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PROTEÇÃO E DEFESA CIVIL NA SEGURANÇA DE BARRAGENS NO MARANHÃO: GOVERNANÇA DE RISCOS E VULNERABILIDADES INSTITUCIONAIS

CIVIL PROTECTION AND DEFENSE IN DAM SAFETY IN MARANHÃO: RISK GOVERNANCE AND INSTITUTIONAL VULNERABILITIES

PROTECCIÓN CIVIL Y DEFENSA EN MATERIA DE SEGURIDAD DE REPRESAS EN MARANHÃO: GOBERNANZA DEL RIESGO Y VULNERABILIDADES INSTITUCIONALES

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Resumo

Os acidentes e incidentes em barragens representam importante desafio para a gestão de riscos e desastres, em razão dos potenciais impactos humanos, ambientais, sociais e econômicos decorrentes

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de falhas estruturais ou eventos hidrometeorológicos extremos. Nesse contexto, o presente estudo teve como objetivo analisar o papel do serviço estatal de Proteção e Defesa Civil como instrumento de integração da segurança de barragens no Estado do Maranhão. A pesquisa possui abordagem quali-quantitativa, de caráter exploratório e descritivo, fundamentada em levantamento bibliográfico com etapa de busca estruturada, pesquisa documental, tratamento estatístico e análise espacial por meio de técnicas de geoprocessamento. Foram utilizados dados do Sistema Nacional de Informações sobre Segurança de Barragens (SNISB), do Sistema Integrado de Informações sobre Desastres (S2ID) e da Coordenadoria Estadual de Proteção e Defesa Civil do Maranhão (CEPDECMA), com apoio dos softwares Excel® e QGIS®. Foram analisadas 101 barragens cadastradas no SNISB, das quais 11 com Dano Potencial Associado alto e quatro com Categoria de Risco alta segundo a base espacial de 2024, e 21 atendimentos da CEPDECMA a barragens entre 2017 e 2022, correspondentes a cinco acidentes, 12 incidentes e quatro ações preventivas. Os resultados evidenciaram limitações potenciais de capacidade institucional associadas à cobertura espacial potencial dos órgãos de Proteção e Defesa Civil, à descontinuidade das ações de gestão de riscos e à limitada articulação entre os atores envolvidos. Esses achados demonstram que a efetividade da segurança de barragens depende não apenas das condições estruturais dos empreendimentos, mas também da capacidade institucional de planejamento, monitoramento e resposta. Como aplicação, apresenta-se, como subsídio técnico ao planejamento, uma proposta de territorialização das capacidades de Proteção e Defesa Civil, visando reduzir vazios de cobertura e fortalecer a integração entre a Política Nacional de Segurança de Barragens e a Política Nacional de Proteção e Defesa Civil.

Palavras-chave: Segurança de barragens; Proteção e Defesa Civil; Governança de riscos; Vulnerabilidades institucionais; Gestão de riscos.

Abstract

Dam accidents and incidents pose a significant challenge for risk and disaster management due to the potential human, environmental, social, and economic impacts resulting from structural failures or extreme hydrometeorological events. In this context, this study aimed to analyze the role of the state Civil Protection and Defense service as an instrument for integrating dam safety in the State of Maranhão. The research employed a mixed-methods approach (qualitative and quantitative) of an exploratory and descriptive nature, based on a literature survey with a structured search stage, document analysis, statistical processing, and spatial analysis using geoprocessing techniques. Data were obtained from the National Dam Safety Information System (SNISB), the Integrated Disaster Information System (S2ID), and the Maranhão State Civil Protection and Defense Coordination (CEPDECMA), utilizing Excel® and QGIS® software. The analysis covered 101 dams registered in SNISB, 11 of which have high Associated Potential Damage and four have a high Risk Category according to the 2024 spatial database, and 21 CEPDECMA responses to dams between 2017 and 2022, comprising five accidents, 12 incidents and four preventive actions. The results revealed potential institutional capacity limitations regarding the potential spatial coverage of Civil Protection and Defense agencies, the lack of continuity in risk management actions, and limited coordination among the stakeholders involved. These findings demonstrate that the effectiveness of dam safety depends not only on the structural conditions of the facilities but also on the institutional capacity for planning, monitoring, and response. As an application, a territorialization proposal for Civil Protection and Defense capacities is presented as technical input for planning, aimed at reducing coverage gaps and strengthen the integration between the National Dam Safety Policy and the National Civil Protection and Defense Policy.

Keywords: Dam safety; Civil protection and defense; Risk governance; Institutional vulnerabilities; Risk management.

Resumen

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Los accidentes e incidentes en represas representan un desafío significativo para la gestión de riesgos y desastres debido a los potenciales impactos humanos, ambientales, sociales y económicos derivados de fallas estructurales o eventos hidrometeorológicos extremos. En este contexto, este estudio tuvo como objetivo analizar el rol del Servicio Estatal de Protección Civil y Defensa como instrumento para la integración de la seguridad de represas en el estado de Maranhão. La investigación emplea un enfoque cualitativo-cuantitativo, exploratorio y descriptivo, basado en un levantamiento bibliográfico con etapa de búsqueda estructurada, investigación documental, tratamiento estadístico y análisis espacial mediante técnicas de geoprocesamiento. Se utilizaron datos del Sistema Nacional de Información sobre Seguridad de Represas (SNISB), el Sistema Integrado de Información sobre Desastres (S2ID) y la Coordinación Estatal de Protección Civil y Defensa de Maranhão (CEPDECMA), con el apoyo de los programas Excel® y QGIS®. Se analizaron 101 represas registradas en el SNISB, 11 de ellas con Daño Potencial Asociado alto y cuatro con Categoría de Riesgo alta según la base espacial de 2024, y 21 atenciones de la CEPDECMA a represas entre 2017 y 2022, correspondientes a cinco accidentes, 12 incidentes y cuatro acciones preventivas. Los resultados revelaron limitaciones potenciales de capacidad institucional asociadas con la cobertura espacial potencial de los organismos de Protección Civil y Defensa, la discontinuidad de las acciones de gestión de riesgos y la limitada coordinación entre los actores involucrados. Estos hallazgos demuestran que la eficacia de la seguridad de las represas depende no solo de las condiciones estructurales de los proyectos, sino también de la capacidad institucional para la planificación, el monitoreo y la respuesta. Como aplicación, se presenta, como subsidio técnico a la planificación, una propuesta de territorialización de las capacidades de Protección y Defensa Civil, con el objetivo de reducir las brechas de cobertura y fortalecer la integración entre la Política Nacional de Seguridad de Represas y la Política Nacional de Protección Civil y Defensa.

Palabras clave: Seguridad de las presas; Protección y defensa civil; Gobernanza del riesgo; Vulnerabilidades institucionales; Gestión del riesgo.

1. Introduction

According to the National Dam Safety Information System (SNISB), Brazil has thousands of registered dams intended for a wide range of uses, including human water supply, irrigation, power generation and tailings containment. Despite the importance of these structures for socioeconomic development, technological accidents and incidents in dams can cause loss of human life, environmental damage, losses to production processes and disruption of social normality (ANA, 2023; BRASIL, 2010).

The contemporary understanding of disasters shows, however, that their impacts do not stem exclusively from the magnitude of the triggering event. The resulting consequences also derive from the pre-existing conditions of exposure, vulnerability and response capacity of the affected territories. In this sense, physical events may act as triggering factors, while territorial, social, structural and institutional vulnerabilities contribute to amplifying the magnitude of the observed damage. This perspective has gained relevance in risk management studies, especially given the

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need to overcome predominantly reactive models of action and to strengthen permanent prevention, mitigation and preparedness strategies.

In the Northeastern context, the State of Maranhão has dams distributed across different regions, with different levels of Associated Potential Damage (DPA) and Risk Category (CRI). However, the monitoring of these structures is fragile, owing to the limited number of inspections, the occurrence of extreme events related to heavy rainfall and the operational vulnerabilities of the agencies responsible for risk management (BRASIL, 2010; FRANÇA, 2024). This scenario makes it particularly relevant to analyze the institutional capacity available in the territory for prevention, preparedness and response to possible accidents and incidents involving dams.

Records of the Maranhão State Civil Protection and Defense Coordination (CEPDECMA) indicate the occurrence of incidents and accidents in dams in Maranhão, highlighting the need to strengthen preventive and response actions. Added to this scenario are the limited institutional coverage of Municipal Civil Protection and Defense Coordination Offices in part of the state territory, as well as difficulties related to the continuity of risk management actions and to the integration among the different actors involved in dam safety (FRANÇA, 2024). This need for institutional strengthening is supported by Rocha et al. (2023), who, when analyzing the actions of the state Civil Defense in Trizidela do Vale, Maranhão, highlighted the importance of shifting from a predominantly reactive approach to one oriented toward risk management, encompassing prevention, mitigation and preparedness, articulated with response and recovery actions.

Given these limitations, there are gaps in the articulation between the National Dam Safety Policy (PNSB) and the National Civil Protection and Defense Policy (PNPDEC), a situation that may compromise the efficiency of actions aimed at the prevention, mitigation, preparedness and response to technological accidents involving dams in Maranhão. The safety of these structures depends not only on regulatory instruments and on the physical conditions of the facilities, but also on the institutional capacity of the agents involved to monitor risks, share information, plan actions and respond adequately to critical situations. From this problem, the following

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research question is established: **how can the state Civil Protection and Defense service act as an effective instrument for integrating dam safety in the territory of Maranhão?**

The contemporary discussion on dam safety therefore goes beyond strictly structural and regulatory aspects, incorporating approaches related to *risk governance*, *Disaster Risk Reduction* (DRR) and *territorial resilience*. From this perspective, the effectiveness of prevention, preparedness and response actions depends on the institutional capacity for coordination among the different actors involved, on the integration of public policies and on the adequate territorial distribution of the resources allocated to risk management. In Maranhão, França et al. (2023) emphasize that the identification, monitoring and territorial analysis of risks are relevant instruments to support Civil Protection and Defense actions and institutional decision-making.

The spatial dimension is particularly important in this process, since the mere existence of institutional structures does not necessarily mean that they are territorially distributed in a manner compatible with existing risks. Geoprocessing and spatial analysis techniques make it possible to integrate territorial information, identify distribution patterns and recognize areas that require greater attention from public authorities. Recent studies have demonstrated the applicability of these tools in identifying vulnerable areas and supporting territorial planning and preventive risk management, expanding the capacity to interpret the relationships between adverse events, exposure and territorial vulnerabilities.

Although the national literature has advanced in the discussion of the regulatory, structural and institutional aspects of dam safety and disaster management, studies that jointly analyze the spatial distribution of dams, the records of accidents and incidents and the territorial distribution of state Civil Protection and Defense capacities remain limited. This gap is particularly relevant in states with large territorial extension and uneven institutional coverage, such as Maranhão. The joint analysis of these dimensions makes it possible to shift the discussion of dam safety

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from a predominantly structural perspective to a territorial and institutional approach to risk management.

The study is thus based on the hypothesis that the technological risks related to dams cannot be understood solely from the physical characteristics of the structures, since their possible impacts result from the interaction among triggering events, territorial exposure, vulnerabilities and institutional limitations. Accordingly, it is considered that the analysis of the spatial distribution of Civil Protection and Defense capacities, when related to the location of dams and to the records of accidents and incidents, can reveal areas of insufficient coverage and contribute to improving planning, prevention and institutional response.

The research is justified by the need to strengthen the prevention and mitigation of technological risks associated with dams in Maranhão, as well as by the scarcity of studies on the integration between the National Dam Safety Policy and the National Civil Protection and Defense Policy at the state level. In addition to its scientific contribution, the study is applicable to public management, as it produces information capable of supporting operational regionalization strategies, the definition of priority areas, the allocation of resources and the strengthening of institutional capacities aimed at protecting life, property and the environment.

The general objective of this study is to analyze the role of Civil Protection and Defense in dam safety in the State of Maranhão, considering risk governance, institutional vulnerabilities and the integration of state capacities for prevention, preparedness and response. Specifically, it seeks to: **i)** characterize the risks associated with dams in Maranhão; **ii)** identify institutional and operational vulnerabilities of Civil Protection and Defense agencies related to dam safety; **iii)** analyze the territorial distribution of state prevention and response capacities; and **iv)** discuss strategies capable of strengthening risk governance and the integration between the National Dam Safety Policy and the National Civil Protection and Defense Policy.

2. Literature Review

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2.1 Risk governance, vulnerability and territorial resilience

The concept of risk governance comprises the set of institutional, regulatory and operational mechanisms aimed at identifying, assessing, communicating and managing the risks that affect society. Unlike approaches focused exclusively on the technical control of hazards, risk governance presupposes the articulated participation of public agencies, private institutions, communities and other actors involved in decision-making processes, recognizing that complex risks require equally integrated management mechanisms (RENN, 2008).

This conception is especially relevant to the management of technological risks and disasters, since the occurrence of damage does not depend exclusively on the intensity of the triggering event. Risk results from the interaction among hazards, exposure, vulnerabilities and the capacities existing in the territory. In this sense, the magnitude of the consequences may be amplified by social, environmental, structural and institutional weaknesses, making strategies based solely on response after the disaster has materialized insufficient.

Studies on the occurrence of extreme events show that pre-existing conditions of vulnerability directly influence the severity of impacts. The analysis of hydrometeorological disasters, for example, shows that events of a similar nature can produce different consequences depending on the conditions of exposure, territorial planning, infrastructure and institutional capacity of the affected areas. Batista et al. (2026) emphasize this distinction by considering that not every rainfall event necessarily results in a recorded disaster and that the magnitude of socio-environmental impacts is related to the conditions of vulnerability and exposure in the territory.

Risk governance is reflected in the international guidelines for Disaster Risk Reduction (*Disaster Risk Reduction* – DRR), especially in the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR, 2015). The document establishes the

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strengthening of disaster risk governance as one of its priorities, emphasizing the need to define responsibilities, intersectoral coordination, stakeholder participation and the integration of public policies. This approach treats prevention, mitigation, preparedness, response, recovery and rehabilitation as articulated dimensions of risk reduction.

Associated with governance, the concept of territorial resilience refers to the capacity of territories, institutions and communities to resist, absorb, adapt to and recover their functions in the face of adverse events. Building resilience is therefore not restricted to the availability of physical infrastructure, but also depends on knowledge about risks, planning, resources, permanent institutions and efficient coordination mechanisms. In this sense, the Sendai Framework emphasizes both the strengthening of governance and preparedness for effective response, as well as the existence of capacities at different territorial levels (UNDRR, 2015).

From this perspective, institutional vulnerability is a relevant component of risk analysis. Insufficient administrative structures, the discontinuity of public actions, staff turnover, the limited availability of resources and weak coordination among institutions can compromise the capacity to anticipate and manage critical situations. In the field of Civil Protection and Defense, such weaknesses can produce significant territorial differences in the state capacity for prevention, preparedness and response, especially in states with large geographic extension and uneven distribution of operational structures.

Thus, risk governance, vulnerability and territorial resilience are interdependent concepts. Applied to dam safety, they make it possible to understand that risk reduction depends not only on the physical stability of the structures, but also on the institutional capacity available to monitor them, communicate critical situations, plan preventive measures, coordinate different actors and respond to possible accidents and disasters.

2.2 Dam safety and the National Dam Safety Policy

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Dam safety is a strategic issue for the protection of life, property, economic activities and the environment. Dams are fundamental structures for different uses, including water supply, irrigation, power generation, water flow regulation and tailings disposal. However, structural failures, maintenance deficiencies, extreme hydrological events and management problems can produce incidents, accidents and disasters with high-magnitude consequences.

In Brazil, Law No. 12,334/2010 established the National Dam Safety Policy (PNSB) and created the National Dam Safety Information System (SNISB). The policy established principles, instruments and responsibilities for controlling the safety conditions of dams, incorporating monitoring, inspection and risk management throughout the different stages of the life cycle of these structures (BRASIL, 2010).

The elements used to classify dams include the Risk Category (CRI) and the Associated Potential Damage (DPA), according to criteria established by CNRH Resolution No. 143/2012 (BRASIL, 2012b). While the risk classification relates to the technical characteristics, state of conservation and safety conditions of the structure, the DPA expresses the potential consequences of failure, leakage, seepage or malfunction, regardless of the probability of the event occurring. This distinction is relevant because structures that do not have a high risk category may be located in areas where a possible failure would produce significant social, economic and environmental consequences.

Among its objectives, the PNSB establishes the prevention of accidents and disasters, the monitoring of safety actions, the expansion of control by public authorities, the production of information for safety management and the strengthening of a risk management culture. The legal framework also provides for emergency procedures and joint action among dam owners, regulatory agencies and Civil Protection and Defense agencies in the event of incidents, accidents or disasters (BRASIL, 2010; BRASIL, 2020).

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Dam safety, therefore, is not the isolated responsibility of a single institution. The dam owner is legally responsible for the safety of the structure, while different regulatory agencies exercise their competences according to the purpose of the dam and the jurisdiction over the resources involved. The multiplicity of regulatory agencies and the limitations related to the availability of technical information and specialized professionals are additional challenges to the effectiveness of dam safety inspection in the country (SILVA; MATTOS; SILVA, 2023). The National Water and Sanitation Agency (ANA), for example, is responsible for inspecting certain water storage dams on federal rivers, in addition to organizing, implementing and managing the SNISB and promoting coordination among regulatory agencies (ANA, 2023).

The multiplicity of institutions and competences involved in dam safety also poses challenges related to coordination among the agencies responsible for regulation and inspection, reinforcing the need for governance mechanisms capable of reducing institutional fragmentation (AZEVEDO, 2023).

This institutional architecture makes it necessary to articulate inspection, emergency management and Civil Protection and Defense. Decree No. 11,310/2022 reinforced this dimension by regulating the federal governance of the PNSB and establishing the Interministerial Dam Safety Committee (CInSB). Its governance competences include the articulation aimed at making the PNSB compatible with the National Civil Protection and Defense Policy and other sectoral policies, showing that structural safety and territorial risk management are complementary dimensions (BRASIL, 2022).

Planning and emergency instruments play a central role in this integration. The Dam Safety Plan, safety inspections, the Periodic Safety Review and, where applicable, the Emergency Action Plan (PAE) contribute to monitoring structural conditions and organizing the measures required in abnormal situations. The effectiveness of these instruments, however, depends on the adequate flow of information and on coordination among dam owners, regulatory agencies, Civil Protection and Defense agencies and potentially affected populations.

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In this sense, Rocha and Freire (2023) highlight the need for integration between the National Dam Safety Policy and the National Civil Protection and Defense Policy. The articulation between these systems brings instruments predominantly related to the structural safety of dams closer to territorial prevention, preparedness and response mechanisms. This integration is particularly important in situations in which the travel time of teams, the availability of local structures and the capacity for institutional mobilization may directly affect the effectiveness of emergency actions.

2.3 Civil Protection and Defense and institutional capacities

The National Civil Protection and Defense Policy, established by Law No. 12,608/2012, consolidated in Brazil an approach oriented toward the integrated management of risks and disasters. From this perspective, Civil Protection and Defense actions encompass prevention, mitigation, preparedness, response and recovery, shifting the focus from an exclusively emergency-based approach to a model in which the anticipation and reduction of risks assume strategic importance (BRASIL, 2012a).

Rocha et al. (2023), when studying the actions of the State Civil Protection and Defense Coordination in Maranhão, emphasize precisely this transformation. Contemporary Civil Defense incorporates risk management activities, seeking not only to manage the consequences of a disaster that has already occurred, but also to develop measures capable of reducing impacts in advance. The authors also emphasize the need to articulate the different federative levels and to integrate public agencies, private institutions and civil society.

This perspective makes institutional capacity a relevant variable in risk analysis. The formal existence of Civil Protection and Defense agencies does not, by itself, ensure the effectiveness of their actions. State capacity depends on factors such as qualified human resources, availability of equipment, administrative continuity, planning, information systems, mobilization capacity and articulation

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among the different levels of government (QUEIROZ; MARCHEZINI; RODRIGUEZ, 2023).

This perspective is also supported by the national diagnosis of municipal Civil Protection and Defense capacities, in which structure, training and governance are fundamental dimensions for assessing the institutional conditions for risk and disaster management (BRASIL, 2021).

In Maranhão, this issue is especially important given the territorial extension of the state and the heterogeneous distribution of institutional structures. Studies carried out in the Brazilian context show that limited institutional support and weak structuring of municipal agencies can be obstacles to the consolidation of local Civil Protection and Defense capacities (LONDE; SORIANO; COUTINHO, 2015).

In this context, the territorial distribution of institutional capacities becomes as relevant as their administrative existence. Municipalities located at great distances from state operational structures or without consolidated municipal agencies may be more dependent on the mobilization of external resources, increasing the challenges associated with response time. In situations involving dams, in which certain scenarios may require rapid communication and mobilization, the regionalization of state capacities is an important aspect of preventive planning.

The role of Civil Protection and Defense in dam safety should therefore be understood beyond emergency response. Its participation involves knowledge of risk scenarios, contingency planning, communication, community preparedness, simulation exercises, integration with dam owners and regulatory agencies, and the articulation of the capacities available in the territory. The PNSB legislation itself provides for joint action by these actors in the event of incidents, accidents or disasters, institutionally reinforcing this integration.

From a governance perspective, the capacity for coordination among these institutions is essential. The fragmentation of information, unclear operational responsibilities, low policy continuity and the absence of permanent local structures may limit the translation of regulatory instruments into effective risk reduction actions.

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Thus, assessing dam safety from the perspective of Civil Protection and Defense implies analyzing not only which institutions exist, but also where they are located, which areas they can serve and how they relate to territorially distributed risks.

2.4 Spatial analysis applied to territorial risk management

The territorial dimension of risks requires instruments capable of spatially representing hazards, exposed elements and institutional capacities. In this context, Geographic Information Systems (GIS) and geoprocessing techniques are relevant tools for organizing, integrating, analyzing and representing spatially referenced information.

Recent studies show that geotechnologies can be used to map risk areas, recognize land-use patterns, monitor affected areas over time and correlate environmental and territorial variables. These tools expand the capacity to interpret phenomena and support preventive planning and decision-making (SILVA et al., 2025).

This approach is not limited to mapping the places where events occur. Spatial analysis can also represent the distribution of the institutional resources available for prevention and response. Thus, overlaying the location of hazards, potentially affected areas, historical records of occurrences and the location of operational structures makes it possible to identify coverage gaps and territories that require institutional strengthening.

The use of GIS therefore has significant potential for Civil Protection and Defense. França et al. (2023) show that the spatialization of responses can contribute to identifying territorial patterns and understanding the distribution of disasters, providing information to support planning and decision-making. This perspective is particularly useful when associated with the analysis of large territories, in which distances and travel times can be important constraints on response capacity.

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In the case of dam safety, spatial analysis makes it possible to integrate the location of dams and their risk and potential damage classifications with the available institutional capacities. The joint representation of these variables makes it possible to move from an exclusively structural analysis of dams to a territorial interpretation of risk, incorporating the prevention, preparedness and response conditions existing in potentially affected areas.

Isochrones are an additional resource for this type of analysis, as they represent the areas reachable from a given point within a given travel time. When applied to the operational units responsible for Civil Protection and Defense actions, they make it possible to estimate potential territorial coverage and to identify areas in which a response may require longer mobilization times. However, their interpretation must consider that travel time does not, by itself, represent operational capacity, since the availability of teams, road conditions, material resources, the characteristics of the event and inter-institutional coordination also influence the response.

In this sense, spatial analysis should not be understood merely as a cartographic instrument for representing results, but as an analytical component of risk governance. By making visible the territorial inequalities in the distribution of prevention and response capacities, geoprocessing provides support for planning, resource allocation, institutional strengthening and the integration between the National Dam Safety Policy and the National Civil Protection and Defense Policy.

3. Methodology

3.1 Research characterization and design

The research was carried out in the State of Maranhão, located in the Northeast Region of Brazil, adopting the entire state territory as the spatial scope. The choice of this scale of analysis resulted from the distribution of dams across different regions of the state and from the need to assess, in an integrated manner, the location of these structures, the records of accidents and incidents and the

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territorial distribution of the institutional capacities responsible for Civil Protection and Defense actions.

As to its approach, the study is qualitative-quantitative, applied in nature and exploratory and descriptive in character. The quantitative dimension comprised the organization and analysis of data on registered dams, their uses, Risk Category (CRI), Associated Potential Damage (DPA), records of accidents and incidents and the distribution of institutional response structures. The qualitative dimension focused on interpreting institutional and operational vulnerabilities and the interfaces between the National Dam Safety Policy (PNSB) and the National Civil Protection and Defense Policy (PNPDEC).

The exploratory character stemmed from the integrated analysis of a topic still little investigated in the context of Maranhão, especially regarding the relationship among dam safety, institutional capacity and the territorial distribution of Civil Protection and Defense resources. The descriptive character, in turn, was associated with the characterization of dams, recorded events and existing institutional structures, as well as with the spatial representation of these variables.

The methodological design was structured around the integration of four complementary procedures: literature survey, documentary research in official databases, descriptive statistical processing and spatial analysis using geoprocessing techniques. This integration made it possible to relate the characteristics of the dams and the historical records of occurrences to the institutional and territorial conditions for prevention, preparedness and response.

3.2 Literature and documentary survey

The literature survey was conducted to support the concepts related to dam safety, risk management and governance, Civil Protection and Defense, institutional vulnerability, disaster risk reduction and territorial analysis. To organize the survey, an initial structured search stage was adopted, with no intention of constituting a systematic review. Searches were carried out on Google Scholar, using combinations of descriptors related to dam safety, Civil Protection and Defense, risk

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governance, institutional vulnerability and disaster management. Priority was given to scientific publications, technical documents and studies directly related to the object of the research, considering thematic relevance, full-text availability and contribution to the theoretical framework and to the discussion of results.

This initial stage was carried out in 2023, in the research that gave rise to this study (FRANÇA, 2024), using the combined descriptors “barragens maranhenses” (Maranhão dams), “desastres” (disasters), “Proteção e Defesa Civil” (Civil Protection and Defense) and “Maranhão”, a time frame from 2018 to 2023 and inclusion only of works available in full text. The search retrieved 131 works; the ten ranked highest by the platform’s relevance ordering were screened by title and abstract, with five excluded for lacking a direct relationship with the research problem and five studies included. This set was complemented by classic works, dissertations, theses and studies published after 2023, selected for thematic relevance in order to update the theoretical framework and the discussion of results.

In parallel, documentary research was carried out on legislation, standards, technical reports and official databases related to dam safety and to risk and disaster management. The regulatory analysis covered, in particular, Federal Law No. 12,334/2010, which established the National Dam Safety Policy; Federal Law No. 12,608/2012, which established the National Civil Protection and Defense Policy; and Federal Law No. 14,066/2020, which amended provisions of the PNSB; in addition to SEMA Ordinance No. 132/2017 and State Law No. 11,687/2022, at the state level.

The documentary analysis sought to identify institutional responsibilities, coordination mechanisms, planning instruments and possible interfaces between the PNSB and the PNPDEC, especially regarding prevention, preparedness and response actions for accidents and incidents involving dams.

3.3 Databases, time frame and selection criteria

Data collection was predominantly secondary, using information from official databases of federal and state agencies. The following were consulted: the National

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Dam Safety Information System (SNISB), databases of the National Water and Sanitation Agency (ANA), the Integrated Disaster Information System (S2ID), the Maranhão State Civil Protection and Defense Coordination (CEPDECMA) and the Maranhão Military Fire Brigade (CBMMA).

Chart 1 summarizes the databases used, the information extracted from each, the reference period or date and the extraction date or period. Since the databases have different time references, the results should be read as the overlay of records from different moments, and not as a synchronic portrait of the territory.

Chart 1 – Databases used, reference period and extraction period

Database	Information used	Reference period or date	Extraction date or period
SNISB/ANA	Registry of dams in Maranhão: purpose of use, DPA, CRI, inspections and new registrations (Table 1)	Registry status in 2023	Sep 13, 2023
SNISB/ANA	Location of dams and DPA/CRI classification for spatialization (Figures 1 and 3; Chart 3)	Registry status in 2024	2024
CEPDECMA	Geographic Database, Technical Reports (RTE), technical opinions, minutes and technical visits for the 21 responses to dams (Table 2)	2017 to 2022	2023–2024
CEPDECMA	Municipalities with an operational COMPDEC	2023	2023
S2ID	Records and recognitions of SE and ECP; municipal Contingency Plans registered	2017 to 2022 (records); 2023 (plans)	2023–2024
CBMMA	Location of UBMs, Civil Protection and Defense Regional Offices and their jurisdictions	2023–2024	2024
IBGE	Territorial meshes of the state and municipalities	Municipal mesh in force at the time of download	2023
OpenStreetMap (OSMDownloader plugin)	Road network for cartographic representation	2023	2023
HERE (Hqgis plugin)	30- and 60-minute isochrones from the UBMs (Figure 2)	Processed in 2023	2023

Source: Prepared by the authors based on ANA (2023), CEPDECMA (2024), S2ID (2024), CBMMA (2024) and IBGE (2024).

Chart 1 shows that the information on dams and occurrences, referring to 2017–2023, precedes part of the institutional data, referring to 2023–2024. This time lag was considered in the interpretation of the results and is revisited in the limitations section.

For the characterization of dams, data on geographic location, municipality, purpose of use, Risk Category (CRI) and Associated Potential Damage (DPA) were

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considered when available. These variables made it possible to identify the distribution of dams in the territory of Maranhão and to recognize those classified under conditions considered most relevant to the analysis of risk management.

The documentary research on occurrences considered the institutional records of accidents and incidents involving dams in Maranhão. The CEPDECMA and S2ID data covered the period from 2017 to 2022, including records of accidents and incidents, associated occurrences, the timing of Situation of Emergency (SE) and State of Public Calamity (ECP) decrees, as well as the triggering events and respective causal links identified in the institutional records.

The 21 records analyzed correspond to CEPDECMA responses to dams, that is, institutional activations documented in Engineering Technical Reports (RTE), technical opinions, minutes and technical visits. The classification assigned by CEPDECMA in each document was preserved: accident, incident or routine preventive action, the latter referring to inspections without a classified anomaly. This institutional classification does not necessarily coincide with the definitions of accident and incident in Law No. 12,334/2010, as amended by Law No. 14,066/2020 (BRASIL, 2020). The term disaster was reserved for events with a recognition of Situation of Emergency or State of Public Calamity recorded in S2ID, so that responses, incidents, accidents and disasters are not treated as synonyms.

Records with an identifiable relationship with dams located in the State of Maranhão and with sufficient information for their documentary or spatial characterization were included in the analysis. Duplicate data, records without identifiable territorial correspondence or information unrelated to the object of study were disregarded in the consolidation of the analytical database.

For the analysis of institutional capacities, information was considered on the Municipal Civil Protection and Defense Coordination Offices (COMPDEC), the regional Civil Protection and Defense structures and the Military Fire Brigade Units (UBM) of the CBMMA. The location of these structures was subsequently used in the spatial analysis of potential spatial coverage and its relationship with the territorial distribution of dams.

The selection and integration of variables thus sought to establish five

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analytical dimensions: i) location and classification of dams; ii) history of accidents and incidents; iii) presence and operationalization of municipal Civil Protection and Defense structures; iv) territorial distribution of state response structures; and v) existence of areas with limited institutional coverage.

3.4 Data processing and statistical analysis

After collection, the data were checked, standardized, organized and tabulated in spreadsheets in Microsoft Excel® (version 2022). The database was structured to reconcile information from different institutional sources and to allow its subsequent integration into the spatial analyses.

The quantitative analysis was carried out using descriptive statistics, with absolute and relative frequencies to characterize the main variables of the study. Among others, the distribution of dams by purpose of use, Risk Category, Associated Potential Damage, territorial location and records of accidents and incidents was analyzed.

The purpose of using descriptive statistics was to synthesize the information and recognize patterns relevant to the interpretation of the state scenario, with no intention of probabilistic inference beyond the set of records analyzed. The results were subsequently represented in tables, charts, graphs and cartographic products.

3.5 Geoprocessing and spatial analysis

The spatial component was developed in a Geographic Information System (GIS) environment, using QGIS® software. The digital cartographic databases were obtained from the Map Portal of the Brazilian Institute of Geography and Statistics (IBGE), including the territorial meshes required to contextualize the State of Maranhão and its municipalities.

The databases were obtained in shapefile format and processed in QGIS version 3.16.4. The road network used for cartographic representation was obtained from OpenStreetMap with the aid of the OSMDownloader plugin.

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The alphanumeric data on dams, accidents and incidents and institutional structures were linked to their respective geographic information, allowing their joint representation and analysis. Thematic layers were produced to spatialize the dams and their CRI and DPA classifications, the recorded occurrences, the COMPDECs, the UBMs and the regional Civil Protection and Defense structures.

The different layers were then overlaid to examine the spatial relationships between the distribution of technological risks and the location of the institutional capacities available for prevention and response. This procedure made it possible to identify territorial concentrations, potentially priority areas and localities in which the presence of dams and records of occurrences coexisted with limited institutional coverage.

3.6 Analysis of territorial coverage using isochrones

To assess the spatial accessibility and potential coverage of operational structures, isochrones were used, understood in this study as the areas reachable from a given point of origin within 30- and 60-minute travel intervals along the road network.

The analysis took as points of origin the Military Fire Brigade Units (UBM) of the CBMMA that serve as Civil Protection and Defense Regional Offices. The isochrones were generated in QGIS 3.16.4 with the Hqgis plugin (isochrone function, multiple addresses option), which queries the isoline routing service of the HERE platform using an access key. For this reason, the calculation used the road network and the speed profiles by road class of the HERE database itself, and not the OpenStreetMap network. The parameters adopted were: origin at the UBMs (start mode); time metric; intervals of 1,800 s and 3,600 s; fastest route; truck travel mode, compatible with operational vehicles; and traffic enabled, which incorporates the traffic conditions estimated by the service at the time of the query. No speed parameters were set manually. Processing was carried out in 2023; since the service's network and traffic data are continuously updated, reprocessing on other dates may produce slightly different areas.

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The choice of the 30- and 60-minute intervals was analytical. The 30-minute threshold relates to the criterion adopted in dam safety regulation to delimit the Self-Rescue Zone (ZAS), corresponding to the downstream stretch reached by the flood wave within 30 minutes or the distance of 10 km, whichever is greater, in which it is assumed that there is not enough time for intervention by the authorities (ANM, 2022). This threshold therefore makes it possible to identify the dams whose surroundings can be reached by state teams within a time compatible with supporting initial emergency actions. The 60-minute interval was adopted as a second level, representing the reach of regional mobilization for actions in the Secondary Safety Zone (ZSS), and makes it possible to distinguish areas of partial coverage from those located beyond any reach within one hour. The intervals should not be interpreted as regulatory response-time targets.

The use of these intervals made it possible to estimate the potential territorial reach of the operational units according to travel time along the road network. The areas reached were subsequently compared with the location of the dams, the municipalities with records of accidents and incidents and the municipal Civil Protection and Defense structures. The results therefore express potential spatial coverage, not actual response time, which also depends on team availability, mobilization time, material resources, road conditions, time of day, the characteristics of the emergency and institutional communication.

Based on this diagnosis, alternatives for the territorialization of operational structures and for strengthening COMPDECs in municipalities considered relevant to the management of dam-related risks were discussed. This stage sought to relate the service areas of the UBMs to the CRI and DPA of the dams, in order to support, as technical input for planning, a proposal for the territorialization of state Civil Defense actions.

The priority municipalities for strengthening COMPDECs were selected based on the coexistence of four criteria: (i) presence of a dam classified in SNISB with high DPA and/or CRI; (ii) absence of an operational COMPDEC in 2023; (iii) absence of a UBM in the municipal seat, with the dam located outside the 60-minute potential spatial coverage of existing UBMs; and (iv) history of CEPDECMA responses

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between 2017 and 2022, used as an aggravating criterion rather than a mandatory condition. Dams with high DPA or CRI located on the Island of Maranhão were not prioritized because they are situated in the area with the highest density of UBMs and COMPDECs in the state.

3.7 Data integration and interpretation

The final stage consisted of integrating the statistical, documentary and spatial results. To this end, the following were considered jointly: the location of dams, their CRI and DPA classifications, the historical records of accidents and incidents, the presence of COMPDECs, the location of UBMs and regional structures and the territorial coverage estimated by the isochrones.

The interpretation of these variables was guided by the concept of institutional vulnerability adopted in the study, understanding that risk management capacity depends not only on the formal existence of institutions, but also on their territorial distribution, operational continuity, inter-institutional coordination and capacity for mobilization in critical situations.

The scope of this interpretation should be delimited. The study did not directly measure dimensions of institutional capacity such as staffing, training, budget, equipment, operational protocols or permanent team availability. Therefore, the results are treated as territorial and organizational indicators of institutional capacity (presence or absence of structures, location of units, potential spatial coverage and documentary records), and the weaknesses identified are expressed as potential capacity limitations.

The evidence on administrative discontinuity, staff turnover and communication gaps was obtained in the research that gave rise to this study (FRANÇA, 2024), from three documentary sources: (i) the CEPDECMA registry of operational COMPDECs, which indicated 54 municipalities with an active coordination office in 2023 (24.88% of the 217 municipalities); (ii) the CEPDECMA technical reports and opinions on the 21 responses, which record dams without a technical supervisor, recurrence of anomalies after inspections and the absence of

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a COMPDEC in municipalities served; and (iii) the S2ID query, which identified only four municipalities in Maranhão with a registered Contingency Plan and no recognition of SE or ECP coded as dam failure or collapse during the period. The association of municipal staff turnover with changes in administration and with the lack of a specific public career derives from documentary analysis and from institutional observation systematized in the original research, and not from a quantitative survey of personnel, and should be understood as qualitative evidence.

The overlay of information made it possible to identify areas in which conditions associated with dam risk coexist with limited institutional coverage, supporting the discussion on territorial priorities and strategies for reorganizing state Civil Protection and Defense capacities. This approach also made it possible to analyze the integration of PNSB and PNPDEC instruments from a territorial perspective, relating structural safety, risk governance and state capacity for prevention, preparedness and response.

4. Results and Discussion

The data analysis made it possible to identify relevant aspects of dam safety in the State of Maranhão and of the institutional capacities available for managing the technological risks associated with these structures. The results show that the integration between the National Dam Safety Policy (PNSB) and the National Civil Protection and Defense Policy (PNPDEC) still has operational and structural limitations that may compromise the effectiveness of preventive and response actions.

The characterization of dams in Maranhão showed a predominance of structures intended for irrigation, confirming their relevance for agricultural activities and regional water security. The universe analyzed comprises 101 dams registered in SNISB, of which 43.56% are intended for irrigation and 14.85% for human water supply (ANA, 2023). As to classification, the 2023 statistical database recorded 11 dams with high Associated Potential Damage (DPA) and one with high Risk Category (CRI), and 63.37% of the dams lacked parameters for DPA classification and 84.16%

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for CRI classification (Table 1). In the 2024 spatial database, used in the maps and in the territorial prioritization, four dams appear with high CRI: Vené I and II (Godofredo Viana), Bacanga (São Luís) and the human water supply dam in Centro Novo do Maranhão, which reflects the updating of classifications between the two moments. These data show that, although the number of registered dams in the state is lower than that observed in other federative units, there are structures that require continuous monitoring, maintenance and specific risk management strategies.

Table 1 – Distribution of dams in Maranhão registered in SNISB by Associated Potential Damage (DPA) and Risk Category (CRI) class

Class	DPA (n)	DPA (%)	CRI (n)	CRI (%)
High	11	10.89	1	0.99
Medium	0	0.00	1	0.99
Low	26	25.74	9	8.91
No parameters for classification	64	63.37	85	84.16
Classification not applicable	–	–	5	4.95
Total	**101**	**100.00**	**101**	**100.00**

Source: Prepared by the authors based on ANA (2023).

The high proportion of unclassified dams limits the interpretation of these results: the numbers of dams with high DPA and CRI represent a floor, not the total number of potentially critical structures in the state. In addition, SNISB recorded only one inspection and no new dam registration in Maranhão in 2023.

The findings can also be interpreted in light of Beck's (2006) Risk Society Theory. According to this perspective, technological development and the expansion of modern infrastructure produce significant benefits for society, but also generate new risks of high complexity. In the case of dams in Maranhão, the risks do not stem exclusively from the physical characteristics of the facilities, but from the interaction among environmental factors, institutional limitations and territorial vulnerabilities. Thus, risk management associated with dam safety requires not only structural interventions, but also governance mechanisms capable of anticipating critical scenarios and strengthening the response capacity of the responsible institutions.

CEPDECMA responses to dams are another relevant component of the analysis. Between 2017 and 2022, 21 responses to 13 dams distributed across 11 municipalities were identified. Keeping the original classification of the CEPDECMA documents, these responses correspond to five accidents, 12 incidents and four

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routine preventive actions (Table 2). The associated events were heavy rainfall (57.14%), routine inspections (33.33%) and lack of maintenance (9.52%). In the same period, no recognition of Situation of Emergency or State of Public Calamity coded as dam failure or collapse was identified in S2ID; where a decree was issued, as in the flood associated with the malfunction of the gates of the Pericumã Dam in Pinheiro (2019), the record referred to the hydrological consequence rather than to the technological origin of the event (S2ID, 2024). For this reason, the term disaster is not applied to the 21 records as a statistical category. This result reinforces the understanding that adverse events involving dams do not stem exclusively from the construction characteristics of the dams, but also from the interaction between natural hazards and the institutional and operational vulnerabilities existing in the territories (ALMEIDA, 2011; BECK, 2006), and highlights the need to strengthen preventive, mitigation and preparedness actions within Civil Protection and Defense.

Table 2 – CEPDECMA responses to dams in Maranhão according to the original classification of the records (2017–2022)

Classification (CEPDECMA)	n	%	Dam (municipality, year)
Accident	5	23.81	Rio Flores (Joselândia, 2017); Pericumã (Pinheiro, 2019); Vené (Godofredo Viana, 2019); Copaíba Reservoir (Barra do Corda, 2020); Pirocaua Lagoon (Godofredo Viana, 2021)
Incident	12	57.14	Balneário Tiúba (Tuntum, 2018, 2019 and 2019); Pindoba Reservoir (Paço do Lumiar, 2019); Angico Reservoir (Marajá do Sena, 2019); Itamacaoca (Chapadinha, 2021); Estreito HPP (Estreito, 2022, two records); Inhauma (Caxias, 2022); Pericumã (Pinheiro, 2022); Bacanga (São Luís, 2022); Rio Flores (Joselândia, 2022)
Routine preventive action	4	19.05	Vené (Godofredo Viana, 2020, 2021 and 2022); ALUMAR tailings dam (São Luís, 2021)
Total	**21**	**100.00**	**13 dams in 11 municipalities**

Source: Prepared by the authors based on CEPDECMA (2024).

Table 2 shows that incidents predominate among the responses and that Godofredo Viana concentrates the largest number of records (five), followed by Tuntum (three). The accidents involved gate operation failures, movement of a waste rock pile and failures associated with heavy rainfall.

The spatial analysis of the data made it possible to identify the distribution of dams in relation to the existing Civil Protection and Defense structures in the State of Maranhão. Part of the dams was found to be in areas with limited institutional coverage, especially regarding the presence of operational Municipal Civil Protection

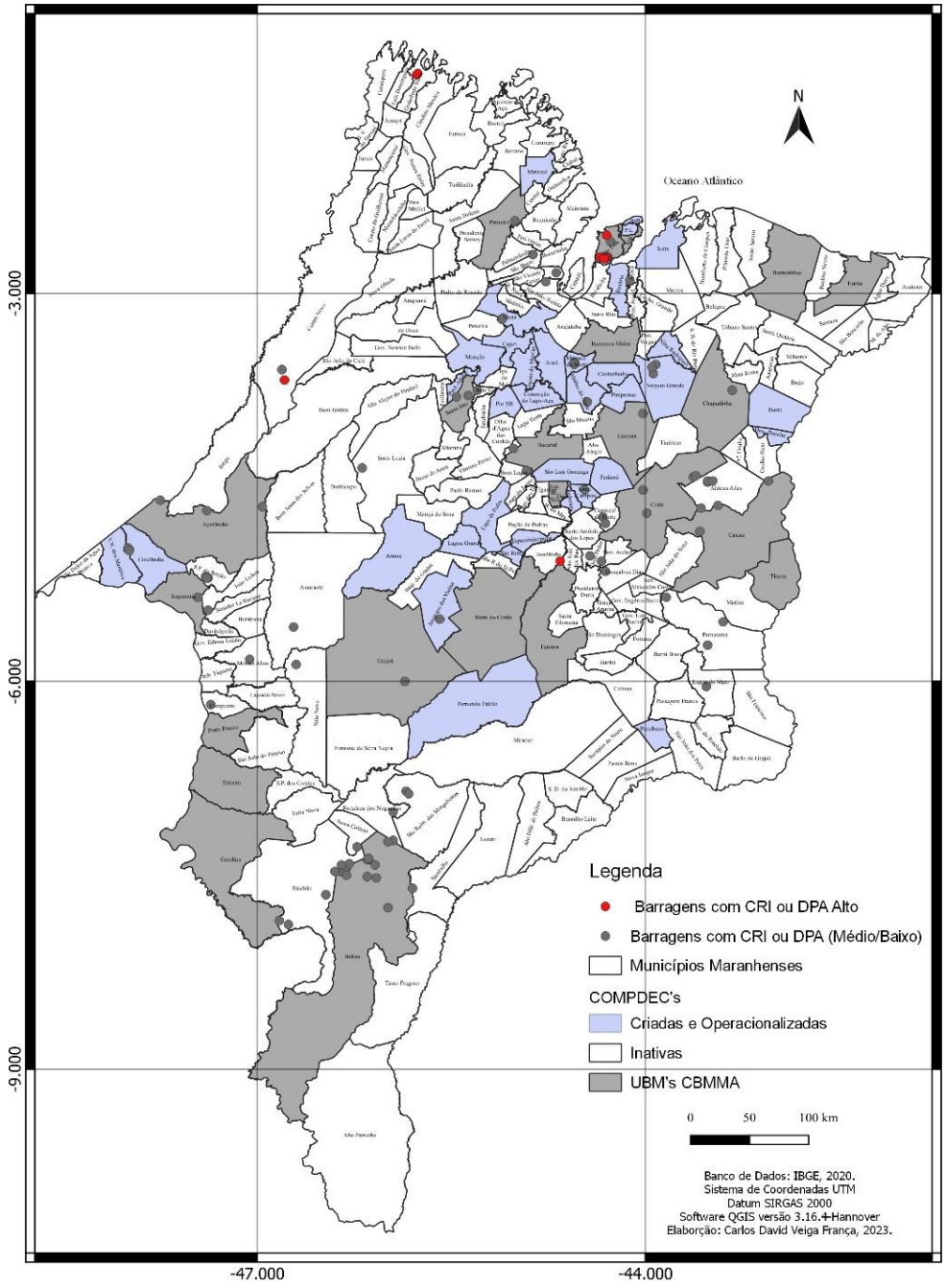
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and Defense Coordination Offices (COMPDECs) and the potential spatial coverage of the Military Fire Brigade Units (UBM) of the Maranhão Military Fire Brigade.

Figure 1 – Spatial distribution of dams and Civil Protection and Defense institutional structures in Maranhão



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Source: Prepared by the authors with data from ANA/SNISB (ANA, 2023), CEPDECMA (2024), CBMMA (2024) and IBGE territorial meshes (2024).

Figure 1 shows the territorial distribution of registered dams in relation to state and municipal Civil Protection and Defense structures. In 2023, only 54 of the 217 municipalities in Maranhão (24.88%) had an operational COMPDEC. Dams with high DPA and/or CRI are concentrated on the Island of Maranhão, the area with the highest density of UBMs and COMPDECs in the state; the institutional gaps most relevant to preventive risk management are associated mainly with the dams located in Godofredo Viana, Joselândia and Centro Novo do Maranhão, municipalities without an operational COMPDEC and without a UBM in the municipal seat. This scenario is more critical in municipalities far from operational centers, where potential travel times tend to be longer. The results indicate that territorial vulnerability is associated not only with the physical presence of dams, but also with the territorial and organizational indicators of the institutional capacity available for monitoring, coordination and response. Among the factors contributing to this situation are the territorial extension of the state, the limits of institutional coverage and, according to the documentary sources described in Section 3.7, the administrative discontinuity of COMPDECs, the turnover of municipal staff and the communication gaps among the actors involved in dam safety, factors that may reduce the effectiveness of the actions provided for by the PNSB and the PNPDEC (FRANÇA, 2024; ROCHA; FREIRE, 2023).

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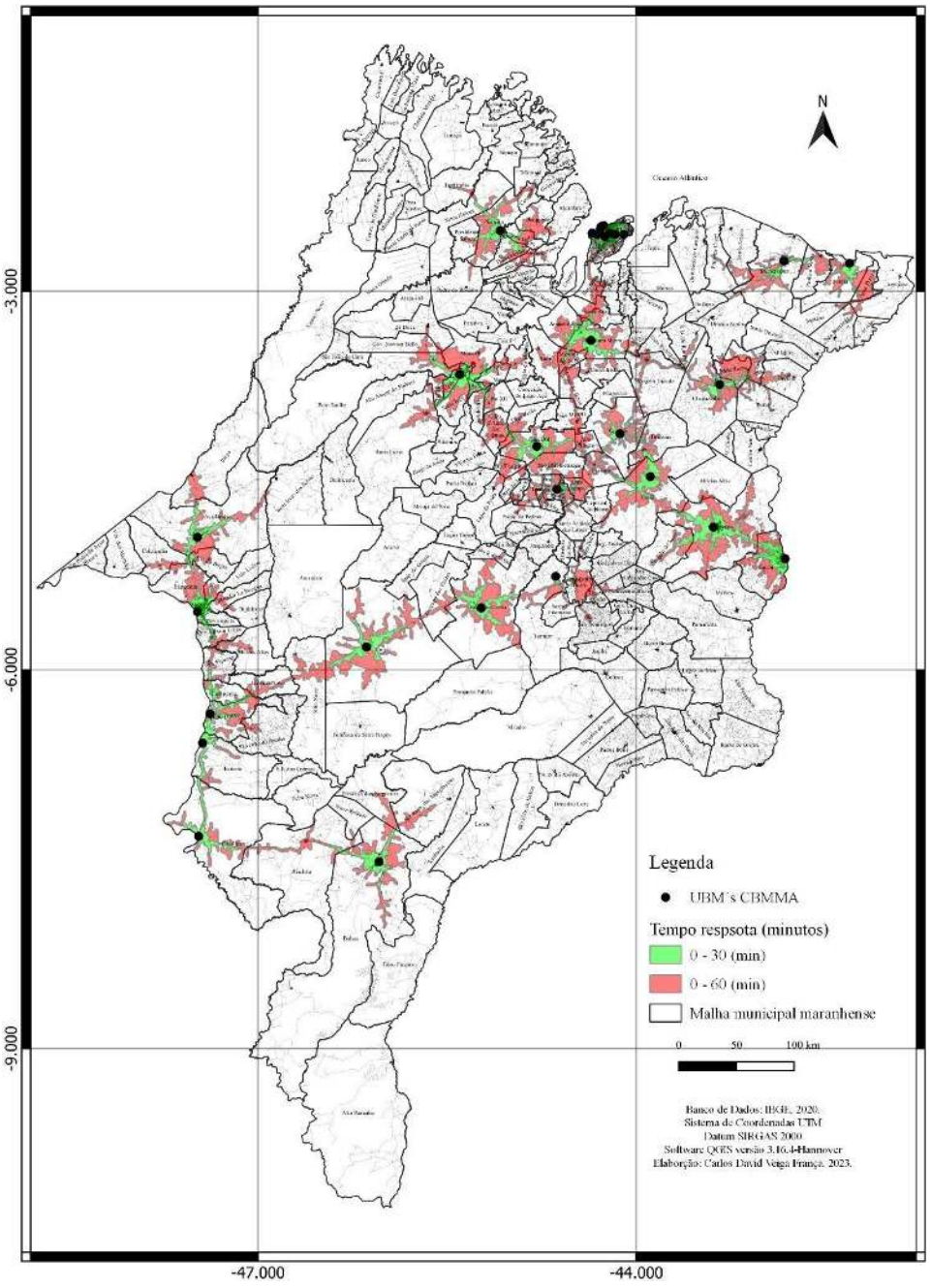
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Figure 2 – Potential spatial coverage of CBMMA UBMs estimated by 30- and 60-minute isochrones

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Source: Prepared by the authors with isochrones generated by the HERE service (Hqgis plugin, processed in 2023), based on the location of the UBMs (CBMMA, 2024) and IBGE territorial meshes (2024).

The isochrone analysis indicates that a significant part of the territory of Maranhão lies outside the 30- and 60-minute potential spatial coverage of the UBMs.

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In the jurisdiction of the 8th BBM, based in Pinheiro, 66.67% of the municipalities fall outside these ranges, including Godofredo Viana; the 13th CIBM, in Trizidela do Vale, does not reach the municipality of Joselândia, where the Rio Flores Dam is located, within 60 minutes. It should be stressed that being inside an isochrone is not equivalent to operational response within the corresponding time: actual response time also depends on team availability, mobilization, material resources, road conditions, time of day, the characteristics of the emergency and institutional communication. Even so, the condition identified indicates a potential access limitation in the face of possible accidents or incidents involving dams and reinforces the relevance of regionalization strategies capable of reducing potential travel times.

The results indicate that the mere existence of operational units does not guarantee adequate coverage of the territory. In states with large territorial extension, such as Maranhão, the potential effectiveness of the response depends on the strategic distribution of these structures and on the integration between the municipal and state levels of Civil Protection and Defense. Another aspect identified, qualitative in nature, concerns the discontinuity of risk management actions in some municipalities. The replacement of municipal Civil Protection and Defense managers and staff during changes of administration, in the absence of a specific public career, tends to cause the loss of accumulated institutional knowledge and to hinder the implementation of permanent prevention and preparedness strategies. As a consequence, reactive actions predominate over structured public policies aimed at risk reduction (SOUSA, 2019).

The results converge with Rocha et al. (2023), who, when analyzing the actions of the State Civil Protection and Defense Coordination in the municipality of Trizidela do Vale, Maranhão, highlighted the need to overcome a predominantly reactive culture and to strengthen prevention, mitigation and preparedness actions. The authors also showed that the magnitude of adverse events does not by itself determine the severity of disasters, since territorial and social vulnerability conditions directly affect their consequences. In the present study, this interpretation is extended to the context of technological risks associated with dams and to the state scale,

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incorporating the institutional and spatial dimension of response capacity into the analysis. The overlay of dam locations, records of accidents and incidents, operationalization of COMPDECs and territorial coverage of the Military Fire Brigade Units showed that vulnerability is related not only to exposure to hazards, but also to the uneven distribution of the institutional capacities responsible for prevention, preparedness and response.

Unlike the municipal scope adopted by Rocha et al. (2023), the present study analyzes the distribution of institutional capacities at the state scale and incorporates geoprocessing and spatial accessibility analysis techniques. The use of isochrones made it possible to represent the potential spatial coverage of operational structures and to identify territorial gaps that would not be revealed solely by the analysis of the formal existence of Civil Protection and Defense agencies. Thus, the results indicate that the effectiveness of the management of technological risks associated with dams depends not only on the availability of institutional structures, but also on their location, territorial reach and capacity for coordination with exposed municipalities.

Chart 2 – Comparison between the results of Rocha et al. (2023) and the present study

Aspect analyzed	**Rocha et al. (2023)**	**Present study**	**Relationship between the results**
Territorial scale	Municipality of Trizidela do Vale, Maranhão	State of Maranhão	The present study extends the analysis from the municipal to the state scale
Object of analysis	Civil Protection and Defense action in the face of risks and disasters	Dam safety, risk governance and institutional capacities	Both analyze institutional action, but applied to different risk contexts
Vulnerability	Emphasis on territorial and social conditions that influence the consequences of events	Incorporates territorial, institutional and operational vulnerabilities	Convergence on the role of vulnerability; expansion of the institutional dimension
Civil Defense action	Need to overcome predominantly reactive action	Identification of coverage limitations, institutional discontinuity and operational gaps	Convergence on the need to strengthen prevention, mitigation and preparedness

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Spatial dimension	Analysis focused on the municipal territory	State-level analysis using GIS, layer overlay and isochrones	Methodological distinction of the present study
Response capacity	Associated with institutional organization and vulnerability conditions	Also associated with the location of structures and potential travel time	The present study adds territorial accessibility to the analysis
Main contribution	Highlights the importance of preventive and integrated risk management	Spatially demonstrates inequalities in the distribution of institutional capacities	The present study broadens the approach by relating risk, territory and state capacity

Source: Prepared by the authors based on Rocha et al. (2023) and on the research results.

The comparison presented in Chart 2 shows that the results of the present study converge with Rocha et al. (2023) regarding the need to strengthen preventive capacities and the influence of vulnerabilities on the consequences of adverse events. The main difference lies in the scale and in the spatial dimension incorporated into the analysis. While the comparative study focuses on Civil Protection and Defense action in a municipal context, the present research shows, at the state scale, that institutional capacity is also conditioned by the territorial distribution of operational structures and by accessibility to potentially exposed areas. In this sense, the use of geoprocessing and isochrones made it possible to identify coverage gaps and to add to the discussion of vulnerability a dimension of potential accessibility directly related to the location and mobilization capacity of state structures.

The research showed the need to strengthen the coordination mechanisms between the instruments provided for by the National Dam Safety Policy and the National Civil Protection and Defense Policy. Although there are fundamental instruments for risk management, such as Dam Safety Plans, Emergency Action Plans and Contingency Plans, limitations persist regarding information sharing, the definition of responsibilities and coordination among dam owners, regulatory agencies and Civil Protection and Defense institutions. These results corroborate Rocha and Freire (2023) in showing that the effectiveness of the integration between the PNSB and the PNPDEC depends on the articulation among these actors. In Maranhão, however, potential limitations associated with the territorial distribution of

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institutional structures persist, which may compromise monitoring, preparedness and response actions.

From the perspective of risk governance proposed by Renn (2008), the results show that the vulnerability associated with dams in Maranhão does not stem exclusively from the physical characteristics of the structures, but from the interaction among exposure, institutional vulnerability, response capacity and coordination mechanisms among the different actors involved. This understanding is close to contemporary approaches to *disaster risk reduction – DRR*, according to which prevention depends on the articulation among monitoring, territorial planning and institutional strengthening.

This interpretation is supported by the guidelines of the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR, 2015), which establishes as a priority the strengthening of risk governance and of local institutional capacities for disaster prevention, preparedness and response. In this sense, the results show that expanding the territorial coverage of Civil Protection and Defense agencies is a strategic measure for increasing territorial resilience to the technological risks associated with dams.

The vulnerabilities identified go beyond exclusively technical aspects, encompassing organizational, communicational and institutional factors that may limit the capacity for coordination among the actors responsible for managing dam-related risks. Such weaknesses show that the effectiveness of dam safety depends not only on the structural conditions of the facilities, but also on the state capacity for planning, monitoring and response.

While Rocha and Freire (2023) focus their analysis on the regulatory integration between the National Dam Safety Policy and the National Civil Protection and Defense Policy, and Carvalho (2019) emphasizes the institutional weaknesses associated with the governance of technological risks, the present research advances by incorporating a geospatial approach applied to the public management of risks. This approach dialogues with França et al. (2023), who demonstrated the applicability of the spatialization of responses and the production of thematic maps for identifying

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risk situations and supporting Civil Protection and Defense actions in the territory of Maranhão.

The data analyzed, which identified 11 dams classified with high Associated Potential Damage (DPA), four dams with high Risk Category (CRI) in the 2024 spatial database and 21 CEPDECMA responses (five accidents, 12 incidents and four preventive actions) distributed across 11 municipalities in Maranhão, revealed limitations of institutional coverage and operational gaps in areas potentially exposed to dam-related risks. Unlike previous studies, the present research shows spatially how the distribution of institutional structures may condition the effectiveness of monitoring, preparedness and response actions. Thus, the central contribution of this work is to show that the effectiveness of dam safety policies depends not only on legal and regulatory instruments, but also on the adequate spatial distribution of the institutional capacities responsible for disaster prevention and response.

The main practical contribution of the study stems from this joint reading: technological risk and state capacity need to be analyzed in the same territory. A dam with high DPA requires attention in itself, but the management priority becomes greater when high potential damage, a history of occurrences, the absence of a consolidated municipal structure and a greater distance from state units coexist. It is this overlap of conditions, and not each variable in isolation, that guides the territorial prioritization presented below.

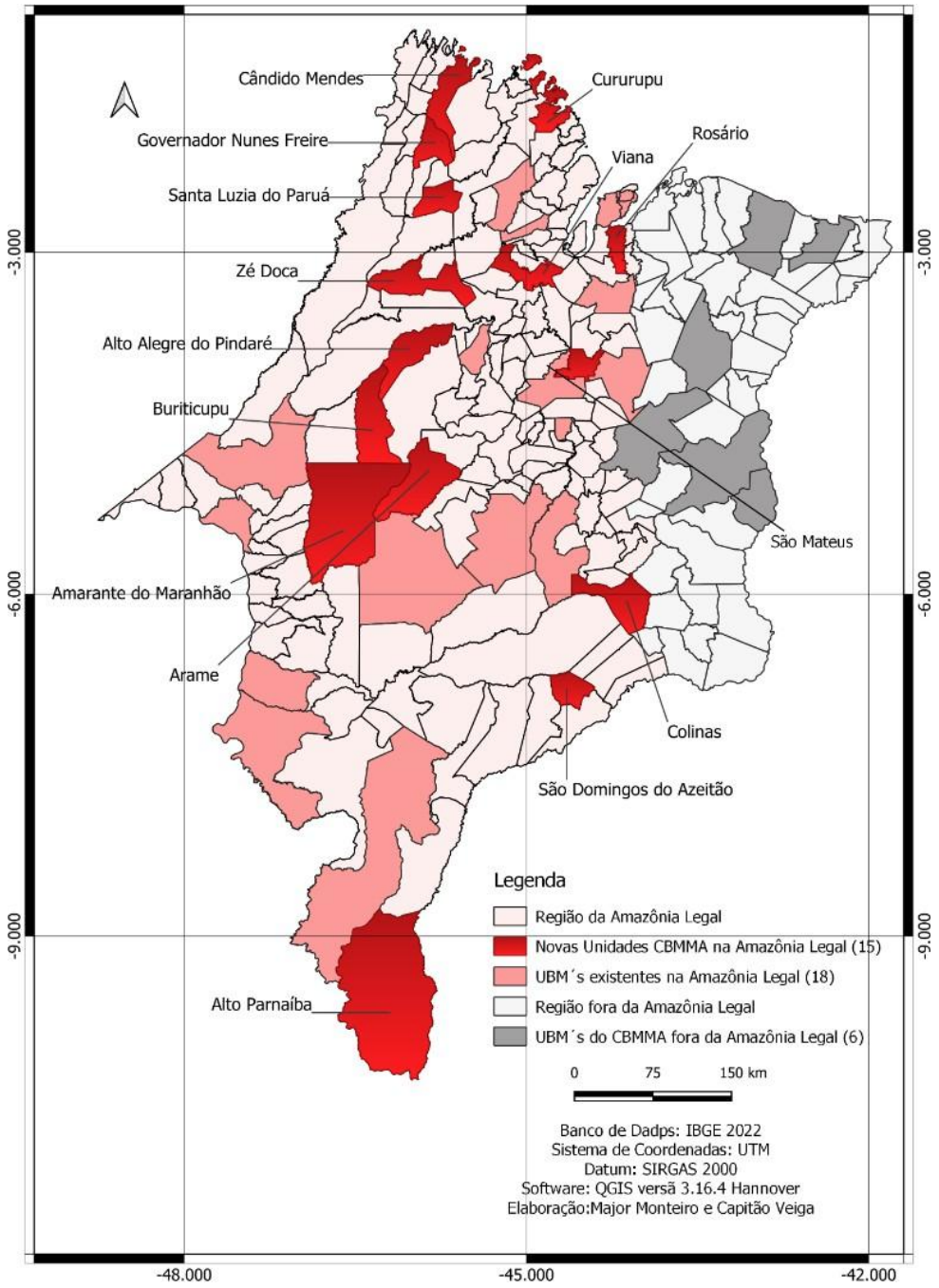
Based on the vulnerabilities identified, a territorialization proposal was prepared, presented as technical input for planning, aimed at strengthening the management of risks associated with dams in Maranhão. The proposal considered the spatial distribution of dams, their levels of Associated Potential Damage and Risk Category, the location of Civil Protection and Defense structures and the coverage area of the Military Fire Brigade Units.

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Figure 3 – Proposed territorialization of Civil Protection and Defense institutional capacities for managing dam-related risks in Maranhão.



Source: Prepared by the authors with data from ANA/SNISB (ANA, 2023), CEPDECMA (2024), CBMMA (2024) and IBGE territorial meshes (2024).

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The proposal presented in Figure 3 seeks to reduce the operational gaps identified throughout the research and to expand institutional response capacity for accidents and incidents involving dams. Among the proposed measures is the strengthening of COMPDECs in strategic municipalities, especially those associated with dams classified with high DPA and/or CRI. The proposal is not a definitive design for administrative reorganization: its eventual implementation depends on further analyses of staffing, budget, logistics, road network, equipment and institutional planning by the CBMMA and the municipalities.

Based on the criteria described in Section 3.6, the municipalities of Godofredo Viana, Centro Novo do Maranhão and Joselândia were identified as priorities for strengthening municipal Civil Protection and Defense structures. Chart 3 sets out the combination of conditions underlying this prioritization.

Chart 3 – Criteria for prioritizing municipalities for strengthening COMPDECs

Municipality	DPA/CRI	Historical occurrences (CEPDECMA, 2017–2022)	COMPDEC (2023)	UBM coverage	Justification for priority
Godofredo Viana	Vené I and II tailings dams: high DPA; high CRI	5 responses: 2 accidents (Vené, 2019; Pirocaua Lagoon, 2021) and 3 preventive actions	Not operational	No UBM in the municipal seat; jurisdiction of the 8th BBM (Pinheiro); outside the 30- and 60-min isochrones	Highest frequency of responses in the state, high DPA and CRI, absence of COMPDEC and distance from state units
Centro Novo do Maranhão	Human water supply dam: high CRI	No response recorded	Not operational	No UBM in the municipal seat; within a gap in the potential spatial coverage of the UBMs	High CRI in a rural area, with no municipal structure and outside the potential reach of the UBMs
Joselândia	Rio Flores Dam (flood control): high DPA; medium CRI	2 responses: 1 accident (gates, 2017) and 1 incident (gates, 2022)	Not operational	No UBM in the municipal seat; jurisdiction of the 13th CIBM (Trizidela do Vale); outside the 60-min isochrone	High DPA, history of occurrences and potential impact on downstream municipalities of the middle Mearim (ROCHA et al., 2023)

Source: Prepared by the authors based on ANA (2023), CEPDECMA (2024) and CBMMA (2024).

Chart 3 shows that the three municipalities simultaneously combine dams with high DPA and/or CRI, the absence of an operational COMPDEC and the absence of

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a UBM in the municipal seat. In Godofredo Viana and Joselândia, the history of responses aggravates the priority; in Centro Novo do Maranhão, the priority stems from the high CRI combined with the distance from the UBMs.

In summary, the results show that the risks associated with dams in Maranhão cannot be understood solely from the structural perspective of the facilities. The territorial distribution of institutional capacities, the existence of operational gaps and the limitations of coordination among the different actors involved are central elements for understanding the vulnerabilities identified and for strengthening risk governance applied to dam safety.

4.1 Limitations of the study

Some limitations should be considered when interpreting the results. First, the databases used have different time references (Chart 1), so the overlay of records from 2017 to 2022 with institutional information from 2023 and 2024 does not represent a synchronic portrait of the territory. Second, the results depend on the quality, completeness and updating of institutional records, which are subject to underreporting of occurrences and inspections. Third, most registered dams have no DPA (63.37%) or CRI (84.16%) classification, and dams not registered in SNISB, although present in CEPDECMA records, are not included in the classification statistics.

Fourth, the isochrones are estimates of potential spatial coverage, dependent on the road network and on the parameters of the routing service, and do not incorporate actual team mobilization times. Fifth, the flood zones resulting from a possible failure (dam break) were not modeled, which prevents delimiting the population and areas actually exposed downstream. Finally, institutional presence cannot be interpreted as synonymous with full operational capacity, since staffing, training, budget, equipment and protocols were not directly measured.

5. Conclusion

The research made it possible to analyze the role of Civil Protection and

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Defense in dam safety in the State of Maranhão based on the integration of risk governance, institutional vulnerabilities and the territorial distribution of prevention, preparedness and response capacities. The results showed that the risks associated with dams in Maranhão do not depend exclusively on the structural conditions of the facilities, but also on the institutional capacity existing in the potentially exposed territories.

The characterization covered 101 dams registered in SNISB and identified 11 with high Associated Potential Damage (DPA) and one with high Risk Category (CRI) in the 2023 database, a number that rises to four in the 2024 spatial database, as well as 21 CEPDECMA responses between 2017 and 2022 (five accidents, 12 incidents and four preventive actions), distributed across 11 municipalities. The integrated analysis of these data with the location of Civil Protection and Defense structures revealed limitations of potential spatial coverage and documentary evidence of administrative discontinuity of municipal structures, staff turnover and difficulties in inter-institutional coordination, factors that may compromise the continuity of monitoring, prevention, preparedness and response actions.

In relation to Rocha et al. (2023), the results converge on the need to overcome predominantly reactive action and to strengthen the preventive capacities of Civil Protection and Defense. The main advance of the present study, however, lies in broadening the scale of analysis and incorporating the spatial dimension of institutional capacities. While the comparative study analyzed Civil Defense action in a municipal context, this research examined the territory of Maranhão at the state scale and integrated the location of dams, the records of accidents and incidents, the operationalization of COMPDECs and the coverage of the Military Fire Brigade Units.

This methodological difference explains the main additional finding of this research: the formal existence of Civil Protection and Defense structures does not necessarily mean adequate territorial coverage. The use of geoprocessing and isochrones made it possible to identify gaps in potential spatial coverage and to indicate that the location and accessibility of institutional structures condition the potential capacity for monitoring, preparedness and response, bearing in mind that isochrones do not represent actual response times. Thus, vulnerability related to dam

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safety should be understood not only in terms of exposure to hazards, but also in terms of the spatial distribution of the state capacities available to manage them. In this sense, the main practical contribution of the study is to show that technological risk and state capacity need to be analyzed in the same territory: the management priority is greater where high potential damage, a history of occurrences, the absence of a consolidated municipal structure and a greater distance from state units coexist.

As an application of the results, the analysis supported a proposal for the territorialization of Civil Protection and Defense capacities, understood as technical input for planning rather than as a definitive design for administrative reorganization, jointly considering the distribution of dams, DPA and CRI levels and the coverage of operational structures. In this context, Godofredo Viana, Centro Novo do Maranhão and Joselândia were identified as priority municipalities for strengthening municipal Civil Protection and Defense structures, due to the coexistence of dams with high DPA or CRI, the absence of an operational COMPDEC and the absence of potential spatial coverage by the UBMs within 60 minutes, aggravated, in Godofredo Viana and Joselândia, by the history of occurrences.

It is therefore concluded that the integration between the National Dam Safety Policy and the National Civil Protection and Defense Policy requires, in addition to regulatory instruments and coordination mechanisms, a territorial distribution of institutional capacities compatible with existing risks. Strengthening COMPDECs, regionalizing operational capacities and coordinating dam owners, regulatory agencies and Civil Protection and Defense agencies are measures capable of expanding prevention, preparedness and response to potential dam emergencies in Maranhão. Future studies may incorporate actual operational response times, dam-break scenario modeling and the evaluation of Emergency Action Plans, deepening the analysis of the relationship between technological risk and institutional capacity.

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