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RISK MITIGATION IN TAILINGS STORAGE FACILITIES: A COMPREHENSIVE APPROACH OF THE RISK CONTROL MANAGEMENT SYSTEM (RCMS)*

MITIGAÇÃO DE RISCOS EM ESTRUTURAS DE DISPOSIÇÃO DE REJEITOS: UMA ABORDAGEM ABRANGENTE DO SISTEMA DE GESTÃO DE CONTROLE DE RISCOS (RCMS)

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ABSTRACT

Tailings storage facilities (TSFs) are structures built to store tailings generated during mineral processing. These facilities have the potential to cause significant environmental and social damage and pose safety concerns. This article proposes a tool called the Risk Control Management System (RCMS) to assess the effectiveness of control measures for mitigating risks associated with TSFs. The RCMS methodology is based on the Global Industry Standard on Tailings Management (GISTM) protocols for evaluating tailings governance and management. It provides a score that measures the performance of TSF management, indicating the maturity level of risk controls, which influence the likelihood or impact of the consequence of a failure. The methodology was applied to 8 TSFs located in 2 countries. The methodology allowed the construction of a Risk Control Maturity Matrix and generated a table demonstrating improvement opportunities for the TSF management and governance process.

Keywords: Tailings storage facility, governance and tailings management, risk mitigation.

RESUMO

As TSFs são estruturas construídas para armazenamento dos rejeitos gerados no processamento mineral. A necessidade de estudar as TSFs decorre do potencial de impacto ambiental, social e preocupações com a segurança. Este artigo propõe uma ferramenta para verificar a eficácia das medidas de controle para mitigação dos riscos associados às estas estruturas, denominada Risk Control Management System (RCMS). A metodologia baseia-se nos protocolos recomendados pelo Global Industry Standard on Tailings Management (GISTM) para uma avaliação da governança e gerenciamento dos rejeitos, fornecendo uma pontuação que mede a performance da gestão das TSFs, indicando o nível de maturidade dos controles de risco, que influenciam na probabilidade ou no impacto da consequência de uma falha. A metodologia foi aplicada para em 8 TSFs localizadas em 2 países. A metodologia permitiu a construção de uma Matriz para avaliar a maturidade de controles do risco e gerou uma tabela que demonstra as oportunidades de melhorias para o processo de gerenciamento e governança de TSFs.

Palavras-chave: Estruturas de disposição de rejeitos, governança e gerenciamento de rejeitos, mitigação de riscos.

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Introduction

According to the Global Industry Standard on Tailings Management (GTR, 2020), a TSF is designed and managed to contain the tailings produced in a mineral processing plant. The term 'Tailings Storage Facilities' (TSF) refers to facilities that contain tailings in mined open pits or on surface structures and the tailings can be in the form of slurry, paste or even dry, depending on the processing technology use. The main purpose of tailings storage facilities is to prevent the release of tailings into the surrounding environment, thus minimizing the potential environmental and social impacts.

There is a consensus among the various organizations such as following references from MAC (2021); CDA (2014b); ICOLD (2012); ICMM (2021b) that value good practice in the tailings management and TSF safety guidelines that proper design, construction, operation, and maintenance of tailings storage facilities are essential to ensure their stability, integrity, and long-term safety. Various factors, such as geotechnical considerations, water management, social and environmental monitoring and controls need to be considered during the planning and implementation stages according to CDA (2014) and reinforced by ICMM (2021b).

Studying TSFs is essential for several key reasons given their vital role in both the mining industry and the environment. The following are the main reasons for studying TSFs:

- *Environmental Impact*: TSFs have the potential to cause significant environmental impacts if not properly designed, operated, and monitored. Pereira *et al*. (2020) in their research on failed dams in Brazil, pointed out that studying the impact of failed TSFs helps to identify potential risks and develop mitigation strategies to protect ecosystems, water bodies and surrounding communities from contamination and other environmental risks;
- *Safety and Risk Assessment*: Studying TSFs is complex and involves comprehensive risk assessments, including hazard identification, geotechnical evaluations, monitoring systems, consequence assessment and emergency preparedness plans. The CDA (2013) pointed out that understanding the potential risks and their likelihood enables the implementation of effective control measures to minimize accidents and protect human lives. CDA (2013) provides a framework for conducting risk assessments considering both the technical aspects and the potential environmental and social impacts. It is a valuable resource for professionals involved in the management of tailings dams and the assessment of their associated risks;
- *Regulatory Compliance*: The ICOLD (2012) considers that the main purpose for the dam safety management system is to create conditions for a safe TSF operation to improve the confidence for protecting people, property, and the environment from possible impacts from any improper operation or TSFs failure. However, despite these impositions we have seen a considerable increase in anomalous events in relation to these structures with significant environmental impact and human life. Conducting studies on TSFs helps mining companies ensure compliance with these regulations, avoiding legal issues and potential financial liabilities;
- *Innovation and leading practices*: Ongoing research and studies on TSFs drive innovation and the development of leading practices in their design, operation, and closure. Fourie, 2009 has already manifested concern about the need for research to increase further sustainable form of tailings management, allowing storage in facilities without water accumulation, can prevent catastrophic failure. In this direction, the mining sector has heavily invested in new technologies, materials, and techniques, guided by the demand for Filtered Stacked Tailings, praised by companies BHP and Rio Tinto through the Tailings Management Consortium in March 2024 (BHP e Rio Tinto, 2024). This initiative aims to provide mining companies with a practice guide for project development for dewatering and storing tailings. Additionally, there is an increase in research contributing to the continuous improvement of TSF management, leading to safer innovations and other cutting-edge practices, such as surveillance, digital resources, risk approaches, and new technologies for modeling. These practices can further enhance the continuous improvement of safe and reliable TSF management;
- *Knowledge Sharing and Collaboration*: There is a significant effort from renowned associations towards contributing to the improvement of dam safety. As good examples, publications from CDA (2014), ICOLD (2012), and ICMM (2021b) can be mentioned, reinforcing the importance of ongoing study of TSFs and knowledge sharing and collaboration among researchers, industry professionals, and stakeholders. By disseminating findings, lessons learned, and leading practices, the industry can collectively enhance its understanding of TSFs and work towards continuous improvement.

The main concern revolves around the proposed methodologies for assessing and managing dam safety, considering the social, economic, and environmental impacts of potential failures. For these topics there are (Widana, 2019a) and (Widana, 2019b) have provide a comprehensive analysis of the socioeconomic and environmental impacts of the mining industry. On the other hand, the ICMM Social and Environmental Report (ICMM, 2022) emphasizes the importance of mining for society, driving economic and social growth, and supporting local businesses. It is concluded that balancing mining activity with community needs is essential to avoid negative impacts.

In this sense, reconciling risk management between ensuring good practices for tailings management under safe conditions and promoting transparency and trust to engage surrounding communities is essential for the mining industry. Good research to example is the of Chovan *et al*. (2021) have developed with the goal to propose a tool for risk assessment for tailings management based on (Silva Rotta *et al*., 2020) focused on addressing geotechnical safety risks inherent to these structures.

This article proposes the implementation of a Risk Control Management System (RCMS) as a tool for standardization and measuring the main controls for a failure risk mitigation. The RCMS aims to enhance the risk management associated with TSFs, by providing a systematic approach for promoting the controls identification, assessment, and addressing through focus area according to their influence on likelihood of failure or impact of their consequence.

Key considerations related to tailing storage facilities.

Global Tailings Review (GTR)

According to the Global Tailings Review website (GTR, 2024), following the catastrophic dam failure at the Córrego do Feijão Mine in Brumadinho, Minas Gerais, Brazil (owned by Vale) on 19 January 2019, the International Council on Mining and Metals (ICMM), the United Nations Environment Programme (UNEP) and the Principles for Responsible Investment (PRI) came together to create the organization named as Global Tailings Review (GTR) with the aim of establishing an international standard for tailings management and governance. Thus, with the support of a multidisciplinary expert panel and the input from a multi-stakeholder advisory group, on 5 August 2020 the Global Tailings Review (GTR) launched the Global Industry Standard on Tailings Management (GISTM) with the goal to active zero harm to people and the environment, with zero tolerance for human fatalities involving Tailings Storage Facility accidents.

Tailings Storage Facility (TSF) concept

According to GISTM, Tailings Storage Facilities (TSFs) are defined as structures that meet specific criteria. To be considered a TSF, a facility must have a height greater than 2.5 meters, measured from the crest elevation to the base elevation of the structure, or a combined volume of water and solids exceeding 30,000 cubic meters, unless the consequence classification is categorized as ‘High’, ‘Very High’, or ‘Extreme’. In these cases, the structure is considered a TSF regardless of its size (GTR, 2020). For classifying TSFs based on consequence classification, the GISTM appoints the table provided by (GTR, 2020). This table serves as a reference for various associations, helping to associate critical controls for mitigating the risk of catastrophic failures.

According to Breitenbach (2010), conventional TSFs, such as a dam, the method of tailings transportation can be by gravity flow or pumping over short or long distances with a large quantity of water or fluids, like the form of tailings slurry, through pipes to be discharged around the tailings dam impoundment in a hydraulic manner.

The main difference between conventional and non-conventional TSFs is that in conventional TSFs, tailings are deposited in the structure in a mechanical and controlled manner, adhering to specific geotechnical parameters required by the project, as highlighted by N. Machado, 2017. An example is a stack that can be constructed by tailings dewatering to reduce the water in the facility. Another example of non-conventional TSFs is the in-pit disposal method, in which tailings can be hydraulically deposited as a slurry inside a mine pit and do not necessarily require a containment structure to be built.

Global Industry Standard on tailings management (GISTM)

The GISTM has undergone a rigorous and inclusive process that involved active engagement with industry stakeholders, governments, civil society organizations, and affected communities (GTR, 2020). This standard offers comprehensive requirements for ensuring the safe management of tailings facilities throughout their life cycle. Additionally, it commits member companies to implementation and recognizes the significance of responsible tailings management as an integral part of their broader commitment to sustainable mining practices.

GISTM comprises 6 key topics divided into 15 principles and 77 requirements. It serves to enhance the performance of enterprises while contributing to social and environmental integrity (GTR, 2020). The Conformance Protocol (ICMM, 2021a) is a document to help and provide additional guidance and instruction on representative methods for meeting the GISTM requirements.

Considering that each mining company has distinct purposes, values, and risk tolerance, their tailings strategy will ultimately reflect these unique characteristics. However, to align with the guiding principles of various organizations, the GISTM establishes a set of minimum requirements for tailings management. The aim is to establish a connection with recognized guidance and promote improvement and standardization in tailings management and governance practices within the mining industry. In this context, the GISTM seeks to foster a commitment between the ICMM and its members to uphold these principles.

Tailings Management and Governance Framework

In 2016, ICMM released a "Position Statement on Preventing Catastrophic Failure of Tailings Storage Facilities," demonstrating its commitment to implementing practices aligned with the Tailings Management and Governance Framework (ICMM, 2016). In 2021, the Tailings Management good practices guide (ICMM, 2021b) emphasized the importance of this concept for tailings management systems and provided a guide focusing on the six Key Elements for good tailings management and governance, with the aim of minimizing the likelihood of TSF failures. The concepts which represent the Key-Elements of tailings management and governance are presented bellow (Table I).

The Tailings Management Good Practice Guide (ICMM, 2021b) provides valuable guidance to support the technical aspects of GISTM implementation with the aim of promoting continuous improvement in tailings management and governance aspects, however, it does not include guidance on the social and environmental issues for tailings management. Then, as a supplementary guides for social and environmental consultation here are, for example, the set of guides which can be found in ICMM website (ICMM, 2024) and the Towards Sustainable Mining (TSM) program, launched by MAC (Mining Association of Canada) in early 2023, and available on the MAC website (MAC, 2024).

The context of tailings management and governance encompasses multiple aspects related to the storage, treatment, and monitoring the TSFs to mitigate environmental and social impacts. It involves the implementation of strategies that ensure the safe and responsible management of tailings throughout their lifecycle (ICMM, 2021b), including project conception, design, construction, operations, closure, and post-closure stages.

Table I - Principles of tailing management and governance.

Tabela I *- Princípios de gerenciamento de rejeitos e governança.*

Key-Elements	Description
1. Accountability, Responsibility, and Competence	These components ensure transparency, commitment, and the necessary expertise to mitigate risks. Accountability entails accepting responsibility for actions and decisions, being transparent to stakeholders, and being answerable for the consequences. Responsibility involves fulfilling duties ethically, implementing measures to minimize negative impacts, and recognizing obligations throughout the lifecycle. Competence encompasses the knowledge, skills, and experience required for roles in tailings management, including technical aspects, environmental monitoring, risk assessment, and continuous learning for improvement.
2. Planning and Obtaining Resources	Planning is a systematic process that involves the development of a comprehensive strategy and framework for tailings management. Resourcing focuses on the allocation of appropriate personnel, financial resources, equipment, and technology needed to implement the tailings management plan effectively. ICMM recognizes the significance of planning and resourcing in tailings management. These aspects are vital for ensuring that the necessary strategies, resources, and actions are in place to effectively address risks. Incorporating effective planning and resource allocation allows for a proactive approach in tailings management, reducing risks and promoting the long-term sustainability of tailings facilities.
3. Risk Management	Risk management process involves identifying, assessing, and mitigating risks in tailings management considering all variables that can influence the outcomes. Factors like geotechnical stability, water management, and community proximity are considered in site-specific assessments. Risk assessment includes analyzing the likelihood and impacts of events, while mitigation measures involve engineering solutions, monitoring systems, and emergency plans. Continuous monitoring and stakeholder engagement enhance transparency and accountability for effective risk management.
4. Change Management	Change management is a crucial aspect of improving tailings management practices within mining operations. This process involves careful planning, stakeholder engagement, communication, and monitoring to successfully implement changes and minimize potential risks or disruptions. Engaging relevant stakeholders such as mining personnel, regulatory authorities, and local communities ensures their perspectives and concerns are considered. Effective communication, training, and support are provided to personnel involved in tailings management to ensure they have the necessary skills and knowledge. Monitoring and adjusting the implemented changes as needed further enhance the effectiveness of tailings management practices, considering safety, environmental impacts, and operational efficiency.
5. Emergency Preparedness and Response	Emergency preparedness and response encompass proactive planning, procedures, and actions to anticipate and effectively address potential emergencies at a tailing's facility. This includes establishing protocols, resources, and systems to mitigate risks, minimize harm, and safeguard human life, the environment, and nearby communities. It is crucial to note that numerous disasters occur without sufficient time to prevent harm to the environment and human life, as evidenced by the cases of Brumadinho and Mariana mentioned in this study and discussed by Silvia's work (Silva, 2020). ICMM emphasizes the importance of a robust emergency preparedness and response plan in minimizing impacts, protecting lives, and facilitating a coordinated and swift response to mitigate risks (ICMM, 2021b).
6. Review and Assurance	Review and assurance encompass processes and activities that ensure the ongoing effectiveness, compliance, and continuous improvement of tailings management practices. These processes involve assessing the design, operation, and monitoring of tailings facilities to identify areas for improvement and ensure the management of risks. The Tailing management good practice guidance (ICMM, 2021b) emphasizes that implementing review and assurance processes allows for regular evaluation, improvement, and validation of tailings management practices, instilling confidence in stakeholders that risks are being effectively managed. In a practice case the Mount Poly failure is a good example where the Independent Experts Panel identify and pointed that if the raise of the project had passed through a review process, the project could be implemented following the corrected sequence and avoidant the failure (Morgenstem *et al.*, 2015).

The Tailings management, good practice guide (ICMM, 2021b) presents robust guidance for the tailings management system for all phases of the TSF, highlighting the proposal for the closure and post-closure phase, demonstrating concern about exposure to long-term risks. This same concept was presented by CDA (2014) with few changes but same concern about TSF closure, considering separated the closure phase in closure active care and closure passive care, such as presented on (fig. 1).

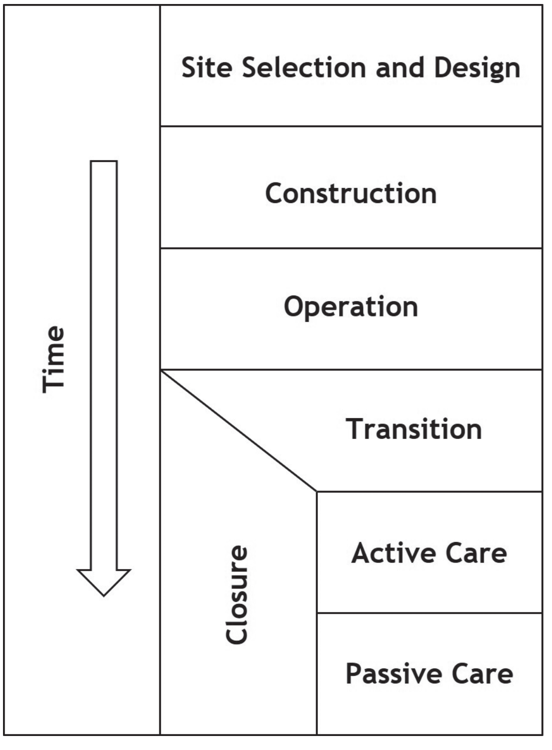

Fig. 1 - Phases in the Life of a Mining Dam (Source: CDA, 2014).

Fig. 1 - Fases da vida útil da barragem de mineração (Fonte: CDA, 2014).

Improper management of tailings in any lifecycle stage can have severe adverse effects on the environment (ICMM, 2021b). These materials may contain toxic substances, heavy metals, and other contaminants that have the potential to leach into soil and water bodies, resulting in pollution and damage to ecosystems. Effective tailings management involves minimizing such impacts and preventing long-term environmental degradation.

Considerations for risk management

Risk is the probability of an event occurring and its potential impact on the operators' objectives, which is directly influenced by the organization's risk appetite (Hopkin, 2017). Risk is inherent in human activities and can be associated with major accidents or natural disasters. In any business, the failure of the control process and the associated risks can lead to irreversible losses, including loss of life, environmental damage, property damage, and hinder the achievement of the enterprise's ultimate objectives (Hopkin, 2017).

Risk Management is a broad framework that can be applied differently depending on the industry, organization, or project. In the context of geotechnical structures like tailings dams, various methodologies are utilized for risk assessment. Some traditional and commonly employed methodologies include:

- Australian standard AS/NZS 4360 (2004) and ABNT NBR ISO 31000 (2009) share a similar concept and provide guidelines for the effective design of the risk management process. In general, these standards recommend the following steps: establishing the context to assess and identify all risks involved, analyzing the risks considering the presence of controls, and assessing the level of criticality to propose a prioritization of activities for risk treatment;
- SWOT Analysis, which assesses an organization's strengths, weaknesses, opportunities, and threats to inform strategic decision-making according to Gürel (2017);
- FMEA (Failure Mode and Effects Analysis), widely used for tailings dam risk assessment, systematically identifies potential failure modes, analyzes their effects, and implements preventive measures to minimize risks (Robertson and Shaw, 2006);
- Bowtie Analysis, a visual risk assessment method that combines cause-and-effect analysis, fault tree analysis, and event tree analysis to identify hazards, evaluate consequences, and develop risk control measures according to Hopkin (2017);
- Event Tree Analysis, which assesses the sequence of events and their likelihood following an initiating event, evaluating potential outcomes and associated risks for each branch of the tree (Robertson and Shaw, 2006);
- Cooper and Schindler (2013) added that the risk control mechanisms can be identified for a gap assessment process as a tool to identify gaps or discrepancies between current practices and desired outcomes during the risk management process. Gap assessments are typically conducted to evaluate the effectiveness of existing control measures and identify areas where improvements or additional controls are needed. It helps organizations understand their current risk management capabilities and determine the steps required to bridge the identified gaps. For the (PMBOK, 2017) the information on gap analysis as part of the project management process. It discusses how gap assessments can be conducted to identify discrepancies between project objectives how it presents itself;
- Hazard Identification and Risk Assessment (HIRA) is a systematic method used to identify potential hazards and assess associated risks in specific environments,

such as workplaces or projects. HIRA draws from relevant occupational health and safety literature and risk management standards, including (ISO 31000, 2009). Companies are adapting this methodology for Tailings Storage Facility risk assessment. In accordance with ABNT NBR ISO 31000, 2009, the risk control is part of the risk management process. The risk controls must be considered during the analyze phase and stablish for risk treatment. The performance of the risk controls is intrinsic of monitoring and review process, as illustrated on fig. 2.

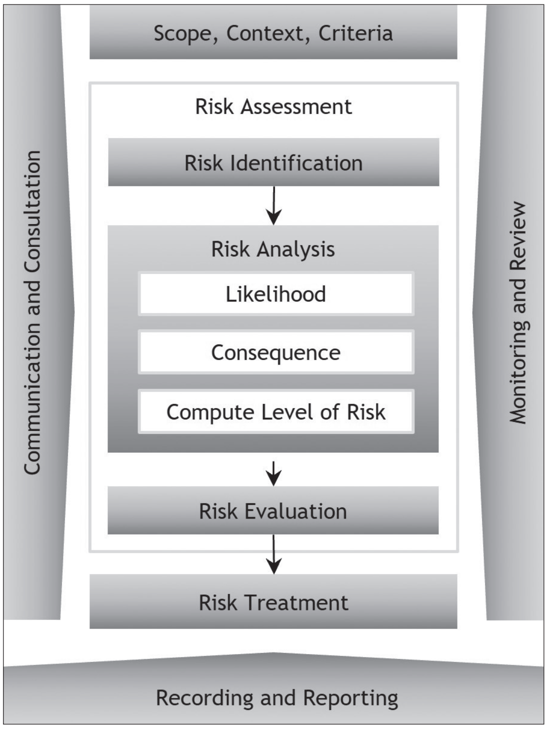

Fig. 2 - Flowchart of the risk management analysis process (Source: ISO 31000, 2009).

***Fig. 2** - Fluxograma do processo de análise do gerenciamento de riscos (Fonte:* ISO 31000, 2009).

Despite growing knowledge and adoption of good practices (ICOLD, 2012; CDA, 2014; ICMM, 2021b; MAC, 2021), TSF disasters continue to occur in mining industry, raising a critical question for TSF risk management. These disasters cause significant loss of life and environmental damage. While seemingly straightforward, answering this question is complex due to the interplay of numerous variables and the inherent challenges of managing uncertainty.

The pilar to develop this research was the six key elements to cover tailings management and governance with the aim of mitigating the risk of TSF failure proposed by ICMM (2021b). These elements consider possible catastrophic failure scenarios and provide robust guidance to reduce the impact of their consequences in the event of failure occurrence.

Materials and methods

The proposed Risk Control Management System (RCMS) was developed as a tool to measure the effectiveness of risk controls and their maturity in relation to tailings management performance and governance. Additionally, it ensures compliance with the requirements of the Global Industry Standard on Tailings Management (GISTM). It also can be used as a procedure for certifying the effectiveness of risk controls, bringing confidence for a safe management of the TSF and addressing opportunities for improvement.

This section presents a diagram of the methodology and the considerations taken during its development. The construction process of the RCMS methodology involved four key steps, which incorporated the concepts and principles for risk mitigation outlined in the Tailings Governance Framework (ICMM, 2016), supported by the Tailings Management Good Practice Guide (ICMM, 2021b) and GISTM Conformance Protocols (ICMM, 2021a).

The construction process of the methodology is presented in fig. 3, which outlines the main inputs and outputs of the process.

The RCMS methodology was constructed to effectively address the risk controls of TSFs failures and ensure adherence to industry practices and guidelines. A description of RCMS construction steps is described bellows:

Step 1: Understanding of the problem.

The primary objective of this step was to establish the scope of application for the methodology, determining which types of TSFs and under what conditions it could be implemented. A thorough understanding of the ICMM guidelines was essential to identify the relevant concepts and criteria applicable to different TSF types and to establish the correlation between the TSFs and the GISTM guidelines.

The guidelines and requirements represent a significant advancement and highlight the importance of improving controls to mitigate the failure risk. Motivated by this realization, the aim was to organize and standardize the key points and proposed controls to assess compliance with these guidelines.

This methodology provides a means to establish a clear and standardized approach for evaluating the adherence to these leading practices, enabling a more tangible measurement of the level of improvement and the quality of the requirements. As an input for developing this methodology, a more general approach was applied to the TSFs known to the authors, considering their current conditions. This served as a foundation for the methodology and can be used as a basis for future studies, should they meet the identified conditions.

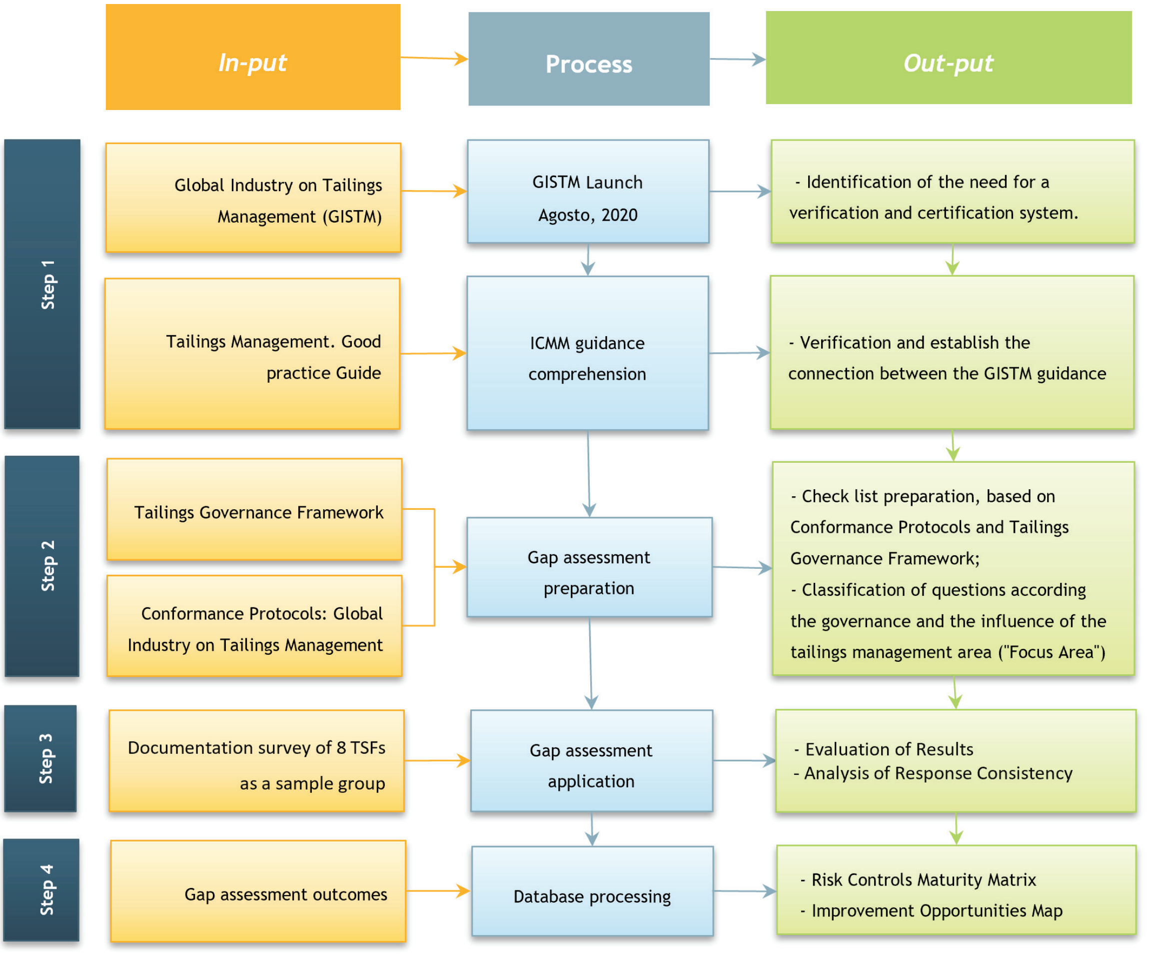

Fig. 3 - Risk Control Management System (RCMS) framework.

***Fig. 3** - Estrutura do Sistema de Gerenciamento de Controle de Riscos (RCMS).*

Step 2: Strategy definition.

In this stage of the research, the primary focus was on establishing a meaningful connection between the GISTM requirements (GTR, 2020) and the Tailings Governance Framework (ICMM, 2016) to develop a standardized approach for assessing TSF performance compliance. Subsequently, a comprehensive list of 271 questions was meticulously curated based on the GISTM Conformance Protocols (ICMM, 2021a). These questions were carefully crafted to facilitate a comprehensive gap assessment, allowing an evaluation of the quality and effectiveness of the implemented controls. To ensure coherence and organization, the questions were grouped into 25 specific focus areas, directly aligned with the 6 key elements of the Tailings Management and Governance Framework reinforced on (ICMM, 2021b).

To minimize subjectivity and introduce a more objective approach to the assessment process, the questions were formulated to elicit binary responses of “yes” or “no,” with the option of “NA” (not applicable) where appropriate. Each response carries a weight of 1, indicating a positive outcome, while questions marked as “NA” are excluded from the analysis. It is important to note that the questions are designed from a positive perspective. A “yes” response indicates that the corresponding focus area positively contributes to risk mitigation and that the implemented controls are effective, aligning with the principles of GISTM. To incorporate the risk concept into the gap assessment, the questions were categorized based on their likelihood and consequences, reflecting their influence on risk control for each focus area.

Step 3: Gap assessment application.

This step played a critical role in assessing the effectiveness of the process and identifying areas for improvement. It served as a comprehensive tool to measure and verify the controls maturity in terms of likelihood and consequences, in line with the core objectives of the Tailings Management and Governance Framework.

The authors conducted a rigorous gap assessment using the provided checklist, diligently following the instructions, and utilizing the available documentation and information pertaining to the TSF at that point in time. It is essential to emphasize that the primary aim of this gap assessment was to evaluate the control maturity was based on the GISTM requirements implementation for each focus area of TSFs analyzed. Hence, a positive response signifies a robust risk mitigation control mechanism.

In this gap assessment method, the criterion was set not to allow the use of the "partially meets" response option due to the breadth of this interpretation. Therefore, if there is any question for which the service is ongoing, the answer must be automatically "No" because it is not fully met. This approach avoids subjectivity in interpreting the question where the response would be "partially meets" which depends on the evaluator's interpretation.

To develop this methodological proposal, the gap assessment was applied to eight TSFs with different features and lifecycle. A detail regarding then are presented in Table II. These TSF were selected as a representative sample of facilities familiar to the author with the multidisciplinary operator team support. They were utilized to implement the developed methodology within the system, assessing its feasibility, and validating the results' representativeness.

This approach proved instrumental in enhancing understanding of GISTM requirements across various types of TSFs. Another noteworthy aspect is the sensitivity and complexity of the subject to construct a TSF database, ensuring compliance with GISTM requirements, all while safeguarding company confidentiality.

A major constraint to the publication of this methodology is the confidentiality of TSF data, to prevent unnecessary exposure and inquiries that could tarnish the company's reputation and diminish interest in participating in future research by this author. However, there was no loss of quality in the information used to implement this methodological proposal.

Step 4:
Application of risk control management system (RCMS).

The data from the gap assessment checklist were processed to facilitate compliance verification and interpretation. The scores were categorized by focus area, considering likelihood and consequence, with a positive answer (Yes) assigned a score of 1. The score obtained was treated and standardized for base 10. Subsequently, the average standardized scores from each focus area were transferred to the Risk Control Maturity Matrix, which consists of a 10x10 matrix representing Likelihood by Consequence. A guidance for outcomes from the matrix with a description assigned to the classes of the analyzed controls were prosed.

The Risk Control Management System (RCMS) brings a proposal to connect the requirements of the (GTR, 2020) and the Tailings Management Good Practice Guide

Table II - Summary of TSFs analysed with this methodology.

***Tabela II** - Resumo das TSFs analisadas com essa metodologia.*

TSF	A	B	C	D	E	F	G	H
Classification (GTR, 2020)	Extreme	Extreme	Extreme	Extreme	High	Low	Low	Low
Constructive method	Upstream	Upstream	Upstream	Upstream	Tailings Stack	In-pit	In-pit	Downstream
Situation	Inactive	Inactive	Inactive	Inactive	Active	Active	Active	Active
Life cycle phase	Closure	Closure	Closure	Closure	Operations	Operations	Operations	Operations
TSF Type	Tailings	Tailings	Tailings	Tailings	Mine wast and earthfill	NA	NA	Compacted
Volume (Mm^3)	129.59	10.3	58.7	0.9	4.3	2.9	2.4	0.5
Height (m)	165	55	70	37	80	30	11	25
Volume/ Height	0.79	0.19	0.84	0.02	0.05	0.10	0.22	0.02
State/Country	Minas Gerais/BR	Minas Gerais/BR	Texas/US	Texas/US	Minas Gerais/BR	Minas Gerais/BR	Pará/BR	Pará/BR
Climate	Subtropical	Subtropical	Semi-arid	Semi-arid	Subtropical	Subtropical	Tropical	Tropical
Hazard Seismic	Low	Low	High	High	Low	Low	Very low	Very low
GISTM inplementation	Yes	Yes	Yes	Yes	Yes	Yes	No	No

(ICMM, 2021b), in order to develop a standardized approach to assessing TSF performance compliance. The list of 271 questions was organized in 25 specific focus areas, directly aligned with the 6 key elements of the Tailings Management and Governance Framework. The connection between these guidelines and their respective number of questions is presented in Table III.

The question organization has resulted in the development of a comprehensive checklist for assessing the compliance of GISTM. The checklist was developed based on Conformance Protocols (ICMM, 2021a) and hierarchized in accordance with the concept defined by Tailings Management Good Practice Guide (ICMM, 2021b) for risk mitigation.

The organization for the Tailings Governance Framework (ICMM, 2016) used in this paper are presented in fig. 4 to improve the comprehension regarding the focus areas from tailings management stablished in this research to analyze and interpret the results, considering the improvement opportunities for the process.

To ensure objectivity and evidence-based assessment, the questions were structured to elicit binary responses (“yes” or “no”), with the option of “NA” (not applicable) where appropriate. Each positive response carries a weight of 1, indicating a favorable outcome, while “NA” responses are excluded from analysis. It is worth noting that the questions are framed positively, indicating that a “yes” response signifies a positive contribution of the respective focus area to risk mitigation and effective implementation of controls, aligning with the principles of GISTM.

Table III - Linking tailings management and governance with GISTM requirements.

Tabela III - Conexão do Gerenciamento e governança de rejeitos e com os requerimentos do GISTM.

Tailings Governance Framework		GISTM	Questions number
Key elements	Tailings Management Areas	Requirement Equivalent	
1. Accountability & Responsibility & Competency	1.01 Accountability for tailings governance and the proper formalization	8.3/ 8.4/ 9.2/ 9.4/ 11.5/ 13.4/	17
	1.02 Communication process	1.3/ 11.5/ 12.1/ 12.2/ 15.1/ 15.3	8
	1.03 Competency and promoting continual Learning	8.5/ 8.6/ 9.1/ 11.3/ 11.4	10
	1.04 Training for staff involved in the TSF’s management	6.1/ 6.4/ 8.2/ 11.1/ 11.2/ 11.3	10
2. Planning and Resourcing	2.01 Corporate Policy on Tailings Management and financial accountability	8.1	5
	2.02 Business Planning Processes impacts	14.3	3
	2.03 Corporate Human Rights Policy	1.1/ 1.2	9
	2.04 Social and environmental engagement	1.3/ 1.4	4
3. Risk Management	3.01 Project Conception and Design criteria for core elements	2.1/ 2.2/ 4.2/ 4.4/ 4.5/ 4.6/ 5.1	22
	3.02 Identification of failure modes, evaluation, and control of associated risks	3.3/ 4.7/ 5.4/ 5.7/ 7.2/ 10.1/ 13.1	18
	3.03 Construction and Operating performance	4.8/ 6.1/ 6.2/ 6.3/ 7.1/ 9.3	9
	3.04 Assessing credible potential consequences	2.3/ 2.4/ 3.3/ 4.1/ 13.1	6
	3.05 Tailings Management System	5.3/ 5.5/ 6.1/ 7.1/ 7.2/ 7.4/ 7.5/ 8.2/ 8.5	21
	3.06 Operation, Maintenance and Surveillance	4.5/ 6.4/ 7.1/ 7.2/ 7.3/ 7.4	15
	3.07 Closure and Post-Closure	3.2/ 4.1/ 5.6/ 10.7	10
4. Change Management	4.01 Process of identifying, assessing, controlling, recording, and addressing changes	3.1/ 3.4/ 4.3/ 4.8/ 5.2/ 6.3/ 6.5/ 6.6/ 7.4/ 10.1	16
	4.02 Changes in the governance structure	6.5/ 8.6/ 9.5/ 10.5	6
	4.03 Changes in risk assessment scenarios	4.2/ 6.5/ 13.1	7
5. Emergency Preparedness and Response	5.01 Monitoring and operating response	13.1	1
	5.02 Emergency Preparedness and Response Plan	5.8/ 13.1/ 13.2/ 13.3/ 13.4/ 14.1/ 14.3/ 14.4	22
	5.03 EPRP communication plan	13.1/ 13.2/ 15.1/ 15.2	10
	5.04 Pos-failure outcomes activities	13.4/ 14.2/ 14.5	6
6. Review and Assurance	6.01 Operation, Maintenance and Surveillance Update	6.4	4
	6.02 Tailings Management System Review	5.2/ 6.4	8
	6.03 Program for Reviewing Tailings Safety	4.3/ 4.4/ 8.2/ 8.7/ 10.1/ 10.2/ 10.3/ 10.4/ 10.5/ 10.6/ 13.1	24
Sum			**271**

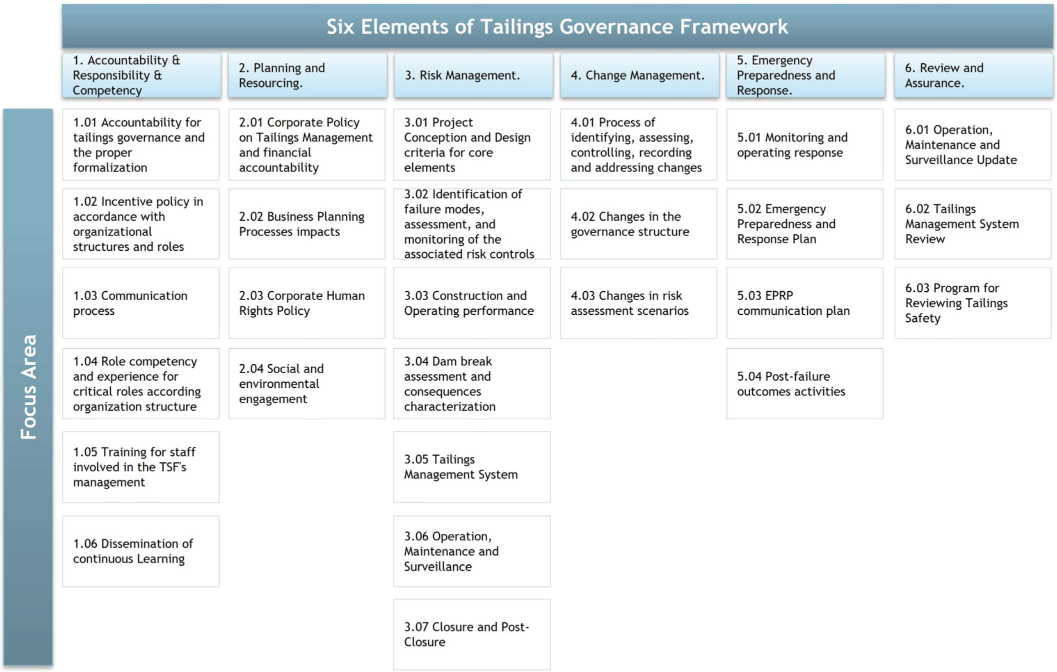

Fig. 4 - Tailings Management and Governance Framework by focus area.

***Fig. 4** - Estrutura de Governança de Rejeitos por área de foco.*

To integrate the risk concept into the gap assessment, the questions were classified according to their likelihood and consequences, reflecting their impact on risk control within each focus area. Table IV presents the maximum score (MS) corresponds to the likelihood (L) and consequence (C) scores. This indicates the best measured performance of the focus areas of the tailings management process, considering a multidisciplinary view and involving all stakeholders in risk mitigation.

So, a score was obtained for each focus area of tailings management. It was processed and standardized on a scale of 10 to achieve equal representativeness for the focus areas under analysis, and the average among them was calculated separately between likelihood and consequence. In this operation, the "Not Applicable" (NA) answers were disregarded.

Following that, a 10x10 matrix was constructed, where the result obtained for the average assessment of factors influencing the likelihood of TSF failure was plotted on the vertical axis of the matrix, and the evaluated factors that may impact the consequence of a possible TSF failure were plotted on the horizontal axis, thus obtaining an assessment index of risk control maturity.

This matrix, named "Risk Controls Maturity Matrix," is so called for presenting a measured indicator representing the level of maturity of tailing management and governance, based on compliance with GISTM requirements, as a reference to a robust set of best practices aimed at risk mitigation.

The organization of the data allows for demonstrating how to enhance tailing management and governance performance by mapping improvement opportunities (to be presented in the next section in Table V). The criterion establishes that if the score for a focus area is evaluated below 5 (standardized to 10), it indicates an opportunity for improvement in identifying a focus area for TSFs.

The analysis and interpretation of the results obtained from the matrix and TSF features analyze, and improvement opportunities will be provided in the following section, that includes descriptions assigned to the maturity level of controls for the analyzed TSFs, serving as a valuable resource for understanding the associated implications and recommendations.

Results and discussion

The authors engaged in discussions with the TSF Operator to obtain answers and ensure a comprehensive understanding of the questions. Furthermore, input from experts in specific disciplines was sought to enhance the accuracy of the assessment.

The gap assessment results with the score for all TSFs are presented in Appendix A. The results are presented organized in accordance with the six key elements of Tailings Governance Framework (ICMM, 2016) and separated by areas of tailings management focus areas.

The management of TSFs is very dynamic and there is a challenge to measure the performance. In this work

Table IV - Question number for focus area classified by Likelihood and Consequence.

Tabela IV - Número da pergunta para a área de foco classificada por Probabilidade e Consequência.

Focuses area for risk mitigation	Maximum Score (MS)	
	L	C
1.01 Accountability for tailings governance and the proper formalization	3	14
1.02 Communication process	6	2
1.03 Competency and promoting continual Learning	3	7
1.04 Training for staff involved in the TSF's management	7	3
2.01 Corporate Policy on Tailings Management and financial accountability	1	4
2.02 Business Planning Processes impacts	3	0
2.03 Corporate Human Rights Policy	9	0
2.04 Social and environmental engagement	4	0
3.01 Project Conception and Design criteria for core elements	1	21
3.02 Identification of failure modes, evaluation and control of associated risks	10	8
3.03 Construction and Operating performance	0	9
3.04 Assessing credible potencial consequences	6	0
3.05 Tailings Management System	3	18
3.06 Operation, Maintenance and Surveillance	0	15
3.07 Closure and Post-Closure	0	10
4.01 Process of identifying, assessing, controlling, recording, and addressing changes	2	14
4.02 Changes in the governance structure	0	6
4.03 Changes in risk assessment scenarios	2	5
5.01 Monitoring and operating response	1	0
5.02 Emergency Preparedness and Response Plan	22	0
5.03 EPRP communication plan	9	1
5.04 Post-failure outcomes activities	6	0
6.01 Operation, Maintenance and Surveillance Update	0	4
6.02 Tailings Management System Review	1	7
6.03 Program for Reviewing Tailings Safety	3	21
Sum	**102**	**169**

Note: (L) Likelihood; (C) Consequence

the application using the standardized score to 10 to allow the construction of the matrix and visualization of the performance of the tailing management and governance according to its controls (fig. 5). In the case of reapplying the gap assessment for the same TSF at another time, the response may be different, and the evolution of the process may be noticed. The matrix is a workable tool to support the discussion and verification of the acceptability of the risk control maturity level throughout the life cycle of the TSF.

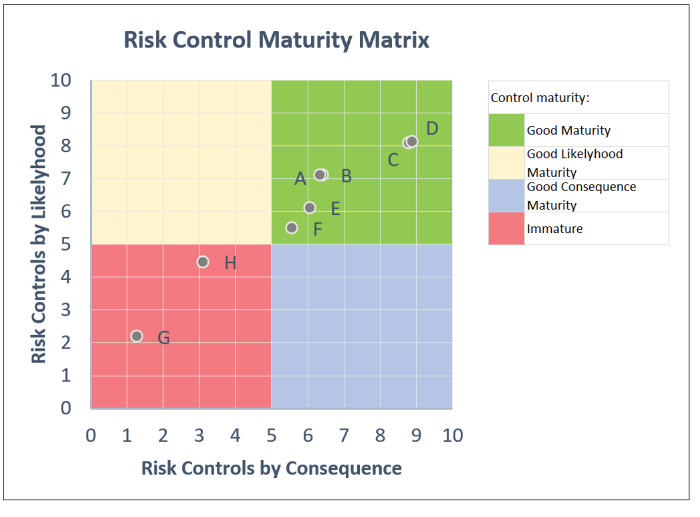

Fig. 5 - Risk Control Maturity Matrix.

***Fig. 5** - Matriz de Maturidade dos Controles de Risco.*

TSFs “A” and “B” are conventional facility (dams) from the same company. They are built using the upstream method and are in the closing phase, both currently active. The factors that most influenced the positive outcome of these TSFs were the issues related to “Emergency Preparedness and Response” (85 %) and “Accountability & Responsibility & Competency” (80 %) for both TSFs. “Change Management” (TSF “A” 56 %; TSF “B” 52 %) and “Review and Assurance” (TSF “A” 62 %; TSF “B” 59 %) were noted as areas of concern and opportunities for improvement in the performance of the tailings governance framework.

TSFs “C” and “D” are conventional facilities (dams) from the same company. They are built using the upstream method and are in the closing phase, both currently inactive. These TSFs achieved 100 % compliance for “Review and Assurance” and 90 % for “Planning and Resourcing”. The factors influencing the reduction of maturity for both TSFs are “Accountability & Responsibility & Competency” (76 %) and “Emergency Preparedness and Response” (STF “C” 75 %; STF “D” 81 %), identified as critical for the proper tailings governance framework.

TSF “E” is a non-conventional facility (stack) in an operational phase. The compliance rate was 82 % for “Accountability & Responsibility & Competency” and 68 % for “Change Management”. It represents a good maturity for risk controls with some improvement opportunities.

TSFs “F” and “G” are non-conventional facilities (in-pits) in an operational phase. These facilities belong to different companies, so the management approach for TSFs is different. The outcomes for TSF “F” were positively influenced by “Accountability & Responsibility & Competency” (81 %) and “Emergency Preparedness and Response” (79 %), while “Review and Assurance” contributed to the reduction of the maturity level. The other elements of the governance framework maintain a level above 60 %.

TSF “G” wasn’t evaluated with a good result for “Planning and Resourcing” (64 %), however, the scores for the other elements of the management were low. In this case, the “Review and Assurance” score was 0. A relevant point is that the company owning this TSF isn’t an ICMM member and there is no obligation to meet the GISTM requirement.

TSFs “G” and “H” belong to the same company, and the standard for the tailings governance framework is very similar, although the TSFs are of different types. For TSF “H”, the highlighted element is “Emergency Preparedness and Response” (96 %).

We can note that facilities belonging to a single company and having similar characteristics apply the same management standard. In this research, it was possible to observe the influence of management culture on the established governance standards and existing organizational procedures in the company when comparing the results of similar TSFs from the same company, or even different structures under the same management.

An additional noteworthy observation regarding TSF “H” is its significant adherence to the “Emergency Preparedness and Response” element, despite lacking a commitment to comply with GISTM. This notable score may be credited to the substantial influence of the country’s regulations, which mandate compliance with various emergency preparedness requirements.

This observation can be verified and connected with the improvement opportunity map (Table V). The maturity level for focus areas is presented in accordance with the opportunities for improving, considering their field of influence, whether likelihood or consequence, to direct efforts to improve the maturity level of the controls and potentially influence the indicator plotted on the Risk Control Maturity Matrix (fig. 5).

The Table V shows consistency with the matrix indicating that TSFs “G” and “H” with “Immature controls” will require greater effort to improve their implemented risk controls and more accurately target which focus area will require greater attention to improve the level of maturity. This reflection can be noted on the Table V.

Based on this analysis, it becomes clear that the tooling offers an excellent solution for enhancing risk control management of a TSF. It does so by providing higher efficiency and intelligence while also enabling the measurement and analysis of the risk control verification process’s evolution.

The results can also be analyzed from two relevant perspectives concerning the methodology in relation of the TSF features:

- Country influence

  Due to the limited sample size of TSFs used to construct this database, there are some restrictions on interpretation and drawing conclusions. The variable “country” provides interesting information for understanding local regulations and whether there is any relation to GISTM compliance. However, to enhance this understanding, the database would need to be expanded to include more TSFs from different countries.

- GISTM Consequence Classification

  There is 50 % of TSFs in the database are classified as “Extreme”, according to the consequences classification (GTR, 2020). Then this characteristic can’t support any conclusion or provide a distinguishing factor for identifying certain interpretations.

Table V - Opportunity for improvement of risk controls.

Tabela V - Oportunidade para melhoria do controle do risco.

TSF	A		B		C		D		E		F		G		H	
Focus area for risk mitigation	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C
1.01 Accountability for tailings governance and the proper formalization		■		■		■		■		■		■	■	■	■	■
1.02 Communication process	■		■			■		■	■		■		■	■	■	■
1.03 Competency and promoting continual Learning						■		■					■	■	■	■
1.04 Training for staff involved in the TSF's management					■		■						■	■	■	■
2.01 Corporate Policy on Tailings Management and financial accountability		■		■						■		■	■	■	■	■
2.02 Business Planning Processes impacts																
2.03 Corporate Human Rights Policy																
2.04 Social and environmental engagement																
3.01 Project Conception and Design criteria for core elements																
3.02 Identification of failure modes, evaluation and control of associated risks		■		■									■	■		■
3.03 Construction and Operating performance															■	
3.04 Assessing credible potencial consequences																
3.05 Tailings Management System										■		■		■		■
3.06 Operation, Maintenance and Surveillance																
3.07 Closure and Post-Closure									■		■		■		■	
4.01 Process of identifying, assessing, controlling, recording and addressing changes		■	■	■						■		■		■	■	■
4.02 Changes in the governance structure													■		■	
4.03 Changes in risk assessment scenarios														■		
5.01 Monitoring and operating response														■		
5.02 Emergency Preparedness and Response Plan																
5.03 EPRP communication plan	■		■						■						■	
5.04 Post-failure outcomes activities																
6.01 Operation, Maintenance and Surveillance Update													■			
6.02 Tailings Management System Review	■		■										■	■	■	■
6.03 Program for Reviewing Tailings Safety														■	■	

Legend:

L	Controls that influence likelihood
C	Controls that influence consequence
■	Opportunity for improvement of risk controls

- TSFs operated by ICMM members and not ICMM members.

  From GISTM (2020) there are a target to compliance the GISTM requirements and for TSFs classified as "Extreme" the timeline is for August 2023, so the ICMM member companies are in process for implementation this standard for tailings management.

For TSFs operated by a mining company that is not a ICMM member, named as "G" and "H", the Control Class was rated as "Weak risk controls" and "Medium risk controls", despite having a Low Consequence Rating. This highlights the need to consider additional factors such as the method of construction of the TSF and other characteristics. This is an important issue to consider when different types of TSF apply similar criteria and can make the control system a more representative method.

- TSFs no-conventional like a tailing stack and n-Pit facilities

  The GISTM is very robust and has a strong focus on mitigating the risk of a possible catastrophic failure of TSFs. However, there are TSF types that are recommended to be aligned with the GISTM requirements, but mapped failure modes don't have a catastrophic impact on the environment and the surrounding community. However, they should meet as few of the requirements as possible, to ensure the safety of the TSF, in terms of risk controls that influence the likelihood of failure and the impact of its consequence, even if these structures do not have relevant impacts on the neighborhood.

In this research, the non-conventional TSFs, such as Tailings Stack and In-Pit facilities ("E", "F", and "G") the number of "Not applicable" answers was relevant and the most significant number was observed for focus areas "5.02 Emergency Preparedness and Response Plan," "5.03 EPRP communication plan," and "5.04 Post-failure outcomes activities", directly related to the consequence of the failure, as the possibility of the impact will be less when compared to a conventional TSF, in a general view. The percentage of "Not applicable" answers for non-conventional TSFs is further illustrated in Table VI.

Considering this result presented in the Risk Control Maturity Matrix is possible to identify an opportunity to improve the method if the gap assessment to consider the specifics characteristics of non-conventional TSFs in relation of GISTM requirements with failure modes scenarios with no catastrophic impacts.

It is reasonable to argue that for non-conventional TSFs, such as Tailings Stack facilities, the consequence of a rupture may be localized within the operator's area and have relatively minor impacts compared to the failure of a conventional TSF in terms of community, socio-economic, and environmental concerns. However, this hypothesis does not negate the need to conduct failure scenarios to confirm the downstream impacts, particularly on workers and to ensure the preparation of an Emergency Preparedness Response Plan (EPRP) aligned with this crucial reference.

Table VI -"Not applicable" answers for non-conventional TSFs.

***Tabela VI** - Respostas "Não aplicável" para TSFs não convencionais.*

Focus area	Not Applicable by TSF (%)		
	E	F	G
TSF type	Tailings Stack	In-pit	In-pit
1.01 Accountability for tailings governance and the proper formalization	0 %	6 %	6 %
1.02 Communication process	0 %	0 %	0 %
1.03 Competency and promoting continual Learning	10 %	10 %	20 %
1.04 Training for staff involved in the TSF's management	0 %	0 %	0 %
2.01 Corporate Policy on Tailings Management and financial accountability	0 %	0 %	0 %
2.02 Business Planning Processes impacts	100 %	100 %	100 %
2.03 Corporate Human Rights Policy	0 %	0 %	44 %
2.04 Social and environmental engagement	0 %	0 %	0 %
3.01 Project Conception and Design criteria for core elements	9 %	32 %	36 %
3.02 Identification of failure modes, evaluation, and control of associated risks	11 %	22 %	22 %
3.03 Construction and Operating performance	0 %	100 %	100 %
3.04 Assessing credible potential consequences	33 %	67 %	67 %
3.05 Tailings Management System	24 %	24 %	33 %
3.06 Operation, Maintenance and Surveillance	0 %	7 %	0 %
3.07 Closure and Post-Closure	0 %	0 %	0 %
4.01 Process of identifying, assessing, controlling, recording, and addressing changes	6 %	31 %	38 %
4.02 Changes in the governance structure	17 %	17 %	17 %
4.03 Changes in risk assessment scenarios	71 %	71 %	71 %
5.01 Monitoring and operating response	0 %	0 %	0 %
5.02 Emergency Preparedness and Response Plan	64 %	77 %	77 %
5.03 EPRP communication plan	30 %	50 %	100 %
5.04 Pos-failure outcomes activities	50 %	50 %	100 %
6.01 Operation, Maintenance and Surveillance Update	0 %	25 %	25 %
6.02 Tailings Management System Review	13 %	25 %	25 %
6.03 Program for Reviewing Tailings Safety	4 %	54 %	54 %
Sum	**18 %**	**31 %**	**37 %**

In a specific case study of TSF "E," a Tailings Stack facility, (Rangel *et al.*, 2021) investigated a "Stack Break" scenario, simulating a global rupture. They observed that the downstream valley configuration becomes more significant when evaluating the impact of the rupture, compared to a stack.

The findings of (Rangel *et al.*, 2021) indicate that the mobilized mass has limited potential after the initial rupture, causing it to fill the downstream valley rapidly and come to a quick stop in a new stable configuration. This case study provides essential insights for the appropriate preparation of an EPRP, considering the magnitude of the impact scenario.

For a conventional tailing like a dam the fool behavior is totally different in compare to a no conventional TSF, as studied by Machado *et al.*, 2018 and Almeida *et al.*, 2020, when they performed retro analyses using different models for the Fundão Dam and although the results obtained showed divergences in relation to the peak flow, which can be attributed to different breach widths, adopted in each case, there was a consensus in relation to the distance from the propagation of the breaking wave to the height reached by the wave.

In addition, (Silva, 2020) pointed in our research, based in Fundão e Brumadinho cases, that a failure of a conventional TSF (Dam) can transcend their spatial, temporal, and territorial scales and can't be resolved immediately. The geographical and socio-environmental studies are an opportunity to verify the diversity of possibilities of approaches to be applied in interdisciplinary studies, given the severity of the impacts, the complexity of the problem and the nature of the of conflicts arising from the risk of dams and disasters themselves.

Conclusions

The methodology for a Risk Control Management System (RCMS) presented demonstrates its feasibility in assessing the level of the control maturity for the analyzed TSFs and identifying areas for mitigation the potential failure risks. The methodology proves to be applicable, providing representative outcomes and offering insights for long-term safety of the facility in accordance with GISTM requirements.

The Risk Control Maturity Matrix effectively represents the maturity controls level based on the verified documents and risk concepts. The methodology provides a practical tool for the operation to support risk appetite and determine acceptable levels of risk controls, aiding in decision-making and defining strategies for risk mitigation.

To further enhance the methodology, it is recommended to conduct additional studies to establish a confidence criterion for verifying the effectiveness of the checklist used in the Gap Assessment exercise. This criterion should be based on correlation and sensitivity analyses of the question nature and answer consistency. Additionally, exploring the influence of focus areas on the Risk Control Maturity Matrix could provide valuable insights into the areas that contribute most to mitigating the risk of TSF disruptions within the satisfactory threshold, which proves its reliability and effectiveness to consider the risk controlled.

To improve the application and calibration of the method parameters, it is crucial to assess gaps in a wider range of TSFs and increase the sample size. Applying statistical techniques and creating clusters can help identify similarities in results among TSF groups, ensuring the validity and representativeness of the evaluation method. Therefore, further research and refinement of the methodology are necessary to enhance its effectiveness and reliability, ultimately contributing to better risk management and the overall safety of TSFs.

Supplementary Material

Appendix A

Acknowledgments

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Appendix A

Gap assessiment results																									
Key elements	Focuses area for risk mitigation	TSF: A			TSF: B			TSF: C			TSF: D			TSF: E			TSF: F			TSF: G			TSF: H		
		Meet	Don't Meet	NA	Meet	Don't Meet	NA	Meet	Don't Meet	NA	Meet	Don't Meet	NA	Meet	Don't Meet	NA	Meet	Don't Meet	NA	Meet	Don't Meet	NA	Meet	Don't Meet	NA
1. Accountability & Responsibility & Competency	1.01 Accountability for tailings governance and the proper formalization	12	5	0	12	5	0	14	3	0	14	3	0	13	4	0	12	4	1	5	11	1	8	9	0
	1.02 Communication process	6	2	0	6	2	0	5	3	0	5	3	0	6	2	0	6	2	0	1	7	0	1	7	0
	1.03 Competency and promoting continual Learning	9	1	0	9	1	0	7	3	0	7	3	0	8	1	1	8	1	1	0	8	2	2	7	1
	1.04 Training for staff involved in the TSF's management	9	1	0	9	1	0	8	2	0	8	2	0	9	1	0	9	1	0	3	7	0	3	7	0
2. Planning and Resourcing.	2.01 Corporate Policy on Tailings Management and financial accountability	4	1	0	4	1	0	5	0	0	5	0	0	4	1	0	4	1	0	0	5	0	0	5	0
	2.02 Business Planning Processes impacts	3	0	0	3	0	0	3	0	0	3	0	0	0	0	3	0	0	3	0	0	3	0	0	3
	2.03 Corporate Human Rights Policy	5	4	0	5	4	0	7	2	0	7	2	0	5	4	0	5	4	0	5	0	4	5	0	4
	2.04 Social and environmental engagement	4	0	0	4	0	0	4	0	0	4	0	0	4	0	0	4	0	0	4	0	0	4	0	0
3. Risk Management.	3.01 Project Conception and Design criteria for core elements	16	6	0	16	6	0	19	3	0	19	3	0	17	3	2	12	3	7	8	6	8	10	6	6
	3.02 Identification of failure modes, evaluation and control of associated risks	9	9	0	9	9	0	16	2	0	16	2	0	11	5	2	10	4	4	0	14	4	8	8	2
	3.03 Construction and Operating performance	8	1	0	8	1	0	8	1	0	8	1	0	7	2	0	0	0	9	0	0	9	3	6	0
	3.04 Assessing credible potencial consequences	5	1	0	5	1	0	4	2	0	4	2	0	2	2	2	2	0	4	2	0	4	3	1	2
	3.05 Tailings Management System	17	4	0	17	4	0	15	6	0	15	6	0	12	4	5	13	3	5	8	6	7	16	4	1
	3.06 Operation, Maintenance and Surveillance	13	2	0	13	2	0	15	0	0	15	0	0	14	1	0	13	1	1	8	7	0	14	1	0
	3.07 Closure and Post-Closure	8	1	1	8	1	1	10	0	0	10	0	0	0	10	0	0	10	0	0	10	0	0	10	0
4. Change Management.	4.01 Process of identifying, assessing, controlling, recording and addressing changes	9	7	0	8	8	0	13	2	1	13	2	1	10	5	1	8	3	5	2	8	6	5	10	1
	4.02 Changes in the governance structure	3	2	1	3	2	1	4	1	1	5	1	0	3	2	1	3	2	1	0	5	1	0	5	1
	4.03 Changes in risk assessment scenarios	2	2	3	2	2	3	7	0	0	7	0	0	2	0	5	2	0	5	0	2	5	1	2	4
5. Emergency Preparedness and Response.	5.01 Monitoring and operating response	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0
	5.02 Emergency Preparedness and Response Plan	20	2	0	20	2	0	17	5	0	19	3	0	8	0	14	5	0	17	1	4	17	16	0	6
	5.03 EPRP communication plan	6	4	0	6	4	0	6	4	0	6	4	0	3	4	3	2	3	5	0	0	10	4	1	5
	5.04 Post-failure outcomes activities	6	0	0	6	0	0	3	0	3	3	0	3	3	0	3	3	0	3	0	0	6	3	0	3
6. Review and Assurance.	6.01 Operation, Maintenance and Surveillance Update	4	0	0	4	0	0	4	0	0	4	0	0	4	0	0	3	0	1	0	3	1	3	1	0
	6.02 Tailings Management System Review	2	5	1	2	5	1	8	0	0	8	0	0	4	3	1	3	3	2	0	6	2	1	6	1
	6.03 Program for Reviewing Tailings Safety	15	8	1	14	9	1	24	0	0	24	0	0	16	7	1	6	5	13	0	11	13	5	13	6

Appendix A (continiation)

Key elements	Focuses area for risk mitigation	Likelihood and Consequence score															
		TSF: A		TSF: B		TSF: C		TSF: D		TSF: E		TSF: F		TSF: G		TSF: H	
		L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C
1. Accountability & Responsibility & Competency	1.01 Accountability for tailings governance and the proper formalization	12	0	12	0	13	1	13	1	12	1	12	0	5	0	7	1
	1.02 Communication process	0	6	0	6	2	3	2	3	0	6	0	6	0	1	0	1
	1.03 Competency and promoting continual Learning	7	2	7	2	6	1	6	1	6	2	6	2	0	0	2	0
	1.04 Training for staff involved in the TSF's management	3	6	3	6	1	7	1	7	3	6	3	6	1	2	1	2
2. Planning and Resourcing.	2.01 Corporate Policy on Tailings Management and financial accountability	4	0	4	0	4	1	4	1	4	0	4	0	0	0	0	0
	2.02 Business Planning Processes impacts	NA	3	NA	3	NA	3	NA	3	NA	NA	NA	NA	NA	NA	NA	NA
	2.03 Corporate Human Rights Policy	NA	5	NA	5	NA	7	NA	7	NA	5	NA	5	NA	5	NA	5
	2.04 Social and environmental engagement	NA	4	NA	4	NA	4	NA	4	NA	4	NA	4	NA	4	NA	4
3. Risk Management.	3.01 Project Conception and Design criteria for core elements	15	1	15	1	18	1	18	1	16	1	11	1	7	1	9	1
	3.02 Identification of failure modes, evaluation and control of associated risks	5	4	5	4	7	9	7	9	6	5	6	4	0	0	5	3
	3.03 Construction and Operating performance	8	NA	8	NA	8	NA	8	NA	7	NA	NA	NA	NA	NA	3	NA
	3.04 Assessing credible potencial consequences	NA	5	NA	5	NA	4	NA	4	NA	2	NA	2	NA	2	NA	3
	3.05 Tailings Management System	15	2	15	2	13	2	13	2	11	1	12	1	7	1	15	1
	3.06 Operation, Maintenance and Surveillance	13	NA	13	NA	15	NA	15	NA	14	NA	13	NA	8	NA	14	NA
	3.07 Closure and Post-Closure	8	NA	8	NA	10	NA	10	NA	0	NA	0	NA	0	NA	0	NA
4. Change Management.	4.01 Process of identifying, assessing, controlling, recording and addressing changes	8	1	7	1	11	2	11	2	9	1	7	1	2	0	5	0
	4.02 Changes in the governance structure	3	NA	3	NA	4	NA	5	NA	3	NA	3	NA	0	NA	0	NA
	4.03 Changes in risk assessment scenarios	1	1	1	1	5	2	5	2	1	1	1	1	0	0	0	1
5. Emergency Preparedness and Response.	5.01 Monitoring and operating response	NA	1	NA	1	NA	1	NA	1	NA	1	NA	1	NA	0	NA	1
	5.02 Emergency Preparedness and Response Plan	NA	20	NA	20	NA	17	NA	19	NA	8	NA	5	NA	1	NA	16
	5.03 EPRP communication plan	0	6	0	6	1	5	1	5	0	3	NA	2	NA	NA	0	4
	5.04 Post-failure outcomes activities	NA	6	NA	6	NA	3	NA	3	NA	3	NA	3	NA	NA	NA	3
6. Review and Assurance.	6.01 Operation, Maintenance and Surveillance Update	4	NA	4	NA	4	NA	4	NA	4	NA	3	NA	0	NA	3	NA
	6.02 Tailings Management System Review	1	1	1	1	7	1	7	1	3	1	2	1	0	0	1	0
	6.03 Program for Reviewing Tailings Safety	13	2	12	2	21	3	21	3	14	2	5	1	0	0	3	2
Sum		**120**	**76**	**118**	**76**	**150**	**77**	**151**	**79**	**113**	**53**	**88**	**46**	**30**	**17**	**68**	**48**

Note: L - likelihood; C - Consequence; NA - Not applicable