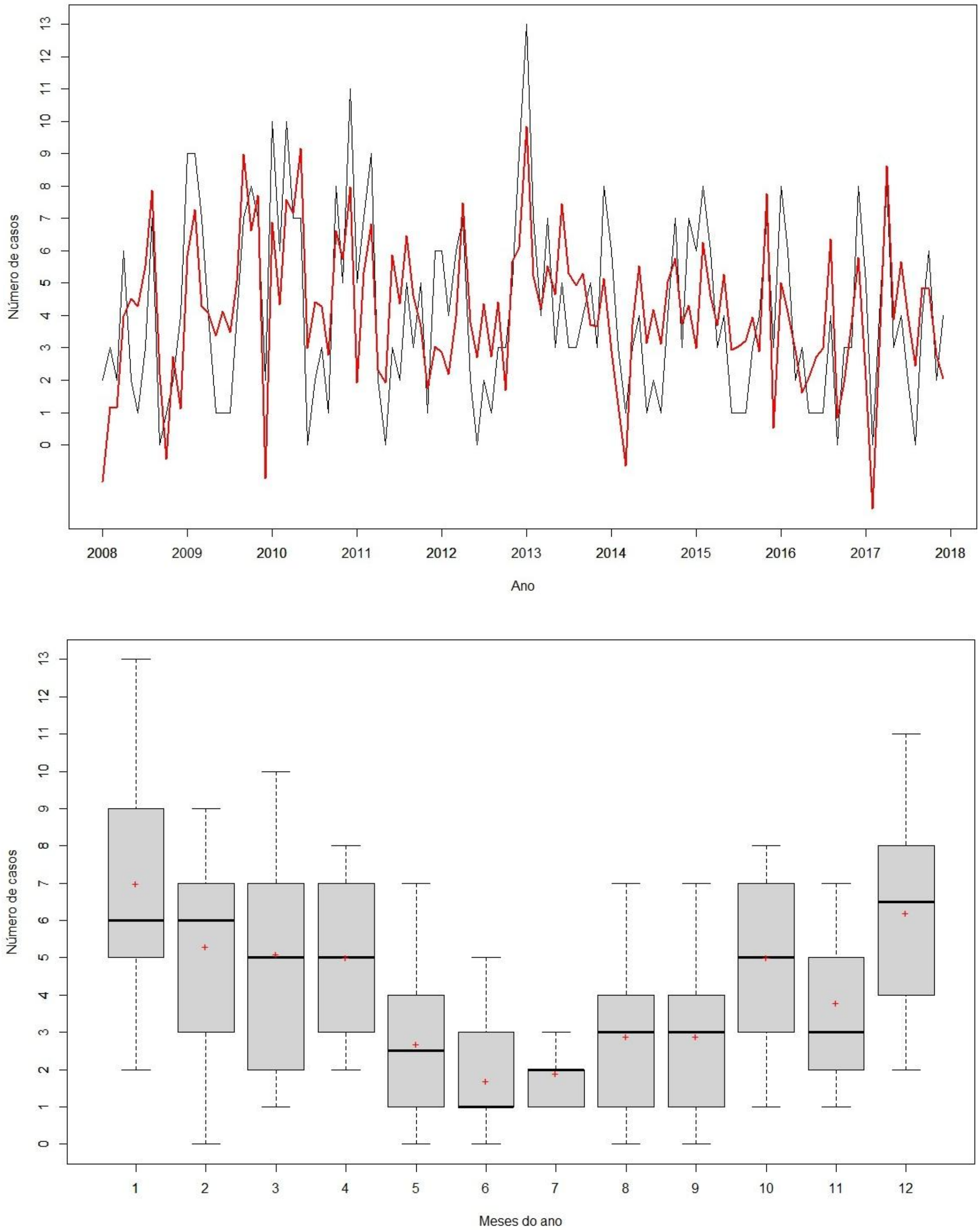
Figure 4

Seasonal behavior of snakebites in neighborhoods in the city of Rio de Janeiro (Brazil). Period from 2008 to 2017



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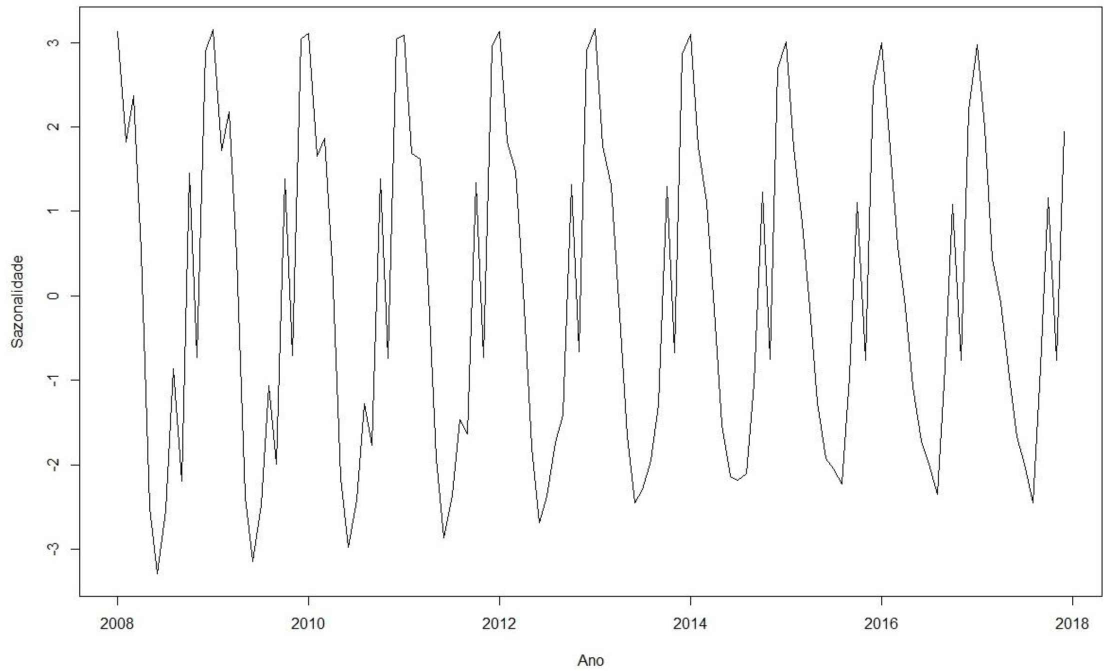

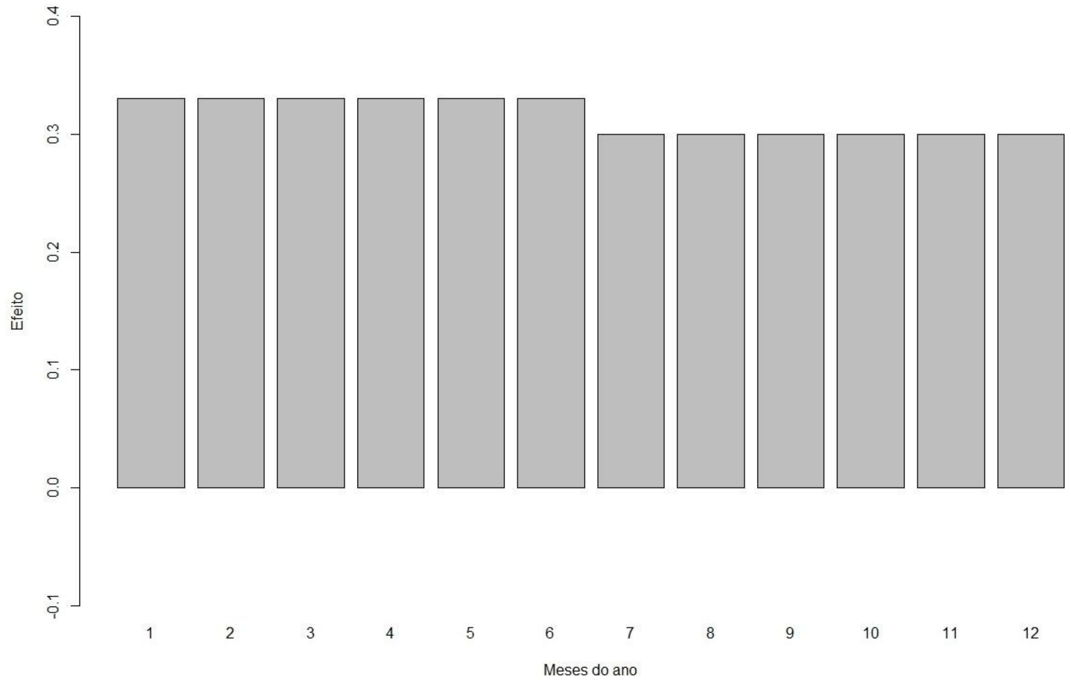

Source: produced by the authors, 2025.

Knowledge of climatic elements such as precipitation, humidity, wind, temperature, and atmospheric pressure gives us a clearer picture of their variability and how these elements impact the entire socioeconomic system of a region [71].

3.5 TREND

Time series analyses of snakebites are excellent strategies for analyzing how these phenomena fluctuate in nature, allowing us to verify whether they show a reduction, increase, or seasonality in incidence in each place [72]. Trends may be influenced by broader environmental and social factors rather than localized hospital data [73].

The results presented in **figure 5** indicate a downward trend in snake bite rates in the municipality of Rio de Janeiro between 2008 and 2017, with an annual percentage change (APC) of -2.1% [95% CI: -8.0; 4.0]. Both the average percentage change over the period (APCC) and the annual trend showed a 2.15% decline over the 10 years, although this reduction did not reach statistical significance.

In the discussion, this decline can be interpreted based on different contextual factors, such as the urbanization process, greater measures to protect the population, migration of snakes to less urbanized areas, reduction in the population density of these animals, or even environmental changes that impact their distribution.

The downward trend in snakebites in the municipality of Rio de Janeiro between 2008 and 2017, although not statistically significant, may reflect environmental and social changes that occurred during this period. Urbanization and real estate expansion tend to modify the natural habitat of snakes, favoring the migration of these animals to peri-urban or rural areas and reducing their presence in densely populated neighborhoods. In addition, increased access to health services, the strengthening of public surveillance policies, and the wider dissemination of preventive information may have contributed to reduced exposure of the population to risk areas.

A study conducted in Ghana between 2018 and 2023 also showed a downward trend. This can be attributed to ongoing community education and awareness efforts. Increased knowledge of preventive measures and safety precautions, greater caution in areas prone to snakebites, resulting in less risky behavior and a reduction in the number of snakebites [68].

Several studies have investigated trends in snakebites in Brazil over recent years. For example, [67] identified stability in the incidence of these accidents between 2002 and 2013. Subsequently, [74] pointed to a progressive reduction between 2007 and 2019. More recently, [75] observed a new downward trend between 2020 and 2022. These results suggest important changes in the epidemiological pattern of snakebites in the country, highlighting the need for continuous monitoring and the adoption of specific prevention strategies. This downward trend may suggest a reduction in the population density of snakes in urbanized areas as well as changes in human behavior in the face of risk (such as the use of protective footwear in rural areas). On the other hand, broader environmental factors, such as climate variations and changes in vegetation cover, which influence the availability of prey and the displacement of venomous species, cannot be ruled out. Thus, the observed decrease in rates should be interpreted in a multifactorial manner, considering the complex interaction between human population dynamics, environmental changes, and snake ecology [76,77].

Studies conducted in regions such as the interior of the Amazon, particularly in the state of Pará, have shown a growing trend in the number of snakebites in recent years, contrary to what has been observed in Rio de Janeiro. Between 2020 and 2023, there was a significant increase in these poisonings in Pará, associated with greater exposure of the rural population, mainly men of working age, to agricultural activities and the environment naturally conducive to the region's biodiversity and tropical climate [77–79]. This factor may be related to changes that have reshaped the food chain, production and reproductive cycles, habitat, and migratory patterns of these animals, contributing to a growing trend in the incidence of these accidents [75].

This increase contrasts with the reduction observed in urban areas such as the municipality of Rio de Janeiro, where urbanization and changes in land use may displace snakes to less populated areas, reducing their incidence. In the Northeast, an increase in cases has also been documented, linked to unfavorable socioeconomic conditions and reduced access to preventive and health measures, which reinforces the importance of regionalizing strategies for the control and prevention of snake accidents in Brazil. Thus, Rio de Janeiro presents a unique scenario in which urbanization and the transformation of territories seem to play a protective role in that decade, while other regions remain at increasing risk [77–79].

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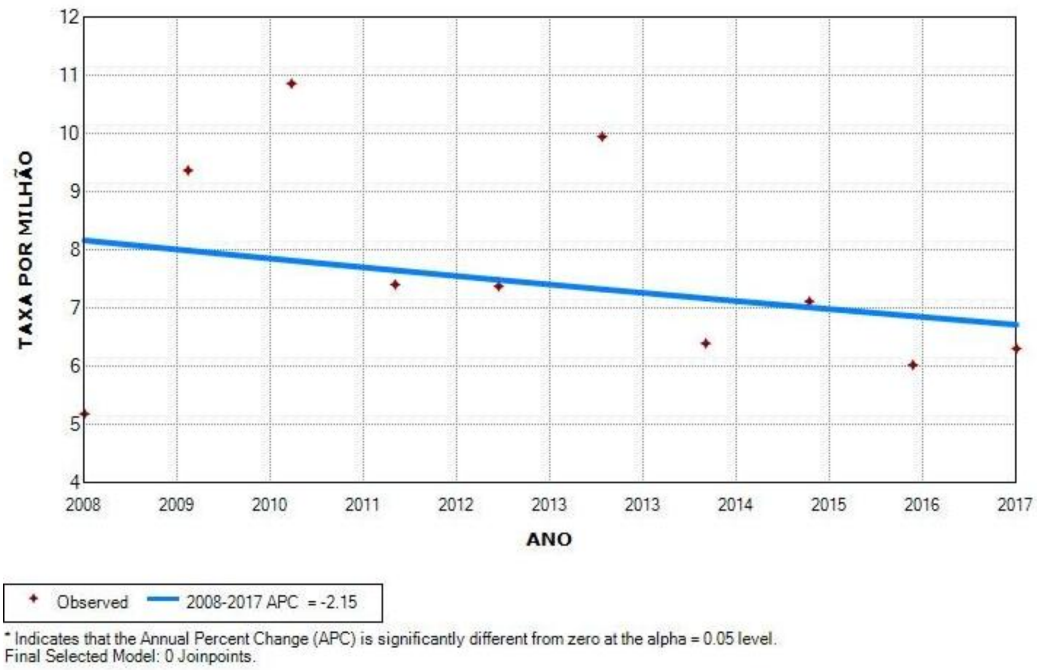
Figure 5

Trend in snake bite rates per 1,000,000 inhabitants in neighborhoods in the city of Rio de Janeiro (Brazil) from 2008 to 2017: All: 0 Joinpoints



Source: produced by the authors, 2025

4 CONCLUSION

In terms of seasonality, a higher number of cases was observed in the warmer and more humid months (spring and summer), with a reduction in the colder months (fall and winter). The positive association between temperature and accident incidence suggests that meteorological variables may act as important risk indicators. Given the relevance of seasonality, there is a need for continuous monitoring of temperature, relative humidity, and seasonal climate variables as tools for preventive epidemiological surveillance.

During the period analyzed, 498 cases of snakebites were reported. The genus *Bothrops spp* (jararacas) had the highest prevalence among the records. The occurrence in urban contexts, particularly in areas where urban expansion meets remnants of native forest, may suggest a process of overlap between human occupation and environments favorable to the presence of snakes. In this sense, preventive actions should be directed mainly at rural workers, construction professionals, and residents of areas identified as being at greater risk for snakebites. The highest concentration of cases was recorded in the West Zone of the municipality of Rio de Janeiro, especially in the neighborhoods of Campo Grande, Guaratiba, Taquara, Vargem Grande, and Santa Cruz—a region characterized by the presence of forest fragments and proximity to areas of native forest.

Regarding the epidemiological profile, men were the most affected, at a ratio of approximately 2:1 compared to women. The predominant age group corresponded to the economically active population (20 to 59 years old) in both sexes, which implies significant socioeconomic consequences. The average ages were estimated at 36 years for women and 37 years for men.

With regard to environmental and urban aspects, the occurrence of cases in urbanized areas reinforces the idea of interaction between phenomena of land occupation, deforestation, and conservation of forest fragments. Elements such as heat islands and local geoclimatic changes seem to influence the dynamics of snakebites, highlighting the need for integrated urban and environmental management strategies. Thus, urban expansion planning should consider the maintenance of ecological corridors and the proper management of urban forest areas.

The study also identified a downward trend in the number of cases in the municipality of Rio de Janeiro.

Finally, in addition to the use of antivenom serums—a fundamental therapeutic resource for treating and reducing the severity of cases—it is necessary to strengthen health education and community environmental education strategies. These may include campaigns targeting communities in the West Zone, which appear to be at greatest risk for snakebites, with an emphasis on first aid practices, immediate referral of the victim to the nearest health facility, and preventive measures, constituting an essential element of effective public policies that can help reduce snakebites.

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.

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