Trends in Health Sciences

Article

https://doi.org/10.47626/ths-2025-0008

Climate change and health vulnerabilities: the case of 2024 floods in Rio Grande do Sul, Brazil

Mudanças climáticas e vulnerabilidades em saúde: o caso das inundações de 2024 no Rio Grande do Sul, Brasil

Diego Ricardo Xavier

Luiza Ribeiro Alves Cunha

Raphael Saldanha

Vanderlei Matos

Heglaucio Barros

Christovam Barcellos

Renata Gracie

Carlos Machado

Juliana W. Rulli Villardi

Guilherme Franco Netto
https://orcid.org/0000-0002-8861-8897

ABSTRACT | This article analyzes the impacts of climate change on health based on data on climate disasters that occurred in southern Brazil, particularly the 2024 floods in the state of Rio Grande do Sul. The research highlights the interrelationship between climate change and its effects on public health, including the increase in vector-borne, water-borne, and food-borne diseases, acute physical injuries, and the worsening of chronic conditions and mental health disorders. The analysis presented in this article is fundamental for advancing the development of public policies and formulating strategies to mitigate and adapt to climate change.
Keywords | Extreme climate events; public health; vulnerabilities

RESUMO | Este artigo analisa os impactos das mudanças climáticas na saúde, com base em dados sobre desastres climáticos ocorridos no sul do Brasil, particularmente as enchentes de 2024 no estado do Rio Grande do Sul. A investigação destaca a inter-relação entre as alterações climáticas e os seus efeitos na saúde pública, incluindo o aumento de doenças transmitidas por vetores, doenças transmitidas pela água e pelos alimentos, lesões físicas agudas e o agravamento de condições crônicas e distúrbios de saúde mental. A análise apresentada neste artigo é fundamental para avançar no desenvolvimento de políticas públicas e na formulação de estratégias de mitigação e adaptação aos impactos das mudanças climáticas.
Palavras-chave | Eventos climáticos extremos; saúde pública; vulnerabilidades

Fundação Oswaldo Cruz (Fiocruz), Rio de Janeiro, RJ, Brazil.

Submitted Jul 28 2024. Accepted Feb 07 2025.

Correspondence: Guilherme Franco Netto
E-mail: guilherme.netto@fiocruz.br

How to cite this article: Xavier DR, Cunha LRA, Saldanha R, Matos V, Barros H, Barcellos C, et al. Climate change and health vulnerabilities: the case of 2024 floods in Rio Grande do Sul, Brazil. Trends Health Sci. 2025;67(1):e20250008.

Introduction

Human activity, mostly through greenhouse gas emissions, has unequivocally caused global warming. Human-caused climate change is a consequence of more than a century of accumulated greenhouse gas emissions from changes in energy and land usage, lifestyle and patterns of consumption and production (1).

Climate change has adversely affected human physical and mental health on a global scale (1). The occurrence of climate-related food-borne and water-borne diseases has increased, the incidence of vector-borne diseases has increased due to range expansion and/or increased reproduction of disease vectors, while animal and human diseases, including zoonoses, are emerging in new areas (1). Climate change is also leading to extreme weather and climate events, contributing to humanitarian crises in which climate hazards interact with high vulnerability, leading to widespread adverse impacts on human health (1).

All these factors are exacerbated during disasters, resulting in physical injuries, vector-borne diseases (for example dengue, Zika, Chikungunya, and malaria), water-borne diseases (such as hepatitis A, leptospirosis, and acute diarrheal diseases), food insecurity, and mental health effects. Additionally, populations displaced to temporary shelters, which are often overcrowded and involve precarious living conditions, suffer an increased risk of severe acute respiratory syndrome, contaminated food or water, dermatitis, violence, and psychosocial effects. Finally, chronic conditions, such as diabetes, hypertension, cardiovascular disease, and mental disorders can be aggravated or become decompensated due to interrupted access to medication and health services (2-5).

There is ample evidence that climate change is significantly impacting the planet, whether through gradual temperature increases or extreme weather events (6). It is urgent to clearly understand how this affects health, how climate change can be mitigated, and how we must adapt to it. Thus, based on data from the 2024 flooding disaster in the state of Rio Grande do Sul, Brazil, this study's objective was to analyze the health impacts of an extreme weather event.

This post hoc evaluation is fundamental for advancing the development of public policies and for guiding initiatives to mitigate and adapt to climate change and its health effects. This article is structured into the following sections: the current impact of climate change on health in Brazil, the assessment methodology, the study's results, and concluding remarks.

The climate change health emergency scenario in Brazil

Brazil is the seventh largest emitter of greenhouse gas on the planet and ranks fourth in per capita emissions, making it one the nation's most responsible for the climate crisis (6). Tropical countries like Brazil are also highly affected by climate change, since a combination of climatic factors, ecosystems, and socioeconomic limitations makes them especially vulnerable.

The southern region of Brazil, which includes the states of Paraná, Santa Catarina, and Rio Grande do Sul, has been especially affected by extreme weather events (3). In 2004, Cyclone Catarina hit the coast of northern Rio Grande do Sul and southern Santa Catarina. In 2008, Santa Catarina was affected by severe flash floods, and in 2015, 2016, 2017, and 2023, Rio Grande do Sul experienced disasters associated with heavy rainfall.

The heavy rainfall in Rio Grande do Sul in 2024 once again demonstrated the region's vulnerability to extreme weather events and its significant challenges in disaster and public health management, with an estimated total of 478 affected municipalities (96% of the total) by torrents, landslides, and flooding, with more than 2 million people directly affected, 806 injured, and 183 confirmed immediate deaths (7). The immediate and long-term needs of the population were enormous. The health impacts of such disasters are not limited to the short term, but are also medium- and long-term in nature (8).

Data and analysis

Flooded area

On May 6, 2024, the flooded areas of metropolitan Porto Alegre, Rio Grande do Sul were identified through radar images processed by the Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research) (9). These images enabled a detailed analysis, identifying high-risk regions and facilitating evacuation and rescue planning. Additionally, high-resolution satellite images from the European Space Agency's Sentinel-2 program and the U.S. National Aeronautics and Space Administration were used to monitor the evolution of the flood area across Rio Grande do Sul (10). These data are provided in raster format and were vectorized to enable operations among geographic layers.

Figure 1 presents the vectorized output of the images used to calculate the flood area. This image enabled identification of affected analysis units according to other data sources used for damage assessment. After the flooded area was identified, points of interest within the affected area were determined.

Affected populations and emergency declarations

Using data from the 2022 Demographic Census from the Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics) (11), a detailed analysis of the population and households affected by the disaster was conducted. This approach enabled an accurate assessment of demographic impacts, aiding in resource allocation according to the number of displaced, homeless, and injured individuals. The census tract analysis was essential for both immediate and long-term response, such as infrastructure reconstruction in densely populated and vulnerable areas.

Simultaneously, emergency declarations were obtained through the S2iD Civil Defense system, identifying the most affected municipalities and areas requiring urgent intervention (based on the number of fatalities, injuries, displaced and homeless individuals, and material damage).

Mapping of vulnerable populations

Indigenous villages registered with the Fundação Nacional do Índio (National Indian Foundation), and *quilombola* communities, identified by the Fundação Cultural Palmares (Palmares Cultural Foundation), were georeferenced along with slums and urban communities based on the 2022 census tracts from the Instituto Brasileiro de Geografia e Estatística (11) to evaluate the disaster's impact on the most vulnerable populations. Due to being in rural or low-lying, unstable areas, both Indigenous and *quilombola* communities, as well as slums and urban communities, are particularly susceptible to flooding.

Information on healthcare facilities and response centers

Using the Cadastro Nacional de Estabelecimentos de Saúde (National Registry of Health Establishments) database, all healthcare units affected by the disaster were geo-referenced. This mapping, conducted by the Fundação Oswaldo Cruz Laboratório de Informação em Saúde, Instituto de Comunicação e Informação Científica e Tecnológica em Saúde (Health Information Laboratory), identified units located in flooded or hard-to-reach areas, providing critical data for the planning of resource redistribution, medical team deployment, and medication supply, as well as for the prioritization of regions that needed immediate restoration of health services.

In addition, data on educational institutions, agricultural establishments, and religious facilities registered in the National Address Register for Statistical Purposes (CNEFE) were used, given that they are essential for disaster mitigation, since many serve as support and shelter points.

The Ministry of Health's Programa Nacional de Vigilância da Qualidade da Água para Consumo Humano (National Program for Monitoring the Quality of Water for Human Consumption)/Sistema de Informação de Vigilância da Qualidade da Água para Consumo Humano (Information System for Monitoring the Quality of Water for Human Consumption) program provided detailed information on water intake points across the state. Many of these points were affected by flooding, which compromised the population's potable water supply.

Mapping risk areas for environmental contamination and poisoning

During flood rescue operations, it is crucial to map areas around factories, tanneries, warehouses, and other industries that pose contamination and poisoning risks. This is especially relevant in large-scale disasters,

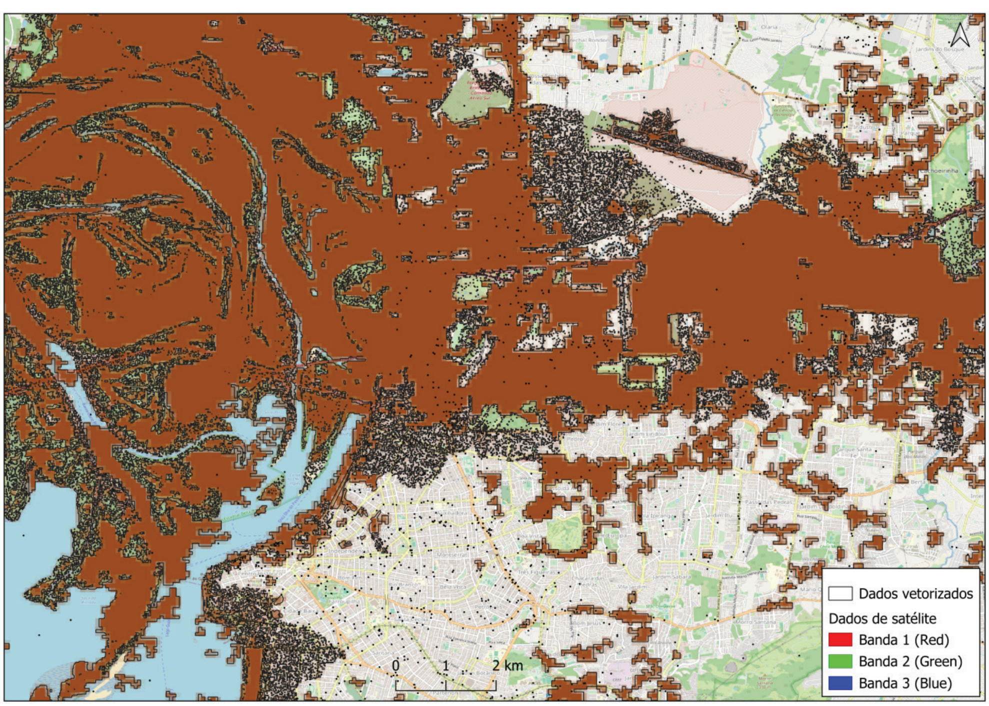

Figure 1. Flooded area based on combined radar and satellite images in Porto Alegre, Rio Grande do Sul, Brazil.

like the 2024 floods in Rio Grande do Sul. Facilities identified by the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (Brazilian Institute of Environment and Renewable Natural Resources, IBAMA) as potential polluters are distributed in high-risk zones within the flood area. These zones, classified as high-, medium-, or low-risk, are overlaid in the map of the affected area. The hierarchical clustering technique was used to group facilities based on similar activities, such as transportation, warehousing, commerce, utility services, natural resource use, and chemical, metallurgical, and mechanical industries. It is essential to categorize these pollution types to assess environmental risk and prioritize monitoring and mitigation actions, especially in flood scenarios.

Epidemiological profile analysis

Epidemiological profile analysis focuses on the most relevant health issues in a region in disaster scenarios, especially floods, which increase the population's exposure to various health risks. In Brazil, these data are extracted from the Sistema de Informação de Agravos de Notificação (Notifiable Disease Information System) and include spider bites, snake bites, hepatitis A, leptospirosis, dengue, and schistosomiasis.

All spatial data from the 2024 disaster were integrated into a geographic information system (QGis 3.36) to identify and quantify the population groups and facilities affected by the floods. QGis 3.36 was used for map preparation, while R 4.3.3 and RStudio 2023.12.1 were used for data tabulation.

Results

According to civil defense data from May 1 to 31, 2024, there were 473 affected municipalities, including 580,111 displaced individuals, 81,285 of whom were housed in shelters during the first 10 days of the disaster. Overall, 2,347,664 residents were affected, including 806 injured, 44 missing persons, 169 confirmed deaths, and 77,729 people rescued.

Figure 2 shows the fatalities and affected municipalities, indicating where rescue and assistance efforts were prioritized. A considerable number of deaths were observed in Porto Alegre, Canoas, Lajeado, Caxias do Sul, Santa Maria, Veranópolis, Arroio do Meio, Bento Gonçalves, Canela, Relvado, and Cruzeiro do Sul, which required special attention.

The floods affected 6,093 census sectors and approximately 1,301,980 households in high-risk areas, requiring adaptations to urban planning and disaster management policies to increase resilience and safeguard quality of life. The data also indicated a substantial impact on healthcare infrastructure. Approximately 1,170 healthcare facilities, including clinics, health centers, and pharmacies were affected. This scenario demands a robust public health strategy to address immediate needs and to strengthen infrastructure for future disasters.

Vulnerable populations were also severely affected, with 167 slum areas and five Indigenous villages directly affected by flood zones. Additionally, seven *quilombola* areas were in high-risk zones, increasing these communities' vulnerability due to socioeconomic factors and historically inadequate infrastructure.

Water security was also compromised, with 119 water intake points located near or within flooded areas. Contamination at these points posed a significant public health risk, since flooding increases the likelihood of drinking contaminated water in affected communities.

In the education sector, the flooding directly affected 823 educational institutions, disrupting access to education for thousands of students and compromising the safety of school facilities. These locations are commonly used as temporary shelters for displaced populations during such events, complicating response efforts. This demands not only immediate efforts to resume classes but also long-term planning to ensure schools are in safe locations and are better prepared for future disasters.

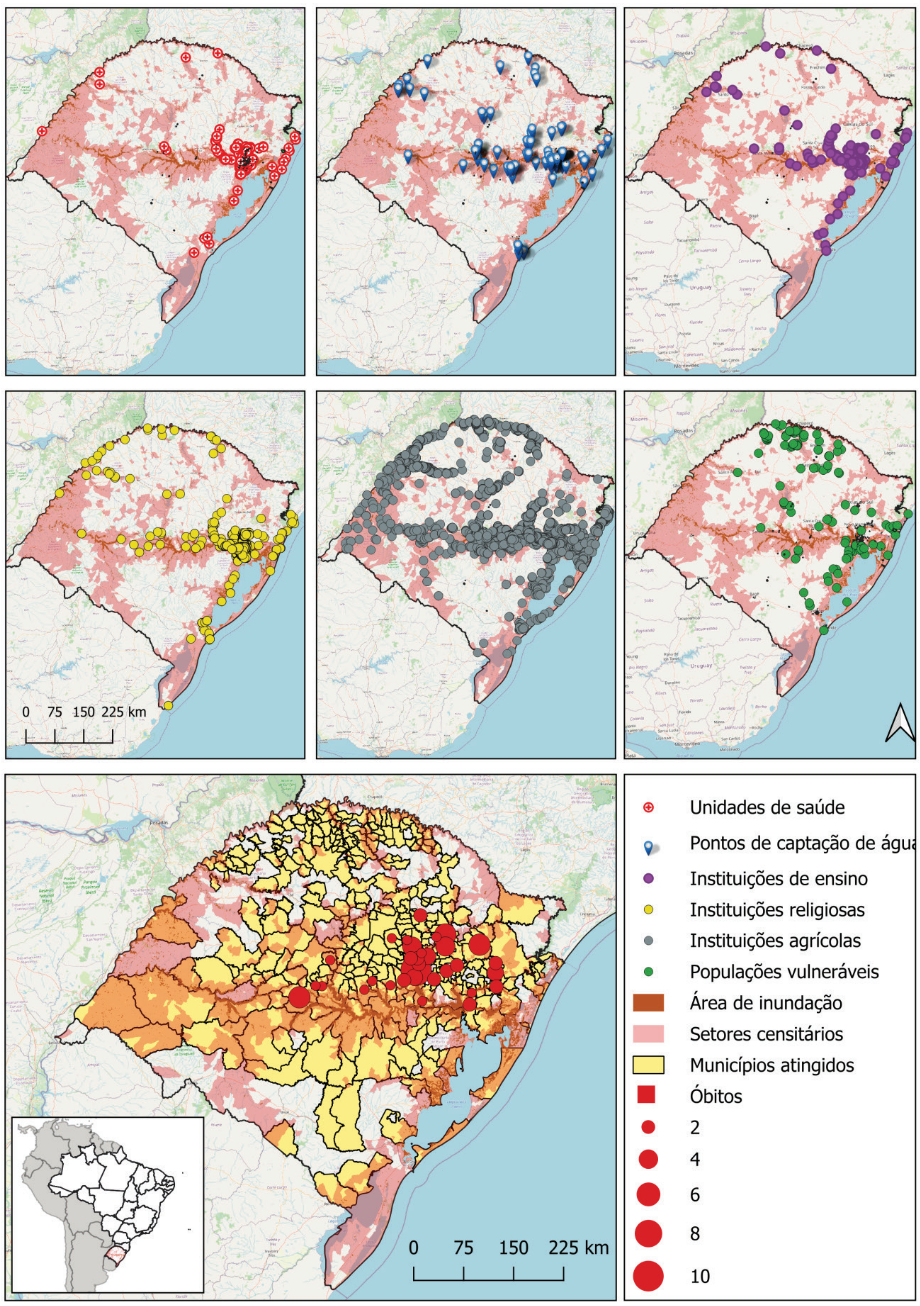

Figure 2. Impact of flooding in Rio Grande do Sul, Brazil: distribution of affected facilities, vulnerable populations, flooded areas, and deaths across municipalities, 2024.

Religious communities were also widely affected, with 1,843 places of worship damaged, interrupting community and spiritual activities. Places of worship unaffected by the flooding were used as temporary shelters and distribution points for essential resources for displaced people.

The agricultural sector suffered devastating losses, with 4,509 facilities affected. This impact threatens food security and the economic sustainability of rural families, with potential repercussions on local and regional food supplies and prices.

Between 2013 and 2023, spider bites were more frequent in the Planalto and northeast regions of the state (Figure 3A). Darker areas on the map (predominantly municipalities) reported a higher frequency of bites. Other regions, such as the Depressão Central, the Planalto Noroeste, and the state's northern coast, also had significant rates. This is strongly influenced by the prevalence of rural activities, natural vegetation, and structures in which spiders can shelter, increasing exposure and accident risk. Additionally, contact with spiders can be intensified in areas affected by flooding and landslides, heightening the risk for local populations.

Between 2013 and 2023, the distribution of snake bites in Rio Grande do Sul was heterogeneous (Figure 3B). Central areas had the highest rates, represented by darker areas on the map. The high incidence in rural zones can be ascribed to direct contact with

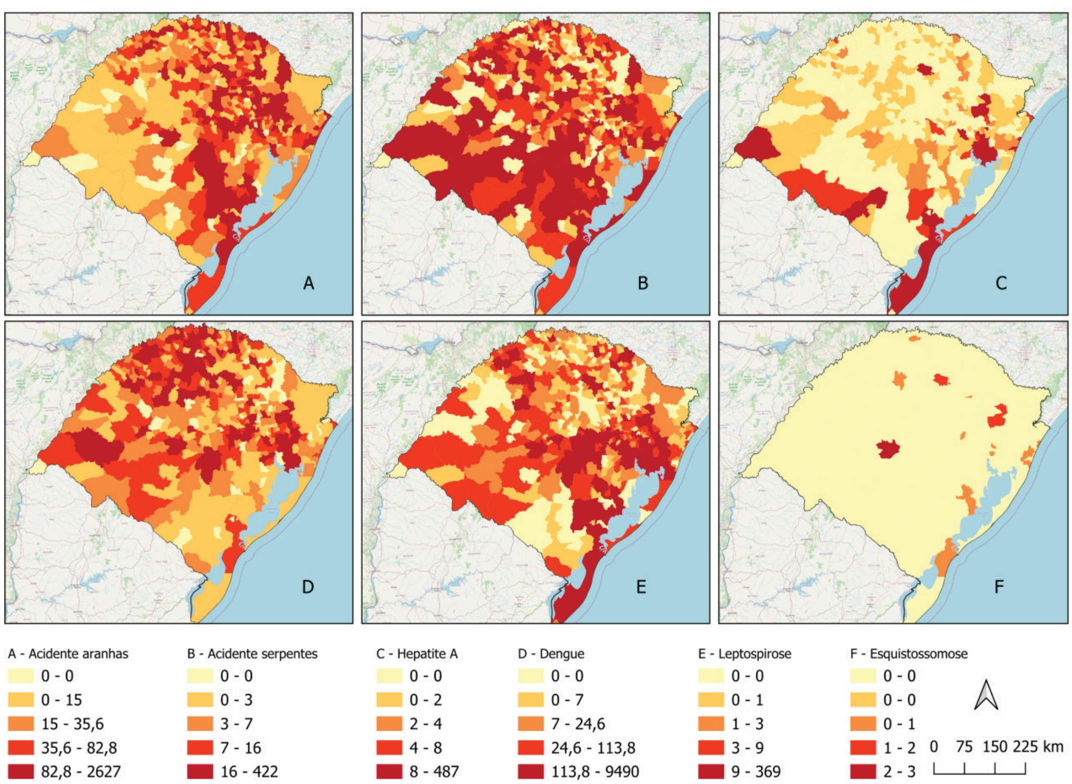

Figure 3. Spatial distribution of average incidence rate of cases of spider bites (A), snake bites (B), hepatitis A (C), dengue (D), leptospirosis (E), and schistosomiasis (F) in the state of Rio Grande do Sul. Source: Sistema de Informação de Agravos de Notificação/Departamento de Informática do Sistema Único de Saúde.

the natural environment, whereas urbanized regions near original vegetation remnants were also affected. On the coast, the dense vegetation of the Atlantic Forest contributed to the higher number cases. Small, isolated municipalities faced additional challenges due to limited health services and infrastructure access.

Between 2010 and 2020, the incidence of hepatitis A was higher along the coastline, the central-southern region, and the southwest region of the state (Figure 3C). Water and food contamination, exacerbated by inadequate sanitation infrastructure, was the main cause of infection. Coastal regions with fishing communities and seasonal tourism had high infection rates due to insufficient sanitary conditions. Small municipalities with limited infrastructure were also affected. The 2024 disaster worsened these conditions, increasing water source contamination and overburdening local health services.

Between 2013 and 2023, the incidence of dengue was highest in the northern and northeastern regions of the state (Figure 3D). The incidence in the southern region and coastal areas was low. The high population density and favorable climatic conditions for the *Aedes aegypti* mosquito explain these patterns. The risk of infection was heightened in flood-affected regions due to water accumulation and the failure of sanitation services, complicating vector control efforts.

Between 2010 and 2022, the incidence of leptospirosis in Rio Grande do Sul was highest in the Depressão Central, Missões, Alto Uruguai, and northern coastal regions (Figure 3E). Lowland areas with irrigated rice fields and poor sanitation infrastructure were most affected. The 2024 disaster exacerbated diseases that are spread by increased contact with contaminated water and mud.

Between 2013 and 2022, schistosomiasis was reported in specific hotspots, particularly the coastal region and northern plateau (Figure 3F). Few cases were reported in the western and southwestern regions of the state. Transmission is associated with specific environmental and socioeconomic conditions.

Figure 4 presents a map generated using IBAMA data, highlighting potentially contaminated sites in Rio Grande do Sul. The sites, represented by black dots, indicate locations in which polluting activities occur. Neighborhood analysis, a data analysis technique used to group objects into hierarchical clusters based on their similarities and distances, was used to identify clusters of potentially polluting establishments.

A total of 1,518 sites were classified within the flood-prone area. The cluster with the highest concentration was the central area of the city, in which 247 sites were located. Due to the high density of potentially polluting establishments in the capital, it is among the most critical zones in the urban context.

The most frequent activities performed at these establishments included: transportation, warehousing and trade, utility services, natural resource use, civil work projects, chemical processing, metallurgy, mechanical industry, mineral extraction and processing, electrical energy production, electronics manufacturing, and communication materials manufacturing, food and beverage production, and plastics manufacturing.

Identifying and categorizing potentially contaminated sites allows for environmental risk assessment, a better understanding of the most vulnerable areas to pollution during a flood, and the prioritization of mitigation actions. Such an approach also facilitates disaster response planning, enabling the preparation and allocation of resources to the most critical areas, ensuring a more efficient response, reducing the impact on the environment and public health, and supporting epidemiological surveillance in cases of confounding factors and differential diagnoses.

The risk of poisoning could also be exacerbated in the months following a disaster. The state monitors suspected poisoning cases through the Sistema Nacional de Informações Tóxico-Farmacológicas (National Toxicological-Pharmacological Information System), which is managed by the Centro de Informações Toxicológicas da Secretaria da Saúde (Toxicological Information Center). During the 2024 floods, the leading cause of poisoning was improper medication use, followed by bites and stings from venomous animals (which aligns with the above-mentioned observations on spiders and snakes) and chemical agents in cleaning products, industrial products, pesticides, and insecticides.

Exposure to these toxic agents may increase in the coming months, both directly, through contact with contaminated products and packaging, and indirectly, through accidental exposure to water, soil, and food that may have been contaminated by the leakage of these substances, particularly from storage sites and industries in the region.

Concluding remarks

The 2024 disaster, the most serious in extent and intensity recorded in Rio Grande do Sul since 1941, occurred in a year with the highest recorded mean temperatures worldwide. It was preceded by other disasters: a flood in September 2023 that affected 30% of the state's municipalities, and droughts in 2021/2022 and 2022/2023, which affected 84 and 78% of the state's municipalities, respectively. Moreover, between the flood disasters in 2023 and 2024, Rio Grande do Sul declared two public health emergencies: a dengue fever outbreak on March 12, 2024,

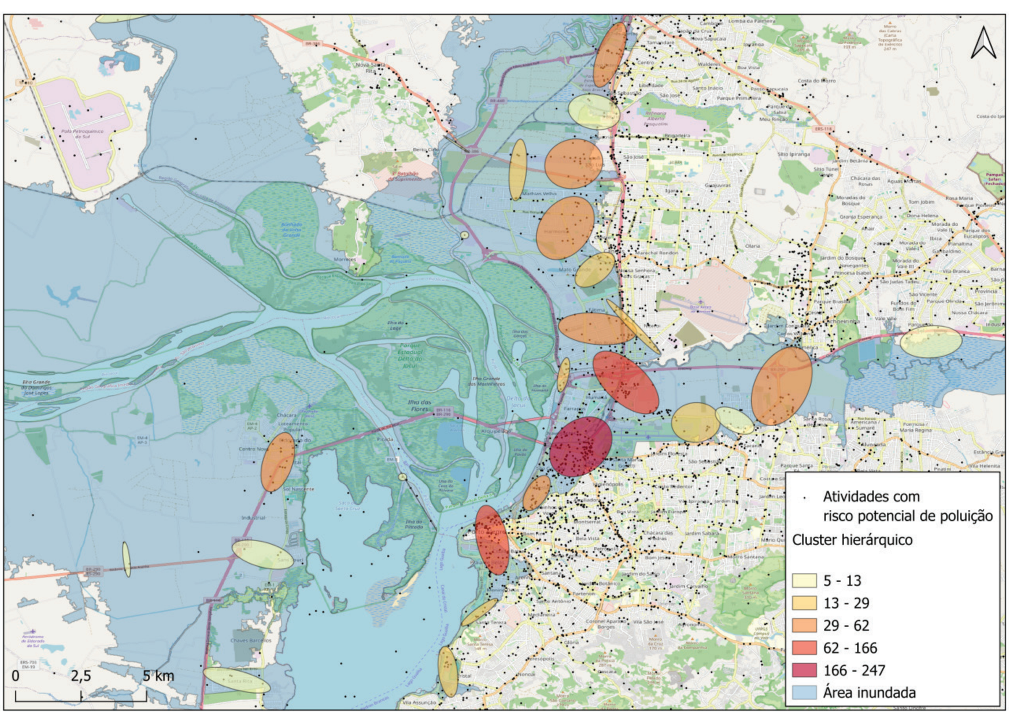

Figure 4. Potentially contaminated sites in Rio Grande do Sul, Brazil.

which resulted in more than 100 deaths, and a severe acute respiratory syndrome outbreak on May 3, 2024. Current scenarios indicate a trend towards more extensive and frequent disasters, in addition to the cumulative effects of sequential and/or concurrent disasters.

Public health policies must consider the new scenarios of climate change and extreme events. Planning for resilience and adaptation will not only protect physical infrastructure but will also support vulnerable communities, which often suffer disproportionately from the effects of these disasters. Combined investment in disaster education, public health, and economic sustainability will better equip citizens to deal with the consequences of disasters.

Therefore, the lessons learned from the 2024 floods should encourage continuous review of and improvement in disaster mitigation strategies and emergency preparedness in Brazil. Commitment to a holistic and sustainable approach to disaster prevention, response, and recovery is essential to protect lives, preserve public health, and strengthen community resilience as climate change and extreme weather events intensify in the future.

DISCLOSURE : The authors report no conflicts of interest.

References

1. IPCC, 2023: Sections. In: Core Writing Team, Lee H, Romero J, editors. Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC; 2023. p. 35-115.
2. Barcellos C, Sabroza PC. The place behind the case: leptospirosis risks and associated environmental conditions in a flood-related outbreak in Rio de Janeiro. Cad Saude Publica. 2001;17:59-67.
3. Xavier DR, Barcellos C, Freitas CM. Extreme weather events and their consequences on health: the 2008 disaster in Santa Catarina taking into account different information sources. Ambient Soc. 2014;17:273-92.
4. Semenza JC, Ko AI. Waterborne Diseases That Are Sensitive to Climate Variability and Climate Change. N Engl J Med. 2023;389:2175-87.
5. Freitas CM, Barcellos C. Disaster in Rio Grande do Sul, Brazil: climate crisis, Brazilian Unified National Health System response, and challenges of the new times. Cad Saude Publica. 2024;40:e00114424.
6. Artaxo P. Mudanças climáticas: caminhos para o Brasil. Cienc Cult. 2022;74:1-14.
7. Governo do Estado do Rio Grande do Sul [Internet]. Defesa Civil atualiza balanço das enchentes no RS – 20/8. 2024 Aug 20 [cited 2025 Apr 23]. Available: https://www.estado.rs.gov.br/defesa-civil-atualiza-balanco-das-enchentes-no-rs-20-8
8. Freitas CM, Silva DRX, Sena ARM, Silva EL, Sales LBF, Carvalho ML, et al. Desastres naturais e saúde: uma análise da situação do Brasil. Cienc Saude Colet. 2014;19:3645-56.
9. Matos A. The International Charter [Internet]. Flood in Brazil. 2024 Apr 30 [cited 2025 Apr 23]. Available: https://disasterscharter.org/web/guest/activations/-/article/flood-in-brazil-activation-875-
10. National Aeronautics and Space Administration [Internet]. AWS S3 Explorer. 2023 [cited 2025 Apr 23]. Available: https://noaa-jpss.s3.amazonaws.com/index.html#JPSS_Blended_Products/VFM_5day_GLB/TIF/2023/
11. Instituto Brasileiro de Geografia e Estatística [Internet]. Malha de Setores Sensitários. 2022 [cited 2025 Apr 23]. Available: https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/26565-malhas-de-setores-censitarios-divisoes-intramunicipais.html