Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Convergence of International Mining Protocols and Compliance of Tailings Structures in Closure: An Integrated Assessment

Raphael Foscarini
raphael.foscarini@aluno.ufop.edu.br
Universidade Federal de Ouro Preto
Dra. Sandra Nogueira
Universidade Federal de Ouro Preto
Danielle Menezes
Universidade Federal de Ouro Preto
Hernani Lima
Universidade Federal de Ouro Preto

Research Article

Keywords: Tailings Governance, Political Ecology, Closure-phase Mining, Protocol Convergence

Posted Date: April 17th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9441668/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Tailings management has become a central concern in mining, especially after disasters such as Mariana (2015) and Brumadinho (2019). In response, several international protocols emerged to guide safer and more responsible practices. This article presents an integrated analysis of five key frameworks – GISTM, MP, TSM, RGMP, and RRA – combined with a case study evaluating 12 Tailings Storage Facilities (TSFs) in closure phase, located in Brazil and the United States. Using the RCMS (Risk Control Management System) methodology, the research assessed the degree of alignment between the GISTM and the other protocols and measured the practical compliance of each TSF against GISTM requirements.

By situating tailings governance within the field of political ecology, this article explores how technical standards mediate power relations between mining companies, regulators, and affected communities (Bridge, 2004; Robbins, 2020). It highlights how the absence of community engagement, residual risk documentation, and post-closure monitoring reflects broader asymmetries in environmental decision-making (Escobar, 1996; Pulido, 1996).

The findings support the CMSI initiative, which proposes consolidating existing standards under a unified framework, with GISTM as technical reference. The RCMS methodology proved effective in mapping compliance and facilitating cross-protocol analysis. The research concludes that TSFs in closure require the same level of rigor as active structures, and that a unified, verifiable standard is essential for advancing socially just and environmentally responsible mining practices (A. J. Bebbington, Hinojosa, Humphreys Bebbington, Burneo, & Warnaars, 2008; Martínez Alier, 2003).

1. Introduction

Mining is a strategic activity for global economic development, providing essential resources for sectors such as energy, construction, technology, and infrastructure. However, the socio-environmental impacts associated with mining activities, especially regarding tailings management, have generated growing concern among civil society, regulatory bodies, affected communities, and institutional investors. The failure of tailings dams, such as those in Brazilian cities Mariana (2015) and Brumadinho (2019), not only highlighted serious flaws in the governance of geotechnical structures but also led to a profound reconfiguration of regulatory requirements and social expectations regarding the mining industry (Costa, Barbosa, Bastos, & Oliveira, 2020; Guimarães, Campanha, Petesse, & Ferreira, 2024). Those extreme events also revealed deep-rooted power asymmetries in environmental decision-making, risk communication, and community protection (A. Bebbington, Hinfelaar, & Sanborn, 2017).

This article is grounded in the interdisciplinary field of political ecology, which examines how environmental governance is shaped by political, economic, and social forces (Bailey & Bryant, 2005; Robbins, 2020). By analyzing tailings governance through this lens, we explore how institutional frameworks, technical standards, and corporate protocols influence access to information, participation in decision-making, and the distribution of environmental risks (Perreault, Bridge, & McCarthy, 2015; Watts, 2003). In particular, it needs to be interrogated how closure-phase TSFs – often overlooked in regulatory discourse – become sites of contested responsibility, where technical closure may obscure unresolved socio-environmental liabilities (Bridge, 2004; Kirsch, 2014).

These events catalyzed a robust institutional response, both in Brazil and internationally. Nationally, measures include State Law No. 23,291/2019, known as "Sea of Mud Never Again," which banned the upstream raising method in Minas Gerais, considered to pose a higher geotechnical risk (MINAS GERAIS, 2019; Stark, Moya, & Lin, 2022). Internationally, several organizations have launched protocols and technical standards aimed at improving tailings governance, most notably the Global Industry Standard on Tailings Management (GISTM), developed by ICMM, UNEP, and PRI, which proposes 77 requirements distributed across six principles and fifteen topics (ICMM, 2020).

In addition to GISTM, other protocols have gained relevance, such as the Mining Principles (MP), Towards Sustainable Mining (TSM), the Responsible Gold Mining Principles (RGMP), and the Risk Readiness Assessment (RRA). Each of these standards addresses distinct dimensions of sustainability in mining, including environmental, social, ethical, and corporate governance aspects. However, the multiplicity of protocols creates practical challenges for companies operating in multiple jurisdictions, requiring significant efforts to simultaneously meet different regulatory requirements, often with overlapping topics and a lack of independent verification mechanisms (Jarvie-Eggart, 2014; Sauer & Hiete, 2019).

An aspect often overlooked in literature and operational practice is the management of tailings storage structures in the process of closure. Although these structures are no longer in operation, they continue to pose significant geotechnical and socio-environmental risks, requiring continuous monitoring, updated emergency plans, and community engagement strategies (Joyce & Kemp, 2020; Lesnikov, Kunz, & Harris, 2023). Failure to adequately address these structures can jeopardize the safety of neighboring communities, environmental integrity, and the reputation of the companies involved.

Given this scenario, this article proposes an integrated analysis of the main international mining protocols and a case study involving 12 Tailings Storage Structures (TSF) in the process of closure, located in Brazil and the United States. The objective is to identify thematic convergences between the protocols, assess the structures' practical compliance

with GISTM requirements, and propose paths for a unified and robust tailings governance approach. To this end, the RCMS (Risk Control Management System) methodology, developed by Menezes (2024), is used. This methodology allows for assessing the adherence of real structures to international standards and transposing the results between different protocols.

By doing so, we contribute to political ecology by revealing how technical standards both reflect and reproduce institutional power, and by identifying opportunities for more inclusive, transparent, and socially responsive closure strategies (Swyngedouw, 1999; Temper & Shmelev, 2015).

The relevance of this article lies in its ability to contribute to the debate on regulatory harmonization in mining, offering a practical tool for compliance assessment and proposing solutions for the responsible management of closed structures. By integrating normative analysis and case studies, the article seeks to fill existing gaps in the literature and offer technical support for public policymakers, mining company managers, and auditing and certification institutions.

2. Materials and Methods

This research adopts an exploratory-descriptive methodological approach, based on pragmatic epistemology, focused on the integrated analysis of international tailings governance protocols and the practical evaluation of structures undergoing closure. This approach was chosen due to the complexity of the study, which encompasses both normative and operational dimensions, requiring a methodology capable of systematically and comparatively integrating theory and practice.

2.1 Data Sources

The data sources used were organized into three main categories: normative documents, technical documents and reports.

Normative documents: These include the official texts of the five international protocols analyzed – GISTM (ICMM, 2020), Mining Principles (ICMM, 2024), Towards Sustainable Mining (MAC, 2004, 2021), Responsible Gold Mining Principles (World Gold Council, 2019), and Risk Readiness Assessment (The Copper Mark, 2020). These documents were examined in depth to identify their structuring principles, thematic scope, and practical applicability to Tailings Storage Facilities (TSF).

Technical data on TSF: Information was collected from 12 TSF in the closure phase, belonging to a multinational mining company. The structures are located in the states of

Minas Gerais (BRA) and Texas (USA) and vary in terms of volume, height, construction method, operating time, and closure stage (MINAS GERAIS, 2019; Stark et al., 2022).

Internal reports and interviews: These include closure plans, monitoring records, stability statements, emergency plans, and interviews with technical managers responsible for the structures. This data allowed us to understand the operational context of the TSF and assess their adherence to international protocol requirements.

2.2 RCMS Methodology

To assess the compliance of TSF with international protocols, the RCMS methodology, developed by Menezes (2024), was used. This is a normative mapping tool that allows:

- Direct assessment: Application of a structured questionnaire with 271 objective questions, linked to the 77 GISTM requirements. The questions were organized by topics and principles, allowing a detailed analysis of each framework's compliance.
- Thematic Transposition: Development of an equivalence matrix between the protocols, based on the identification of common themes and overlapping requirements. This matrix allowed the transposition of the results obtained from GISTM to the other protocols, generating comparable adherence rates.
- Statistical analysis: The data were statistically processed to generate compliance indicators by TSF and by protocol. Thematic aggregation, weighted average calculation, and dispersion analysis were used to identify patterns, gaps, and best practices.

RCMS stands out for its ability to integrate multiple regulatory standards into a single assessment tool, reducing audit effort and increasing accuracy in identifying nonconformities. Furthermore, it allows for a modular approach, adaptable to different operational and regulatory contexts.

2.3 Characterization of TSF

The 12 TSF analyzed were selected based on criteria of geographic representation, technical diversity, and stage of closure. The following are some general characteristics on the TAB 1:

Table 1
– Characteristics of the TSFs

TSF	Volume (Mm³)	Height (m)	Construction Method	Location
04	129.59	165	Upstream	Minas Gerais / BRA
05	10.3	55	Upstream	Minas Gerais / BRA
08	58,7	70	Upstream	Texas / EUA
09	0,9	37	Upstream	Texas / EUA
10	22,98	98.14	Upstream	Minas Gerais / BRA
12	8,5	77	Upstream	Minas Gerais / BRA
13	19,48	35	Upstream	Minas Gerais / BRA
15	2,17	60,67	Upstream	Minas Gerais / BRA
16	5,95	85	Upstream	Minas Gerais / BRA
20	37	85,6	Upstream	Minas Gerais / BRA
21	23	98,14	Upstream	Minas Gerais / BRA
32	42,77	71	Center Line	Minas Gerais / BRA
Source: Elaborated by authors, based on (Menezes, 2024)				

The diversity of frameworks allowed for a rich comparative analysis, encompassing different regulatory, cultural, and operational contexts. Furthermore, the inclusion of frameworks at different stages of closure made it possible to assess the evolution of compliance over time and identify critical factors for post-operational sustainability.

The diversity of frameworks allowed for a rich comparative analysis, encompassing different regulatory, cultural, and operational contexts. Furthermore, the inclusion of frameworks at different stages of closure made it possible to assess the evolution of compliance over time and identify critical factors for post-operational sustainability.

3. Results

3.1 Gaps Identified

A detailed analysis of the responses obtained through the RCMS revealed critical gaps in the closing of TSF structures. Among the most significant issues identified are the absence of formal relationship plans with neighboring communities, particularly in rural areas or regions with low levels of education, which undermines effective community engagement (Joyce & Kemp, 2020). There is also a lack of technical documentation addressing residual

risks after closure, such as geotechnical stability, erosion, and water contamination (ICMM, 2020). Furthermore, post-closure monitoring is insufficient, with no long-term environmental monitoring plans that establish clear indicators and verifiable targets. Transparency is another major gap, as public communication channels regarding the status of structures, closure plans, and inspection results are missing. Finally, independent verification is lacking, with no external audits or certifications to validate compliance with international protocols. Collectively, these shortcomings compromise the safety of structures, erode community trust, damage corporate reputation, and hinder the fulfillment of ESG commitments made to investors and multilateral organizations.

3.2 Good Practices Observed

Despite the identified gaps, some TSF have demonstrated good practices that can serve as valuable references for other operations. Notable examples include the integration of TSF into broader land use plans, where structures have been incorporated into environmental recovery or community projects such as parks and recreational areas. Participatory monitoring initiatives also stand out, as they involve local residents in the collection of environmental data, fostering both environmental education and transparency. In addition, certain structures publish annual reports that provide public access to stability data, inspection outcomes, and corrective actions. Together, these practices illustrate that it is possible to align technical closure with social and environmental responsibility, provided there is adequate planning, sufficient resources, and strong institutional commitment.

3.3 Thematic Similarity and Equivalence between Protocols

To evaluate thematic convergence among international mining standards, a comparative mapping was conducted using the GISTM as a reference. The analysis examined four protocols – Mining Principles (MP), Towards Sustainable Mining (TSM), Responsible Gold Mining Principles (RGMP), and Risk Readiness Assessment (RRA) – to determine their alignment with the 77 GISTM requirements.

The equivalence matrix developed based on the analysis of the five protocols revealed distinct levels of thematic similarity with GISTM. The RRA protocol showed the greatest convergence, with 84% thematic overlap, followed by TSM (64%), RGMP (44%), and MP (35%). The numbers can be found on TAB 2.

Table 2
– Protocol Similarity Matrix:

Protocol	Average Adherence (%)
MP	35%
TSM	64%
RGMP	44%
RRA	84%
Source: Elaborated by authors, based on (ICMM, 2020, 2024; MAC, 2004; The Copper Mark, 2020; World Gold Council, 2019)	

This variation can be explained by the nature of the protocols: while GISTM is dedicated exclusively to tailings management, MP and RGMP adopt a broader perspective, addressing corporate sustainability and responsible mining practices in general. TSM, in turn, provides specific indicators for tailings facilities, which accounts for its greater compatibility with GISTM. A thematic analysis shows that the most recurring topics across these protocols include risk-based management, stakeholder engagement, transparency and public communication, environmental monitoring, and closure planning. Conversely, issues such as diversity, human rights, and local culture appear less frequently in technical protocols, being more commonly emphasized in broader ESG frameworks like MP and RGMP.

3.4 Transposition of Results to Other Protocols

The data obtained from GISTM were transposed to the other protocols using the thematic equivalence matrix. This approach allowed for the calculation of indirect adherence indices – estimates of the TSF' compliance with other standards, based on the correspondence between the requirements. The average adherence is summarized on TAB 3:

Table 3
– The average adherence results were:

Protocol	Average Adherence (%)
MP	32%
TSM	32%
RGMP	32%
RRA	42%
Source: Data prepared based on thematic transposition via RCMS (Menezes, 2024)	

Low adherence to broader protocols indicates that non-technical aspects – such as human rights, diversity, and culture – are still neglected during the closure phase of operations. This reinforces the need to incorporate these topics into closure plans and stakeholder communication strategies.

3.5 Summary of Protocol Performance via RCMS Transposition

To consolidate the findings of this study, the RCMS methodology was used to transpose GISTM-based compliance scores into equivalent performance metrics for four major international protocols: Mining Principles (MP), Towards Sustainable Mining (TSM), Responsible Gold Mining Principles (RGMP), and Risk Readiness Assessment (RRA). This transposition was grounded in a previously established equivalence matrix, which mapped GISTM requirements to similar items in each protocol.

The following TAB 4 presents the average performance of the 12 evaluated TSFs across the four protocols, considering only the items identified as thematically similar to the GISTM. The results show that TSFs TSF15, TSF16, TSF20, and TSF21 consistently achieved high scores – mean above 85% across all protocols. In contrast, TSFs TSF04 and TSF05 recorded the lowest performance, averaging below 60%. The overall mean scores were 67% for MP, 75% for TSM, 78% for RGMP, and 82% for RRA, indicating strong thematic convergence, especially with RRA.

Table 4
– Average performance evaluated for the TSFs across the protocols

TSF Code	MP	TSM	RGMP	RRA	Mean
TSF04	47%	48%	61%	69%	56%
TSF05	49%	47%	61%	69%	56%
TSF08	65%	61%	65%	75%	66%
TSF09	66%	61%	66%	75%	67%
TSF10	71%	87%	75%	87%	80%
TSF12	71%	71%	87%	88%	79%
TSF13	69%	72%	83%	87%	78%
TSF15	74%	93%	91%	91%	87%
TSF16	73%	93%	90%	90%	86%
TSF20	80%	96%	96%	93%	91%
TSF21	78%	97%	97%	94%	91%
TSF32	59%	71%	65%	63%	64%
Source: Elaborated by authors					

To assess broader protocol adherence, the TAB 5 combines these transposed scores with each protocol’s overall similarity to the GISTM. This calculation yields a weighted estimate of total protocol compliance per TSF.

Table 5
– Transposed scores of the TSFs from the GISTM to the protocols similarity

TSF Code	MP (48%)	TSM (44%)	RGMP (41%)	RRA (52%)	Mean
TSF04	23%	21%	25%	35%	26%
TSF05	24%	21%	25%	35%	26%
TSF08	31%	26%	27%	39%	31%
TSF09	32%	27%	27%	39%	31%
TSF10	34%	38%	31%	45%	37%
TSF12	34%	31%	36%	45%	37%
TSF13	33%	31%	34%	45%	36%
TSF15	36%	40%	37%	47%	40%
TSF16	35%	41%	37%	46%	40%
TSF20	39%	42%	40%	48%	42%
TSF21	32%	32%	32%	42%	35%
TSF32	26%	34%	27%	32%	30%
Mean	32.16%	31.78%	31.92%	42.36%	
Source: Elaborated by authors					

Results ranged from 23% to 48%, with RRA again showing the highest alignment (mean value of 42.36%), followed by RGMP (31.92%), TSM (31.78%), and MP (32.16%). These values demonstrate that even partial GISTM compliance – when mapped through RCMS – can reflect meaningful adherence to other global standards. The methodology thus offers a strategic pathway for operators to prioritize improvements, especially in areas not covered by GISTM but required by other protocols.

4. Discussion

The results obtained through the application of the RCMS methodology reveal a complex and multifaceted panorama of tailings governance at structures undergoing closure. The integrated analysis of international protocols and TSF data allows us not only to identify levels of compliance but also to understand the factors that influence regulatory adherence, recurring gaps, and opportunities for improvement. This section discusses the findings considering the specialized literature, regulatory trends, and practical implications for the mining industry.

4.1 Thematic convergence between protocols

The equivalence matrix constructed between the five protocols analyzed – GISTM, MP, TSM, RGMP, and RRA – revealed significant thematic convergence, especially on topics such as risk management, stakeholder engagement, transparency, and closure planning. This convergence is particularly evident between GISTM and RRA, which share 84% thematic overlap. TSM also presents high compatibility, with 64% similarity, due to the presence of specific indicators for tailings structures (Jarvie-Eggart, 2014; MAC, 2004, 2021).

On the other hand, the MP and RGMP protocols, while relevant in the ESG context, have a broader and more generic scope, making their direct application to TSF difficult. This difference in approach highlights the need to distinguish between technical protocols and corporate protocols, with the former focused on the safe operation of structures and the latter on the reputation and social responsibility of companies (Fonseca, 2010; Sauer & Hiete, 2019).

The WSIS (2024) initiative's proposal, which aims to consolidate the four corporate protocols under a common framework, using GISTM as the technical reference for tailings management, is supported by the findings of this study. The observed thematic convergence reinforces the viability of a unified approach capable of reducing redundancies, facilitating audits, and promoting greater regulatory coherence.

4.2 Performance of TSF at closing

The evaluation of the 12 TSF revealed a wide variation in GISTM compliance levels, with rates ranging from 56% to 91%. This heterogeneity can be attributed to factors such as:

- Closure time: More recently closed structures tend to have greater adherence, as they were subject to more stringent regulatory requirements.
- Geographic location: TSF located in Minas Gerais, where there is specific state legislation for tailings (MINAS GERAIS, 2019), demonstrated greater compliance in technical aspects.
- Organizational culture: units with a history of external audits and environmental certifications performed better in the areas of transparency and engagement.

The GISTM analysis revealed that the topics with the highest adherence were "Risk Management" and "Design and Construction," while those with the lowest adherence were "Social Engagement" and "Transparency." This thematic asymmetry indicates that, although technical aspects are relatively well addressed, social and communication components are still neglected, especially in structures that are no longer in active operation.

4.3 Critical gaps and implications

Closure-phase TSFs revealed gaps with direct consequences for safety, environmental integrity, and corporate reputation. Missing community engagement plans hinder trust and risk communication; lack of residual risk documentation limits structural assessment and emergency response; and absent post-closure monitoring weakens early detection and corrective action. The absence of independent verification—such as audits or third-party inspections—undermines data credibility and regulatory oversight, a concern amid rising demands for transparency and accountability (Dladla & Ramsamy, 2022; Joyce & Kemp, 2020).

4.4 Good practices and replication potential

Despite these gaps, some TSFs showcased replicable good practices: integration with land use plans (e.g., parks, gardens), participatory monitoring involving local communities, and publication of annual stability reports. These initiatives demonstrate that technical closure can align with social and environmental responsibility when supported by planning, resources, and institutional commitment. Scaling such practices require regulatory incentives, recognition of voluntary certification, and a sustainability-oriented organizational culture.

4.5 Proposals for advancing governance

To strengthen governance in closing TSFs, this study recommends: (i) adopting a unified protocol with GISTM as the core (WSIS proposal); (ii) enhancing independent verification via third-party mechanisms (e.g., GTMI); (iii) embedding social dimensions into closure plans; (iv) promoting active transparency through public reporting; and (v) fostering environmental education and community participation. These measures aim to improve compliance and reinforce mining’s social legitimacy.

5. Conclusion

This study aimed to analyze the thematic convergence among the main international mining protocols – GISTM, MP, TSM, RGMP, and RRA – and assess the practical compliance of 12 Tailings Storage Facilities (TSF) in the process of closure, located in Brazil and the United States. The application of the RCMS methodology allowed us to accurately map the degree of adherence of the structures to GISTM requirements, transpose the results to other protocols, and identify critical gaps in tailings governance.

The results demonstrated significant overlap between the protocols, particularly on topics related to risk management, transparency, community engagement, and closure planning. The RRA protocol showed the greatest similarity with GISTM (84%), followed by TSM (64%), while MP and RGMP showed the least thematic compatibility. This convergence

reinforces the viability of an integrated approach, as proposed by the Convergence of Mining Standards Initiative (CMSI, 2024) initiative, which seeks to consolidate existing standards into a unified framework, with GISTM as one of the technical references for tailings management.

The analysis of the TSF revealed a wide variation in compliance levels, with rates ranging from 56% to 91%. The best-performing facilities presented robust documentation, updated emergency plans, and evidence of community engagement. Conversely, the facilities with the lowest compliance demonstrated weaknesses in social aspects, post-closure monitoring, and public communication. The overall average compliance rate was 61%, indicating that, while progress has been made, significant challenges remain in ensuring effective governance in closed facilities.

From a political ecology perspective, these findings underscore how tailings governance is not merely a technical exercise but a deep political process (Escobar, 1996; Robbins, 2020). The uneven distribution of environmental risks, the exclusion of communities from decision-making, and the lack of transparency reflect broader structural inequalities embedded in extractive economies (A. J. Bebbington et al., 2008; Martínez Alier, 2003).

The identified gaps – such as the absence of engagement plans, lack of documentation on residual risks, and lack of independent verification – compromise not only the safety of the structures, but also the trust of communities and the reputation of companies. These deficiencies highlight that closing structures should not be treated as forgotten liabilities, but rather as critical assets that require continuous attention, strategic planning, and institutional commitment. Closure-phase TSFs thus represent contested spaces where institutional power, environmental justice, and community agency intersect (Watts, 2003).

The RCMS methodology has proven effective in assessing compliance and transposing protocols, establishing itself as a practical tool for companies, auditors, and regulators. Its application can be extended to other operations, thereby contributing to regulatory harmonization and reinforcing responsible mining practices. In addition, RCMS enables the identification of replicable best practices—such as participatory monitoring, integration with land use plans, and the publication of public reports—that can serve as benchmarks for the sector. Based on the findings, several strategic guidelines are proposed. First, the adoption of a unified protocol is recommended, consolidating international standards under a common framework with GISTM as the technical core, which would facilitate audits, certifications, and communication with stakeholders (Sauer & Hiete, 2019). Second, the integration of political ecology principles should be pursued, embedding considerations of power, justice, and community agency into closure planning and governance frameworks (Bailey & Bryant, 2005; Perreault et al., 2015). Third, independent verification must be strengthened through the promotion of third-party audits

and transparent reporting to enhance accountability and public trust (Temper & Shmelev, 2015). Fourth, fostering community participation is essential, with inclusive engagement strategies that recognize local knowledge and empower affected populations (Kirsch, 2014; Pulido, 1996). Finally, closure should be reframed as a political process, acknowledging that post-operational structures remain embedded in socio-environmental landscapes and therefore require long-term governance (Bridge, 2004; Swyngedouw, 1999).

In general, incorporate social dimensions into closure plans by addressing human rights, local culture, diversity, and community engagement, thereby expanding the scope of tailings governance. Promote active transparency and public communication by establishing accessible channels to share information on the status of structures, closure plans, and inspection results, fostering trust and social legitimacy. Additionally, develop environmental education and community participation programs to involve local stakeholders in post-closure management, strengthening the connection between the company and the territory.

These guidelines not only respond to the technical requirements of the protocols, but also engage with the UN Sustainable Development Goals, especially SDG 6 (clean water and sanitation), SDG 8 (decent work and economic growth), SDG 13 (climate action) and SDG 16 (peace, justice and strong institutions) (ONU, 2015).

It follows that responsible mining requires more than regulatory compliance: it requires a long-term vision, ethical commitment, and the ability to actively listen. Structures in the process of closure represent a turning point for the mining sector – they reflect what has been achieved and foreshadow what can still be built. Treating these structures with technical rigor and social sensitivity is not only a regulatory obligation, but also an opportunity to transform liabilities into legacies.

Declarations

Data availability

The datasets generated or analyzed during this study are not publicly available due to confidentiality agreements with participants but may be obtained from the corresponding author upon reasonable request.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Compliance with ethical standards

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Publisher’s note

Springer Nature remains neutral regarding jurisdictional claims in published maps and institutional affiliations.

Open Access

This article is distributed under the terms of the Creative Commons Attribution 4.0 International License, which allows use, sharing, adaptation, distribution, and reproduction in any medium or format, provided appropriate credit is given to the original author(s) and source, a link to the license is provided, and any changes are indicated. Images or other third-party material are included under this license unless otherwise noted in a credit line. If material is not covered by this license and your intended use is not permitted by law or exceeds the license terms, you must obtain permission directly from the copyright holder. A copy of the license is available at http://creativecommons.org/licenses/by/4.0/.

References

1. BAILEY, Sinead; BRYANT, Raymond. *Third World Political Ecology: an Introduction*. Taylor and Francis, 2005.
2. BEBBINGTON, A.; HINFELAAR, M.; SANBORN, C. Political Settlements and the Governance of Extractive Industry: A Comparative Analysis of the Longue Durre in Africa and Latin America. *SSRN Electronic Journal*, 2017. DOI: https://doi.org/10.2139/ssrn.2986786..
3. BEBBINGTON, A. J.; HINOJOSA, L.; HUMPHREYS BEBBINGTON, D.; BURNEO, M. L.; WARNAARS, X. Contention and Ambiguity: Mining and the Possibilities of Development. *SSRN Electronic Journal*, 2008. DOI: https://doi.org/10.2139/ssrn.1297212..
4. BRIDGE, G. Contested Terrain: Mining and the Environment. *Annual Review of Environment and Resources*, v. 29, n. 1, p. 205–259, 2004. DOI: https://doi.org/10.1146/annurev.energy.28.011503.163434..
5. CMSI. *Consolidated Mining Standard Initiative*. 2024. Disponível em: https://miningstandardinitiative.org/about-the-initiative/.. Acesso em: 10 jun. 2025.
6. COSTA, D.; BARBOSA, K. F. M.; BASTOS, M. A.; OLIVEIRA, S. F. de. Responsabilidades decorrentes de desastres ambientais em Minas Gerais. *Revista do*

Curso de Direito do UNIFOR, v. 11, n. 2, p. 242–263, 2020. DOI: https://doi.org/10.24862/rcdu.v11i2.1147..

7. DLADLA, S. D.; RAMSAMY, S. Practical steps to Global Industry Standard on Tailings Management (GISTM) compliance for operational tailings storage facilities in South Africa. *The Journal of the Southern African Institute of Mining and Metallurgy*, v. 122, 2022. DOI: https://doi.org/10.17159/2411..
8. ESCOBAR, A. Construction nature. *Futures*, v. 28, n. 4, p. 325–343, 1996. DOI: https://doi.org/10.1016/0016-3287(96)00011-0.
9. FONSECA, A. How credible are mining corporations' sustainability reports? A critical analysis of external assurance under the requirements of the International Council on Mining and Metals. *Corporate Social Responsibility and Environmental Management*, v. 17, n. 6, p. 355–370, 2010. DOI: https://doi.org/10.1002/csr.230..
10. GUIMARÃES, V. de O. G.; CAMPANHA, P. M. G. de C.; PETESSE, M. L.; FERREIRA, C. M. Socio-environmental and economic impacts due to the disaster at Vale S.A. in Brumadinho, MG, Brazil: A systematic review. *Boletim do Instituto de Pesca*, v. 50, 2024. DOI: https://doi.org/10.20950/1678-2305/bip.2024.50.e879..
11. ICMM – INTERNATIONAL COUNCIL ON MINING AND METALS. *Global Industry Standard on Tailings Management*. Global Tailings Review, 2020. Disponível em: https://globaltailingsreview.org/wp-content/uploads/2020/08/Global-Industry-Standard_EN.pdf..
12. ICMM – INTERNATIONAL COUNCIL ON MINING AND METALS. *Our Principles*. 2024. Disponível em: https://www.icmm.com/en-gb/our-principles..
13. JARVIE-EGGART, M. E. Towards Sustainable Mining. In: *Sustainable Practices*. IGI Global, 2014. p. 846–866. DOI: https://doi.org/10.4018/978-1-4666-4852-4.ch047..
14. JOYCE, S.; KEMP, D. Social performance and safe tailings management: a critical connection. *Towards Zero Harm*, 2020.
15. KIRSCH, Stuart. Mining Capitalism: the Relationship between Corporations and their Critics. University of California Press, 2014.
16. LESNIKOV, P.; KUNZ, N. C.; HARRIS, L. M. Gender and sustainability reporting – Critical analysis of gender approaches in mining. *Resources Policy*, v. 81, 103273, 2023. DOI: https://doi.org/10.1016/j.resourpol.2022.103273..
17. MAC – THE MINING ASSOCIATION OF CANADA. *Towards Sustainable Mining – TSM*. 2004. Disponível em: https://tsminitiative.com/protocols-frameworks..
18. MAC – THE MINING ASSOCIATION OF CANADA. *OMS Guide*. 2021. Disponível em: https://mining.ca/our-focus/tailings-management/oms-guide/.. Acesso em: 5 jun. 2025.
19. MARTÍNEZ ALIER, Juan. The Environmentalism of the Poor: a Study of Ecological Conflicts and Valuation. Edward Elgar, 2003.

20. MENEZES, D. A. de. Sistema de gerenciamento de controle de riscos (RCMS) para avaliação da gestão e governança de estruturas para disposição de rejeitos. Tese (Doutorado) – Universidade Federal de Ouro Preto, Ouro Preto, 2024.
21. MINAS GERAIS. Lei Estadual nº 23.291, 2019.
22. ONU – ORGANIZAÇÃO DAS NAÇÕES UNIDAS. *Organização das Nações Unidas*. 2015.
23. PERREAULT, T. Albert; BRIDGE, Gavin; McCARTHY, James. *Routledge Handbook of Political Ecology*. Routledge, Taylor & Francis Group, 2015.
24. PULIDO, Laura. Environmentalism and Economic Justice: Two Chicano Struggles in the Southwest. University of Arizona Press, 1996.
25. ROBBINS, Paul. Political Ecology: a Critical Introduction. Wiley-Blackwell, 2020.
26. SAUER, P. C.; HIETE, M. Multi-Stakeholder Initiatives as Social Innovation for Governance and Practice: A Review of Responsible Mining Initiatives. *Sustainability*, v. 12, n. 1, 236, 2019. DOI: https://doi.org/10.3390/su12010236..
27. STARK, T. D.; MOYA, L.; LIN, J. Rates and Causes of Tailings Dam Failures. *Advances in Civil Engineering*, v. 2022, n. 1, 2022. DOI: https://doi.org/10.1155/2022/7895880..
28. SWYNGEDOUW, E. Modernity and Hybridity: Nature, Regeneracionismo, and the Production of the Spanish Waterscape, 1890–1930. *Annals of the Association of American Geographers*, v. 89, n. 3, p. 443–465, 1999. DOI: https://doi.org/10.1111/0004-5608.00157..
29. TEMPER, L.; SHMELEV, S. Mapping the frontiers and front lines of global environmental justice: the EJAtlas. *Journal of Political Ecology*, v. 22, n. 1, 2015. DOI: https://doi.org/10.2458/v22i1.21108..
30. THE COPPER MARK. *The Risk Readiness Assessment Criteria Guide*. 2020. Disponível em: https://coppermark.org/standards/.. Acesso em: 4 maio 2025.
31. WATTS, M. Political Ecology. In: *A Companion to Economic Geography*. Wiley, 2003. p. 257–274. DOI: https://doi.org/10.1002/9780470693445.ch16..
32. WORLD GOLD COUNCIL. *Responsible Gold Mining Principles*. 2019. Disponível em: https://www.gold.org/industry-standards/responsible-gold-mining.. Acesso em: 4 maio 2025.