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TRAINING OF PROFESSIONALS INVOLVED IN DAM SAFETY, ACCORDING TO THE NEW LEGAL FRAMEWORK

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ABSTRACT

This study analyzed the training of professionals and communities potentially affected by dam failures, focusing on the new Brazilian regulatory framework. The work examined the evolution of training programs, especially after the Brumadinho disaster in 2019. The methodology included a bibliographical survey, case studies, and comparative analysis with international programs, such as the model of the Federal Emergency Management Agency in the United States. The results revealed that, although there are regulatory advances,

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deficiencies persist in preventive approaches and community training. It was observed that 96% of the studies analyzed prioritize technical aspects, neglecting the social and educational preparation of vulnerable communities. The analysis highlighted the need to integrate emergency action plans with training and practical simulations to strengthen local resilience. Proposals include the adoption of continuous training cycles, based on the Homeland Security Exercise and Evaluation Program model, as well as the strengthening of compliance and governance policies. It was recommended that internal teams dedicated to dam management be created and that digital platforms be developed for disseminating information and monitoring in real-time. It is concluded that the implementation of proactive strategies, combined with the modernization of management and training practices, is essential to reduce vulnerabilities and mitigate the impacts of disasters. The study provides applicable guidelines for both entrepreneurs and public managers, contributing to environmental safety and sustainability.

Keywords: Dam Safety. Risk Management. Training. Civil Defense. Legislation.

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INTRODUCTION

Historically, dam safety has evolved over the years, integrating preventive approaches based on regulatory frameworks, such as Federal Law 12,334 of 2010, and international standards, including programs from the Federal Emergency Management Agency (FEMA). These regulations have shaped contemporary dam safety paradigms, highlighting the continuous need for improvements in the techniques of these structures.

Their applications range from hydroelectric power, irrigation, flood defense, recreation, animal watering, flow regulation, human supply, and environmental protection. They are also used for industrial waste containment, mining, and industrial tailings containment (ANA, 2023).

Despite regulatory developments, the increasing incidence of dam failures has highlighted persistent vulnerabilities. Factors such as the aging of structures, climate change, and inefficient management have contributed to the worsening of the problem. Striking examples, such as the Mariana and Brumadinho disasters in Minas Gerais, according to Sérgio (2024), highlighted the urgency of efforts to ensure safer operations. These events exposed the fragility of dams and the challenges associated with their management.

Clarkson and Williams (2020) estimate that, in a three-decade period, the probability of failures could increase up to 20 times. This trend is amplified by extreme weather events, such as heavy rains, which intensify pressure on structures, and by the lack of preventive maintenance or adequate modernization.

In the national context, Brazil has approximately 27,000 declared dams, of which more than 4,000 have the potential to cause damage in the event of a rupture, and around 15,000 do not have a risk classification (ANA, 2023). This information gap directly impacts the capacity for planning and responding to disasters.

Dams play a fundamental role in power generation, flood control, and water supply. However, their negative impacts, such as changes to river systems, displacement of communities, and environmental degradation, often outweigh the perceived benefits. Lerer and Scudder (1999) and McCartney (2009) highlight that, despite their contributions to economic development, dams often impose disproportionate social and environmental burdens on local communities, who rarely benefit financially from these infrastructures.

Internationally, the construction and operation of dams have been the subject of debates regarding transboundary impacts, geopolitical disputes, and water resource

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management (Beck; Claassen; Hundt, 2012; Richter et al., 2010; Tilt; Braun; He, 2009). In Brazil, the relevance of the topic is reinforced by the need for policies that balance economic development, environmental sustainability, and social justice. Dam safety requires legislative updates, implementation of evidence-based risk management strategies, and ongoing training of professionals and communities exposed to these risks. Therefore, it is essential to strengthen governance structures and emergency plans to minimize the impacts of potential disasters. Therefore, the research problem was: what is the reality regarding the training of professionals and communities, who respectively work and live in areas at risk of dam failure?

The present research aims to present, to the scientific, professional, and population communities, the reality of training in dam safety, within the scope of current legislation, with the aim of strengthening the actions of those who work in areas at risk of dam failure, as well as increasing the resilience of the people who live and inhabit this environment.

Dam safety is a growing concern, given the potential for disasters with human losses and irreparable environmental damage. Improving these practices is essential to mitigate risks and protect lives.

This study was motivated by the urgent need to safeguard lives and minimize the environmental impacts associated with dam failures. It highlighted the importance of effective emergency response strategies, training workers, local communities, and civil protection and defense agents. Furthermore, the need to expand the location and registration of dams and identify the responsible developers was highlighted, considering that many structures are still not officially registered with the National Water Agency (ANA).

In theory, the relevance of this work lies in its ability to influence public policies and corporate practices, ensuring that preventive measures and evacuation plans are applicable. The study provided evidence-based guidelines for dam safety training. Therefore, it was expected that the results would contribute to the protection of vulnerable communities.

METHODOLOGY

This work was based on the Final Course Work of the Master's Degree in Defense and Civil Security at the Fluminense Federal University, according to Sérgio (2024), where the author describes in detail data that technically and scientifically support this article.

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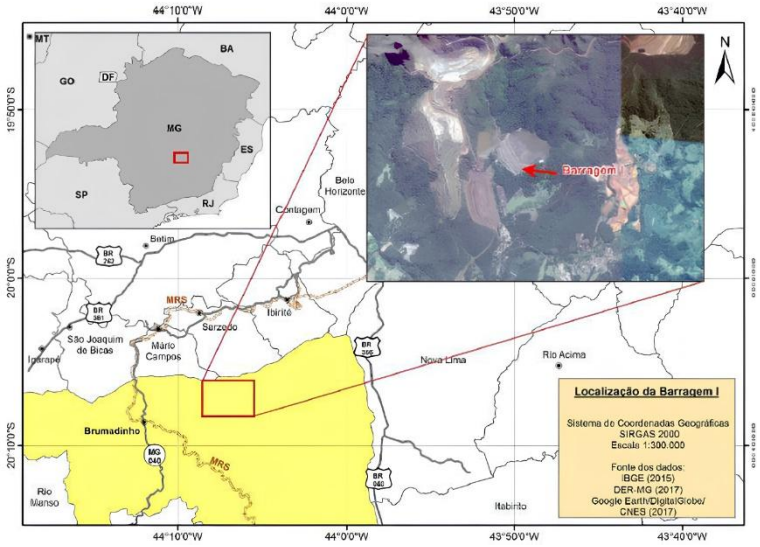
The data processing followed the qualitative approach according to Gil (2019), Lakatos and Marconi (2017) and Yin (2015).

Sérgio (2024) used a case study, highlighting entrepreneurs' practices in relation to dam safety under the influence of current legislation; where methods were integrated, seeking to elucidate the interactions between legislation, business practices, and professional training, highlighting ways to improve risk management in dams, including community preparation.

THE CASE OF BRUMADINHO – MG IN 2019

The dam called B1, located at the Córrego do Feijão mine in Brumadinho, Minas Gerais, as shown in Figure 1, was designed to store waste from iron ore extraction. Built and operated by the mining company Vale S.A., the structure used the upstream raising method, recognized for presenting structural risks. The dam rupture, which occurred on January 25, 2019, was one of the most severe environmental and human disasters in the history of Brazil, resulting in 272 deaths and irreversible environmental damage. (Sérgio, 2024).

Figure 1 - Location of the Brumadinho Dam in the state of Minas Gerais



Source: Adapted from Sérgio (2024)

Brazil has approximately 27,000 declared dams, according to the National Water and Sanitation Agency (ANA, 2023). Minas Gerais, known for its intense mining activity, is home to a significant portion of these structures. Brumadinho, a municipality that is part of

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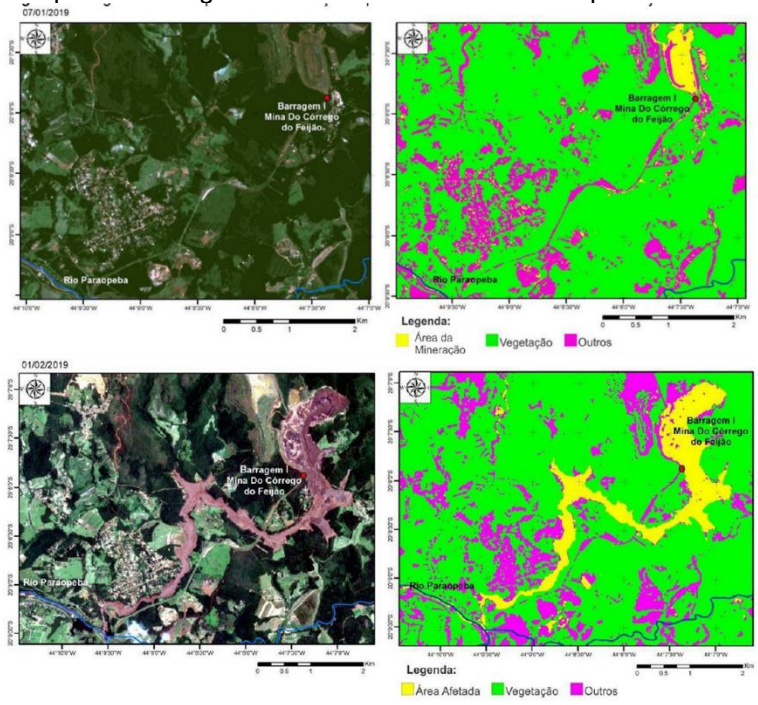
the metropolitan region of Belo Horizonte, is crossed by the Paraopeba River and had an estimated population of 38,915 inhabitants in 2022 (IBGE, 2022).

The local economy is characterized by its diversity, encompassing sectors such as agriculture, services, and tourism. However, mining plays a predominant role in the region, driven by the activities of Vale S.A., one of the largest global producers of iron ore. The notoriety acquired by Brumadinho is largely due to the tragedy associated with the collapse of Dam B1, whose impacts reverberated globally (IBGE, 2022), as shown in Figure 2 with the comparison between before and after the disaster in Brumadinho.

The importance of mining in Minas Gerais requires the maintenance of dams to contain waste, making monitoring and safety measures for these infrastructures essential. (BRASIL, 2020; Neves *et al.*, 2016).

Figure 2 - Comparative image before and after the dam collapse in Brumadinho – MG



Source: Adapted from Sérgio (2024)

The magnitude of the disaster and the volume of waste displaced posed difficulties for rescue operations. Firefighting teams from Minas Gerais, with support from other corporations, the Brazilian Armed Forces, and volunteers, played a role in the search for missing people (Andreoni; Darlington, 2019). Technological resources, such as sniffer dogs and cell phone tracking systems provided by Israel, were used to locate victims. Airspace management and the implementation of decontamination protocols were used to ensure

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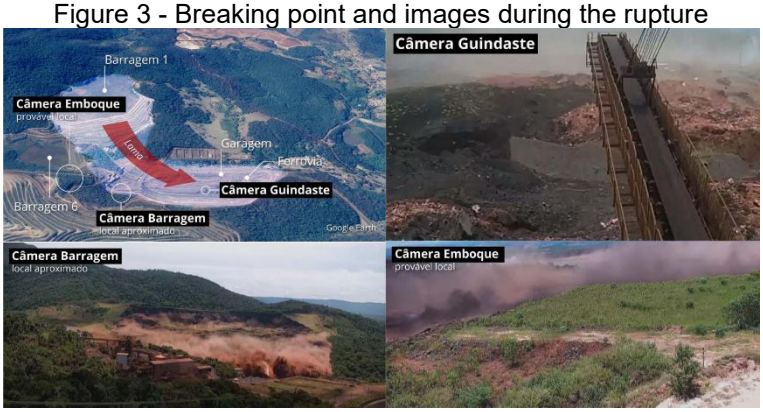
the protection of rescue teams (Andreoni; Darlington, 2019). In Figure 3, the trajectory and speed of the waste flow captured by the other cameras indicate the magnitude of the disaster, highlighting the impact of damage and losses caused by these disasters. The flow followed the riverbed, spreading the contamination to several points downstream, affecting communities and local biodiversity, and causing immeasurable environmental and human impacts (Alvarenga; Cavalini, 2019).

Figure 3 - Breaking point and images during the rupture



Source: Adapted from Sérgio (2024)

Brumadinho is on the list of municipalities vulnerable to events such as landslides and floods, according to the registry established by Federal Law 12.608/2012, amended by Law 14.750/2023, and supplemented by Law 12.340/2010.

REGULATORY COMPLIANCE

The concept of compliance refers to the observance of applicable legal and regulatory standards. In the context of dam safety, compliance is essential to mitigate risks and protect communities and ecosystems. Studies, such as that by Botelho et al. (2023), highlight gaps in compliance with these standards by Vale S.A., contributing to the disaster.

Despite the existence of regulations, failures in maintenance and monitoring were identified. Reports indicated the absence of an effective emergency plan and the prioritization of economic gains over structural safety (Furtado Louzada; Ravena, 2019).

The Work Accident Analysis Report in Brazil (2019) highlighted the following deficiencies in Vale's management:

- Absence of a specific emergency plan for the dam.
- Irregularities in the Emergency Action Plan for Mining Dams (PAEBM) of B1.
- Lack of efficient warning to the local population.

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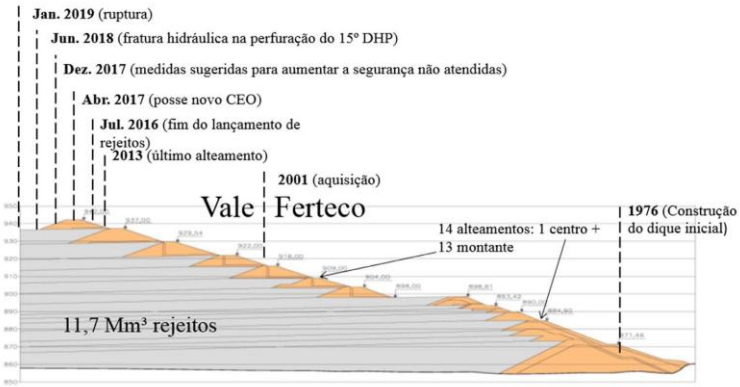
- Failure to activate sirens at the time of the collapse.
- Disregard for inadequate escape routes.

The history of Dam B1, shown in Figure 4, was marked by management decisions that raised questions about the effectiveness of the safety practices adopted (Rotta et al., 2020). Begun in the 1970s, its construction involved multiple heightenings using the upstream method, recognized as less safe compared to other construction techniques (Almeida; Jackson Filho; Vilela, 2019).

Figure 4 - Timeline of dam B1



Source: Adapted from Sérgio (2024)

Botelho et al. (2023) point out that, although Vale has made significant profits and distributed substantial dividends to its shareholders over the years, investments in dam safety and maintenance were considered inadequate. The search for cost optimization and increased profitability were prioritized over investments in preventive measures and structural reinforcements. This assessment is supported by the impacts of the collapse, which resulted in significant human and environmental losses. These findings highlight the need to strengthen compliance and risk governance strategies, with a focus on continuous monitoring to prevent or mitigate future adverse events.

SOCIAL AND ENVIRONMENTAL IMPACTS AND EMERGENCY RESPONSE

The collapse of Dam B1 resulted in the release of approximately eleven million cubic meters of tailings, seriously affecting the course of the Paraopeba River and compromising the water supply, in addition to causing irreparable damage to local fauna and flora. The

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socioeconomic effects included the interruption of commercial, tourist, and mining activities in the region, highlighting the complexity and scale of the losses generated (Sérgio, 2024).

The analysis of the disaster highlighted the need to convert this experience into a sustainable development model for dam management. This transformation requires training professionals and communities in risk management and emergency response, as well as the formulation of more effective public policies and responsible corporate actions.

The Brumadinho case study exemplifies the urgency of structural, operational, and legislative improvements aimed at mitigating risks and protecting vulnerable communities. The lessons learned should serve as a basis for improving dam safety and management practices, promoting socio-environmental resilience, and minimizing future disasters.

RESULTS

The analysis carried out was based on the research by Sérgio (2024), as shown in graph 1. The results indicated that 57% of the projects analyzed had explicit training programs on dam safety.

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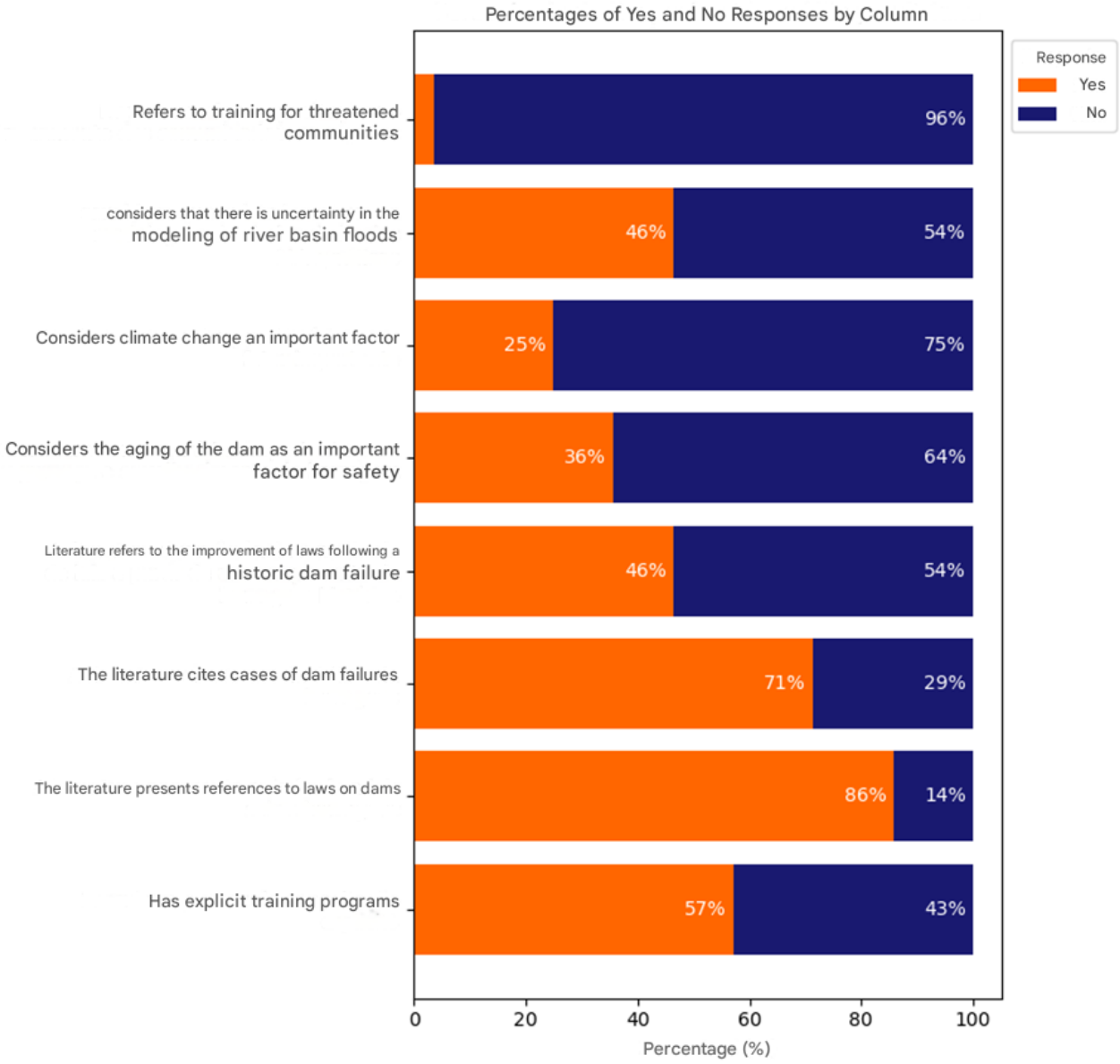
Graph 1 - Frequency of responses to the analyzed documentation



Source: Adapted from Sérgio (2024)

However, the analysis revealed a structural deficit in approaches aimed at community empowerment, with 96% of publications neglecting social inclusion strategies in risk management.

The excessive emphasis on technical approaches denotes a disproportionate confidence in the ability of operational protocols to eliminate risks. However, the works analyzed highlighted that this perspective underestimates external variables, such as climate change and the aging of infrastructure. Only 25% of the studies mentioned climate change as a relevant factor, and 36% pointed to structural aging as a critical element. In

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addition, 46% highlighted uncertainties in predictive models for extreme flows, highlighting the need for management plans that integrate social and environmental dimensions.

The perception of risk was also shown to be uneven among the various actors involved in dam management. Developers often presented a more optimistic view of the effectiveness of their operational procedures, while local communities expressed greater concern about the lack of information or training. This discrepancy highlights the importance of more inclusive communication strategies, addressing existing gaps in risk perception and emergency preparedness.

In the case study, a cultural underestimation of risks was observed before the Brumadinho disaster. The experts interviewed reported that the perception of vulnerability was reassessed after the event, driven by social pressures and regulatory actions. Official reports highlighted structural flaws, such as the lack of warnings and inadequate escape routes, indicating critical weaknesses in the implementation of the Emergency Action Plan (EAP).

In addition, it was identified that the gap in community capacity resulted in inadequate and uncoordinated responses during the emergency. This aspect highlights the need to develop continuous training and periodic simulations, not only for dam operators but also for potentially impacted communities. This approach would contribute to building a culture of resilience and disaster preparedness.

COMPARISON BETWEEN TRAINING PROGRAMS

A comparison between Brazilian programs and those developed by FEMA in the United States revealed discrepancies in terms of methodology. In Brazil, training is based on civil defense practices and includes three types of exercises: expository, internal unification, and simulations. On the other hand, North American programs employ seven types of exercises, divided into administrative and operational approaches.

Comparison Table 1 – Brazilian Dam Training Program vs. FEMA	Brazil	United States
Types of Exercises	There are three types of exercises: Internal expository exercises, Internal unification flow exercises, and Internal simulated exercises (hypothetical or practical).	There are seven types of exercises, divided into two approaches: Administrative (Seminars, Workshops, Tabletop Exercises, and Games) and Operational (Training, Functional Exercises, and Full-Scale Exercises).

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Exercise Frequency	Every 6 months to 1 year.	Every 1 to 5 years.
Purpose of Exercises	Contribute to maintaining readiness by allowing greater familiarity of those involved with their roles and responsibilities outlined in the PAEBM, leading to the operational evolution of the plan.	Validate plans, policies, agreements, and procedures; clarify roles and responsibilities; and identify resource gaps in an operational environment.
Integration with Emergency Plans	Internal training exercises are integrated into the PAEBM through the teaching of specific procedures and responsibilities detailed in the plan.	There is no requirement in the HSEEP program for all seven exercises; the program must be built from scratch, starting with simple exercises and progressing to more complex ones.
Support from Doctrine	Based on national civil defense practices (Guidelines for Supporting the Development of Municipal Contingency Plans for Dams – 2016). There is no mention of specific doctrine or science.	Supported by the Homeland Security Exercise and Evaluation Program (HSEEP) doctrine, which follows standardized methodologies aimed at ensuring uniformity in the execution and assessment of exercises while maintaining flexibility and accessibility.
Effectiveness Assessment	The effectiveness of training exercises is assessed through periodic simulations. During these simulations, team readiness, response, and reaction time are observed and measured. Feedback is collected to make continuous adjustments to the PAEBM and training procedures, improving emergency response safety and efficiency.	The HSEEP program evaluates the effectiveness of exercises through predefined criteria, including direct observation of performance during exercises, participant feedback collection, and analysis of actions and decisions taken in response to proposed scenarios. Based on these data, evaluation reports are developed to identify strengths, areas for improvement, and recommendations for future actions, ensuring a continuous cycle of preparedness and response enhancement. The program follows a PDCA (Plan-Do-Check-Act) model.
Source: Adapted from Sérgio (2024)		

While Brazil integrates training into the Emergency Action Plan for Dams (PAEBM), the United States adopts the Homeland Security Exercise and Evaluation Program (HSEEP) doctrine, structured in cycles: Plan, Do, Check, Act (PDCA), prioritizing flexibility and continuous learning. This North American approach allows for incremental adjustments and greater adaptability based on the results of the exercises.

In addition, it was found that Brazilian programs lack systematic mechanisms for evaluating and providing feedback on the results obtained in the simulations. In contrast, the HSEEP model establishes criteria for evaluating performance, allowing for continuous adjustments and ensuring the effectiveness of the training over time. This difference highlights the importance of reviewing the evaluation methods adopted in Brazil.

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In Brazil, the evaluation of effectiveness is limited to periodic simulations focused on the execution of plans and response time. In contrast, the North American model adopts reports that analyze performance, collect feedback, and propose specific recommendations for improvements, configuring itself as a more comprehensive and adaptable methodology.

CHALLENGES AND GAPS IDENTIFIED

Despite legislative advances following the Brumadinho disaster, Sérgio (2024) highlighted persistent gaps in training programs. The mandatory periodic training, as stipulated by Federal Law 14,066/2020 (2020), still presents incipient implementation and broad interpretations. Experts reported that training in municipalities such as Itabira and Barão de Cocais prioritized audible alerts and escape routes, but neglected specific content to prepare communities for complex situations.

The analysis revealed a misalignment between theory and practice. While 86% of publications mentioned relevant legislation, only 46% addressed improvements in regulation after the disaster. This contrast suggests that, although regulatory advances have been made, practical implementation remains fragmented and insufficient.

Another critical point was the limitation of cultural changes associated with legislation. Although new responsibilities were imposed on entrepreneurs, the reactive nature of the measures limited their effectiveness. The lack of integrated strategies for community empowerment and ongoing training highlights the need for more comprehensive and adaptable policies.

An analysis of the results highlighted the inadequacy of the prevailing technical approaches in dam management, as well as the insufficiency of community empowerment programs. According to Sérgio (2024), the evidence found in the literature indicated the need to incorporate more inclusive practices, with a focus on social and environmental preparedness. Comparison with international models, such as FEMA's HSEEP program, reinforced the importance of methodologies based on continuous learning and evaluation cycles.

The implementation of a training system, combined with more comprehensive emergency action plans, is essential to strengthen resilience and response capacity in critical situations. The analysis suggests that approaches based on the integration of practices, supported by specific legislation and periodic assessments, can mitigate risks and optimize dam management.

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These results highlight the need to review training strategies and promote public policies aligned with international standards.

DISCUSSION

The analysis of training programs revealed a lack of initiatives specifically aimed at communities exposed to risks of dam failures that take into account prevention, mitigation, preparedness, response, and recovery from disasters.

While existing programs prioritize the technical operability and structural maintenance of dams, few offer effective training aimed at preparing communities for emergencies related to dam failures. This gap compromises the effectiveness of Emergency Action Plans (EAPs), especially in rapid and large-scale events, such as the Brumadinho dam failure.

The work accident analysis report, developed by the Regional Labor Superintendence in Minas Gerais (2019), highlighted that even with the audible warning system in operation, the speed at which the rupture occurred prevented a successful evacuation. This fact highlights the need for more realistic training programs adapted to the dynamics of adverse events. In comparison, FEMA's approach, based on the Deming cycle (PDCA), presents a more interventionist model, with continuous evaluations and improvements.

In addition, a gap was identified in the integration between training programs and response practices. While the trainings superficially address evacuation, They fail to consider variables such as the speed of tailings movement and the logistical difficulties faced by rescue teams. This disconnect highlights the need to align training programs with realistic scenarios for each dam.

STRUCTURAL AND MANAGERIAL CHALLENGES IN DAM MANAGEMENT

One of the most recurring problems is the lack of an integrated approach that considers not only structural safety but also the social and educational training of vulnerable communities. Although dam operations involve technical complexity, neglecting community training perpetuates social vulnerabilities, increasing the damage and losses resulting from disasters.

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The aging of dams has also been identified as a critical factor. Old structures, often abandoned or decommissioned without clear decommissioning plans, pose ongoing risks. These dams require constant monitoring and effective preventive actions, especially in climate change scenarios that increase hydrological and geotechnical risks. Another point identified was the transfer of legal responsibility to third-party companies hired to conduct audits and issue technical opinions. According to Sérgio (2024), this practice creates an environment conducive to the dilution of responsibilities. The absence of internal teams dedicated exclusively to dam safety management compromises continuous monitoring and rapid response in emergencies. Excessive dependence on external consultants weakens the institutional capacity of entrepreneurs to take an active role in risk mitigation and the implementation of preventive actions.

PROPOSALS FOR RESTRUCTURING TRAINING AND MANAGEMENT PROGRAMS

In view of the gaps identified, the need to reformulate current training and risk management practices became evident. First, it was recommended to implement continuous training programs, based on evaluation and improvement cycles, similar to the HSEEP model used by FEMA. This approach not only standardizes procedures but also creates a cycle of continuous learning, allowing strategies to be adapted and improved over time.

Another crucial point is the integration of specific training for local communities. These programs should include practical simulations, evacuation exercises, and instructions on warning systems and escape routes. In addition, strategies should be developed to disseminate clear and accessible information, promoting greater engagement and public awareness.

The creation of internal teams dedicated exclusively to dam management should also be prioritized. In addition to continuously monitoring the structural conditions of dams, these teams should act as communication facilitators between developers, communities, and regulatory agencies, promoting greater transparency and efficiency in emergency response.

The analysis conducted reinforced the need to adopt more proactive approaches to dam safety training. The study highlighted the importance of educational programs aligned with international best practices, adapted to local realities, and geared toward risk mitigation. Among the proposed contributions, as shown in Table 2, are courses and

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training aimed at managers, technicians, and community members, addressing topics such as vulnerability analysis, evacuation plans, and integrated risk management. These courses must be complemented by periodic simulations and evaluation mechanisms that guarantee the efficiency of the practices implemented.

Table 2 – Proposed Courses and Training Programs Adapted to Dam Risk Management

Period/Cycle	Areas	Topics
Risk Management	**Prevention and Mitigation**	**Risk Analysis** – Assessment and Mitigation of Dam Failure Risks; Risk and Vulnerability Assessment; Flood Mapping
	Risk Reduction Measures	Dam Safety Regulations and Compliance; Improvement of Dam Surveillance and Inspection Practices; Mitigation of Environmental Impacts; Animal Management in Emergency Situations; Rehabilitation of Degraded Areas
	Preparedness	**Preparedness and Monitoring Actions** – Technological Integration in Emergency Management; Planning and Development of Full-Scale Exercises; Resource Management During Emergencies; Emergency Communication Protocols; Integration of Actions with SINPDEC
Disaster Management	**Response**	**Relief** – Emergency Response Team Training; Use of Technologies for Enhanced Emergency Response; First Aid Training and Certification; Rescue and Safeguarding of Cultural Heritage; Emergency Potable Water Supply; Emergency Notification Procedures; Evacuation Drills
	Restoration and Humanitarian Assistance	Independent Technical Advisory for Communities; Organization of Escape Routes and Safety Points; Preparation and Execution of Evacuation Drills; Legal Responsibility and Compliance; Communication with Regulatory Agencies; Stakeholder Engagement and Information Sharing; Post-Incident Analysis and Continuous Improvement
Recovery	**Reconstruction and Recovery Projects**	Provision of Temporary Housing; Resettlement Planning; Social Reintegration of Affected Populations; Health Assistance for Disaster Victims

Source: Adapted from Sérgio (2024)

Additionally, it is suggested that digital platforms be created to disseminate information and guidance on dam safety. These platforms could serve as repositories for best practices, technical reports, and educational materials, fostering knowledge sharing and experience exchange among various stakeholders involved in risk management.

Furthermore, the research highlights the necessity of strengthening institutional and community capacities, along with a more adaptable regulatory framework, as fundamental measures to reduce vulnerabilities and prevent the recurrence of tragedies like Brumadinho. The presented recommendations aim not only to enhance existing mechanisms but also to establish new guidelines for a more efficient and inclusive risk management approach.

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CONCLUSION

This study investigated dam safety practices, beginning with an introductory analysis that emphasized the relevance of the topic and the need for improvements in current practices. The research examined the existing regulatory framework, gaps in training strategies, and challenges in disaster risk management, particularly in the context of the Brumadinho dam collapse.

The findings revealed deficiencies in integrating technical dam management approaches with community training strategies and regulatory compliance. Comparing Brazilian practices with international guidelines, such as those adopted by FEMA, it became evident that more manageable models should be implemented, with clear metrics and community integration. This gap underscores the importance of strategies that include not only technical aspects but also social and educational preparedness for at-risk communities.

The study reaffirms the urgency of strengthening public policies and corporate practices to ensure that training programs cover topics aligned with scientific literature and the regulatory framework established by the National Dam Safety Policy (PNSB). It is expected that the contributions of this research will help guide improvements in risk management and dam safety, ensuring the protection of vulnerable populations and environmental preservation.

The objective was achieved by proposing guidelines and strategies for training entrepreneurs, civil defense agents, and local communities. The proposed measures include continuous training programs and the development of more efficient management structures aligned with international best practices. These initiatives contribute to strengthening disaster preparedness and response, enhancing social and operational resilience.

One of the key findings is the need to reformulate training strategies, emphasizing the active and informed participation of at-risk communities. Moreover, the study highlighted the importance of aligning safety practices with more effective legislation to mitigate risks and protect the environment.

Additionally, this research underscores the necessity of shifting dam management culture from a reactive approach to a preventive and proactive model. To achieve this, compliance with regulations and guidelines must evolve beyond a mere formal requirement and become an integral part of the organizational culture of the involved entities.

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The contributions of this study extend beyond academia, offering practical insights for managers, policymakers, and professionals engaged in risk management. It is hoped that the recommendations presented will foster initiatives aimed at training and developing more effective tools for dam safety. Among the key implications is the need to establish training programs that integrate technical, operational, and social aspects, promoting a multidisciplinary and interdisciplinary approach.

The analyses also indicate the importance of incorporating emerging technologies in dam management and monitoring, including early warning systems and digital platforms for information dissemination and training. These tools can strengthen response strategies and enhance transparency in project management.

This study paves the way for further research that can deepen the understanding of dam safety. It is recommended to conduct more detailed international comparisons, analyzing the policies and practices of countries such as the United States and China, which have a high number of dams. Longitudinal studies could assess the evolution of these policies and their practical implementation, providing valuable insights for improving the Brazilian model.

Additionally, empirical data and case study analyses should be used to evaluate the effectiveness of current strategies. Future research can explore emergency response actions, evacuation procedures, and policy reviews after disasters, identifying patterns and opportunities for improvement.

Another relevant perspective involves adopting interdisciplinary approaches to investigate how dam safety relates to ecological, social, and economic aspects. This could include analyzing long-term impacts on local communities and ecosystems and contributing to the formulation of more sustainable and integrated policies.

Finally, it is crucial to foster a culture of prevention and continuous improvement, consolidating a management model that protects both vulnerable populations and the environment, ensuring a safer and more sustainable future.

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