



# Association between temperature and snakebite incidents in the state of Rio Grande do Sul, Brazil

Livia da Silva Freitas<sup>1,2</sup> · Fernanda Machado da Silva<sup>1</sup> · Paula Florencio Ramires<sup>1,2</sup> · Gabriella Mello Gomes Vieira de Azevedo<sup>1,2</sup> · Bruno Martins da Costa Batista<sup>4</sup> · Rafael Kenji Anzai<sup>4</sup> · Isabela da Silva Pereira<sup>4</sup> · Matheus Pissarelli<sup>4</sup> · Fabiano Morezi de Andrade<sup>4</sup> · Romina Buffarini<sup>2</sup> · Xesús Feás<sup>5</sup> · Selma Maria Almeida-Santos<sup>4</sup> · Flavio Manoel Rodrigues da Silva Júnior<sup>1,2,3</sup>

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## Abstract

Climate change has significant implications for public health, including an increase in incidents involving venomous animals like snakes. This study investigates the relationship between temperature and snakebite incidents in the state of Rio Grande do Sul, Brazil. We analyzed data from 2009 to 2019 on snakebite notifications and monthly average temperatures across 35 microregions in Rio Grande do Sul. Data were obtained from the Brazilian Unified Health System (DATASUS) and the Agricultural Meteorological Monitoring System (Agritempo). Multilevel Poisson models with robust variance were used to assess the association between snakebite rates and temperatures. The study found a positive correlation between temperatures and snakebite incidents in all microregions, with an average increase in temperature of 1 °C over the study period. Snakebite notifications increased by an average of 50.4%, with some microregions experiencing increases of over 90%. The highest correlations were found in Passo Fundo ( $r=0.885$ ), Caxias do Sul ( $r=0.875$ ), and Santa Maria ( $r=0.820$ ). Each degree increase in temperature was associated with an 8–22% increase in the risk of snakebite incidents. The findings indicate a significant relationship between rising temperatures and the increase in snakebite incidents. This underscores the need for public health strategies to mitigate the impact of climate change on snakebite risks.

✉ Flavio Manoel Rodrigues da Silva Júnior  
f.m.r.silvajunior@gmail.com

Livia da Silva Freitas  
liviafreitas05@gmail.com

Fernanda Machado da Silva  
nanda\_machado92@hotmail.com

Paula Florencio Ramires  
cienla277@gmail.com

Gabriella Mello Gomes Vieira de Azevedo  
gabriellagomesdeazevedo@gmail.com

Bruno Martins da Costa Batista  
bruno.costa@butantan.gov.br

Rafael Kenji Anzai  
rafael.anzai.esib@esib.butantan.gov.br

Isabela da Silva Pereira  
isabela.pereira.esib@esib.butantan.gov.br

Matheus Pissarelli  
matheus.pissarelli@butantan.gov.br

Fabiano Morezi de Andrade  
fabiano.morezi@fundacaobutantan.org.br

Romina Buffarini  
romibuffarini@gmail.com

Xesús Feás  
xesusfeas@gmail.com

Selma Maria Almeida-Santos  
selma.santos@butantan.gov.br

<sup>1</sup> LEFT - Laboratório de Ensaios Farmacológicos e Toxicológicos, Instituto de Ciências Biológicas, Universidade Federal do Rio Grande - FURG, Av. Itália, km 8, Campus Carreiros, Rio Grande, RS CEP 96203-900, Brazil

<sup>2</sup> Programa de Pós-Graduação em Ciências da Saúde, Universidade Federal do Rio Grande - FURG, Rua Visconde de Paranaguá, 102, Rio Grande RS CEP 96203-900, Brazil

<sup>3</sup> Instituto de Ciências Biológicas e da Saúde, Universidade Federal de Alagoas – UFAL, Av. Lourival Melo Mota, s/n, Tabuleiro do Martins, Maceió AL CEP 57073-620, Brazil

<sup>4</sup> Laboratório de Ecologia e Evolução, Instituto Butantan, Avenida Vital Brazil, 1500, Butantã, São Paulo, SP 05503-900, Brazil

<sup>5</sup> Academy of Veterinary Sciences of Galicia, Edificio EGAP, Rúa Madrid, No. 2-4, Santiago de Compostela A Coruña 15707, Spain

## 1 Introduction

The World Health Organization (WHO) highlights the growing concern about the substantial impact of climate change on human health. Between 2030 and 2050, approximately 250,000 deaths per year are projected to occur due to climate change-related issues such as malnutrition, malaria, diarrhea, and heat stress (WHO 2022). Beyond direct impacts on population health, climate change entails significant socioeconomic and financial costs. Estimates indicate that by 2030, health-related expenditures alone stemming from this problem will reach between two and four billion US dollars annually (WHO 2022). These costs encompass medical treatments, disease prevention, and other investments necessary to address the impacts of climate change on public health.

Climate change poses a significant threat not only to human health and economies but also to biodiversity and ecological stability. Changes in temperature, precipitation patterns, and extreme weather events disrupt ecosystems, directly impacting the survival of many species (Barcellos et al. 2009). Among the most affected are ectothermic animals, such as venomous snakes, which depend on ambient temperature to regulate their physiology (Weiss and Paiva 2018). Altered climatic conditions can lead to the loss of suitable habitats, the food scarcity, and the difficulty in finding appropriate sites for hibernation or reproduction, compromising these species ability to adapt or migrate to more favorable areas (Justin et al. 2011).

These disruptions can lead to increased contact between humans and venomous animals, such as snakes, raising the risk of incidents. Species migration may result in biodiversity loss, ecosystem imbalance, and the loss ecosystem services such as vector control, as well as food web regulation, all of which have direct implications for food production, human health, and the economy (Martinez et al. 2024; Pecl et al. 2017).

Snakebite envenomation in human is one of the most severe outcomes of such interactions. It is estimated that 1.8 to 2.7 million cases occur each year, causing 81,000 to 138,000 deaths and leaving about 400,000 people with permanent physical or psychological sequelae (Gutiérrez et al. 2017). Accidents involving venomous animals, especially snakebites, were classified by the WHO in 2017 as a neglected tropical disease, commonly occurring in regions of social vulnerability, where water security, sanitation, and access to healthcare are precarious (WHO 2010). In the Brazilian scenario, the official notification of snakebite case is mandatory and has a significant impact on public health (WHO 2022).

The average annual occurrence of these accidents in Brazil over the past 11 years is approximately 177,000, with

an average of 262 deaths per year (DATASUS, 2024). Rio Grande do Sul has one of the highest incidence rates of snakebites in the country, with a strong association to its agricultural context (Alcoba et al. 2022). The state is primarily focused on agribusiness, with extensive areas allocated to agricultural and livestock production. Certain agricultural practices and characteristics of agroecosystems can intensify the risk of snakebites. In addition, deforestation, burning, and other processes associated with ecological imbalance are common in this context, creating environments conducive to the presence of snakes and increasing the likelihood of human (Babo et al., 2022). In 2023 alone, the state recorded 8,355 snakebite incidents (DATASUS, 2024).

Since the pre-industrial era, greenhouse gas (GHG) levels in the atmosphere have drastically risen due to fossil fuel combustion, deforestation, and industrial activities (Parteka et al. 2013). According to the Intergovernmental Panel on Climate Change (IPCC), the planet is expected to warm by 1.5 °C in the coming decades, resulting in severe climate impacts, especially in tropical countries like Brazil (IPCC 2022). Ecosystems may disappear, and between 3% and 14% of terrestrial species face a high risk of extinction. Additionally, rising temperatures may influence the behavior of venomous snakes, potentially leading to an increase in reported envenomation cases (da Costa et al. 2019).

The hypothesis of the present study is that the rise in snakebite incident is related to increasing temperatures, as higher temperatures promote greater snake activity. Warmer conditions are associated with extended periods of surface activity, elevated metabolic rates, enhanced digestive efficiency, and increased overall mobility of snakes (Huang et al. 2013; Costa et al. 2012). Considering these concerns, this study aims to investigate the relationship between snakebite notifications and temperature in different microregions of the state of Rio Grande do Sul from 2009 to 2019.

## 2 Materials and methods

### 2.1 Study area

Rio Grande do Sul, with a land area of 281,707.151 km<sup>2</sup>, accounts for over 3% of Brazil's territory, making it the ninth-largest state in the country. With an estimated population of 11,466,630 inhabitants according to 2021 data from the Brazilian Institute of Geography and Statistics (IBGE), it represents approximately 6% of the national population. The state comprises 497 municipalities and can be divided into seven macroregions and 35 microregions, with the latter being adopted as the territorial basis for this study (Fig. 1) (IBGE 2024).

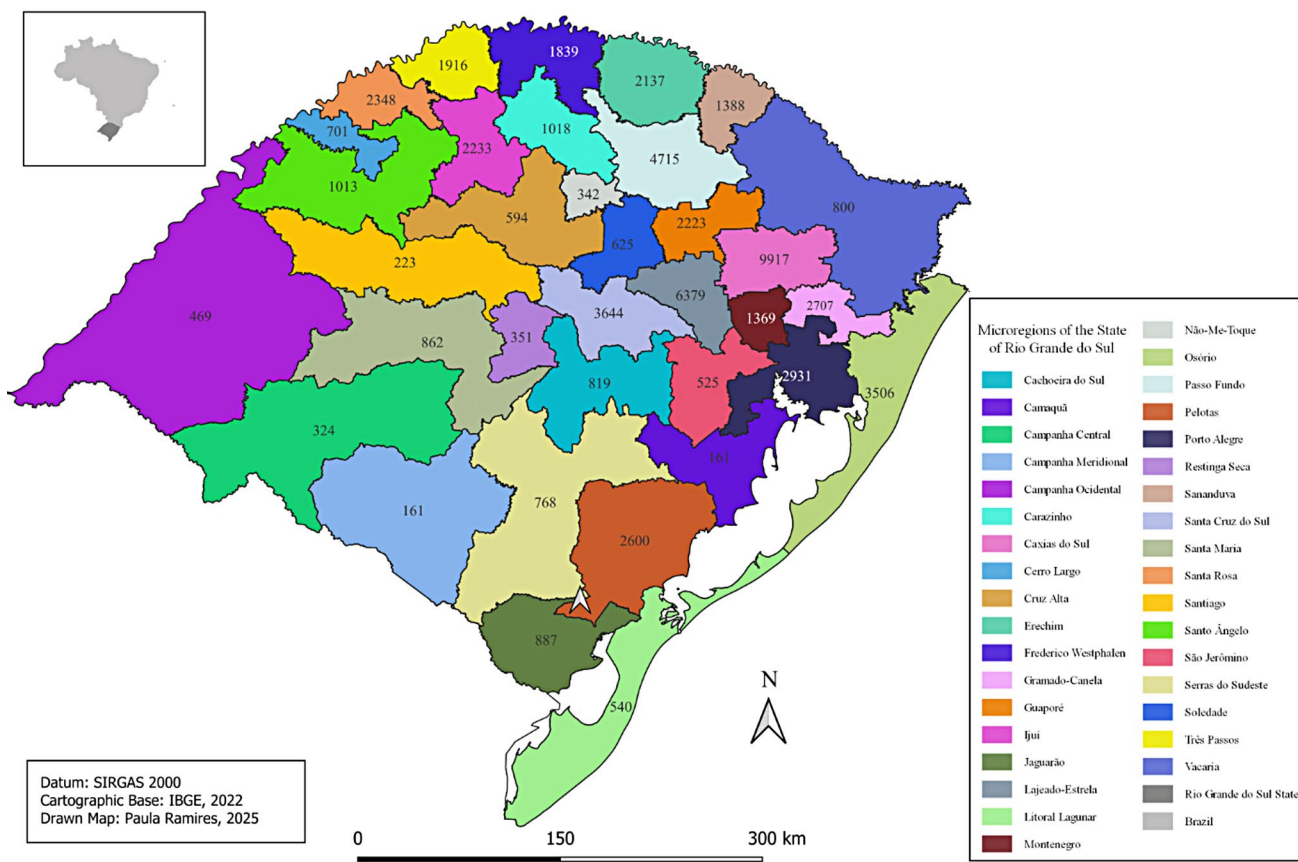


Fig. 1 Microregions and total snakebite notifications by microregion of the State of Rio Grande do Sul in the study period

Microregions are a regional division based on the specificity of the productive structure (agriculture, industry, mining, and fishing), as well as information about the natural environment and specific social and economic relations, institutionalized in Brazil by Resolution PR-51 of 1989 (IBGE, 2017). Despite the existence of seven macroregions, we chose to use the microregional division due to its detailed nature, which provides more specific information for our analysis.

The predominant climate in Rio Grande do Sul is humid subtropical. This climate classification is characterized by hot summers and mild to cool winters. During the summer, average temperatures range between 25 °C and 30 °C (77 °F to 86 °F), with some regions exceeding 40 °C (104 °F). This season is typically marked by frequent rainfall and intense thunderstorms. In winter, temperatures are milder, with averages ranging between 10 °C and 15 °C (50 °F to 59 °F). In some southernmost areas, temperatures can drop even lower, reaching negative values. Frost and snowfall are common in certain regions (IBGE 2024).

Beyond seasonal variations, the climate in Rio Grande do Sul is also influenced by the presence of air masses originating from the Atlantic Ocean. This maritime influence helps to moderate temperatures and contributes to the region's

humidity. It is important to note that, due to the state's vast territorial extent, climatic variations can occur between different regions. For instance, areas near the coast tend to exhibit a more humid climate and slightly milder temperatures compared to areas located further inland (IBGE 2024).

## 2.2 Data collection and variables

Monthly notifications of snakebite accidents per 100,000 inhabitants were collected over an eleven-year period (2009 to 2019) using data from the Department of Informatics of the Unified Health System (DATASUS, 2024). Average monthly temperatures for all municipalities in the study area were obtained from the Agrometeorological Monitoring System (Agrimtempo), a government-certified platform developed and maintained by Embrapa Digital Agriculture in partnership with the Center for Meteorological and Climatic Research Applied to Agriculture (Cepagri) of Unicamp.

To analyze the data at the microregional level, the municipalities were grouped according to their respective microregions. The eleven-year period was selected to identify significant trends and patterns in the relationship between snakebite accidents and temperature over time, excluding

data from 2020 to 2022 due to the pandemic, which could have interfered with notifications as the population was subject to circulation restrictions.

### 2.3 Data analysis

First, data on monthly temperature and snakebites rates were described through spatial distribution of the exposure and the outcome variables per microregions. Microregions were spatially represented using QGIS 3.28.10 software based on the 2022 IBGE cartographic database of municipalities within each microregion of the state of Rio Grande do Sul.

Second, the association between monthly snakebite rates (outcome) and monthly temperatures (exposure) was assessed using multilevel Poisson models with robust variance for each microregion separately. The first level comprised the monthly mean temperatures, and the second level comprised a time unit variable (eleven years, ranging from 2009 to 2019). The use of the multilevel regression model

with time as the second level is justified due to the hierarchical structure of our data, where monthly snakebite notifications are nested within months across several years. Also, this approach accounts for the correlation of observations within the same time period, such as seasonal and annual effects. Also, Spearman correlation was performed.

All analyses were performed in STATA version 16.1.

### 3 Results

When analyze the complete time period, we observed that the average temperature in the 35 microregions showed a mean increase of 1°C from 2009 to 2019, varying from 0.4 °C rise in Três Passos and Campanha Central to 2 °C rise in Gramado; Canela (Fig. 2). These absolute increases in degrees represent a mean increase of 5% (ranging from 2 to 12%) in the state in an eleven-period time (Table 2).

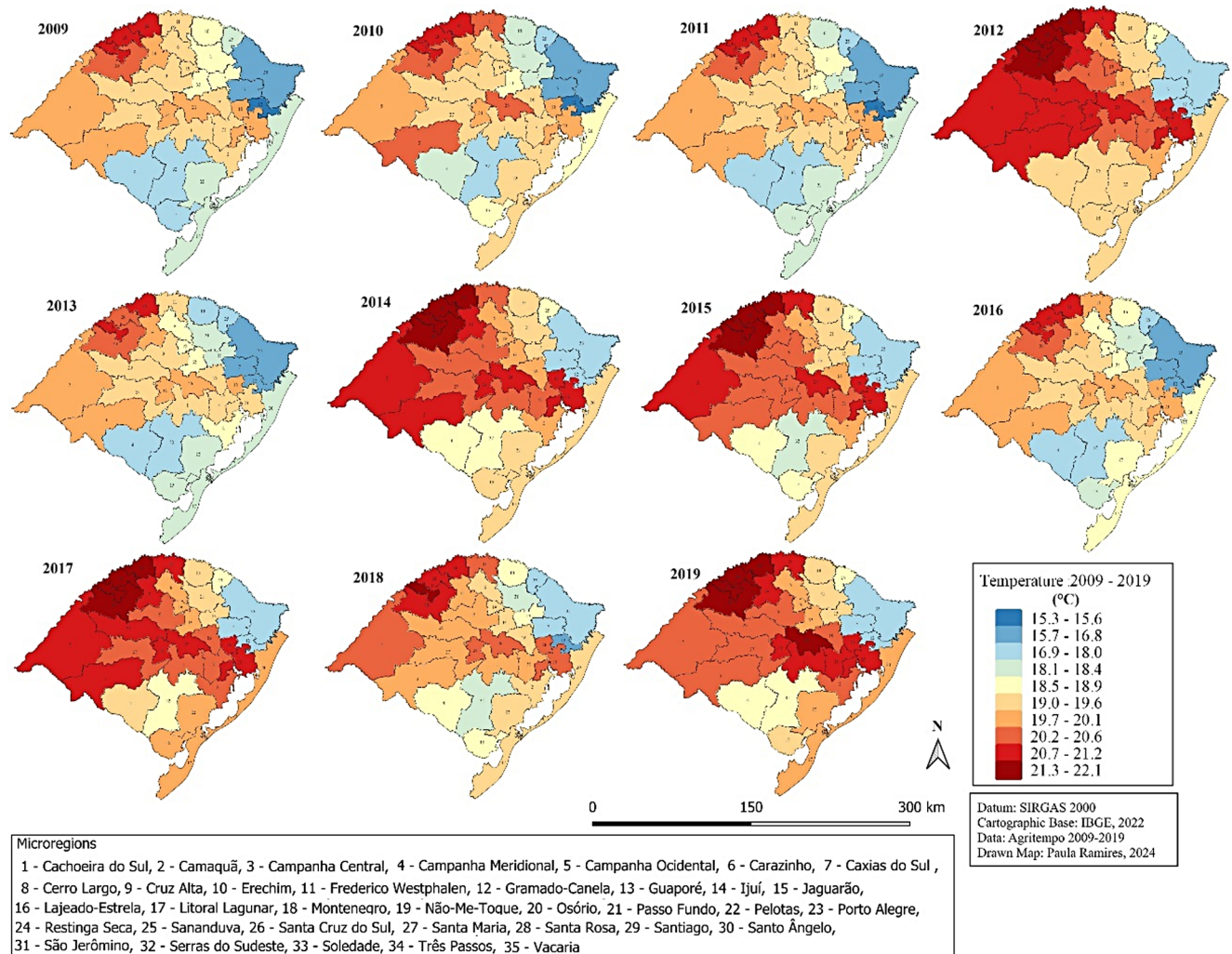


Fig. 2 Mean annual temperature in microregions, from 2009 to 2019

**Table 1** Association between mean monthly temperature and snakebites in microregions

Macroregions	Microregions	<i>R</i>	RR (CI 95%)	
Noroeste	Santa Rosa	0.705	1.13 (1.11;1.15)	
Rio-grandense	Três Passos	0.783	1.15 (1.13;1.18)	
	Frederico Westphalen	0.736	1.16 (1.13;1.19)	
	Erechim	0.728	1.17 (1.14;1.19)	
	Sananduva	0.667	1.11 (1.09;1.13)	
	Cerro Largo	0.554	1.09 (1.07;1.10)	
	Santo Ângelo	0.699	1.12 (1.09;1.14)	
	Ijuí	0.631	1.15 (1.12;1.19)	
	Carazinho	0.496	1.09 (1.06;1.13)	
	Passo Fundo	0.885	1.16 (1.14;1.18)	
	Cruz Alta	0.586	1.13 (1.10;1.16)	
	Não-Me-Toque	0.527	1.12 (1.08;1.15)	
	Soledade	0.577	1.13 (1.11;1.16)	
	Nordeste	Guaporé	0.606	1.10 (1.09;1.12)
	Rio-grandense	Vacaria	0.498	1.14 (1.09;1.18)
Caxias do Sul		0.875	1.17 (1.15;1.19)	
Centro Ocidental Rio-grandense	Santiago	0.512	1.14 (1.09;1.19)	
	Santa Maria	0.820	1.17 (1.14;1.20)	
Centro Ocidental Rio-grandense	Restinga Seca	0.673	1.22 (1.18;1.27)	
	Santa Cruz do Sul	0.704	1.11 (1.09;1.13)	
	Lajeado-Estrela	0.749	1.09 (1.08;1.11)	
Metropolitana de Porto Alegre	Cachoeira do Sul	0.685	1.16 (1.13;1.19)	
	Montenegro	0.504	1.07 (1.05;1.10)	
	Gramado-Canela	0.672	1.11 (1.09;1.13)	
	São Jerônimo	0.670	1.14 (1.12;1.17)	
	Porto Alegre	0.698	1.10 (1.08;1.12)	
Sudoeste Rio-grandense	Osório	0.735	1.15 (1.11;1.19)	
	Camaquã	0.739	1.18 (1.16;1.21)	
	Campanha Ocidental	0.484	1.10 (1.07;1.12)	
	Campanha Central	0.555	1.19 (1.15;1.22)	
Sudeste Rio-grandense	Campanha Meridional	0.627	1.22 (1.18;1.27)	
	Serras do Sudeste	0.774	1.23 (1.18;1.28)	
	Pelotas	0.817	1.18 (1.16;1.20)	
	Jaguarão	0.318	1.15 (1.10;1.20)	
	Litoral Lagunar	0.566	1.15 (1.10;1.21)	

R: Spearman correlation; RR: relative risk. RR interpreted as increase in snakebite rate per 100,000 inhabitants per each grade increase in mean monthly temperature

Regarding snakebite notification, in the total evaluated period, we observed that in almost all microregions, snakebite notification increased in mean 50.4%, with some microregions where the snakebite notification was scarce in 2009 and increased more than 90% in 2019 (Jaguarão and Vacaria) (Fig. 3). When analyzing the absolute change in snakebite notification per 100,000 inhabitants, we observed that Sananduva (Noroeste Rio-grandense), Vacaria (Nordeste Rio-grandense) and Erechim (Noroeste Rio-grandense) has the highest rise, showing 123, 127 and 141 snakebite notifications per 100,000 inhabitants more in 2019 compared with 2009, respectively. Only two microregions, namely,

Cerro Largo (Noroeste Rio-grandense) and Restinga Seca (Centro Ocidental Rio-grandense) had less notification from 2009 to 2019 (Table 2).

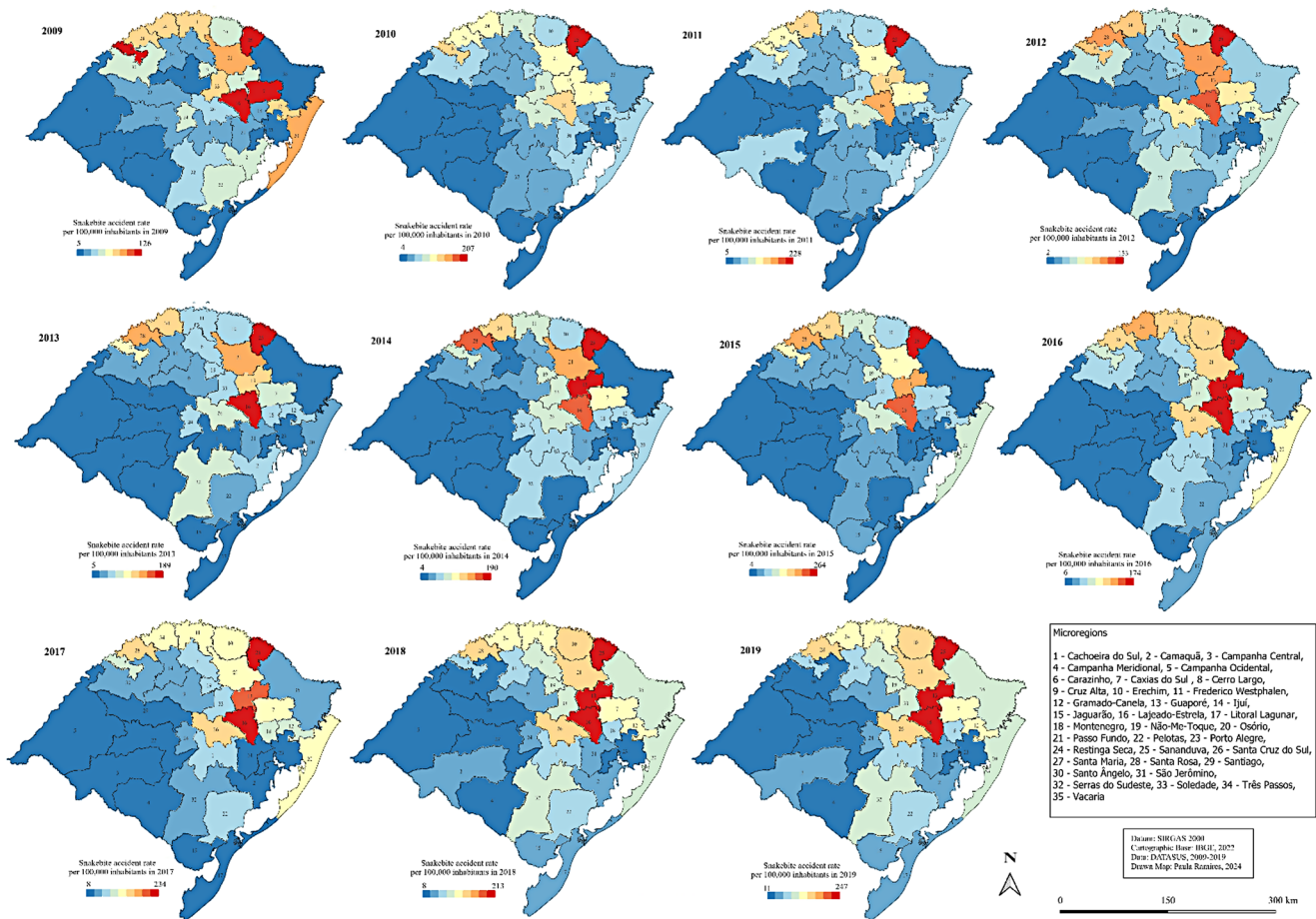
The correlation between the snakebite incident and temperature variable was found to be positive in all 35 microregions studied, indicating that as temperature increases, the number of accidents also increases, as shown in Table 1. The highest correlation values, considering correlations above 0.7, occurred in Passo Fundo ( $r=0.8849$ ), Caxias do Sul ( $r=0.8748$ ), Santa Maria ( $r=0.8200$ ), Pelotas ( $r=0.8170$ ), Três Passos ( $r=0.7827$ ), Serras do Sudeste ( $r=0.7735$ ), Lajeado-Estrela ( $r=0.7488$ ), Camaquã ( $r=0.7392$ ), Frederico Westphalen ( $r=0.7356$ ), Osório ( $r=0.7345$ ), Erechim ( $r=0.7276$ ), Santa Rosa ( $r=0.7054$ ) e Santa Cruz do Sul ( $r=0.7038$ ).

The multilevel regression models showed that each degree increase in average temperature is significantly associated with an increase in the risk of snakebite incidents per 100,000 inhabitants, with a variation of 8–22% increase in risk (Table 1). The microregions with the highest coefficient values were Serras do Sudeste (32), Restinga Seca (24), and Campanha Meridional (4), where the risk of snakebite were 1.22 times higher for each degree in temperature (Fig. 4).

## 4 Discussion

Our results indicate an association between rising temperatures and the increase in snakebite in the state of Rio Grande do Sul from 2009 to 2019. During this period, the average temperature across the 35 microregions increased by approximately 1 °C, with regional variations ranging from 0.4 °C to 2 °C. In parallel, snakebite increased by an average of 50.4%, with some microregions showing increases of over 90%. The correlation between temperature and snakebite incident was positive in all microregions, with several displaying correlation coefficients above 0.7. Moreover, multilevel regression models revealed that each 1 °C increase in temperature was significantly associated with an 8–22% increase in the risk of snakebite per 100,000 inhabitants.

These findings reinforce the importance of understanding the environmental and behavioral mechanisms that explain the increase in snakebite incidents in the context of rising temperatures. Our results are consistent with those da Costa et al. (2019) and Landry et al. (2023), which show that snake activity is strongly influenced by temperature (da Costa et al. 2019; Landry et al. 2023). Although our analysis covers 11 years period, shorter than the 30-year standard for defining climate, it captures temperature trends that may influence biological patterns. For example, in the microregions of Jaguarão and Vacaria, temperature increases of 1.4 °C



**Fig. 3** Annual snakebite rate per 100,000 inhabitants, from 2009 to 2019, according to microregions

and 1.1 °C, respectively, were associated with increases of over 90% in snakebite incident reports.

Similar to our finding of an 8–22% increase in risk per 1 °C in Rio Grande do Sul, Landry et al. (2023) also identified a positive association between temperature and snakebite risk in Georgia, USA, where a 1 °C increase in the same day was associated with a 5.6% increase in the likelihood of venomous snakebites and a 5.8% increase in non-venomous snakebites (Landry et al. 2023). Schneider et al. (2021) also observed that most snakebite cases in Brazil occur in warmer regions, particularly in the Legal Amazon. The study also found that a significant increase in cases was observed in municipalities with higher temperatures in the state of Rio Grande do Sul. Of the 496 municipalities in Rio Grande do Sul, 56 were classified as “high risk” for snakebite incidents. The classification was based on the presence of multiple risk factors, such as elevation, forest cover, forest loss, urbanization, temperature, precipitation, and venomous snake richness. Among these factors, temperature had a significant impact on the distribution of snakebite (Schneider et al. 2021).

A study, conducted in the state of Rio Grande do Norte, in northeastern Brazil, revealed that environmental factors significantly influence snakebites incidence. The study analyzed data between 2007 and 2016 and found that temperature had a positive effect on snakebite occurrence, with a 22% increase for each one-degree Celsius rise. In contrast, population density was associated with a 15% reduction in cases, likely due to other factors rather than a lower risk. Humidity showed a trend toward increasing incidence, 28%, although with lower statistical significance compared to temperature. Rainfall did not exhibit a significant influence on the results (da Costa, 2019).

Another key point is the modification of vegetation cover. In Rio Grande do Sul, data showed that the remaining vegetation in the Pampa biome is 36% (INCT BioNat, 2024) and the Atlantic Forest lost 23% of its vegetation in 2020 (MapBiomias, 2021). In relation to forest loss, Schneider et al. pointed to a relationship between deforestation and the increased risk of snakebite incidents in the eastern region of the state of Pará, in the Amazon. Evidence showed that municipalities such as Santarém, which underwent a significant transformation of their natural landscapes due to the

**Table 2** Increase in mean temperature and changes in snakebite incidents in Rio Grande do Sul (2009–2019)

Macroregions	Microregion	Increase in mean temperature from 2009 to 2019		Change in snakebites from 2009 to 2019	
		Absolute (grades centigrates)	Relative (%)	Absolute (number of snakebite notifications)	Relative (%)
Noroeste Rio-grandense	Santa Rosa	0.7	3.2	1448.5	58.0
	Três Passos	0.4	1.9	1333.9	55.4
	Frederico Westphalen	1.4	6.7	1043.6	54.7
	Erechim	0.9	4.6	965.9	75.8
	Sananduva	0.5	2.7	2211.1	49.7
	Cerro Largo	1.0	4.5	1053.3	-83.0
	Santo Ângelo	0.8	3.7	512.5	28.0
	Ijuí	0.7	3.4	451.8	76.2
	Carazinho	0.5	2.5	600.1	73.6
	Passo Fundo	0.6	3.1	1346.6	24.1
	Cruz Alta	0.8	3.9	379.9	73.6
	Não-Me-Toque	0.5	2.5	780.6	39.7
	Soledade	0.9	4.5	849.0	57.7
	Nordeste Rio-grandense	Guaporé	0.8	4.1	1610.3
Vacaria		1.1	6.2	471.0	94.9
Caxias do Sul		1.1	6.1	1143.0	25.5
Centro Ocidental Rio-grandense	Santiago	1.0	4.9	185.2	24.5
	Santa Maria	1.1	5.4	222.9	30.2
	Restinga Seca	1.0	4.8	520.8	-86.4
Centro Ocidental Rio-grandense	Santa Cruz do Sul	1.2	5.6	1042.3	72.1
	Lajeado-Estrela	1.1	5.4	1897.2	37.9
	Cachoeira do Sul	1.3	6.3	508.9	57.9
Metropolitana de Porto Alegre	Montenegro	1.3	6.1	584.4	66.8
	Gramado-Canela	2.0	11.6	803.0	5.9
	São Jerônimo	1.3	6.3	350.0	23.0
	Porto Alegre	1.3	6.2	75.3	54.9
	Osório	1.3	6.6	894.1	23.8
Sudoeste Rio-grandense	Camaquã	1.2	5.9	531.5	0.3
	Campanha Ocidental	0.5	2.4	120.8	59.3
	Campanha Central	0.4	2.0	165.4	43.7
Sudeste Rio-grandense	Campanha Meridional	0.7	3.7	88.2	45.4
	Serras do Sudeste	0.9	4.8	646.3	63.2
	Pelotas	1.4	7.1	493.5	32.9
	Jaguarão	1.4	7.2	258.6	91.6
	Litoral Lagunar	1.4	7.1	199.3	75.3

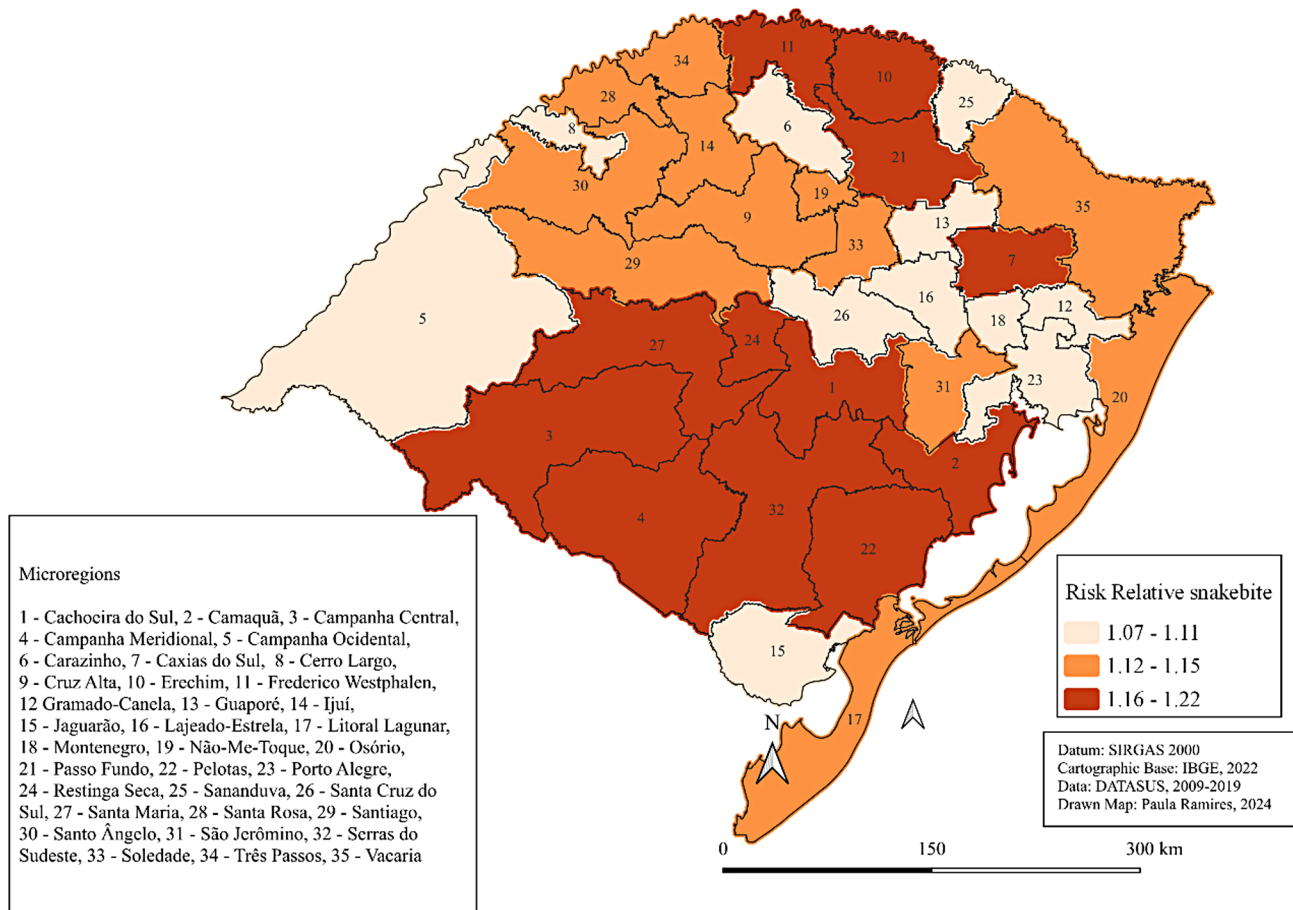
conversion of pastures into soybean plantations, recorded the highest number of cases (Schneider et al. 2021).

Rio Grande do Sul, with its economy centered on agribusiness, especially in the areas of agriculture and livestock, presents significant risks of snakebite incident (Schneider et al. 2021). In the countryside regions, agriculture and livestock predominate, while in the south and coast, agriculture stands out, especially in the production of rice and tobacco (Rio Grande do Sul 2022). These activities result in the displacement of snakes in search of suitable environmental conditions, as evidenced by previous studies (Watt et al. 1987).

Geographical distribution change is another significant impact of climate change (Chowdhury et al. 2021;

Schneider et al. 2021). Over 50 years, nine snake species have significantly modified their geographical distribution, mainly due to variations in the country's thermal index (Wu 2016). What could have happened in the highest risk microregions, Restinga Seca, Campanha Meridional, and Serras do Sudeste.

The Restinga Seca microregion, located in the central-west of the state, experienced a decrease in the number of snakebite notifications, despite an average temperature increase of 1 °C over the 11 years study period. Interestingly, the calculated risk remained high, with a risk ratio of 1.22. For example, in a scenario where temperature is 20 °C and 100 snakebites occurred per 100,000 inhabitants: at 21 °C, you would expect in mean, 122 snakebites per



**Fig. 4** Risk relative snakebites per microregions in the total period (from 2009 to 2019)

100,000 inhabitants may occur (assuming that other factors, such as precipitation, population density, land use remain constant). Although these variables were not included in the model, this assumption allow us to isolate and interpret the potential influence of temperature, independently, on the risk of reported snakebite incidents. Similarly, the Campanha Meridional (southwest) and Serras do Sudeste (southeast) microregions exhibited risks values of 1.22 and 1.23, respectively, associated with temperature increases of 0.7 °C and 0.9 °C and snakebite increases of 44% and 63%.

One possible explanation is that these areas are predominantly rural, where livestock farming and agriculture are the main economic activities. The landscape is characterized by low, creeping vegetation, which is typically less favorable as a natural habitat for snakes (Bochner and Struchiner 2004). Although our data do not directly assess land use or habitats characteristics, previous studies suggest that habitat degradation in more favorable areas can promote the geographic redistribution of snakes to regions with anthropogenic activity (Mise et al. 2016). This could partially explain the increased risk observed even in areas with less favorable ecological conditions. It is also important to consider that

improvements in surveillance systems over time may have influenced the number of reported cases.

Moreover, a study conducted by Needleman et al. (2018) provides evidence that snake species are experiencing shifts in response to climate change. This phenomenon has led some species to move away from specific regions in search of more favorable climatic conditions. This change in geographical distribution to temperate zones does not change the population number, especially for snakes, but species are appearing in places and seasons that they did not previously occur (Needleman et al. 2018). In addition to distributional shifts, physiological responses to temperature may also play a key role. Along the same lines, another study demonstrated that warmer snakes are also more prone to striking. In addition to increased strike propensity, the study found that snakes attack with greater speed and acceleration and reach maximum mouth gape more quickly. These findings suggest that higher temperatures may enhance defensive performance, making encounters with humans more likely to result in envenomation (Whitford et al. 2020). It is important to highlight that this study is based on secondary data obtained from public health databases, specifically

notification records of snakebite incidents. As with many surveillance systems, there is a possibility of underreporting due to factors such as limited access to healthcare in rural areas, variability in the quality of local reporting, or cases that are treated outside the official health system and not documented (Fiszon and Bochner 2008). Consequently, the actual number of incidents may be higher than reported, which could lead to an underestimation of the true magnitude of the problem. Despite these limitations, the consistent trends observed across microregions support the relevance of our findings. Understanding these interactions is essential for the development of effective prevention and management strategies. Furthermore, integrating studies on climate change can contribute to more comprehensive and targeted approaches to mitigate the risks associated with snakebite incidents in the region.

Health managers should consider including education and awareness programs on snake behavior and preventive measures. In addition, it is necessary to adapt public health policies, strengthen epidemiological surveillance systems and implement efficient health infrastructures. The adequate availability of antivenom serum in more vulnerable regions is an essential measure to guarantee the proper treatment of snakebites and minimize the impacts of accidents (Zimmerman et al. 2023). According to the article “The relationship and consequences of venomous animal encounters in the context of climate change,” climate change has a significant impact on the frequency and distribution of encounters with venomous animals. Temperature and humidity affect the behavior, reproduction, and activity of species such as snakes, scorpions, and spiders, leading to an increase in the incidence of these encounters. This context highlights the importance of improving case notification, training health professionals, and environmental education to mitigate the risks associated with these animals (da Silva Freitas et al. 2024).

Challenges posed by climate change require proactive adaptations, including the establishment of safe areas and promotion of sustainable agricultural practices. In this context, the State Program for Payment for Environmental Services (PEPSA) emerges as a key component in mitigating the impact of climate change on the population of Rio Grande do Sul. PEPSA plays an essential role in mitigating the consequences of climate change through a series of strategies that may also be beneficial in reducing snakebite incidents. These strategies include habitat preservation, restoration of native vegetation, promotion of sustainable agricultural practices, and environmental education promotion (Brasil 2022).

## 5 Conclusion

Our results suggest that temperature plays a relevant role in increasing the risk of snakebite incidents across different microregions of Rio Grande do Sul. However, this association should be interpreted with caution, as the study provides an initial exploratory approach to a complex and multifactorial issue. Given the state’s strong agricultural and livestock profile, further research is needed to better understand how these activities interact with environmental changes to influence the incidence of snakebites. The potential link between land use changes and increased risk highlights the importance of incorporating ecological, behavioral, and social variables into future analyses. Moreover, the observed association should be considered within the broader context of climate change scenarios, reinforcing the urgency for more detailed and interdisciplinary studies to guide effective public health interventions.

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**Data availability** No datasets were generated or analysed during the current study.

## Declarations

**Competing interests** The authors declare no competing interests.

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