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ARTICLE

CLIMATE CALAMITY IN RIO GRANDE DO SUL: A COMPARATIVE ANALYSIS WITH PREVIOUS DISASTERS

CALAMIDADE CLIMÁTICA NO RIO GRANDE DO SUL: ANÁLISE COMPARATIVA COM DESASTRES ANTERIORES

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ABSTRACT

Purpose: To analyze the factors that contributed to the recent calamity in Rio Grande do Sul, Brazil, comparing it with other major disasters, such as Hurricane Katrina in the United States, the 2011 Tohoku earthquake and tsunami in Japan, and the Mariana dam disaster and Brumadinho dam disaster in Minas Gerais,in order to identify patterns and lessons applicable to future disaster prevention.

Methodology/approach: A qualitative and comparative analysis was conducted based on secondary data, official reports, and academic literature. The study examined structural, institutional, and governance-related aspects of each case, focusing on preparedness, infrastructure resilience, and intergovernmental coordination.

Originality/Relevance: By establishing a comparative perspective between climate-related and technological disasters, this study highlights recurring governance failures and structural vulnerabilities. It contributes to the debate on climate adaptation and risk management in subnational contexts, particularly in Southern Brazil.

Key findings: Despite contextual differences, common patterns were identified, including insufficient preventive planning, weak resilient infrastructure, and limited coordination between governments and civil society. Climate issues tend to enter the public agenda reactively, following critical events. Furthermore, the coproduction of policies still faces barriers such as limited resources and institutional fragmentation.

Theoretical/methodological contributions: The study reinforces the importance of integrated, preventive, and participatory governance frameworks. It provides analytical insights to support more effective climate policies and disaster risk reduction strategies in Rio Grande do Sul.

Keywords: Rio Grande do Sul calamity. Climate Change. Climate Policies. Disaster Risk Management.

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RESUMO

Objetivo: Analisar os fatores que contribuíram para a recente calamidade no Rio Grande do Sul, Brasil, comparando-a com outros grandes desastres, como o Furacão Katrina nos Estados Unidos, o terremoto e tsunami de Tohoku de 2011 no Japão, e os desastres das barragens de Mariana e Brumadinho em Minas Gerais, a fim de identificar padrões e lições aplicáveis à prevenção de futuros desastres.

Metodologia/abordagem: Foi realizada uma análise qualitativa e comparativa com base em dados secundários, relatórios oficiais e literatura acadêmica. O estudo examinou aspectos estruturais, institucionais e de governança de cada caso, com foco na preparação, na resiliência da infraestrutura e na coordenação intergovernamental.

Originalidade/Relevância: Ao estabelecer uma perspectiva comparativa entre desastres climáticos e tecnológicos, o estudo evidencia falhas recorrentes de governança e vulnerabilidades estruturais. Contribui para o debate sobre adaptação climática e gestão de riscos em contextos subnacionais, especialmente no Sul do Brasil.

Principais conclusões: Apesar das diferenças contextuais, foram identificados padrões comuns, como planejamento preventivo insuficiente, fragilidade da infraestrutura resiliente e limitada articulação entre governos e sociedade civil. As questões climáticas tendem a ingressar na agenda pública de forma reativa, após eventos críticos. Além disso, a coprodução de políticas ainda enfrenta barreiras como restrição de recursos e fragmentação institucional.

Contribuições teóricas/metodológicas: O estudo reforça a importância de modelos de governança integrados, preventivos e participativos. Oferece subsídios analíticos para o aprimoramento de políticas climáticas e estratégias de redução de riscos de desastres no Rio Grande do Sul.

Palavras-chave: Calamidade no Rio Grande do Sul. Mudanças Climáticas. Políticas Climáticas. Gestão de Riscos de Desastres.

1 INTRODUCTION

We live in an era of rapid technological and social transformations, where changes occur dynamically. In this scenario, it is essential to understand the various factors that influence our society, from technological advances to economic and environmental issues. From this perspective, climate change constitutes a topic of extreme importance that needs to be debated with seriousness and urgency. The issue of sustainability stands out as fundamental, as it plays an essential role in raising awareness among civil society about the importance of protecting the environment and, consequently, ensuring the survival and health of our planet.

The denial of the impacts of climate change, in turn, prevents the implementation of urgent actions, resulting in higher greenhouse gas emissions and the intensification of natural disasters. This denial not only worsens economic losses and compromises public health, exacerbating extreme climate events such as heat waves, droughts, floods, and storms, but also accelerates environmental degradation and threatens future sustainability, putting the lives of millions of people at risk (Puertas and Marti, 2021).

There is evidence that disasters are caused by several variables and that they are directly linked to previous events. The most common climate disasters are heavy rainfall, earthquakes, and hurricanes (Daniell et al., 2011). The problem extends even further, since the literature

indicates that climate challenges are intrinsically linked to a series of socioecological factors, such as demographic changes, soil degradation and biodiversity loss, in addition to economic problems. These issues worsen the impacts of climate change and require profound transformations in economic and environmental development models (Daniell et al., 2011; Field et al., 2014; IPBES et al., 2019; De Boon et al., 2022).

Thus, it becomes evident that the effects of climate change do not occur in isolation, but as part of a broader process of environmental and social degradation.

In this context, the extreme climate events that devastated the state of Rio Grande do Sul in May 2024, resulting in the declaration of a state of public calamity, are clear and undeniable evidence of the urgent need to implement the issues discussed above. These events bring to light the importance of a debate to understand what led us to this calamity.

The severity of the situation in RS serves as a strong warning of the urgency of actions, not only in Brazil, but as part of a global pattern of extreme climate phenomena. Furthermore, according to Ghosh et al. (2024), the capitals of Indian states present the highest levels of carbon monoxide (CO) pollution. In view of this, extreme climate events, such as the floods in Germany in May 2024 and the heat wave in India, which reached temperatures of up to 50°C, highlight the urgency of measures to mitigate the impacts of pollution. These occurrences reinforce the need for continuous monitoring of air quality and the implementation of effective strategies to reduce health risks caused by atmospheric pollution.

In November 2024, Valencia, in Spain, was devastated by torrential rains that caused flooding and were considered the largest flood of the century in the region (G1, 2024). These events illustrate how global warming is intensifying the frequency and severity of extreme meteorological phenomena, requiring public policy makers to quickly develop mitigation and adaptation strategies, in addition to coordinating actions to manage post-disaster situations.

From this perspective, the intense rains that hit Rio Grande do Sul in 2024 had a devastating impact in several regions of the state, causing a series of significant disruptions. Among the most serious problems were floods that inundated urban and rural areas, affecting homes, businesses and essential infrastructure. During the rainy period in RS, 9,158 localities were affected, with 78 of the 497 municipalities in a state of public calamity and 340 in a state of emergency, most of them located in the Taquari Valley and in the Metropolitan Region of Porto Alegre. Nearly 95% of the municipalities of Rio Grande do Sul, totaling 471 cities, suffered from the heavy rains in 2024 (RS GOV, 2024).

However, this situation had already been evidenced previously. On September 4, 2023, the municipality of Muçum (RS) was devastated by a flood when the Taquari River reached 30.27 meters above normal, surpassing the flood level of 18 meters. More than 80% of the urban area was flooded, with 20 confirmed deaths and severe damage to infrastructure (Ruas, 2024). This highlights that the warnings were given, however, no effective policy was adopted so that events like this would not happen again.

In this sense, to better understand the role of environmental governance in facing disasters, it is important to reflect on examples of environmental catastrophes that occurred in other states and regions of the world. The literature points out that in addition to heavy rains, earthquakes and hurricanes are also events of great impact (Daniell et al., 2011). Cases such as the disasters of Mariana and Brumadinho, in Brazil, Hurricane Katrina, in New Orleans, and the tsunami in Southeast Asia reveal how regional responses and local governance can have a profound impact on disaster management and on the recovery of affected communities.

Thus, the objective of this study is to analyze the factors that contributed to the occurrence of the recent calamity in Rio Grande do Sul, with the purpose of understanding the particularities of this event in relation to other similar crises, such as Hurricane Katrina in the United States, the tsunami in Japan and the dam collapses in Minas Gerais, in order to identify patterns and lessons applicable to the prevention and mitigation of future disasters. From this perspective, a bibliographic survey was conducted, using a comparative approach with other historical episodes of calamity, in order to provide an in-depth analysis of the causes and consequences of the disaster in the current context.

2 THEORETICAL FRAMEWORK

This section presents the main theoretical approaches related to climate change mitigation and adaptation, environmental governance, and public policy integration. It discusses international and regional experiences in order to understand the institutional, political, and social challenges involved in addressing climate change.

2.1 Addressing Climate Change

Climate change results from natural and anthropogenic processes that affect the composition of the atmosphere and land use, leading to significant impacts on ecosystems, productive activities, and human well-being. Addressing these challenges requires coordinated and integrated actions that consider the complex interactions between biophysical and social factors, as well as more efficient and less fragmented governance to mitigate negative effects and promote sustainable adaptation (Billi et al., 2021). Zhao et al. (2025) complement this view by arguing that climate change mitigation requires legal reforms and integrated policies, with incentive mechanisms and differentiated taxation, combined with a green transition through clean technologies, renewable energy, and the decarbonization of strategic sectors such as construction, transportation, and heavy industry.

Due to the complexity of climate change, it is expected that opinions on the topic are diverse and still evolving. Many opinion surveys on climate change have mirrored public debate, focusing on agreement or disagreement with climate scientists, levels of concern, and support for mitigation, and to a lesser extent, adaptation policies (Hulme, 2009; Tvinnereim et al., 2017). A study conducted in Norway revealed that most respondents favor climate change mitigation, such as energy transitions and government measures, rather than adaptation. Adaptation is rarely mentioned, probably because it is perceived as a distant problem. This indicates that mitigation policies have greater public acceptance, suggesting that behavioral changes without government support will be challenging (Tvinnereim et al., 2017).

Biesbroek (2021) supports this perspective by discussing the challenges of policy integration in climate adaptation. Although integration is essential for effective action, different interpretations of "success" make its evaluation complex. The distinction between programmatic success (policy coherence) and political success (political commitment) does not always align. The literature still needs to develop clear frameworks and indicators to assess policy integration and its effects in different contexts (Biesbroek, 2021).

In California, United States, a study shows that cities adopt plans to combat climate change, known as Climate Action Plans (CAPs), influenced by different factors. Some cities follow the example of neighboring cities, while others are influenced by large regional cities such as Los Angeles. In areas without a major city, municipalities tend to imitate their neighbors more frequently. Researchers suggest that cities learn or replicate what works, although the motivations behind these choices are not yet fully understood. Understanding these differences is important for developing better climate change strategies in the future (An et al., 2023).

A study conducted in the Netherlands suggests that although the roles of local governments are becoming more flexible and varied, more research is needed to fully understand the interactions between governments and citizen initiatives. It also highlights the importance of local governments balancing the facilitation of citizen initiatives with ensuring that all communities benefit equally. The continuous development of the "ladder of government participation" is encouraged to better capture the complexity of interactions between citizens and government across various public policy areas (Mees et al., 2019).

In South America, although Brazil and Colombia initiated their climate adaptation policies simultaneously and under similar international influences, the outcomes differ significantly. In Brazil, adaptation was integrated into existing policies, but without fully considering climate risks. In Colombia, the integration of objectives was unsatisfactory, resulting in limited changes. The study suggests that the adoption of climate policies does not guarantee concrete change without consistent efforts to integrate climate issues into all sectoral policies

and overcome institutional barriers and political resistance, especially from agribusiness and mining sectors. Policymakers are advised to adjust their approaches to consider climate variability and align adaptation strategies with support for affected populations (Milhorance et al., 2022).

According to Almeida, Márquez and Fonsah (2024), addressing the climate crisis in a fair manner requires recognizing the overlaps between institutional and non-institutional actions. These interactions often result in significant political changes, as environmental justice movements play a crucial role in pressuring for equitable low-carbon transitions, ensuring that the most vulnerable communities are included in and benefit from climate solutions.

According to Murshed (2024), promoting green growth in developing countries is essential to make their economic processes more sustainable. Investments in Technology and Innovation for Development (TID) have contributed to reducing CO2 emissions, particularly by mitigating the impacts of dependence on natural resources and international trade. The effectiveness of corruption control in reducing emissions is highlighted, while urbanization and Foreign Direct Investment (FDI) do not significantly influence emission rates. The study also suggests policies to improve environmental sustainability, such as increasing investments in TID, developing clean technologies, and adopting sustainable urbanization and trade practices (Murshed, 2024).

From this perspective, good governance not only promotes the adoption of clean technologies and sustainable practices but also ensures the effective implementation of environmental policies, addressing the challenges of dependence on natural resources and the expansion of international trade. To combat climate change, environmental governance must integrate norms, legislation, processes, and institutions in a decentralized, coordinated, and participatory manner. Ecological balance and quality of life, which are fundamental for a more sustainable economy, must be prioritized. Environmental management should address inequalities in environmental impacts, especially in vulnerable communities, and strengthen environmental institutions to ensure a more integrated and efficient approach (Araújo, 2021; Candido and Kato, 2023; Murshed, 2024; Santos and Freitas, 2020; Vargas, 2021).

2.2 Environmental Governance

Santos and Freitas (2020) state that environmental governance involves the integration of norms, legislation, processes, and institutions, where public actions are decentralized, coordinated, and participatory, aiming to address environmental issues. This implies an institutional structure that differs from the traditional top-down government management model. According to Candido and Kato (2023), ecological balance, biodiversity preservation, and quality of life are essential for sustainability to transform the current economic system into a more sustainable form of organization. Effective environmental governance is crucial to mitigate the impacts of climate change, as it enables the creation of robust public policies, encourages sustainable technological innovation, and promotes responsible management of natural resources, ensuring a resilient future for coming generations (Wang et al., 2025).

However, environmental governance presents complex challenges that require a collaborative approach between neighboring countries. For effective policies, it is essential that local governments have autonomy and technical capacity to address environmental issues in an integrated manner. In this context, environmental governance involves the creation of integrated policies and strategies that promote sustainable management of natural resources, encouraging responsible practices through regulations, market mechanisms, and social participation, with the goal of balancing economic development and environmental preservation. Without coordinated efforts across borders, policies tend to be ineffective, especially in contexts of interdependence and shared environmental problems (Brito, Martins, and Lamberti, 2019; Zhang, Iqbal, and Shahzad, 2024).

In addition to the challenges mentioned, environmental governance requires integration between the public and private sectors. Gilligan and Vandenbergh (2020) highlight that despite contradictions in corporate actions, private governance can complement public governance by

providing reductions in greenhouse gas emissions. For these initiatives to be effective, it is necessary to overcome political, cultural, and legal barriers, as well as to involve local populations and private sector actors. In binational contexts, decentralization and cross-border cooperation are crucial to addressing specific environmental challenges (Gilligan and Vandenbergh, 2020).

Environmental governance in the Netherlands is undergoing transformation, with local governments adopting more flexible roles and collaborating with citizen initiatives. There is a shift from a rigid regulatory approach to facilitative practices, particularly in adapting to urban flooding. This change reflects a new form of governance that requires greater flexibility and innovation in public practices, with collaboration between government and citizens to tackle climate challenges. This movement also aligns with the Rights of Nature movement, which proposes integrating nature into legal and policy decisions (Mees et al., 2020).

The implementation of the Rights of Nature represents a paradigmatic shift in environmental governance, recognizing the intrinsic value of natural elements and moving away from anthropocentric legal frameworks. Cases such as the Whanganui River in New Zealand and constitutional amendments in Ecuador demonstrate how legal systems can incorporate ecocentric values and human-nature interdependence. However, this transformation faces challenges in reconciling with legal and economic paradigms that prioritize human interests and economic development. Success depends on strong legal frameworks, political will, and a cultural shift that values nature and its entities (Dias, 2024).

With the advancement of artificial intelligence, this technology can play a key role in participatory environmental management by facilitating stakeholder engagement, predictive modeling, and chatbots. These tools provide real-time access to data, assist in environmental decision-making, and enable more efficient responses to issues such as air quality and illegal waste disposal. Moreover, their use in agricultural forecasting and disaster management strengthens sustainable practices and collaboration between communities and governments (Santos and Carvalho, 2025).

3 METHOD

Regarding the methodological procedure, the monographic and comparative methods were employed, with the research having an applied nature, aiming at acquiring knowledge to be applied to a specific topic. The monographic method was used to conduct an in-depth study of the recent calamity in Rio Grande do Sul, allowing for a detailed analysis of the causes, consequences, and institutional responses to the event. According to Marconi and Lakatos (2022), this approach included the collection of data from local sources, government documents, news reports, and related academic studies, providing a comprehensive overview of the tragedy.

The comparative method was applied to contrast the calamity in Rio Grande do Sul with other significant disasters, such as Hurricane Katrina in the United States, the tsunami in Japan, and the dam failures in Minas Gerais. For this purpose, specific comparison criteria were adopted, including emergency responses, mitigation measures implemented, and economic and social impacts. This comparative analysis was essential to identify patterns, differences, and effective practices in other contexts that could provide relevant insights for the prevention and mitigation of future disasters. According to Schneider and Schmitt (1998), comparison, as a cognitive activity, is inherent to the process of knowledge construction in the social sciences, enabling the discovery of regularities, the identification of similarities and differences, and the clarification of the general determinants that govern social phenomena.

Therefore, the study adopts an indirect approach to data treatment, based on analyses and discussions conducted through a literature review (Marconi and Lakatos, 2022). This review was grounded in a careful survey of published studies, focusing on academic articles, institutional reports, and other reliable sources selected from recognized databases.

In addition, the research has an exploratory nature, as it seeks to provide greater familiarity and understanding of the topic addressed (Gil, 2010). This characteristic made it

possible to investigate new perspectives and to identify factors that contributed to the occurrence of the calamity in Rio Grande do Sul, analyzing how these factors compare with those of similar crises in other contexts.

Thus, the adopted methodology enables a comprehensive and in-depth analysis of the causes and consequences of the disaster, contributing to the identification of important lessons that can be applied in the formulation of public policies and the improvement of risk management practices.

4 ANALYSIS AND DISCUSSION

This section presents a comparative analysis of major disasters, examining their causes, consequences, and institutional responses. The discussion seeks to identify similarities and differences in governance, infrastructure resilience, and social vulnerability, drawing lessons applicable to the context of Rio Grande do Sul.

4.1 Hurricane Katrina (USA)

Hurricane Katrina, which occurred in August 2005, is widely remembered as one of the most devastating natural disasters in United States history. It formed in the Atlantic and quickly reached Category 5 in the Gulf of Mexico before weakening to Category 3 upon making landfall. The most severe impact occurred in New Orleans, where levee failures caused massive flooding, inundating approximately 80% of the city and resulting in more than 1,200 deaths, in addition to significant economic losses (Congleton, 2006).

The main reasons for the magnitude of the disaster were failures in flood control infrastructure, delayed and insufficient responses from authorities, and the vulnerable socioeconomic conditions of a large portion of the affected population. The existing flood protection infrastructure in New Orleans was outdated and designed to withstand smaller storms, which exposed the city to substantial risks. This structural vulnerability highlights the importance of continuous investment in infrastructure adapted to confront extreme phenomena that are becoming more frequent due to climate change (Bullard and Wright, 2008). Comparatively, the disaster in Rio Grande do Sul in 2024 reflects a climatic pattern related to intense rainfall within a short period, also indicating the need for strengthened infrastructure and preventive measures to mitigate the impacts of extreme natural events.

New Orleans faced social inequality issues that exacerbated evacuation and recovery challenges, highlighting the intersection between natural disasters and socioeconomic conditions. The most vulnerable communities had less access to transportation, information, and resources, which hindered evacuation and increased human and material losses (Paidakaki et al., 2020). A similar situation can be observed in Rio Grande do Sul, where the socioeconomic conditions of the affected population also played an important role in how communities were able to respond to the crisis. This analysis reveals that, in both Katrina and Rio Grande do Sul, the impact of disasters is amplified among populations with fewer resources, underscoring the need for policies that ensure greater equity in access to protection and recovery measures.

The response to Katrina revealed failures in interinstitutional cooperation among local, state, and federal governments. In the case of Rio Grande do Sul, the analysis of emergency responses allows for the evaluation of the efficiency of crisis management mechanisms in Brazil, highlighting the role of local and federal authorities in mitigating disaster impacts. The experience of New Orleans emphasizes the importance of resilience strategies that involve not only public authorities but also the preparedness of communities themselves for natural disasters. Beyond the immediate response, Katrina generated complex reconstruction plans that faced difficulties both in infrastructure recovery and in the resettlement of families. Similarly, Rio Grande do Sul faces challenges in restoring housing and essential services. The efforts of both governments, through public policies and revitalization programs, are fundamental to ensuring sustainable recovery and reducing future losses.

In terms of community preparedness, the Katrina experience highlighted the importance

of warning systems and risk management education for populations in vulnerable areas. Strengthening awareness and local preparedness is essential so that communities can respond quickly and safely. In the context of Rio Grande do Sul, these lessons demonstrate that, in addition to institutional responses, it is indispensable to rely on well-informed and prepared communities to minimize the consequences of future calamities. These comparisons emphasize that, although the specific characteristics of each event vary, the lessons regarding resilient infrastructure, interinstitutional cooperation, social equity, and community preparedness are universal and essential for reducing the devastating impacts of natural disasters. Thus, Figure 1 provides an illustration of the causes, consequences, and actions taken based on Hurricane Katrina.

	Causes	**Consequences**	**Actions Taken**	**Authors**
Katrina (EUA)	By a classic hurricane formation in a tropical maritime environment.	Storms, strong winds, levee failures causing massive flooding, inundating cities and resulting in more than 1,200 deaths; financial losses, irreparable damage, delayed and insufficient response from authorities, and the vulnerable socioeconomic conditions of a large portion of the affected population.	Improvements in Emergency Response Plans; Investments in Intergovernmental Coordination; Strengthening of Preparedness and Prevention Policies; Federal and State Support for Economic and Social Recovery; Critical Policy Analysis and Institutional Learning.	Congleton (2006); Irons (2005); Bullard and Wright (2008).

Figure 1. Impacts and Lessons of Hurricane Katrina: An Analysis of Causes, Consequences, and Measures Taken
Fonte:Prepared by the authors based on the literature.

4.2 Brumadinho and Mariana Dams

The Fundão dam, located in the municipality of Mariana, in the state of Minas Gerais, was one of the structures responsible for storing mining tailings, particularly waste resulting from iron ore extraction by the company Samarco S/A. This dam was designed to contain large volumes of waste generated during the mining process and was primarily owned by Companhia Vale do Rio Doce and BHP Billiton. However, on November 5, 2015, the catastrophic collapse of the structure triggered one of the largest environmental disasters in Brazil's history. The dam failure unleashed a wave of destruction whose impacts persist to this day (Lopes, 2016).

The rupture released more than 55 million cubic meters of iron ore tailings, a volume equivalent to five Maracanã stadiums filled with water. The disaster caused the death of 18 people and left one person missing, directly affecting the Gualaxo do Norte River, the Carmo River, and the Doce River, as well as surrounding riparian forest areas. In total, 39 municipalities were impacted along the route between Mariana (MG) and the mouth of the Doce River, in the village of Regência, in Linhares (ES). Part of the tailings reached the Atlantic Ocean, affecting regional beaches and altering the marine ecosystem.

In 2019, another severe environmental tragedy occurred in Brumadinho, Minas Gerais, with the collapse of the tailings dam at the Córrego do Feijão Mine, operated by Vale. The failure resulted in a massive mudflow that devastated nearby communities, such as Vila Ferteco, caused more than 270 deaths, and left thousands homeless. This disaster is considered one of the largest workplace accidents in Brazil's history (Santos, 2019). The Brumadinho dam failure had profound environmental impacts, including the destruction of part of the Atlantic Forest and the contamination of the Paraopeba River, polluting soil and water and causing significant

biodiversity loss. In addition to environmental damage, there were also economic losses, reflected in the increased cost of living in the affected region.

The tragedy of the Brumadinho dam, operated by Vale, occurred due to a series of structural and construction failures, exacerbated by the use of the upstream raising method, which allowed water accumulation in the early stages due to the lack of an adequate drainage system. This accumulation generated internal pressure that destabilized the tailings, making the structure fragile and prone to collapse under undrained conditions. In contrast, the Mariana disaster also involved disruptions in the diversion system and issues with the stability of the dam raising process, but it was aggravated by the removal of material over a surrounding base composed of sand and mud, in addition to three seismic tremors that acted as triggers for structural deterioration. While Brumadinho presented imminent risk due to structural instability under high shear stress, the Mariana disaster was further aggravated by tremors that accelerated the liquefaction process.

Beyond environmental damage, the tragedy brought severe social consequences for the local population. The destruction of public and private infrastructure, the loss of material and immaterial assets, and changes in residents' physical and mental health conditions generated a crisis of major proportions. Waterborne diseases, fishing restrictions, and water shortages for human and animal consumption directly affected small producers, drastically altering the region's way of life and limiting the safe use of water resources. Figure 2 illustrates the similarities between the Brumadinho and Mariana dams, which, although located in different regions, presented similar characteristics and impacts within their respective territories.

	Causes	Consequences	Actions Taken	Authors
Brumadinho/ Mariana (Brasil)	Environmental tragedy in Mariana (2015) and Brumadinho (2019) in Minas Gerais, when the tailings dams collapsed; The causes include failures in environmental and operational risk management: inadequate licensing and lack of effective oversight of dam safety procedures.	Deaths and impacts on local communities, with hundreds of victims; Large-scale environmental destruction: contamination of rivers, loss of biodiversity, and long-term impacts on local ecosystems; Indication of latent risks in the relationship between large corporations and local communities, highlighting greater fragility in institutional and governmental trust in the mining sector.	Implementation of Law 12,334/2010 (National Dam Safety Policy); Creation of the Renova Foundation to implement recovery and compensation programs; however, it is managed by the private sector, raising questions about its impartiality; Review of environmental licensing and pressure for stricter regulations; nevertheless, new laws still need to be implemented and rigorously enforced.	Rezende e Silva (2019); Fabrício, Ferreira e Borba (2021); Armada (2021); Teixeira e Sebastião (2023).

Figure 2. Similarity of Causes, Consequences, and Measures Taken in the Mariana and Brumadinho Dam Disasters. Fonte: Prepared by the authors based on the literature.

4.3 Earthquake and Tsunamis in Japan

To build a comprehensive analysis of the impact and response to the 2011 Great East Japan Earthquake, it is essential to consider the geophysical and human effects of the tragedy, as well as the reactions and adaptations in infrastructure and public management during and after the disaster. The earthquake, followed by a devastating tsunami, caused remarkable impacts both on the region's geography and on local communities, shifting the island of Honshu and even altering the Earth's rotation due to the enormous energy released.

These effects, which exceeded those of previous disasters such as the 2004 tsunami in Indonesia, expanded the scale of the impact and reinforced the need for rapid and effective adaptation to new local and global conditions (Norio et al., 2012).

The internal response to the disaster exposed the fragility of Information and Communication Technology (ICT) infrastructure in Japanese municipalities, which lacked robust business continuity plans to face extreme situations of this magnitude. Failures in backup

management and the absence of adequate collaborative networks between government and the private sector hindered recovery and the maintenance of essential services, directly affecting the capacity for a rapid response to the population's needs. The study of ICT in the affected regions highlighted the urgency of more collaborative planning and the use of technologies such as cloud storage, which can mitigate the risk of data loss in future crises (Sakurai and Kokuryo, 2012).

The disaster also brought to light the complexity of rebuilding communities in the aftermath of a catastrophe of such magnitude. Physical destruction and the crisis at the Fukushima nuclear power plant forced the creation of new forms of community, based both on local solidarity and on the integration of immigrants and survivors. This new dynamic challenged the traditional view of unity in Japan by proposing a redefinition of the concept of community through shared bonds of loss and collective reconstruction. Jean-Luc Nancy's theory of the "community of sharing" helps interpret these post-disaster interactions as a significant social evolution, one that not only reflects the experience of destruction but also promotes cohesion among different affected groups (Shindo, 2015).

Finally, the analysis of damage and recovery in coastal cities showed that although initial efforts focused on saving lives, ICT infrastructure and municipal operations faced ongoing challenges in restoring normalcy. As the response evolved, the role of ICT became essential in supporting municipal functions and ensuring communication with citizens. This case study by Sakurai and Kokuryo (2013) indicated that future responses to large-scale crises require more dynamic ICT strategies, capable of accommodating the growing complexity of needs as events unfold. Progressive adaptation over time was crucial to the efficiency and resilience of cities in emergency situations (Sakurai and Kokuryo, 2013).

The Great Japan Earthquake and the flooding in Rio Grande do Sul, although distinct in scale and origin, reveal common vulnerabilities and challenges in disaster situations. In both events, the lack of business continuity planning and insufficiently robust Information and Communication Technology (ICT) infrastructure hindered efficient response and recovery in the affected communities. Figure 3 illustrates an overview of what occurred during the earthquakes and tsunamis in Japan.

	Causes	Consequences	Actions Taken	Authors
Earthquakes/Tsunamis (Japan)	Tectonic activity in the Pacific Ring of Fire region. A magnitude 9.0 earthquake on March 11, 2011. A subsequent tsunami that struck the coast..	Significant damage to infrastructure and the economy. A humanitarian crisis with thousands dead and missing. Lack of preparedness and rapid response. Reduction in energy security and increased dependence on imports. Radioactive contamination due to failures at the Fukushima nuclear power plant.	Strengthening of building codes and urban planning. Implementation of emergency measures and evacuation centers. Gradual decommissioning of nuclear power plants and investment in renewable energy. Development of a new energy plan focused on efficiency and renewable sources.	Sakurai e Kokuryo (2012); Nesheiwat e Cross (2013); Okada et al (2012);

Figure 3. Similarity of Causes, Consequences, and Measures Taken in the Earthquakes and Tsunamis in Japan
Fonte: Prepared by the authors based on the literature.

In Japan, the disruption of ICT systems impaired communication and the management of essential services. Meanwhile, in Rio Grande do Sul, many municipalities face difficulties in distributing aid and communicating with the most severely affected areas, particularly due to the lack of an integrated emergency response structure. Furthermore, according to Matsuura et al. (2025), preventive measures include strengthening climate monitoring systems and

disseminating information about risks in order to minimize the impacts of other extreme conditions. These examples highlight the importance of collaborative networks between government and the private sector, as well as the need for backup technologies and digital resilience strategies, such as cloud storage and contingency plans, to ensure continuous support for essential services even in crisis situations.

4.5 Calamity in Rio Grande do Sul

Given the chaotic context of the floods in Rio Grande do Sul, caused by excessive rainfall and the resulting economic, social, and structural impacts of this water accumulation, strategic actions by the federal and state governments were necessary to mitigate the identified environmental damages. In this regard, the allocation of financial resources became one of the main measures required in moments such as this. In response, the governments implemented programs and initiatives to allocate funds to the affected communities, as highlighted in Figure 4.

Action	Level	Amounts/Details	Amount Announced	Amount Disbursed
Auxílio Reconstrução	Federal	Financial assistance for displaced or homeless families in the amount of R$5,100.00.	R$2,22 Bi	R$2,21 Bi
Volta por Cima	State	Financial assistance for families displaced or left homeless in the amount of R$2,500.00.	R$240 Mi	R$251,24 Mi
PIX SOS RS	State	Financial assistance for displaced or homeless families in the amount of R$2,000.00, as well as financial transfers to Individual Microentrepreneurs (MEIs).	R$101,51 Mi	R$73,75 Mi
Saque Calamidade FGTS	Federal	Withdrawal of up to R$6,220.00 from the FGTS balance for each worker.	RS4,20 Bi	R$3,46 Bi

Figure 4. Main actions carried out at the federal and state levels in response to the public calamity in the State of Rio Grande do Sul
Fonte: Prepared by the authors based on official information from 2024.

These financial resources were primarily intended to support affected communities through the reconstruction of basic infrastructure, particularly through the Reconstruction Assistance program. In addition, funds were made available to displaced or homeless families through initiatives such as “Volta por Cima,” “PIX SOS RS” (donations managed by the state of Rio Grande do Sul), and the FGTS Calamity Withdrawal, which benefited all workers in the state (RS GOV, 2024).

Furthermore, the federal and state governments allocated resources to different sectors through 25 provisional measures under consideration in Congress, aimed at repairs, restructuring, and investments in hospitals, schools, Salgado Filho Airport, dikes, bridges, state highways, and housing construction. The government, in partnership with established institutions, also implemented important subsidies, such as the provision of credit through BNDES, the suspension of payments under the Minha Casa Minha Vida program, the payment of Bolsa Família benefits to those affected by the floods, additional unemployment insurance installments, income tax refunds, and the expansion of the Continuous Cash Benefit (Brasil, 2024).

Beyond the cases analyzed in depth, recent urban flooding events in international contexts, such as Valencia (Spain), illustrate the current and recurring challenges associated with environmental governance, particularly regarding urban reconstruction and institutional

coordination. Figure 5 comparatively summarizes the main institutional lessons drawn from the disasters analyzed, linking them to the case of Rio Grande do Sul as a model of interregional learning in environmental governance.

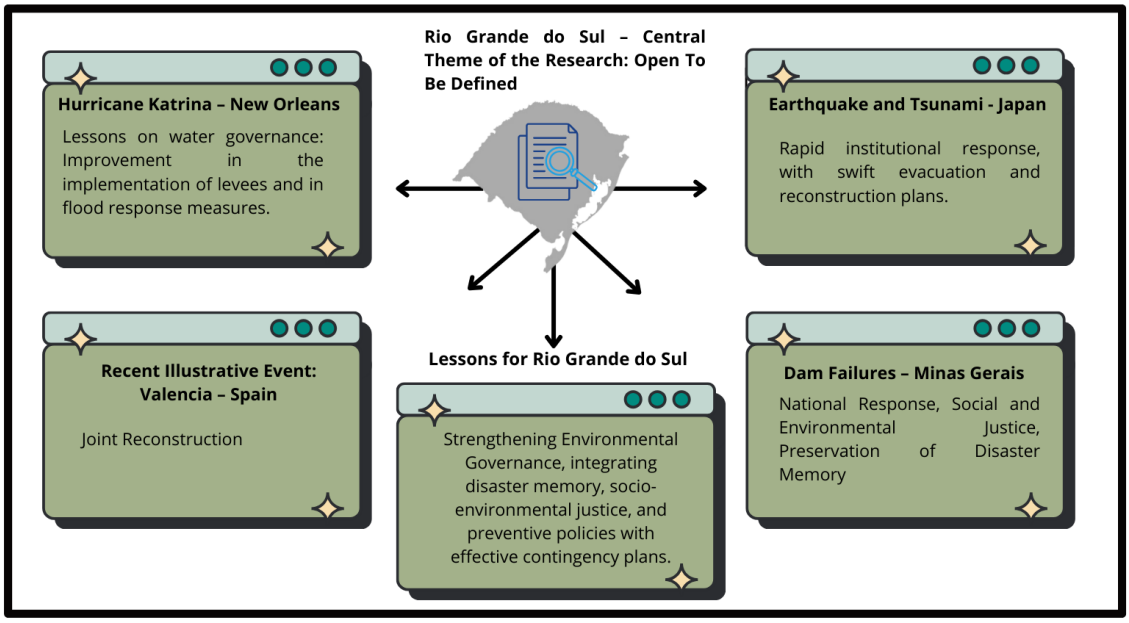

Figure 5. Comparative synthesis of institutional lessons from environmental disasters and implications for Rio Grande do Sul
Fonte**:** Prepared by the authors based on the results. Note: The Valencia (Spain) event is presented as contemporary illustrative evidence and does not constitute a comparative case analyzed in depth.

The synthesis presented in Figure 5 shows that, although the disasters analyzed have distinct natures, scales, and institutional contexts, common patterns emerge regarding the importance of environmental governance, state capacity for response, and the incorporation of disaster memory into public policy formulation. In the case of Rio Grande do Sul, the comparative analysis suggests that the lack of prior articulation between preventive planning, adequate infrastructure, and interinstitutional coordination mechanisms amplified the social and environmental impacts of the extreme event.

Thus, the lessons derived from both international and national cases reinforce the need for public policies oriented not only toward emergency response, but above all toward prevention, socio-environmental justice, and the institutionalization of robust contingency plans. Considering that the disaster in Rio Grande do Sul is still unfolding, the reflections presented here point to analytical limitations and to the need for continuous further study, an aspect revisited in the final considerations.

5 FINAL CONSIDERATIONS

Throughout this study, it was possible to achieve the proposed objective, namely, to identify and analyze the factors that contributed to the occurrence of the recent calamity in Rio Grande do Sul, comparing it with disasters of different natures, such as Hurricane Katrina in the United States, the tsunami in Japan, and dam failures in Minas Gerais. The analyses revealed that, despite regional and contextual differences, there are common patterns, such as failures in preparation and mitigation, low coordination among different levels of government, lack of integration with civil society, and insufficient investment in resilient infrastructure. It was also observed that the inclusion of climate issues on the government agenda tends to occur reactively, often driven by large-scale events, reinforcing a culture of emergency response at the expense of prevention.

Furthermore, the co-production of climate policies, with the active participation of citizens, NGOs, and private agents, still faces significant barriers, particularly due to the lack of clear institutional channels and resources for engagement. However, Rio Grande do Sul, in its

trajectory, presents processes of popular participation with low civil society engagement and government measures that are only partially effective in expanding this participation.

Responsibility for climate policies lies with a complex network of actors, including local, state, and federal governments, as well as international organizations and corporations. However, transnational actors often act more prominently in knowledge dissemination and the promotion of narratives that favor sustainability and climate adaptation, while facing challenges in implementing policies in specific local contexts.

Regarding previous climate narratives, it was observed that, in general, discourses emphasize the urgency of action and the need for global cooperation. However, in local contexts, these narratives must be adapted to address the socioeconomic and cultural realities of affected populations. It is up to Rio Grande do Sul to extract lessons from these past national and international tragedies to implement effective measures that, in the case of future disasters, enable authorities to act quickly and in a coordinated manner, minimizing impacts and damage to both the population and the environment.

This study presents some limitations, such as the availability and quality of up-to-date data on strategies adopted in different disaster contexts, as well as the complexity of comparing events with distinct characteristics. Cultural, social, and economic aspects that influence the implementation of preventive policies in different countries and regions were also not explored in depth.

For future studies, it is suggested to investigate how governments can more effectively integrate climate policies across different levels and sectors, as well as explore the role of emerging technologies and innovative practices in strengthening disaster resilience. Additionally, studies could analyze the active participation of civil society and transnational actors in the formulation and execution of climate policies..

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