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ABSTRACT

This article analyzes the socio-environmental impacts of the extreme weather events that occurred in Rio Grande do Sul in 2024, with special attention to small cities in the regions of Vale do Rio Pardo and Vale do Taquari. A timeline of these events, which resulted in floods, torrential flows, and landslides, is presented. Several roads were closed and bridges were washed away throughout the state; in the Vales region alone, approximately 43,600 structures were affected. These impacts revealed the fragility of infrastructure and the inadequacy of spatial planning policies. This article emphasizes the importance of reflecting on the articulation of policies and spatial planning instruments at different spatial scales (municipality and drainage basin), in addition to the institutional support provided by the state and federal governments to the small cities that were highlighted in this scenario — many still on the margins of urban policies —, especially in the face of climate change.

Keywords: Extreme weather events. Socio-environmental impacts. Small cities.

RESUMO

O artigo analisa os impactos socioambientais dos eventos climáticos extremos ocorridos em 2024 no Rio Grande do Sul, com foco nas cidades pequenas das Regiões do Vale do Rio Pardo e do Vale do Taquari. Apresenta-se uma cronologia desses eventos, que resultaram em inundações, enchentes, enxurradas e deslizamentos. Diversas estradas ficaram interditadas e pontes foram levadas pela força das águas em todo estado; somente na região dos Vales, aproximadamente 43.600 edificações foram atingidas. Esses impactos revelaram a fragilidade das infraestruturas e a inadequação das políticas de ordenamento territorial. Enfatiza-se a importância de se pensar a articulação das políticas e instrumentos de ordenamento territorial em diferentes escalas espaciais (município e bacia hidrográfica), bem como o apoio institucional do governo estadual e federal às cidades pequenas que foram destacadas neste cenário, muitas ainda à margem das políticas urbanas, sobretudo diante das mudanças climáticas.

Palavras-chave: Eventos climáticos extremos. Impactos socioambientais. Cidades pequenas.

INTRODUCTION

A large portion of the territory of the state of Rio Grande do Sul was affected by weather events involving heavy rainfall between the end of April and mid-June 2024. Municipalities in Rio Grande do Sul experienced impacts of varying intensities, with several cities having been devastated. Particularly notable is the critical situation of the Guaíba Basin Hydrographic Region, which encompasses areas from the Central Region and Vale do Rio Pardo, Vale do Taquari, and Vale do Caí to its mouth, located in Lake Guaíba in Porto Alegre and its metropolitan region. It was observed that, in the mountainous areas, the water arrived with force and speed, while in the lowland areas, water remained accumulated for several days. Furthermore, in the Southern Region, cities located along the shores of the Patos Lagoon also experienced prolonged flooding.

According to the report published by the Civil Defense[1], after more than a month since the first incidents were recorded, 475 municipalities were affected, covering a population of 2,390,556 inhabitants. Out of the total of 579,457 displaced people, 37,154 were still in temporary shelters, as in some areas the water had not completely receded, and in others, the destruction was complete. Concerns arise regarding the safety of the population returning to damaged homes

1 Civil Defense updates the report on the floods in RS — 03/06/24, 9:00 a.m. Available at: https://bit.ly/3xjREgu. Access on: June 4, 2024.

and the proposals for resuming and rebuilding housing in the same locations. It is also necessary to critically examine plans aimed at creating temporary cities to shelter people (Fuão, 2024) and those that propose relocating communities — or even entire cities — to alternative areas.

Understanding the socioeconomic effects of these weather events is essential for planning emergency actions in the short, medium, and long term. In the face of this devastating and complex scenario, in which the impacts on cities were experienced and managed in various ways, this article aims to document the extreme weather events that occurred in Rio Grande do Sul in 2024 and analyze the significant socio-spatial consequences that resulted, as well as the current state of public policies for spatial planning in small cities.

In this regard, the theoretical/methodological framework of this study is presented, guided by reflections on the socio-environmental impacts and the current spatial planning legislation. Subsequently, the timeline of the events is documented, with an emphasis on small cities located in the regions of Vale do Rio Pardo and Vale do Taquari, which were severely affected. In this context, some of the socio-spatial impacts on these cities are analyzed. Finally, the status of the spatial planning legislation in these municipalities is presented, focusing on the presence, revision, and attention to aspects and dimensions related to the context and effects of climate change.

THEORETICAL/METHODOLOGICAL REFLECTION

The extreme weather events experienced in Rio Grande do Sul are changing the way the state's society perceives its existence in relation to the physical environment it occupies. Acselrad (2004) asserts that human existence is based on social relations and the ways in which humans appropriate the material world. This aligns with the perspective of critical Social Sciences, which argue that it is impossible to separate society from its environment. The elements of the environment cannot be reduced to quantities of matter and energy, as they are also cultural and historical; society and the environment connect and interact both materially and socially, whether through water, soil, or the atmosphere (Acselrad, 2004). Souza (2021) also presents the perspective that holds that to understand space, it is not enough to analyze it in isolation: it is necessary to delve into social relations.

Therefore, it is understood that the weather events experienced in Rio Grande do Sul caused socio-spatial impacts, because, in addition to the environment being affected, these events brought — and continue to bring — consequences to the residents of these areas; that is, to society itself. Thus, for this study, social relations and space are inseparable through a dialectical composition. This understanding is reinforced by the concept of disaster adopted in the National Policy for Civil Protection and Defense, PNPDEC (Brasil, 2012), which considers disasters to be the result of adverse events — whether natural or induced by human actions — that impact ecosystems and vulnerable populations, causing significant human, material, and environmental damage, as well as economic and social losses.

Furthermore, it is important to acknowledge that socio-spatial impacts affect the population in different ways, with more intense repercussions on the most vulnerable social segments, since the relationship between society and the environment tends to reinforce social inequality (Ventura & Davel, 2021). It is not the objective of this article to delve deeper into this topic, but it is important to note that it is necessary to take social inequality into account in an in-depth analysis of these impacts.

Given the conflicting ways in which human beings appropriate the material world, it is important to consider the role of the State as a mediator of these relationships. However, the environmental constraints present in the territory (terrain, vegetation cover, hydrography, among others), the guidelines and recommendations found in regional drainage basin plans, and the need to promote sustainable modes of land occupation and use (both urban and rural) have not been considered in the ongoing urbanization processes, nor incorporated into municipal public policies for spatial planning.

In this study, which analyzes the socio-spatial impacts caused by heavy rains, floods, torrential flows, and landslides, it is necessary to observe the conformation of drainage basins — that is, the portions of the territory that naturally capture rainwater, which then flows superficially to the main watercourses and their tributaries. In this regard, it is worth noting that, since the State Constitution (RS, 1989, art. 171), drainage basins have been adopted as basic units for planning and management, with the establishment of their management committees and their articulation

with the State Water Resources System (Law No. 10,350/1994). In total, there are 25 Drainage Basin Committees, organized into three main regions: the Guaíba Basin, the Coastal Basin, and the Uruguay River Basin (SEMA, 2018).

The social space — appropriated, transformed, and produced by society — is diverse and plural both in Rio Grande do Sul and in Brazil, and its organization is guided and legislated by the City Statute (Law 10,257/2001), which "establishes rules of public order and social interest that regulate the use of urban property for the collective good, the safety and well-being of citizens, as well as environmental balance".

The weather event discussed in this article underscores the need for effective spatial planning, especially in urban areas. Espindola and Ribeiro (2020, p. 366) highlight the importance of cities in global climate governance, "both because they suffer from the impacts of these climate changes and because they contribute to the intensification of this process". Despite the concentration of large manufacturing companies, heavy traffic, and polluting activities in medium and large cities — which exacerbates climate change — the resulting impacts do not respect political or territorial boundaries (Espindola & Ribeiro, 2020); it is therefore necessary to also consider small cities affected by the 2024 tragedy in the state of Rio Grande do Sul within this context.

In this context, two aspects are fundamental for defining the territorial scope of this study. The first concerns the focus on small cities, initially characterized by low population density. According to Endlich (2009), small cities are also part of the reality of human settlements, and failing to study this concrete aspect of Brazilian spatiality could compromise not only the issues of cities with higher population densities but also the possibilities for territorial intervention as a whole.

The literature indicates that municipalities polarized by small cities tend to face greater technical, financial, and operational difficulties and limitations in the development of public policies (Arretche, 2010). Building on previous studies, this research focuses on small cities in the regions of Vale do Rio Pardo and Vale do Taquari to emphasize the second key aspect guiding this study: the importance of spatial planning and land-use control to prevent exposing populations to disaster risks.

Despite the nationwide constitutional requirement to promote municipal planning instruments, demographic criteria determine the obligation to implement a master plan, which is required only for municipalities with more than 20,000 inhabitants. Consequently, the vast majority of municipalities in Rio Grande do Sul (approximately 80%) are excluded from these public policies for spatial planning, as implementing a master plan — the main urban planning instrument, according to the Federal Constitution (1988) and the City Statute (2001) — is optional. However, among other scenarios outlined in Article 41 of Law No. 10,257/2001[2], the master plan also became mandatory for cities included in the national registry of municipalities with areas susceptible to high-impact landslides, flash floods, or related geological or hydrological processes, as stipulated by the National Civil Defense Policy (Law No. 12,608/2012).

In this regard, municipal-level spatial planning laws must provide effective guidelines that account for current climate changes. Municipal laws are essential tools, as they enable local stakeholders to exert greater control in guiding the proper growth of cities. Such legislation ensures the legitimacy of settlements and environmental preservation, upholds the fulfillment of the social function of property and the population's needs in terms of quality of life and social justice, and guarantees compliance with the guidelines established in the City Statute.

In general, there is a lack of articulation between environmental planning instruments established at the regional scale and the urbanization and territorial planning processes at the municipal scale. Adding to this issue are a lack of transparency, limited social participation, and the failure to update and/or adapt master plans to climate changes — factors that have exacerbated the catastrophic consequences of extreme weather events. Consequently, beyond the destruction of residential areas, economic activities, and rural properties in many municipalities, there was also partial or total damage to road and air networks, technical supply systems (water and energy), communication networks (internet), and sanitation

2 According to the City Statute, municipalities with less than 20,000 inhabitants must also create their master plans when: 1) they are part of metropolitan regions and urban agglomerations; they are part of areas of special tourist interest; they are located in an area of influence of enterprises or activities with significant environmental impact at regional or national level (Brasil, 2001).

systems (sewage, stormwater drainage, and solid waste management) following the intense rainfall in Rio Grande do Sul.

Given the significant transformations in the Earth's cycle patterns over time (manifested in climate changes that predict an increasing frequency of extreme events), the analysis of impacts on small cities in the Vales regions is grounded in a socio-spatial perspective. Methodologically, to reflect on the importance of adopting networked infrastructures with a focus on the scope of small cities, the scenario of the extreme rainfall of 2024 at the state level is described, aiming to establish a timeline of events. It is argued that recording the timeline of the events is essential for understanding the sequence of occurrences throughout the state. The timeline was constructed based on news reports, university researchers' reports, and records from official national and state agencies. To grasp the spatial extent of the flood, a mapping of flood lines and zones in the most affected municipalities in the Vales regions was carried out. Records of deaths and missing persons, as well as estimates of built-up areas inundated in urban and rural areas of each municipality, were also gathered. Additionally, the content covered by the current spatial planning legislation of these municipalities was reviewed. This survey was conducted based on an analysis of the municipal master plan laws of the Vale do Taquari municipalities.

TIMELINE OF THE EXTREME WEATHER EVENTS

The extreme weather events that occurred in the first half of 2024 in Rio Grande do Sul began in April 2024. Between April 13 and 14, accumulated rainfall reached 300 mm in some parts of the state due to a cyclone that had impacted the coast of Argentina (Metsul, 14/04/2024). On April 27, after a week of high temperatures, a downburst struck the central region of the state, accompanied by intense hailstorms. The result was the flooding of several cities (Metsul, 28/04/2024).

In Vale do Rio Pardo (Rio Pardo Drainage Basin), at the headwaters of the rivers crossing the region, located in the Meridional Plateau and the upper Serra Geral, precipitation peaks of up to 540 mm were recorded. By the evening of Sunday (28/04), the Civil Defense received the first calls for help from rural families. On the same day, an evacuation alert was issued for residents of the Várzea neighborhood in the city of Santa Cruz do Sul.

On Monday (29/04), the National Institute of Meteorology (Inmet) issued the first red alert for heavy rainfall. The rain intensified the currents of the Pardinho River, the Pardo River, and the Castelhano Stream. Between Monday (29/04) and Tuesday (30/04), the rising waters and strong currents of the Pardinho River devastated the urban center of Sinimbu. Subsequently, the urban center of Candelária was flooded by the Pardo River; the city of Vera Cruz was isolated due to the flooding of access roads caused by the overflow of the Pardinho River; and the municipal government of Santa Cruz do Sul issued an emergency decree (Manifesto PPGDR/UNISC, 2024). To the north of Vale do Rio Pardo, on Wednesday (01/05), Sobradinho was hit by heavy rains of 500 millimeters and there was a consequent overflow of the Carijinho Stream, which cuts through the urban center. This caused the collapse and blocking of several bridges, which isolated several areas of the city and flooded homes and businesses located on its banks (Metsul, 01/05/2024). On the same day, the currents of the Pardinho River destroyed the access bridge to the urban center of Rio Pardo.

In Vale do Taquari (Taquari Antas Drainage Basin), the heavy rains that also reached the region on Sunday (28/04) and Monday (29/04) caused landslides in several municipalities. On Tuesday (30/04), the cities of Marques de Souza and Travesseiro, located along the Forqueta River, experienced significant rainfall, exceeding 150 millimeters. Streams overflowed and flooded urban areas in Forquetinha and Progresso. The torrential rains in the headwaters of the Antas River and in Santa Tereza, in the upper part of the region, led to the rapid rise in the level of the Taquari River as it runs through the region. In Roca Sales, the river rose by more than 1 meter per hour. On the same day, in Lajeado, nearly 190 millimeters of rain fell within 24 hours, causing the Taquari River to overflow and rapidly reach 27 meters in the early hours of the morning, leaving hundreds of families homeless (Souza, 2024).

On April 30, the first fatalities were reported. In Vale do Rio Pardo, one death occurred in the city of Pantano Grande; in Vale do Taquari, there were two fatalities, one in Paverama and another in Encantado; and there was one more in the Central Region, in Santa Maria. On Wednesday (May 1), the state government declared a public calamity and suspended classes (Decree No. 57,596, of May 1, 2024).

On May 1, the level of the Taquari River continued to rise in Lajeado, surpassing the 2023 flood level by exceeding 29.75 meters. On the same day, the first helicopters from the federal and state governments arrived at Parque do Imigrante in Lajeado to conduct rescue operations for residents isolated in urban and rural areas affected in the region. The following day (02/05), the Taquari River reached its new historic level — 33.35 meters — in Lajeado at 1:30 p.m. The force of the Forqueta River's current severely impacted regional logistics, washing away part of the ERS-130 bridge and the historical Ponte de Ferro (Iron Bridge), both connecting Lajeado and Arroio do Meio, as well as destroying the bridge between Marques de Souza and Travesseiro.

In Cruzeiro do Sul, few houses withstood the flooding in the neighborhoods of Passo de Estrela, Glucostark, and Zwirtes, making it one of the most devastated cities in the region. On Friday (03/05), the rain weakened in the region, and the clearing of roads and access routes revealed scenes of destruction in Cruzeiro do Sul, Forquetinha, and Marques de Souza. Several areas remained without electricity, phone service, and internet for up to three days, as was the case in Muçum (Souza, 2024).

The regions of Vale do Rio Pardo and Vale do Taquari, characterized by intense daily interactions of human, input, and product flows among municipalities (reflecting their regional economy), due to this major disaster, had their intra-regional road interconnectivity greatly impaired, with some points completely collapsed (Maraschin et al., 2024).

In the Central Region (Vacacaí–Vacacaí Mirim Drainage Basin), the initial impacts of this extreme weather event were also felt. On Monday (29/04), Santa Maria experienced heavy rainfall, with 214 millimeters recorded in 24 hours (Immig, 2024). In the city, residents of Vila Fighera (Camobi district) were severely affected and had to evacuate their homes urgently with the help of firefighters. Near this area, the bridge over Arroio Grande (on RSC-287 in the Palma district) could not withstand the force of the water and partially collapsed, cutting off the main connection between Santa Maria, neighboring municipalities in the Quarta Colônia region, and Porto Alegre. Estrada do Perau (Perau Road —

connecting Santa Maria and Itaara) was also completely blocked due to landslides on the roadway. On Wednesday (01/05), a landslide occurred on Morro do Cechella in the Itararé neighborhood of Santa Maria, resulting in the deaths of two people.

The Quarta Colônia Region (Baixo Jacuí Drainage Basin), known for its gastronomy and beautiful landscapes, was also affected. Communities were left isolated, and residents had to be rescued by boats or by a Brazilian Air Force (FAB) aircraft. Rescue operations involving the Civil Defense and armed forces were organized to assist families stranded in various cities in the region — such as Faxinal do Soturno, São João do Polêsine, and Agudo —, where more than 600 people were left without communication and unable to leave their homes (Immig, 2024).

The Serra Region (Taquari–Antas Basin) experienced the partial rupture of the 14 de Julho Dam, between Cotiporã and Bento Gonçalves, on May 2, due to the overflow of the Antas River. Throughout May, simultaneous floods and landslides were recorded. These events left many people at risk or homeless, with some fatalities reported. Additionally, on 13/05, tremors measuring 2.3 on the Richter scale were recorded in Caxias do Sul (Zanrosso, 2024).

In the northern part of the state (Uruguay River Basin Hydrographic Region), the most critical situation occurred in Barra do Rio Azul, whose urban area is crossed by the Paloma and Azul Rivers. Within less than six months, this small city experienced two floods, with the one on May 3, 2024, being of historic proportions. It is worth noting that the municipality has been working with regional universities to explore the possibility of relocating the urban area and widening the riverbed (Polesello; Possa, 2024).

It was observed that, as the rains decreased in the Vales and Central regions, and in other parts of the nine sub-basins that make up the Guaíba Basin Hydrographic Region, the flooding phenomenon reached the metropolitan region of Porto Alegre (on Friday, 03/05). The waters from the aforementioned rivers cross the state and flow into Lake Guaíba, which, in turn, flows into Lagoa dos Patos towards the sea. However, the combination of intense precipitation and unfavorable wind conditions hindered the drainage of Lake Guaíba's waters, which reached a height of 5.3 meters on Monday (05/05), surpassing the historic level recorded in 1941. Failures in the flood protection system and issues with stormwater drainage left urban areas in cities such as Porto Alegre, Canoas, Guaíba,

Eldorado do Sul, Novo Hamburgo, and São Leopoldo[3], among others, submerged for over a month.

In the context of the Guaíba Hydrographic Region, researchers from IPH/UFRGS (Possanti et al., 2024) presented a mapping of areas potentially affected by flooding from the Patos Lagoon, which corresponds to the Coastal Hydrographic Region and includes the municipalities of Pelotas, São Lourenço do Sul, Rio Grande, Capão do Leão, São José do Norte, Arambaré, Tapes, Palmares do Sul, Capivari do Sul, and Viamão. The water level of the Patos Lagoon (classified as a "lagoon" due to its connection to the sea) does not depend solely on the dynamics of the volume of water that flows out; it can vary according to the conditions of the winds and ocean tides. Thus, the south wind situation — when the water outflow to the sea slows down — and the new moon phenomenon — which causes significant tidal fluctuations — led to an increase in Civil Defense alerts throughout the month of May.

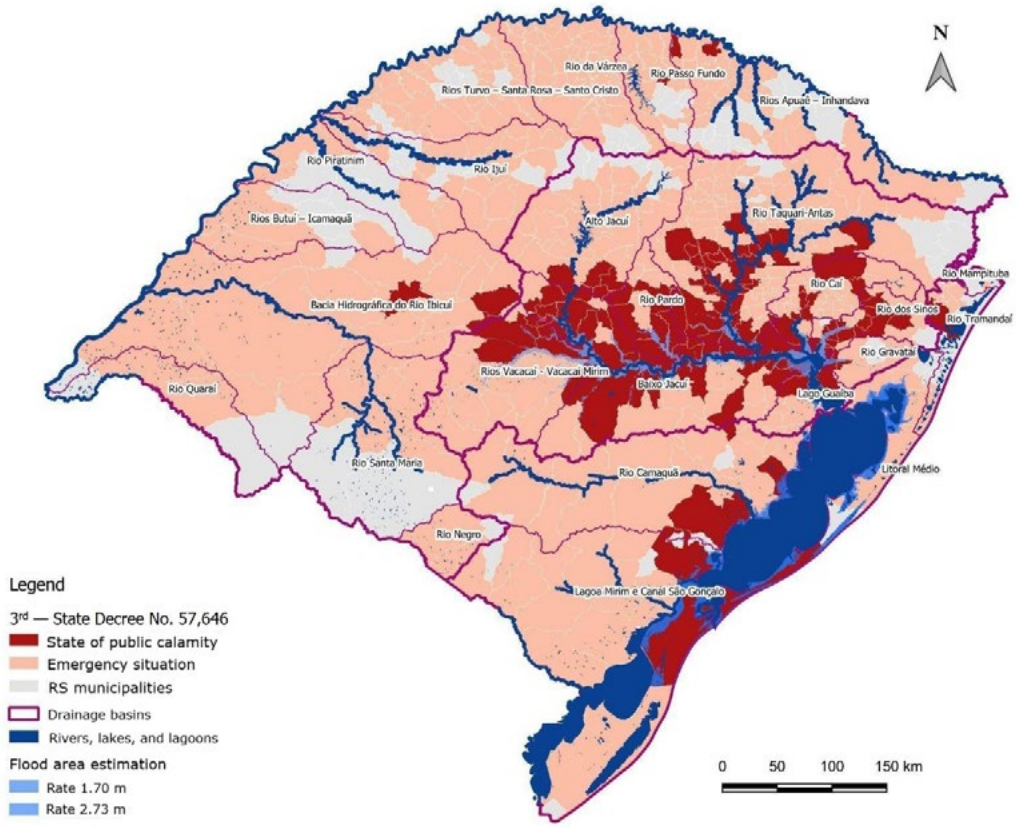
In the southern region of the state (Mirim Lagoon and São Gonçalo Channel Drainage Basin), the most affected area was the Z3 Fishermen's Colony in Pelotas, which remained isolated until June 9, when an emergency bridge was built by the Army (Gaúcha ZH, 09/06/24). The second most impacted area was the beachside sections of the Laranjal neighborhood. Several other urban areas in the municipality remained on alert but were protected by dike, pump, and canal systems designed to prevent overflow from the São Gonçalo Channel (which connects the Patos Lagoon to the Mirim Lagoon) and the intra-urban Santa Bárbara Stream watercourse. Between May 7 and June 12, the Municipal Government of Pelotas[4] shared daily maps identifying alert areas and zones requiring immediate evacuation.

With BR-116 blocked in the metropolitan region of Porto Alegre, the alternative route to access municipalities in the southern region was BR-101 (the road between the sea and the lagoon), which leads to São José do Norte, where a ferry crossing connects to the city of Rio Grande. However, both cities also suffered from flooding, and the ferry crossing had to be suspended numerous times. The water level of the Patos Lagoon in the Costa Doce cities also surpassed the mark recorded during the floods of 1941. Notable levels included 2.36 meters in Rio Grande and 3 meters in Pelotas, recorded on Thursday, May 16, and 2.9 meters in São Lourenço do Sul on May 19.

3 See more at: https://storymaps.arcgis.com/stories/9ad77c4a98494d9ba4737bb5d663db75
4 See more at: https://bit.ly/3zbpiFG

The extreme weather events described led to the enactment of State Decree No. 57,646 on May 30, 2024, which stated that out of the 497 municipalities in Rio Grande do Sul, 96 were in a state of calamity and 323 were in a state of emergency. Based on the mapping of these municipalities (Image 1), it is notable that, while 65% of the territory was affected, the worst scenario was predominantly concentrated in the Guaíba Hydrographic Region due to flooding in the sub-basins of the following rivers: Vacacaí–Vacacaí Mirim, Pardo, Baixo Jacuí, Taquari–Antas, Caí, Sinos, Gravataí, and Lake Guaíba. In the southern portion of the Coastal Hydrographic Region, municipalities with urban areas near the Patos Lagoon were also significantly impacted.

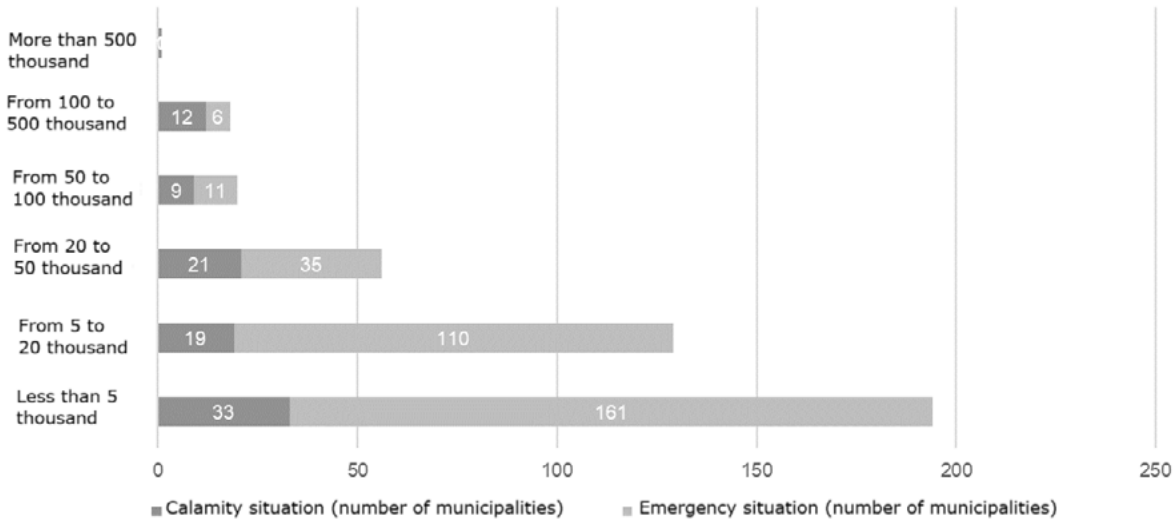
Image 1 | Map of municipalities in state of calamity and in emergency situation (RS), drainage basins, and flood area estimation



Source: Prepared by the authors, based on Decree No. 57,646 RS (2024); SEMA (2018); Possanti et al. (2024).

From Image 2, it is possible to see that the majority of municipalities, both those in a state of public calamity and those in a state of emergency, have less than 50,000 inhabitants. When looking at municipalities with a small demographic size (which correspond to the definition of "small cities" in this study), there is a greater concentration in the range of less than 5,000 inhabitants (followed by the population range of 5,000 to 20,000 inhabitants) when it comes to municipalities in a state of emergency and the population range of 20,000 to 50,000 inhabitants when it comes to municipalities in a state of calamity.

Image 2 | Chart of municipalities in state of public calamity and emergency situation by demographic levels (RS)



Source: Prepared by the authors, based on Decree No. 57,646 RS (2024); IBGE (2023).

According to MUNIC — Basic Municipal Information Survey (IBGE, 2021), of the 418 municipalities in a state of public calamity or emergency, 161 (38.6%) reported not having master plans, with 160 of them having a population of less than 20,000 inhabitants.

Given these circumstances, in addition to understanding the socio-environmental impacts, it is necessary to study the situation of the spatial planning legislation of these municipalities in order to support the planning of medium- and long-term actions for the recovery of the affected municipalities.

SMALL CITIES IN THE REGIONS OF VALE DO RIO PARDO AND VALE DO TAQUARI

In 2022, the Vales region had a total population of 773,124 inhabitants, with 73.2% residing in urban areas and 26.8% in rural areas. Despite the predominance of the urban population, of the 59 municipalities in the region, 28 have more than 50% of their population living in rural areas (IBGE, 2022). This rural area is divided into three zones, with the central and northern parts of Vale do Rio Pardo standing out, characterized by small family-owned properties focused on tobacco and corn production; Vale do Taquari, with an emphasis on poultry farming, pig farming, and dairy products; and the southern part of Vale do Rio Pardo, with large rural properties specialized in rice, soybeans, livestock, and forestry.

Of its 59 municipalities, 30 have a total population of fewer than 5,000 inhabitants, representing 51% of the municipalities and housing 11.3% of the regional population. In turn, municipalities with populations between 5,000 and 20,000 inhabitants account for 29% of the municipalities and have 19% of the regional population. Together, these municipalities with smaller cities total 240,360 inhabitants, which corresponds to 30% of the total population of the Vales region (IBGE, 2022).

ANALYSES OF SOCIO-SPATIAL IMPACTS

The data used to analyze the socio-spatial impacts of flooding in small cities in the regions of Vale do Rio Pardo and Vale do Taquari are based on a database organized by Possanti et al. (2024) and researchers from UFRGS and other institutions (particularly regarding the flood extent in the Guaíba Basin Hydrographic Region). Using the mapping of this extent, identified by the researchers through satellite images from May 6, a correlation was established with data on structures provided by Open Buildings[5] (2024). This enabled the calculation of the total number of structures affected in urban and rural areas, with urban areas calculated based on the census tract grid from the 2010 Demographic Census. Additionally, the number of deaths and missing persons in the studied cities was recorded using data from the Civil Defense (18/05/24).

5 Google Open Buildings is a powerful tool that provides a vast dataset of building footprints derived from high-resolution satellite imagery.

In Vale do Rio Pardo, according to the spatial analysis calculations, 16,967 structures were affected, and 11 deaths were reported (Table 1). Proportionally, Sinimbu, Venâncio Aires, and Candelária were the most affected municipalities in urban areas, with over 8% of their structures flooded. Venâncio Aires and Rio Pardo also stand out for the percentage of flooded structures in rural areas (more than 6%).

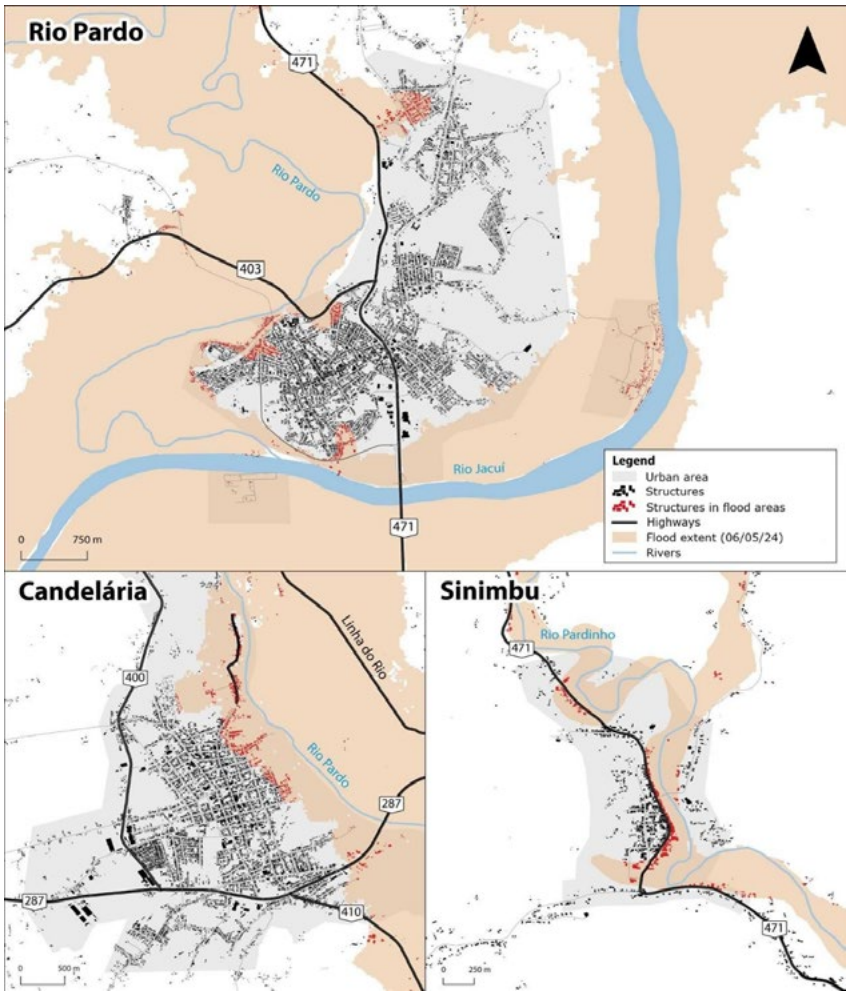
Table 1 | Deaths, missing persons, and flooded structures in Vale do Rio Pardo

Municipality	Total population (2022)	Number of deaths (May 15, 2024)	Number of missing persons (May 15, 2024)	Percentage of flooded structures in rural areas	Percentage of flooded structures in urban areas
Sinimbu	8,578	3	-	2.79	18.51
Venâncio Aires	68,763	5	-	10.66	16.89
Rio Pardo	34,654	-	-	6.87	9.2
Candelária	28,906	-	-	5.86	8.71
Santa Cruz do Sul	133,230	2	-	1.49	5.36
Vera Cruz	26,710	-	-	7.7	3.25
Vale do Sol	9,897	1	-	1.12	0
Passo do Sobrado	6,025	-	-	4.09	0

Source: Prepared by the authors, based on IBGE (2022); Civil Defense (18/05/24); Possanti et al. (2024); and Open Buildings (2024).

The maps in Image 3 show the flood extent in the cities of Rio Pardo, Candelária, and Sinimbu, highlighting the substantial expansion of the rivers compared to their original courses. In Sinimbu, the main road in the city center was submerged, with the water reaching the Catholic church and the main square. In Candelária, a significant portion of the urban area's edge was affected, and the bridge connecting the city to Santa Cruz do Sul via RS-287 was destroyed. In Rio Pardo, specific areas of the city were severely impacted, as well as a significant portion of the structures in rural areas.

Image 3 | Map of the flood extent in municipalities of Vale do Rio Pardo: Candelária, Rio Pardo, and Sinimbu



Source: Prepared by Carolina Rezende Faccin, based on Possanti et al. (2024) and Open Buildings (2024).

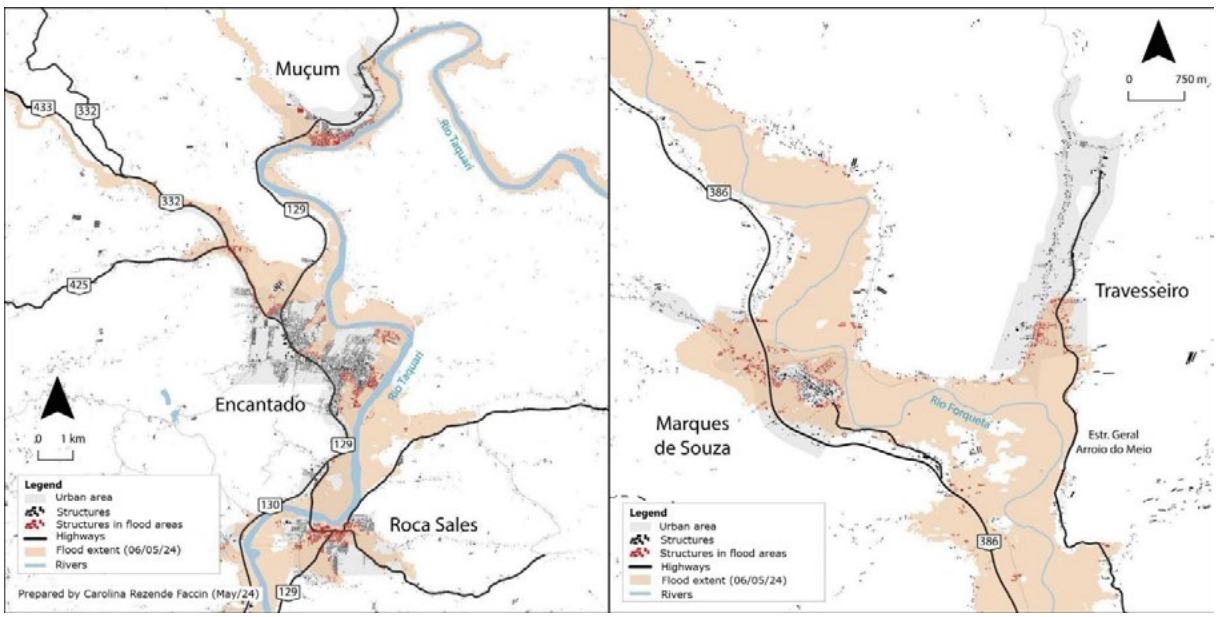
In Vale do Taquari, in turn, the spatial analysis identified 26,624 affected structures, with 33 deaths and 20 missing persons recorded (Table 2). Based on the maps in Image 4, it is possible to see that the worst situations occurred in the cities of Marques de Souza, Muçum, Roca Sales, Cruzeiro do Sul, and Estrela, which had more than 40% of their structures affected in urban areas. In relation to rural areas, Cruzeiro do Sul, Forquetinha, and Muçum had more than 15% of their structures affected. The impact on these municipalities was caused by the torrential flow phenomenon, when the rivers' waters ran with excessive force, destroying structures and taking the lives of 13 people in Roca Sales and 12 in Cruzeiro do Sul.

Table 2 | Deaths, missing persons, and flooded structures in Vale do Taquari

Municipality	Total population (2022)	Number of deaths (May 18, 2024)	Number of missing persons (May 18, 2024)	Percentage of flooded structures in rural areas	Percentage of flooded structures in urban areas
Marques de Souza	3,969	-	1	12.92	53.63
Muçum	4,601	-	-	16.76	50.66
Roca Sales	10,418	13	3	8.96	43.91
Cruzeiro do Sul	11,600	12	6	29.11	43.44
Estrela	32,183	1	1	11.03	40.24
Travesseiro	2,152	1	-	10.32	29.66
Encantado	22,962	1	2	12.33	25.81
Colinas	2,423	-	-	12.18	23.78
Arroio do Meio	21,958	-	1	7.32	20.07
Forquetinha	2,393	2	-	16.3	14.07
Lajeado	93,646	2	5	0	8.25
Relvado	1,796	1	1	1.27	0
Imigrante	3,080	-	-	0.88	0
Doutor Ricardo	1,888	-	-	1.44	0
Canudos do Vale	1,656	-	-	2.58	0

Source: Prepared by the authors, based on IBGE (2022); Civil Defense (18/05/24); Possanti et al. (2024), and Open Buildings (2024).

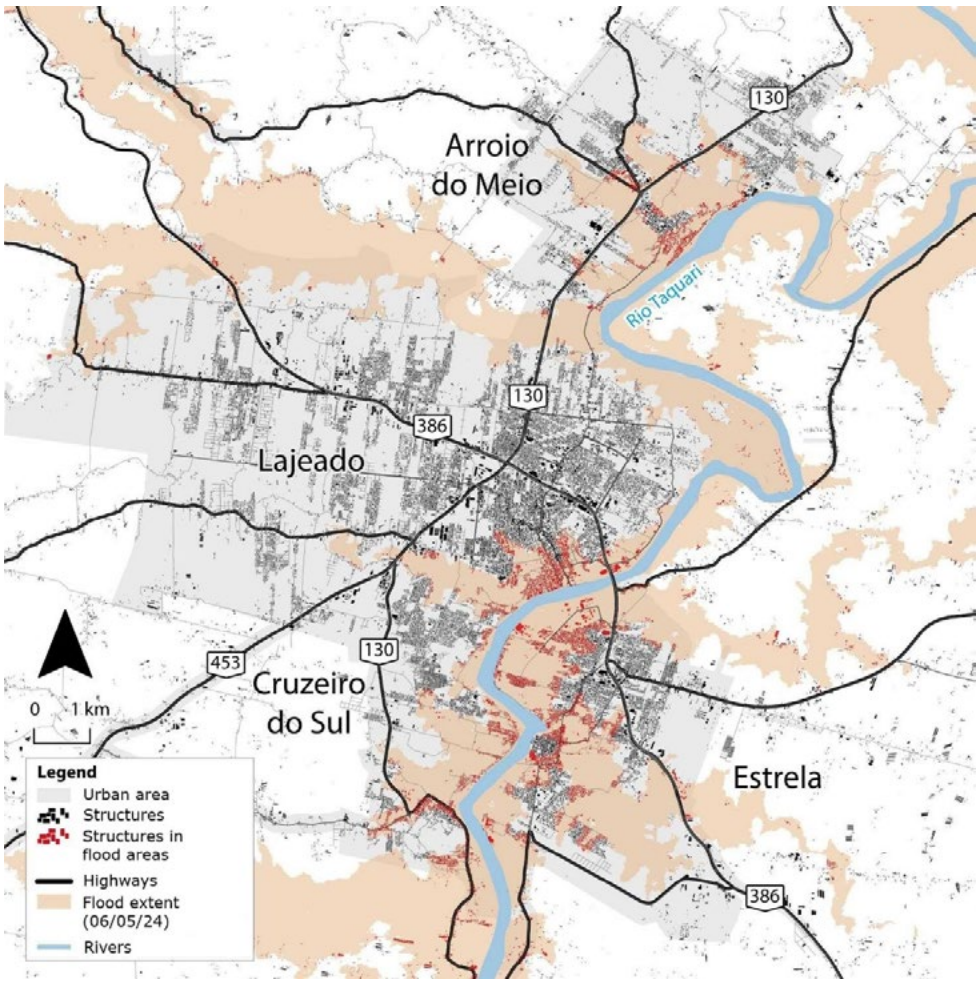
Image 4 | Map of the flood extent in municipalities of Vale do Taquari: Encantado, Roca Sales, and Muçum; Marques de Souza and Travesseiro



Source: Prepared by Carolina Rezende Faccin, based on Possanti et al. (2024) and Open Buildings (2024).

It is also important to highlight the scale of the flooding phenomenon in Lajeado and the neighboring municipalities of Estrela, Arroio do Meio, and Cruzeiro do Sul. On May 2, at 1:30 p.m., the Taquari River reached a record level of 33.35 meters in Lajeado. The map in Image 5 shows the flood extent and the significant number of affected structures in these cities: 2,635 in Arroio do Meio, 3,942 in Cruzeiro do Sul, 6,500 in Estrela, and 3,122 in Lajeado.

Image 5 | Map of the flood extent in municipalities of Vale do Taquari: Lajeado, Arroio do Meio, Cruzeiro do Sul, and Estrela



Source: Prepared by Carolina Rezende Faccin, based on Possanti et al. (2024) and Open Buildings (2024).

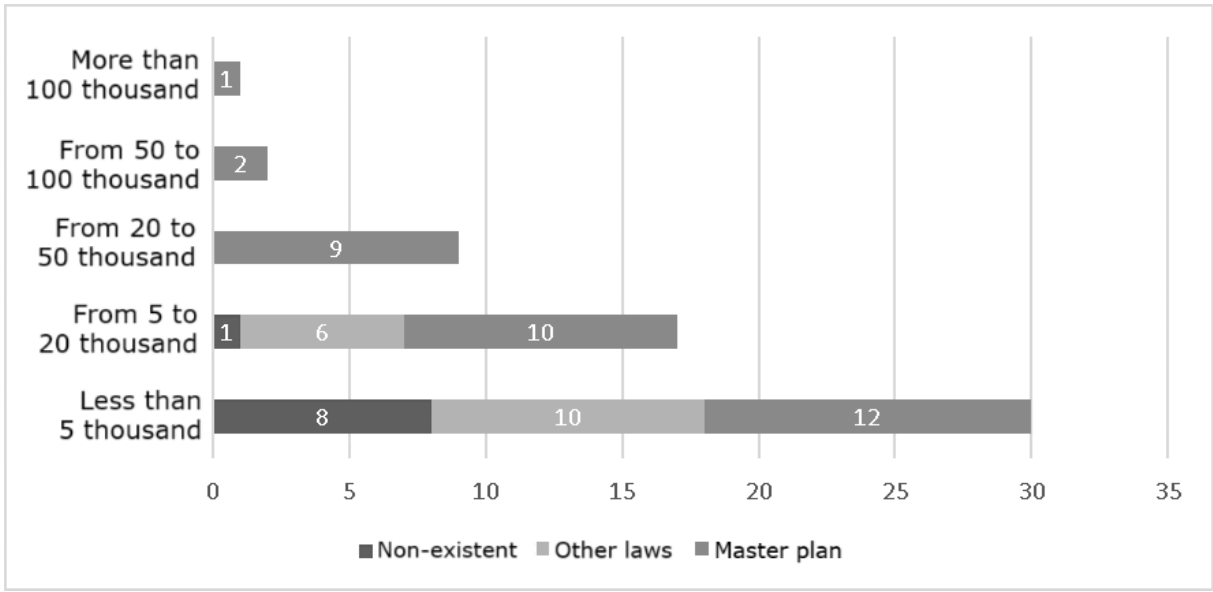
It is worth noting that, although the socio-spatial impacts of the floods are represented through the maps, the calculations resulting from this analysis should be understood as approximate values, as satellite imagery verification may not precisely correspond to reality.

However, it is important to mention that the weather events affected the municipalities in different ways, with the scale of the impacts being much more significant in the urban areas of the small cities in the region.

MUNICIPAL LAWS REGARDING SPATIAL PLANNING

To determine the existence or absence of spatial planning legislation, official websites of municipal governments in the Vales region were consulted. It was found that all municipalities with more than 20,000 inhabitants have a master plan, as shown in Image 6. Among the 47 municipalities with fewer than 20,000 inhabitants, 22 have a master plan, 16 have adopted other spatial planning laws, and 9 have no regulations of this kind. Additionally, Roca Sales and Putinga are currently in the process of developing their master plans, while Doutor Ricardo has adopted the master plan of Encantado.

Image 6 | Chart of the situation of municipalities in the regions of Vale do Rio Pardo and Vale do Taquari concerning laws related to spatial planning



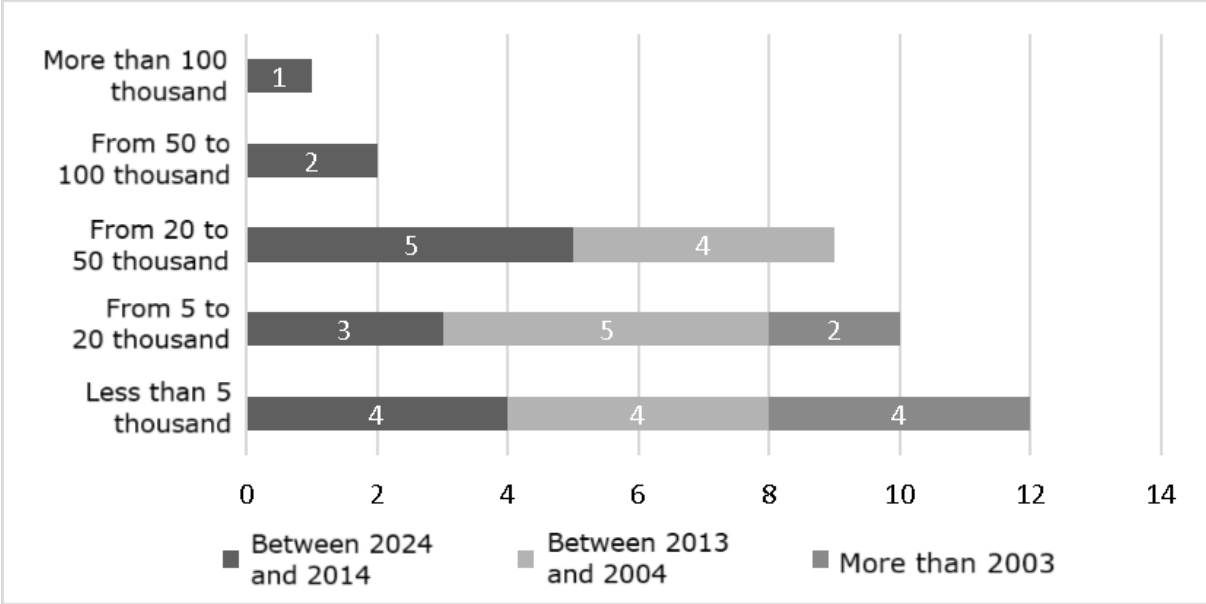
Source: Prepared by the authors, based on information gained from research on the websites of the municipal governments.

Municipalities that use other planning instruments generally have very broad urban guidelines, referencing only the urban perimeter of the municipality rather than the entire territory. In these cases, there is also a predominance of a lack of regulation and guidance for land use and occupation in rural municipal areas.

A more detailed analysis of the master plans and urban guidelines reveals the common practice of "copy and paste". Many municipalities required to have a master plan (or needing to present one to access certain state or federal public resources) end up using master plan versions from other municipalities as a "model", reproducing the same structure and content without making appropriate adaptations to their specific territorial realities. In this replication process, many municipalities fail to consider the particularities of urbanization processes and the environmental, economic, and social specificities of each city and municipality. As an example of this practice, the legislation of the municipalities of Herveiras, Segredo, and Sinimbu, in Vale do Rio Pardo, was identified.

Another important aspect to consider is the mandatory revision of master plans every 10 years. This revision aims to ensure that the documents are adjusted to new urban dynamics and the sustainable development demands of the municipalities (Brazil, 2001). In this regard, the chart in Image 7 shows that municipalities with more than 20,000 inhabitants comply with the legislation, while small cities with such instruments have revisions dating back to before 2013. Among municipalities with 5,000 to 20,000 inhabitants, three revised their master plans between 2024 and 2014, five between 2013 and 2004, and two before 2003. For municipalities with fewer than 5,000 inhabitants, the revisions are equally distributed: four between 2024 and 2014, four between 2013 and 2004, and four before 2003. In total, seven master plans are in compliance with the revision deadline, while 15 are overdue for revision.

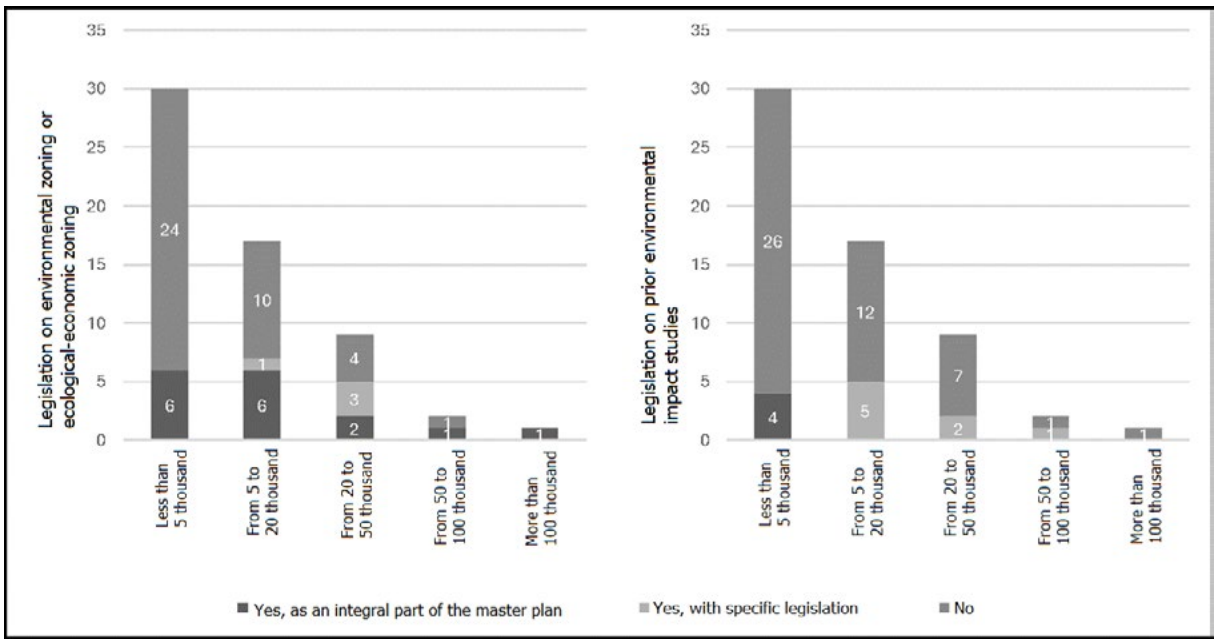
Image 7 | Chart showing the frequency of revision of master plans in municipalities in the Vales region



Source: Prepared by the authors, based on information gained from research on the websites of the municipal governments.

Based on the 2021 Basic Municipal Information Survey (MUNIC), it was examined whether the analyzed municipalities have legislation on environmental zoning or ecological-economic zoning, as well as legislation on prior environmental impact studies. The charts in Image 8 indicate that most municipalities in the Vales region lack legislation on environmental zoning or ecological-economic zoning, as well as prior environmental impact studies. Regarding zoning, 66% of the municipalities do not have such legislation, and concerning environmental impact studies, this figure rises to 80%, with the situation being more critical in small cities. Among the municipalities that address these issues, environmental zoning is more frequently included in master plans. However, prior environmental impact studies are present in the master plans of only four municipalities, all with fewer than 5,000 inhabitants: Putinga, Canudos do Vale, Fazenda Vilanova, and Ilópolis.

Image 8 | Chart of the presence of legislation on environmental zoning or ecological-economic zoning and legislation on prior environmental impact studies in the municipalities in the regions of Vale do Rio Pardo and Vale do Taquari



Source: Prepared by the authors, based on IBGE (2021).

In summary, it is evident that, in addition to developing master plans, revising these instruments is essential for addressing climate challenges that are projected to become more intense and frequent in the coming years (Clarke, Barnes, Rodrigues, et al. 2024). However, even in municipalities with updated master plans, climate change is not explicitly addressed in the legislation in force.

CONCLUSION

It is hoped that the brief analysis of socio-spatial impacts presented here will assist in identifying and reflecting on interventions in urban and rural areas, particularly in the context of small cities. The chronological and cartographic survey, in addition to serving as documentary record, enables the understanding, visualization, and analysis of the scale of the impacts generated. The extreme weather events of 2024 in Rio Grande do Sul highlighted the vulnerability of infrastructure and the inadequacy of spatial planning policies. The analysis of socio-environmental impacts reveals

the urgent need to develop and revise master plans, especially to ensure that these spatial planning instruments incorporate urban/environmental mitigation and adaptation strategies that take into account the realities of each locality and their regional context.

Small cities play an important role in the urban network and in the occupation of drainage basins, as they constitute a significant part of human settlement and are essential for territorial cohesion. However, these cities did not receive adequate attention during the catastrophe, despite being severely affected. Including these cities in public policies is crucial to ensuring the resilience and safety of their populations in facing the challenges posed by climate change. Since 2012, the City Statute has required municipalities included in the national registry to have master plans, as they include areas susceptible to large-scale landslides, flash floods, or related geological or hydrological processes. The extreme events experienced demand a reassessment of the municipalities included in this registry — at least in Rio Grande do Sul. In this regard, intervention by the Public Prosecutor's Office to enforce the requirement for master plans in municipalities recently affected by landslides, floods, and other impacts is essential.

The socio-spatial consequences observed in the regions of Vale do Rio Pardo and Vale do Taquari resulted from the impacts caused by climate change, which disregards political or territorial boundaries. Although small cities generally experience relatively less intense urbanization processes compared to medium and large cities, they were the most affected by the weather events of 2024. It is worth noting that human settlement in the affected areas of the Vales region is very old, dating back to the beginning of the colonization of Rio Grande do Sul. Therefore, the discussion about the actions needed to prevent such situations from recurring is complex and requires, above all, listening to and involving the affected population.

Writing this article amid the experience of the catastrophe was a challenging but necessary task. A thorough understanding of the impacts of the rains on the territory is vital for developing more suitable measures to promote sustainability and socio-spatial equity. It should be emphasized that collective efforts are crucial to addressing the issue of small cities — which are often left out of discussions — to ensure that their needs and vulnerabilities are fully acknowledged and addressed.

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