JIRRS
Journal International Review of Research Studies

Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Cross-Regional Critical Review of Major Tailings Dam Failures: Case Histories, Failure Mechanisms, Governance Breakdowns, and Lessons Learned

Antonio Clareti Pereira, PhD
PhD in Chemical Engineering
University of São Paulo (USP)
Belo Horizonte, Minas Gerais, Brazil
E-mail: claretipereira@gmail.com
ORCID: https://orcid.org/0000-0001-8115-4279

Abstract

Tailings storage facilities are long-lived engineered systems whose failure can transform a localized geotechnical instability into a rapid, far-reaching disaster. This structured critical narrative review provides a cross-regional synthesis of historical case evidence, geotechnical and hydrological mechanisms, breach and runout behavior, environmental and social consequences, governance, and monitoring. The evidence base comprises a pre-curated corpus of 110 scientific and technical publications and two international standards; it is not presented as an exhaustive systematic search or a statistically representative global inventory. Sources were coded by primary evidence type, analytical domain, case or geographic scope, synthesis role, and use in causal-confidence assessment. Physical-mechanism confidence and organizational/control confidence were evaluated separately at claim level using source independence, proximity to the event, cross-method convergence, observational quality, competing interpretations, and dependence on retrospective back-analysis. The synthesis shows that catastrophic outcomes rarely arise from a single isolated defect. Instead, failure develops through interacting vulnerabilities in material state, pore-pressure and water control, geometry, foundations, construction history, operations, surveillance, and decision-making. The distinctive contribution is a case-to-control architecture linking predisposing state, trigger, mechanism, breach/runout, hazard, exposure and vulnerability, consequences, and the degradation of preventive, detective, and mitigative barriers. Monitoring is decision-relevant only when weak signals are evaluated against baselines, trends, measurement uncertainty, mechanistic plausibility, and corroborating observations. Multiple controls are not necessarily independent because common data, models, teams, or authority structures can create common-cause failures. The framework therefore emphasizes auditable evidence boundaries, barrier independence, escalation factors, and timely action across the facility lifecycle.

Keywords: Tailings dam failure; Static liquefaction; Tailings storage facility; Risk governance; Failure monitoring; Disaster prevention

CC BY 4.0
Attribution 4.0 International
Deed

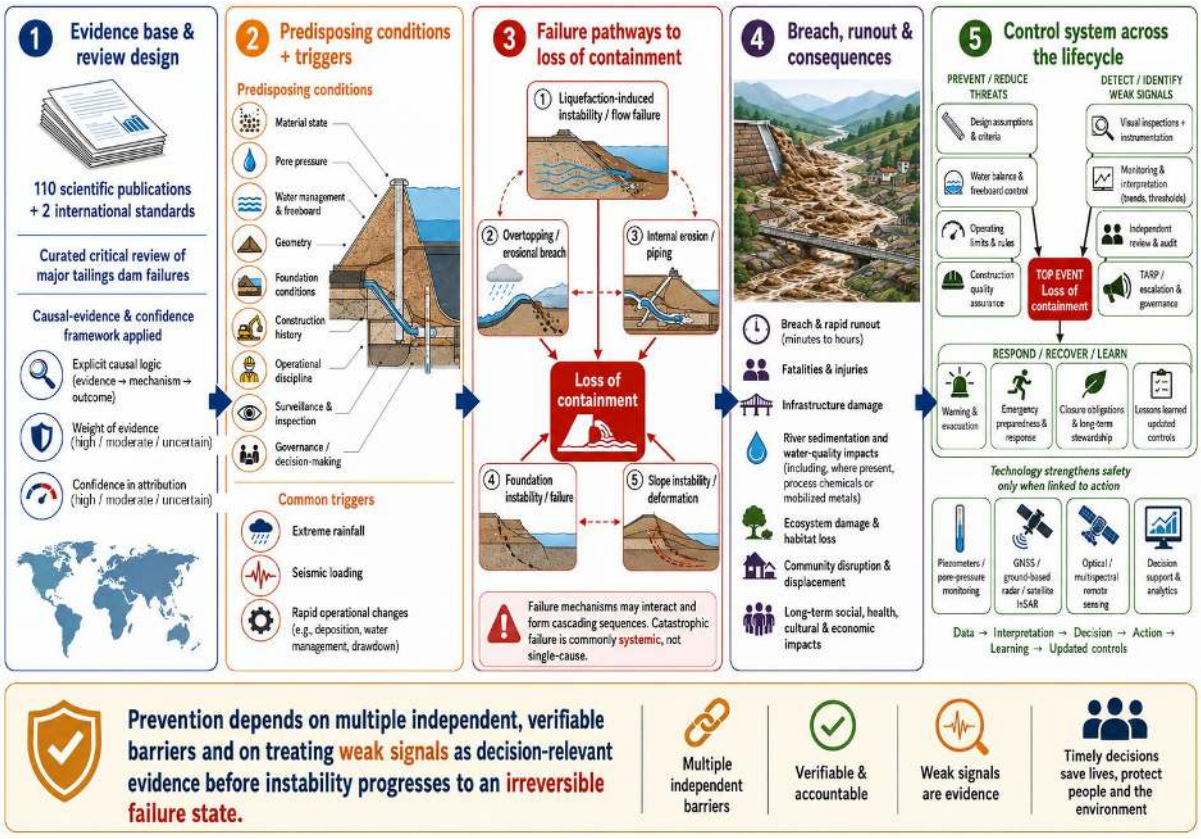
JIRRS
Journal International Review of Research Studies

Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Highlights

- Catastrophic tailings failures emerge from coupled technical and organizational weaknesses, not single causes.
- Static liquefaction, overtopping, piping, foundation weakness, and operational water imbalance form recurrent failure pathways.
- Monitoring reduces risk only when validated observations are connected to explicit trigger-action-response decisions.
- Lifecycle governance, independent review, transparent disclosure, and tested emergency preparedness are central preventive barriers.

Graphical abstract



1. Introduction

Tailings storage facilities (TSFs) are unusual civil–mining structures because their geometry, loading, material inventory, and operating boundary conditions evolve throughout the mine life. The retained material is often deposited hydraulically, can remain saturated for long periods, and may exhibit low permeability, contractive behavior, or marked spatial

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

variability. These characteristics make tailings safety inseparable from construction history, deposition strategy, water balance, drainage performance, and the quality of operational surveillance. Historical reviews have repeatedly shown that failures continue to occur despite major advances in geotechnical engineering, suggesting that the problem cannot be reduced to the absence of technical knowledge alone (Adamo et al., 2021; Armstrong et al., 2019; Azam & Li, 2010; Davies, 2002; Halabi et al., 2022; Lyu et al., 2019; Stark et al., 2022; Williams, 2021).

The consequences also distinguish TSF failures from many conventional slope instabilities. Once containment is lost, stored water and fine solids may mobilize as a high-concentration flow, creating rapid runout, burial, erosion, river contamination, ecosystem disruption, loss of livelihoods, and long-duration institutional conflict. A facility with apparently modest geometric deformation can therefore carry an extreme downstream consequence profile if the released mass can rapidly transform into a mobile flow. Global impact analyses and recent syntheses reinforce the need to evaluate the complete chain from the initiating condition to downstream exposure, rather than treating stability as an isolated factor-of-safety problem (Fourie, 2009; Hudson-Edwards et al., 2024; Islam & Murakami, 2021; Pereira, 2026).

The modern debate has increasingly shifted from the question of whether individual failures were technically foreseeable to whether the management system was capable of recognizing weak signals, challenging assumptions, and acting before the available margin disappeared. This shift is important because design, governance, monitoring, and emergency preparedness are not substitutes for one another. A strong governance framework cannot stabilize a contractively saturated deposit, while excellent constitutive modeling cannot compensate for uncontrolled pond encroachment or a decision system that normalizes adverse trends. Safe performance requires the barriers to work together across the full facility lifecycle (Franks et al., 2021; Jefferies, 2022; Kemp et al., 2021; Owen et al., 2020; Schoenberger, 2016; Wilson, 2021).

Previous reviews have made major contributions by cataloguing failures, examining conventional geotechnical mechanisms, synthesizing breach/runout methods, assessing

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

failure statistics, evaluating monitoring practice, or analyzing disaster-risk disclosure and governance (Azam & Li, 2010; Clarkson & Williams, 2021; Kheirkhah Gildeh et al., 2021; Lyu et al., 2019; Owen et al., 2020; Piciullo et al., 2022; Hudson-Edwards et al., 2024; Zare et al., 2024). Those perspectives are complementary, but they do not all use the same unit of synthesis. The present review uses the coupled failure pathway and barrier-degradation sequence as that unit: evidence is followed from predisposing state and trigger through mechanism, breach/runout, hazard, exposure and vulnerability, consequences, and the controls and decisions that can interrupt the sequence. Table 1 positions this contribution against the principal emphases of representative reviews already included in the corpus.

Table 1. Comparison of representative prior syntheses with the case-to-control architecture used in the present review

Source	Primary emphasis	Mechanism–consequence linkage	Governance/monitoring integration	Explicit case-to-control chain
Azam & Li (2010)	Historical failure record	Partial	Not central	No
Lyu et al. (2019)	Case-history causes and failure reasons	Strong	Limited	No
Clarkson & Williams (2021)	Conventional geotechnical mechanisms	Strong	Control implications	No
Kheirkhah Gildeh et al. (2021)	Breach methods and uncertainty	Strong for breach/runout	Limited	No
Owen et al. (2020)	Disaster-risk disclosure and governance	Limited physical detail	Strong	Partial
Piciullo et al. (2022)	Failure statistics and denominators	Pattern-level	Limited	No
Hudson-Edwards et al. (2024)	TSFs, failures, impacts, and disaster risk	Broad integration	Broad integration	Partial
Zare et al. (2024)	Monitoring and emerging surveillance	Failure-mode linkage	Strong monitoring focus	Partial
Present review	Cross-regional critical narrative synthesis	Explicit mechanism→breach→hazard chain	Explicit control/governance chain	Yes: case→degradation→decision

Note. “Primary emphasis” describes how each source is used in this review and is not intended as an exhaustive characterization of each publication. The comparison demonstrates the additional analytical step introduced here: explicit tracing from case evidence to barrier degradation and decision requirements.

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

This review evaluates major case histories and failure literature with four goals: (i) identify recurring pathways to containment loss; (ii) examine how breach dynamics turn local instability into regional issues; (iii) assess governance, monitoring, disclosure, and emergency management; and (iv) extract lessons for design, operation, closure, and future research. The focus is on interactions and preventability, not just cataloging disasters.

2. Review methodology and analytical framework

2.1 Review design and scope

A structured critical narrative review was adopted rather than a systematic review or meta-analysis. The evidence base comprises a pre-curated corpus of 110 scientific and technical publications published from 1983 through 2026, complemented by the Global Industry Standard on Tailings Management (GISTM) and International Commission on Large Dams (ICOLD) tailings-safety guidance. The corpus was assembled before the present analytical synthesis through purposive bibliographic curation focused on tailings-storage-facility failures, failure mechanisms, consequences, risk controls, monitoring, and governance. Because the discovery stage was not a de novo reproducible database search, this review does not claim exhaustive coverage, a PRISMA-style selection process, or statistical representativeness. The methodological objective is instead to make the analytical treatment of the supplied evidence auditable and to state explicitly where the corpus supports, constrains, or cannot resolve causal interpretations.

2.2 Corpus construction and analytical eligibility

All 110 publications were re-screened for analytical eligibility in the present synthesis. A source was retained when it informed at least one predefined domain: history/database patterns; case reconstruction; geotechnical or hydrological mechanisms; breach/runout; environmental or social consequences; governance/risk control; monitoring/early warning; or closure/climate resilience. Each source was then coded for primary evidence type, primary analytical domain, geographic or case scope, role in the synthesis, and whether it contributed to physical-mechanism confidence, organizational/control confidence, or contextual interpretation. Repeated reporting across reviews was not treated as independent

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

confirmation, and publications drawing on substantially the same event record were considered potentially dependent evidence. Supplementary Table S1 provides the source-level traceability matrix. Table 2 summarizes the corpus descriptively; these frequencies characterize the supplied evidence base and are not probability estimates or measures of global prevalence.

Table 2. Descriptive characterization of the pre-curated evidence corpus

Dimension	Category	n	Interpretive boundary
Publication period	1983–2009	9	Scientific/technical publications
Publication period	2010–2019	18	Scientific/technical publications
Publication period	2020–2022	36	Scientific/technical publications
Publication period	2023–2024	24	Scientific/technical publications
Publication period	2025–2026	23	Scientific/technical publications
Primary analytical domain	Geotechnical/hydrological mechanisms	28	Author-coded primary role
Primary analytical domain	Governance/risk control	23	Author-coded primary role
Primary analytical domain	History/database/synthesis	18	Author-coded primary role
Primary analytical domain	Environmental/social consequences	13	Author-coded primary role
Primary analytical domain	Case reconstruction	12	Author-coded primary role
Primary analytical domain	Breach/runout	7	Author-coded primary role
Primary analytical domain	Monitoring/early warning	5	Author-coded primary role
Primary analytical domain	Closure/climate resilience	4	Author-coded primary role
Geographic/case scope	Non-case-specific	75	Mechanistic, methodological, governance, monitoring, or synthesis studies
Geographic/case scope	Global/cross-regional	7	Explicit global or multi-region scope
Geographic/case scope	Brazil	11	Case- or country-specific
Geographic/case scope	South Africa	5	Case- or country-specific
Geographic/case scope	Canada, China, Romania, Serbia	2 each	Case- or country-specific
Geographic/case scope	Japan, Kazakhstan, Russia, Spain	1 each	Case- or country-specific

Note. Counts exclude the two institutional standards. Categories are descriptive author codes used to expose concentration and gaps in the pre-curated corpus; a publication was assigned one primary

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

domain for this summary even when it informed multiple secondary domains. Full source-level coding is provided in Supplementary Table S1.

2.3 Operational definition and selection of major failures

For this review, a major tailings failure was eligible for detailed case synthesis when it met at least one consequence or analytical criterion and the corpus contained sufficient evidence for a defensible interpretation. The four inclusion criteria were coded as L = severe life-safety consequences; R = large or highly mobile release with important downstream environmental or infrastructure effects; S = persistent social, health, environmental, or institutional consequences; and F = exceptional forensic value for understanding a distinct physical pathway or control breakdown. The cases were selected from the available corpus on these stated criteria before cross-case synthesis; they were not selected retrospectively to populate the proposed barrier architecture. The case set is illustrative rather than a severity ranking, and inconsistent release volumes, fatality reporting, and consequence metrics were not combined into a composite score. Table 4 makes the inclusion rationale and documentary limitation explicit for each retained case.

2.4 Evidence-role classification and causal confidence

Causal confidence was assigned at the claim level rather than to publications as a whole and was evaluated separately for (a) the physical mechanism/pathway and (b) organizational or control interpretation. Six criteria were used: source independence; proximity of the evidence to the event; convergence across methods; quality and completeness of observational data; presence of materially competing interpretations; and dependence on retrospective back-analysis. High confidence required at least two substantively independent lines of evidence with cross-method convergence and no unresolved competing interpretation capable of materially changing the claim; retrospective back-analysis could support but not be the sole basis. Moderate confidence was assigned when one strong line of evidence had partial corroboration, or when several lines converged but remained incomplete, partly dependent, or materially model-dependent. Uncertain confidence was assigned when evidence was sparse or indirect, depended primarily on a single retrospective model or secondary account, contained major unresolved competing interpretations, or lacked the organizational records

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

necessary for a defensible governance attribution. No intermediate "moderate-high" category is used in the revised manuscript. Table 3 operationalizes these criteria and their claim-level application.

Table 3. Operational criteria for claim-level causal confidence

Criterion	High	Moderate	Uncertain	Primary applicability
Source independence	≥2 substantively independent evidence lines	Some corroboration but partial dependence	Single/derivative line or dependence cannot be resolved	Both
Proximity to event	Direct measurements, contemporaneous records, or event-proximal forensic evidence	Mixture of direct and retrospective evidence	Predominantly indirect/late reconstruction	Both
Cross-method convergence	Different methods support the same claim	Partial convergence or one method dominates	Methods conflict or only one method available	Primarily physical; also organizational when applicable
Observational quality	Adequate data quality and coverage for the claim	Important gaps but interpretable evidence	Sparse, uncertain, or poorly documented observations	Both
Competing interpretations	No unresolved alternative that materially changes the claim	Alternatives remain but principal interpretation is better supported	Material alternatives remain unresolved	Both
Back-analysis dependence	Not sole basis; independently constrained	Material but bounded dependence	Claim relies mainly on retrospective fit or assumed parameters	Primarily physical
Organizational record sufficiency	Documented control/decision record or convergent independent analyses	Partial documentation and contextual corroboration	Plausible inference without adequate decision/record evidence	Organizational/control

Note. Confidence refers to the specific claim summarized, not to the overall quality of a publication. Physical and organizational/control confidence are reported separately where their documentary bases differ.

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

2.5 Analytical framework and boundary of inference

The evidence was interpreted using two linked chains: the physical-consequence chain (predisposing conditions → triggers → failure mechanism → breach formation → flow hazard → exposure and vulnerability → consequences → response) and the control chain (design assumptions → operating limits → barriers → monitoring → interpretation → threshold/TARP → decision → action). Figure 1 shows these dimensions. Three reporting levels are used: "Evidence from the reviewed corpus" for findings supported by sources; "this review interprets" for the author's integration; and "the control implication is" for normative risk-control practice. Normative statements are not direct empirical findings unless they are prescribed by standards, especially in governance, where the literature offers less event-proximal data than in geotechnical reconstruction.

The revised title uses "cross-regional" instead of "global" to avoid suggesting a complete global inventory. The corpus includes evidence from South America, North America, Europe, Africa, Russia, and Asia, but regional representation is uneven, and most sources are non-case-specific. Cross-regional comparison tests transferability of failure pathways and controls, not regional frequencies. Figure 1 summarizes the linked physical-consequence and control chains.

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45



Figure 1. ***Analytical architecture used to connect case evidence, failure mechanisms, consequences, and governance.***
Note. Author synthesis based on Hudson-Edwards et al. (2024), Chen et al. (2022), and the GISTM lifecycle concept.

The framework prevents the review from treating failures as isolated anecdotes and makes uncertainty visible across the causal chain. Weak evidence at any stage limits confidence in the final interpretation, and a convincing back-analysis does not by itself establish a unique trigger or governance explanation. Table 2 characterizes the composition of the supplied corpus, Table 3 operationalizes claim-level confidence, and Supplementary Table S1 provides source-level traceability.

3. Cross-regional evidence base and failure landscape

Evidence from the reviewed corpus consistently indicates that tailings failures are geographically widespread and recurrent rather than confined to a single commodity, construction era, or jurisdiction. Direct comparison of failure rates remains difficult because facility inventories are incomplete, definitions of incident and failure vary, and reporting intensity differs across countries and over time (Azam & Li, 2010; Halabi et al., 2022; Lin et

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

al., 2022; Massignan & Sánchez, 2024; Mpanza, 2024; Piciullo et al., 2022; Rico, Benito, Salgueiro, et al., 2008; Stark et al., 2022). The descriptive corpus coding in Table 2 similarly shows geographic concentration and a large number of non-case-specific studies. This review therefore interprets geographic recurrence as a cross-regional pattern in the available record, rather than an unbiased estimate of the absolute regional failure probability.

Regional evidence also shows that the apparent concentration of failures can reflect both real risk drivers and differences in disclosure. China has a large TSF inventory and a substantial historical record of incidents, while Kazakhstan and other mining regions face additional challenges related to public databases and exposure to extreme weather. Global disclosure studies show that important stability information is still inconsistently reported. Consequently, a country with more transparent reporting may appear worse than one with weak public records, and a raw event count should never be interpreted as a direct proxy for engineering quality (Atakhanova et al., 2026; Franks et al., 2021; Ma et al., 2026; Su et al., 2024).

A second pattern is the persistence of catastrophic outcomes despite increasing technical sophistication. Historical and contemporary analyses identify upstream construction, high pond levels, inadequate water control, liquefiable tailings, foundation deficiencies, and overtopping among recurrent contributors. The evidence therefore supports a barrier perspective: failures occur when several controls are absent, degraded, bypassed, or based on incorrect assumptions. This interpretation is more useful than ranking a single 'main cause' because it preserves the sequence through which an adverse condition leads to an uncontrolled release (Armstrong et al., 2019; Clarkson & Williams, 2021; Otieno & Shukla, 2023; Stark et al., 2022; Williams, 2021).

The historical record of major tailings dam failures demonstrates that catastrophic events have occurred under markedly different geological, climatic, operational, and regulatory settings, yet recurrent technical and organizational patterns remain identifiable. Figure 2 presents a chronological selection of representative failures from 1963 to 2022 and highlights the dominant analytical lesson associated with each case. The timeline illustrates the recurring roles of liquefaction susceptibility, foundation instability, seismic triggering,

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

deficient water management and overtopping control, and weaknesses in governance and institutional response. These classifications should not be interpreted as single-cause explanations; rather, they identify the principal mechanism or lesson within failure sequences that commonly involved interacting geotechnical, hydraulic, operational, environmental, and organizational factors.

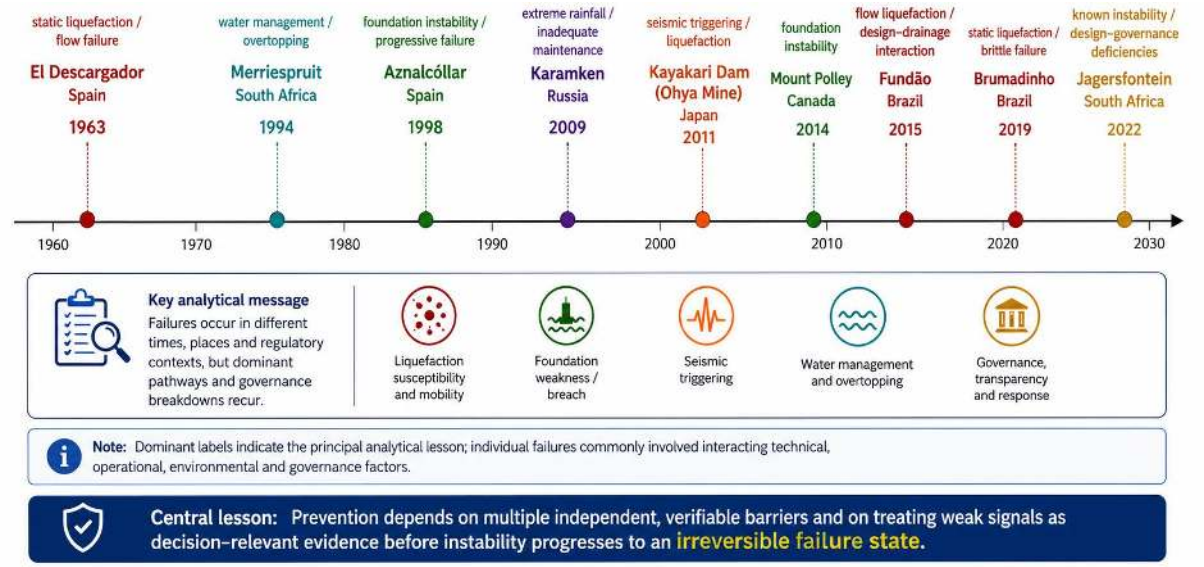


Figure 2. Timeline of selected illustrative failures and dominant analytical lessons across different geographic and regulatory contexts.
Note. Author synthesis based on Rodríguez-Pacheco et al. (2022), Fourie et al. (2001), Glotov et al. (2018), Ishihara et al. (2015), Marais et al. (2024), Sadrekarimi and Riveros (2020), Van Niekerk and Viljoen (2005), and Zabolotnii et al. (2022).

The timeline shows recurrence rather than a simple historical progression toward elimination of failure. Newer events occur alongside increasingly advanced analytical tools, reinforcing the argument that knowledge must be converted into effective lifecycle controls.

4. Major case histories and regional lessons

Case histories remain indispensable because they expose the difference between a theoretically plausible failure mode and a documented sequence. The cases below satisfy the operational criteria in Section 2.3 and were retained because the supplied corpus supports at least one distinctive failure pathway, consequence pattern, or control lesson. Physical-mechanism confidence and organizational/control confidence are intentionally separated. A strong geotechnical reconstruction does not automatically justify an equally strong attribution

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

about decision-making, accountability, or governance, particularly where official or proprietary organizational records are absent from the corpus.

4.1 South America: Fundão and Brumadinho

The 2015 Fundão failure in Brazil highlighted liquefaction-related instability in upstream iron-ore tailings. Seismic, land-cover, environmental, and geotechnical studies helped identify possible triggers and downstream changes. Evidence shows liquefaction risk depends on factors like deposition, saturation, drainage, stress path, material state, and the geometry of raises, which must be interpreted together (Agurto-Detzel et al., 2016; Aires et al., 2018; Fernandes et al., 2016; Kütter et al., 2023; Sadrekarimi & Riveros, 2020).

Brumadinho in 2019 intensified this lesson because the failure occurred with extremely severe loss of life and demonstrated the consequences of rapid mobilization with little effective evacuation time. Research has examined hydrological triggering, static liquefaction susceptibility, environmental contamination, remote sensing evidence, and broader institutional implications. The key critical point is that a stable-looking external geometry is not proof of adequate margin where contractive saturated tailings can experience a sharp loss of undrained strength (Alizadeh et al., 2026; Buch et al., 2024; Cheng et al., 2021; Coutinho et al., 2025; Guimarães et al., 2022; Pacheco et al., 2025).

Brazilian case studies show that consequence management is linked to stability management. Flood-warning and evacuation analyses reveal that life safety depends on predicting inundation, warning latency, population locations, route viability, and the speed at which the released mass reaches occupied areas. The value of emergency planning depends on testing plans against realistic arrival times, not just on documentation (Silva & Eleutério, 2023).

4.2 North America and Europe: Mount Polley and European failures

The 2014 Mount Polley failure in Canada is important because it broadens the discussion of causation beyond liquefaction. Subsequent work highlighted the role of foundation conditions and the need to challenge geotechnical assumptions that can remain embedded through successive design stages. Health and community studies additionally show that a

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

low-fatality event can still create prolonged social concern, particularly where downstream communities depend on affected aquatic and land resources (Shandro et al., 2017; Zabolotnii et al., 2022).

European experience provides a wide range of mechanisms and pathways of consequence. Long-term studies of the Maramureş failures in Romania document the persistence and redistribution of contaminant metals within river systems, while Serbian investigations illustrate both operational risk assessment and post-failure learning. Historical European compilations also show that failure mechanisms and consequences vary substantially with topography, stored water, tailings properties, and downstream connectivity (Bird et al., 2008; Macklin et al., 2003; Nišić et al., 2018; Nišić et al., 2024; Rico, Benito, Salgueiro, et al., 2008).

The El Descargador case in Spain shows the value of analyzing older failures. Using modern ideas of static liquefaction to reinterpret historical events helps distinguish between generic labels such as 'slope failure' and mechanisms that indicate rapid strength loss and flow. This retrospective approach is especially useful for legacy facilities with incomplete records but similar material states and geometries to older failures (Rodríguez-Pacheco et al., 2022).

4.3 Africa, Russia, and Asia: recurring vulnerabilities under different contexts

The Merriespruit failure in South Africa remains a foundational case for understanding how saturation, overtopping-related conditions, and liquefaction-like mobility can interact. Later critical-state reinterpretation has reinforced the importance of state-dependent behavior and residual strength. The 2022 Jagersfontein disaster, although occurring under a different institutional and operational setting, again demonstrated that legacy, ownership history, and long-term management can accumulate risk over decades (Fourie et al., 2001; Marais et al., 2024; Mánica et al., 2022; Van Niekerk & Viljoen, 2005).

Karamken in the Russian Far East illustrates the interaction between remote setting, climatic exposure, structural condition, and environmental consequence. Asian evidence includes earthquake-induced breach behavior in Japan and a large body of Chinese work on regional failure histories, monitoring, stability, and experimental mechanisms. Together,

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

these studies demonstrate that regional hazard differs—seismicity, monsoon rainfall, freeze–thaw or extreme continental climate—but the management requirement remains the same: credible failure modes must be connected to measurable operating and monitoring controls (Glotov et al., 2018; Ishihara et al., 2015; Su et al., 2024; Yin et al., 2011). Table 4 documents the inclusion criteria, evidence confidence, and principal documentary limits for each illustrative case.

Table 4. Selection rationale, evidence confidence, and documentary limits for illustrative major failures

Case	Inclusion criteria	Analytical purpose / physical pathway	Physical confidence	Organizational / control confidence	Principal documentary limitation
Merriespruit, South Africa (1994).	L, R, F	Saturation/overtopping-related conditions; liquefaction-like mobility	High	Moderate	Later reinterpretation strengthens physical mechanism; organizational record in corpus is incomplete
Aznalcóllar / European cases (1998 and regional)	R, S, F	Foundation/breach pathways; downstream contaminant transport	Moderate	Uncertain	Historical/environmental evidence stronger than organizational reconstruction
El Descargador, Spain (1963).	R, F	Retrospectively interpreted static-liquefaction flow failure	Moderate	Uncertain	Older event; incomplete original records; mechanism relies on modern reinterpretation
Karamken, R. (2009).	R, S, F	Structural/climatic vulnerability and containment loss	Moderate	Uncertain	Detailed case evidence but limited organizational documentation in corpus
Japan earthquake case (2011)	R, F	Seismic triggering, breach, and mobility	High	Uncertain	Dedicated event study supports physical sequence; governance not a primary evidence domain
Mount Polley, Canada (2014).	R, S, F	Foundation weakness and structural instability	High	Moderate	Mechanism well constrained; community evidence does not reconstruct every organizational decision
Fundão, Brazil (2015)	R, S, F	State-dependent instability and liquefaction-related failure	High	Moderate	Multiple physical/environmental studies; organizational records not systematically represented
Brumadinho, Brazil (2019)	L, R, S, F	Rapid liquefaction-related failure and highly mobile runout	High for rapid mobility;	Moderate	Strong event evidence; trigger details remain debated and governance

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Case	Inclusion criteria	Analytical purpose / physical pathway	Physical confidence	Organizational / control confidence	Principal documentary limitation
			Moderate for specific trigger		evidence is heterogeneous
Jagersfontein, South Africa (2022)	R, S, F	Legacy/institutional accumulation interacting with physical vulnerability	Moderate	Moderate	Contextual reconstruction is strong, but complete technical and decision records are not in corpus

Note. L = severe life-safety consequences; R = large/highly mobile release or important downstream physical effects; S = persistent social, health, environmental, or institutional consequences; F = exceptional forensic value. Confidence applies to the specific interpretation summarized and reflects only evidence represented in the present corpus.

5. Geotechnical and hydrological failure mechanisms

Evidence supports five mechanism families: static/flow liquefaction; overtopping/surface erosion; internal erosion/piping; foundation/structural instability; and seismic/operational instability. These are not mutually exclusive. High pond levels can increase gradients and saturation; rainfall can change conditions and reduce freeboard; deformation can damage drains or cause seepage (Chen, 2022; Clarkson & Williams, 2021; Elacoste et al., 2026; Otieno & Shukla, 2023; Zhen et al., 2022; Zheng et al., 2022). These are seen as coupled pathways, not single causes. Precursors and controls are in Table 7 to avoid repetition. Figure 3 shows these as converging pathways to loss of containment.

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

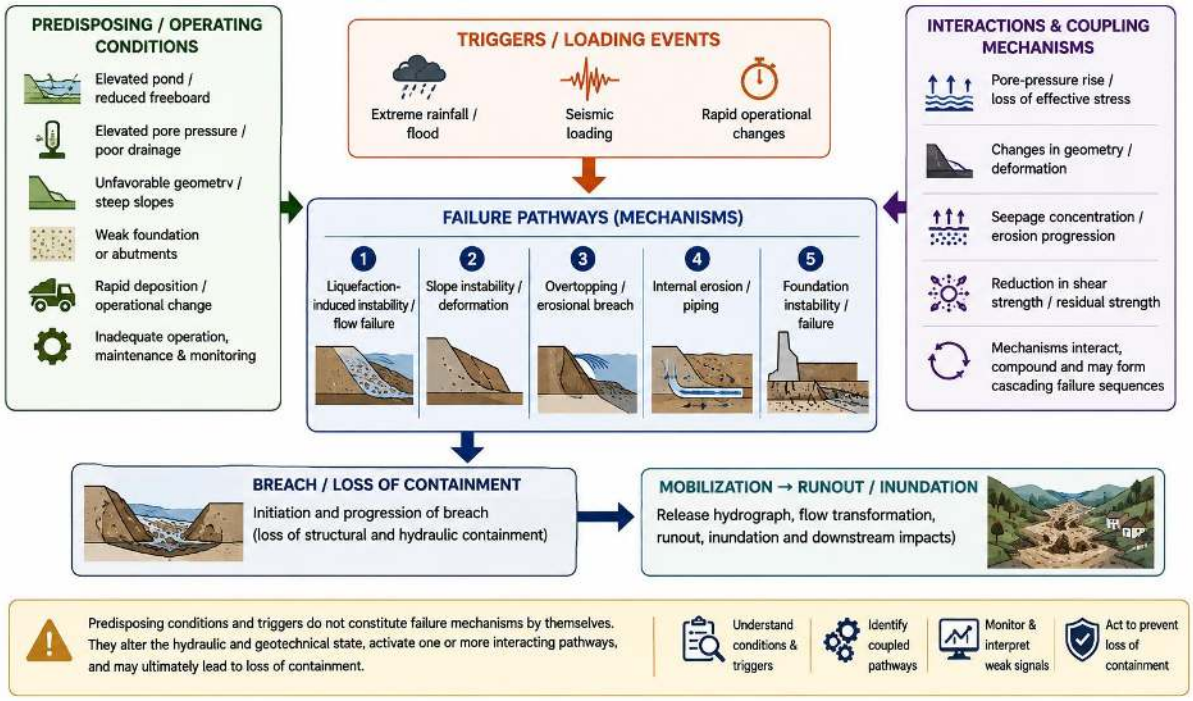


Figure 3. ***Coupled geotechnical and hydrological pathways that can converge on loss of containment.***
Note. Author synthesis based on Clarkson and Williams (2021), Lyu et al. (2019), Verdugo (2024), and Wang et al. (2025).

This representation emphasizes that a failure investigation should test interacting pathways. For example, rainfall may not be the geotechnical mechanism itself, but it can change saturation, pore pressure, freeboard, and erosion susceptibility sufficiently to activate another mechanism.

5.1 Static liquefaction, flow instability, and post-trigger mobility

Static liquefaction is best understood as a state-dependent loss of strength under undrained or partially drained loading in contractive materials. Classical flow-failure investigations and modern critical-state studies show why density alone is an insufficient descriptor: fabric, confining stress, fines, depositional method, stress history, and proximity to the critical or steady-state line influence whether loading produces dilation or contraction. For tailings dams, the practical implication is that susceptibility assessment must combine laboratory characterization with a defensible model of in-situ state and stress path (Jeyapalan

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

et al., 1983; Ledesma et al., 2022; Liu et al., 2024; Riveros & Sadrekarimi, 2021; Verdugo, 2024).

This review distinguishes four linked stages: susceptibility, triggering, instability/strain softening, and post-trigger mobility. A contractive saturated state causes susceptibility; stress changes may trigger undrained instability; strength loss can lead to flow failure; and residual strength controls mobility and runout. Treating these stages as interchangeable can obscure evidence for diagnosis and controls for prevention (Liu et al., 2024; Rógenes et al., 2025; Sordo et al., 2025; Verdugo, 2024).

Contemporary modeling has expanded the available tools but also made model governance more important. Critical-state constitutive models such as NorSand and the Clay And Sand Model (CASM) can represent contractive behavior and post-peak softening, yet predictions are sensitive to calibration and parameter uncertainty. Laboratory testing, numerical back-analysis, and probabilistic or simplified screening methods should therefore be interpreted as complementary layers. A complex model with poorly constrained parameters is not necessarily more reliable than a simpler model whose assumptions are transparent and conservatively bounded (Coutinho et al., 2025; D'Hyppolito et al., 2024; Lü et al., 2024; Rógenes et al., 2025; Silva et al., 2024; Wang et al., 2024).

Physical and centrifuge modeling further show that liquefied-flow and non-liquefied slide failures can have different kinematics and consequences. Residual strength becomes particularly important after triggering because it controls acceleration, deformation, and the extent to which material can enter a highly mobile runout phase. This is why stability analysis and consequence analysis cannot be separated at the instant of first yield (Ng et al., 2023; Sordo et al., 2025).

5.2 Overtopping, erosion, and breach enlargement

Overtopping can initiate a rapidly accelerating erosion process in which a shallow overflow cuts the crest, steepens the breach, increases discharge, and progressively mobilizes tailings. Experimental research has clarified the influence of reinforcement, particle size, rainfall intensity, flow concentration, and erosion geometry. The key operational control is freeboard, but freeboard is itself the outcome of water-balance forecasting, beach

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

development, deposition management, storm assumptions, and reliable measurement of pond level (Duan et al., 2024; Jing et al., 2019; Luo et al., 2025; Sun et al., 2012; Wang et al., 2022; Wu & Qin, 2018; Yao et al., 2021; Zhao et al., 2025).

Hydrograph studies show peak discharge and breach timing depend on breach geometry, water volume, rheology, and water-tailings erosion coupling. Using a single-breach hydrograph may give false precision. Emergency plans should test plausible scenarios, including faster breaches and more mobile material states if supported by evidence (Eghbali et al., 2025; Tian et al., 2021).

5.3 Internal erosion, seepage, foundation weakness, and coupled failure

Internal erosion and piping occur when seepage gradients, defects, or poorly filtered transitions allow particle migration. Large-scale modelling shows that pore-water-pressure surges and piping can be nonlinear. Risk studies indicate seepage anomalies may spread through systems of hazards, so measurements must consider drains, abutments, foundations, and interfaces (Wang et al., 2025; Zhen et al., 2021).

Foundation weakness and structural instability are equally important because they can invalidate otherwise reasonable embankment assumptions. Mount Polley is the clearest case in the present corpus, but the broader lesson is universal: foundation characterization must be periodically revalidated when new loading stages, new data, or unexpected deformation challenge the original model. Risk frameworks that explicitly screen credible and noncredible failure modes can help prevent analytical effort from being concentrated on familiar modes while less obvious pathways remain insufficiently tested (Chapman & Cummins, 2025; Chen et al., 2024; Gao et al., 2025; Massignan et al., 2025; Menezes et al., 2025; Menezes et al., 2026; Yuan et al., 2024; Zabolotnii et al., 2022).

6. Breach dynamics, runout, and consequence modeling

A dam failure doesn't automatically determine downstream consequences. The process involves loss of containment, breach development, flow intensity, runout hazard, exposure, vulnerability, and response capacity. Breach models convert containment loss into a discharge hydrograph, while runout models convert this into depth, velocity, arrival time,

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

erosion, and reach. Exposure covers people, infrastructure, ecosystems, and assets within that reach; vulnerability assesses their susceptibility and resilience. Response capacity affects outcomes but isn't a hazard property. Tailings breach analysis reviews highlight uncertainty in breach size, erosion, rheology, and water–solids partitioning, impacting hazard zones and warning time (Kheirkhah Gildeh et al., 2021; Rico et al., 2008; Sreekumar et al., 2024).

The uncertainty is therefore a linked chain rather than a set of independent model errors: uncertainty in material state and residual strength affects initiation and released mass; breach assumptions affect the discharge hydrograph; rheology and topography affect runout; and these outputs determine arrival time, exposure, and life-safety decisions. A defensible consequence analysis should propagate plausible scenario envelopes through this chain rather than reset uncertainty at each modeling stage (Liu et al., 2024; Sordo et al., 2025; Sreekumar et al., 2024).

Experimental and numerical studies show that breach geometry evolves with flow Concentration, erodibility, particle size, and hydraulic loading, and that residual strength and large-deformation mechanics in liquefaction-induced runout influence modeling. Consequence models should be updated when pond conditions, volume, embankment geometry, tailings state, or downstream development change significantly (Duan et al., 2024; Luo et al., 2023; Sordo et al., 2025; Tian et al., 2021; Yao et al., 2021; Zhao et al., 2025).

Model credibility also depends on the separation of calibration from validation. Back-analysis of a known event can reproduce the final inundation for different combinations of breach and rheological parameters, leading to equifinality. A defensible analysis, therefore, documents parameter ranges, alternative scenarios, sensitivity analyses, and model limitations. This is especially important when model outputs are converted into warning thresholds or claims about available evacuation time (Eghbali et al., 2025; Kheirkhah Gildeh et al., 2021; Sreekumar et al., 2024).

Table 5 shows that consequence estimates should be reported as scenario ranges rather than single predictions. The most relevant uncertainty affects the extent of hazards, evacuation zones, arrival times, exposed populations, or critical infrastructure vulnerability.

Table 5. Sources of uncertainty in breach, runout, exposure, and consequence analysis

Model element	Uncertain inputs	Potential effect on decision

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Model element	Uncertain inputs	Potential effect on decision
Breach initiation	Failure location, trigger timing, erosion onset	Changes warning lead time
Breach growth	Width, depth, side slopes, erosion rate	Changes peak discharge and released volume
Tailings mobility	Rheology, concentration, residual strength	Changes runout distance, depth, and velocity
Topography	Digital elevation model (DEM) resolution, channel change, downstream structures	Changes flow routing and local depth
Exposure	Population location, occupancy, road access	Changes life-loss and evacuation feasibility

Note. Author synthesis based on Kheirkhah Gildeh et al. (2021), Rico et al. (2008), Sordo et al. (2025), and Sreekumar et al. (2024).

7. Environmental, health, social, and long-term consequences

7.1 Acute and environmental consequences

The environmental footprint of a tailings failure can persist long after the visible mudflow has stabilized. River systems redistribute contaminated sediment through remobilization, overbank deposition, channel migration, and floodplain exchange. Studies from Romania and Brazil show that water quality and contaminant fate must be assessed over multiple spatial and temporal scales; a declining dissolved concentration immediately after an event does not imply that stored sediment no longer represents a source (Bird et al., 2008; Kütter et al., 2023; Macklin et al., 2003; Pacheco et al., 2025).

7.2 Health, social, and institutional consequences

Ecological and socio-economic effects are coupled. The Fundão disaster altered land cover, aquatic systems, local economies, cultural relationships with rivers, and access to ecosystem services. Brumadinho raised serious concerns about human health and soil contamination. These effects demonstrate why consequence classification based only on direct fatalities or released volume is incomplete. A lower-volume failure can still generate high chronic impact if contaminants persist in soils, sediments, food chains, or water-supply systems (Aires et al., 2018; Buch et al., 2024; Fernandes et al., 2016; Garcia et al., 2025; Guimarães et al., 2022).

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Community health and social trust also shape recovery. Mount Polley research involving First Nations illustrates that risk perception is influenced by dependence on land and water, confidence in institutions, and the adequacy of post-event information. Global supply chain analysis further extends the ethical boundary: fatalities and social impacts associated with mineral production are linked to downstream consumers and to corporate responsibility. Tailings risk, therefore, belongs within broader environmental, social, and governance accountability rather than only to mine-site engineering (Shandro et al., 2017; Sugiyama et al., 2025).

7.3 Long-term legacy and closure

Long-term integrity adds a further temporal dimension. Closed and inactive facilities may persist for centuries, while erosion, climate, drainage performance, and land-use change continue to evolve. Long-term geomorphic assessments show that valley fill and other landform configurations require an explicit evaluation of erosional stability. The safety case at closure must therefore be based on enduring physical processes and maintainable controls, not on the assumption that risk ends when ore processing stops (Hancock & Coulthard, 2022; Hancock, 2021; Schoenberger, 2016).

8. Governance, regulation, and risk management

Governance has become a central theme after repeated catastrophic failures, but the literature cautions against treating governance as a substitute for engineering. The strongest interpretation is that governance creates the conditions under which engineering assumptions are challenged, data are disclosed, responsibilities are assigned, and action is taken. Technical and governance barriers are therefore complementary: a competent design requires a management system that preserves its assumptions during operation, and a strong management system requires technically credible limits and failure-mode analyses (Jefferies, 2022; Kemp et al., 2021; Owen et al., 2020; Wilson, 2021; Yu et al., 2025).

The GISTM formalizes this lifecycle perspective by connecting affected people, integrated knowledge, design, management, monitoring, emergency preparedness, disclosure, and accountability (International Council on Mining and Metals et al., 2020). ICOLD

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

guidance similarly emphasizes dam-safety fundamentals, review, surveillance, and lifecycle responsibilities (International Commission on Large Dams, 2022). These international frameworks are most effective when translated into site-specific controls rather than implemented as documentation exercises. The critical test is whether a facility can show how each credible failure mode is prevented, detected, escalated, and mitigated.

Risk-analysis methods are evolving from qualitative matrices toward bow-tie, network, three-dimensional matrices, decision trees, and other structured approaches. These tools are valuable when they force explicit representation of threats, preventive barriers, a clearly defined top event, mitigative barriers, escalation factors, and consequences. Their weakness is potential model formalism: a sophisticated diagram can still conceal missing evidence, correlated barriers, or uncertain probabilities. Figure 4 therefore uses a conventional bow-tie architecture in which threats are separated from preventive controls, loss of containment is the top event, and mitigative barriers act before consequence realization (Chapman & Cummins, 2025; Chen et al., 2022; Chen et al., 2024; Massignan et al., 2025; Menezes et al., 2026; Yuan et al., 2024; Zhen et al., 2022; Zheng et al., 2022).

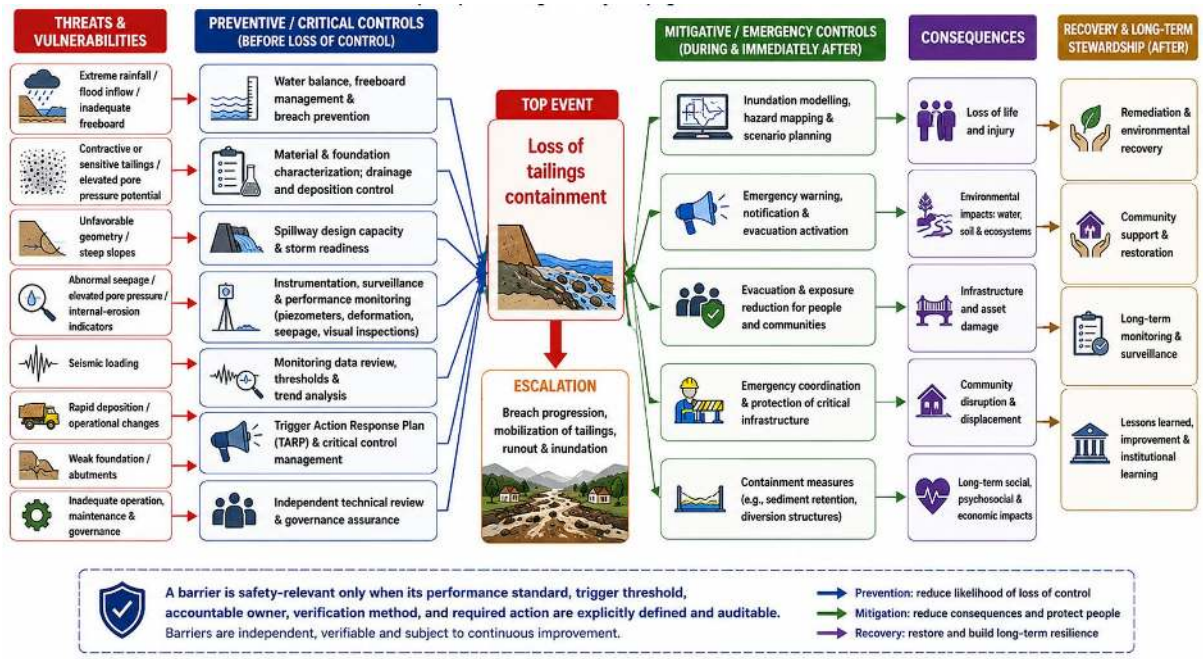


Figure 4. Bow-tie representation of threats, preventive barriers, loss of containment, mitigative barriers, and principal consequences.
Note. Author synthesis based on Chen et al. (2022), Massignan et al. (2025), and Owen et al. (2020).

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Evidence from the reviewed risk literature supports separating threats, preventive controls, loss of containment as the top event, and mitigative controls (Chen et al., 2022; Massignan et al., 2025; Owen et al., 2020). This review interprets high pond level, contractive tailings, extreme rainfall, seepage anomalies, and seismic or operational loading as threats or pathway conditions rather than barriers. Water balance, material-state characterization, drainage, spillway capacity, filters, independent review, and change management are preventive barriers; breach/runout mapping, validated warning thresholds, TARPs, evacuation, emergency coordination, and recovery are detective or mitigative barriers. The control implication is that a barrier is auditable only when its performance standard, data source, threshold, accountable owner, verification method, and required action are explicit.

Public disclosure is another necessary but incomplete barrier. Global studies show gaps in facility databases and risk information, while industry research suggests that transparency can change incentives and external scrutiny. However, disclosure reduces risk only if the information is technically meaningful, current, and capable of triggering action. The same principle applies internally: risk registers should be living decision tools linked to surveillance and change management, not static compliance records (Franks et al., 2021; Kemp et al., 2021; Massignan & Sánchez, 2024; Mpanza, 2024; Owen et al., 2020).

Operational risk control requires clear ownership of water balance, deposition, inspections, instrumentation, change management, and emergency readiness. Comprehensive risk-control systems and prevention studies emphasize that controls must be verified in the field. For example, 'drainage available' is not equivalent to demonstrated drainage capacity; 'monitoring installed' is not equivalent to valid data; and 'emergency plan approved' is not equivalent to an executable warning and evacuation process (Dong et al., 2020; Fourie, 2009; Gao et al., 2025; Menezes et al., 2025; Rodríguez et al., 2021; Wang et al., 2018).

Multiplicity of controls must not be equated with independence. Functional independence asks whether barriers interrupt the pathway through genuinely different mechanisms; data independence asks whether they rely on different measurements or information channels; and organizational independence asks whether review, interpretation,

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

and decision authority are sufficiently separated to challenge the same assumption. Common-cause failure can defeat several nominal barriers simultaneously. For example, monitoring, interpretation, TARP escalation, and management response may all depend on the same faulty sensor network, data pipeline, model, team, or reporting culture; similarly, several hydrological controls may share one incorrect water-balance assumption. The control implication is that the safety case should identify shared dependencies and escalation factors, not merely count the number of controls (Chen et al., 2022; Massignan et al., 2025; Menezes et al., 2025; Owen et al., 2020).

Applied retrospectively, the corpus supports three different levels of governance statement that are kept distinct here. A documented control failure is reported only when the cited evidence directly identifies the deficient control or assumption. A convergent literature interpretation is used when independent publications point to a similar control problem without providing a complete organizational record. A plausible but incompletely documented organizational inference is stated cautiously and is not treated as demonstrated causation. Under this calibration, Mount Polley supports a strong technical lesson about the ground model and foundation assumptions; Fundão and Brumadinho support the need to connect material state, monitoring, escalation, and downstream exposure, while case-specific organizational attribution remains more limited; and Jagersfontein supports a broader interpretation of legacy and institutional accumulation without implying a uniquely reconstructed decision chain (Cheng et al., 2021; Marais et al., 2024; Sadrekarimi & Riveros, 2020; Zabolotnii et al., 2022).

9. Monitoring, early warning, and emerging technologies

Evidence from monitoring reviews shows that instrumentation has safety value only when measurements are reliable, interpreted against credible failure modes, and connected to timely decisions (Clarkson & Williams, 2020; Hui et al., 2018; Zare et al., 2024). Real-time systems improve temporal resolution but also increase dependence on validation, communications, and disciplined response protocols. This review therefore treats monitoring as a decision chain rather than a sensor inventory: measurement → validation → baseline

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

comparison → trend/rate assessment → mechanistic interpretation → threshold/TARP → decision → action.

Piezometers remain central because pore pressure and phreatic conditions directly affect effective stress and stability, yet a sparse piezometer network can miss localized conditions or create false confidence. Deformation monitoring through survey, Global Navigation Satellite System (GNSS), ground-based radar, and satellite interferometric synthetic aperture radar (InSAR) provides a different line of evidence. Global and remote monitoring studies show the value of spatial coverage, particularly for detecting broad deformation patterns that may not be captured by point sensors. The strongest monitoring architecture uses independent data types that can corroborate or challenge one another (Li et al., 2020; Stefaniak & Wróżyńska, 2018).

Monitoring design should be failure-mode based. A facility screened for static liquefaction requires data capable of testing the assumed state, pore-pressure regime, deformation trend, and water conditions; a facility vulnerable to overtopping requires robust pond-level, rainfall, freeboard, and water-balance controls; a seepage-sensitive facility requires flow, turbidity, pore-pressure, and inspection evidence around drains, abutments, and foundations. Susceptibility models and stability analyses can prioritize variables, but the monitored variables must remain linked to physical mechanisms (Coutinho et al., 2025; D'Hyppolito et al., 2024; Elacoste et al., 2026; Lü et al., 2024; Pereira, 2025; Silva et al., 2024; Verdugo, 2024).

Data-driven approaches can strengthen prioritization and anomaly detection, especially where large multivariate datasets are available. Decision-tree and network-based risk methods demonstrate the potential to connect observed variables to credible failure modes. Nevertheless, predictive algorithms should be treated as decision support rather than autonomous safety authorities. Sparse failure datasets, changing sensor networks, nonstationary operating conditions, and class imbalance all limit statistical generalization (Menezes et al., 2026; Yuan et al., 2024; Zhen et al., 2022; Zheng et al., 2022).

In this framework, a weak signal is not any anomalous measurement. It is a low-amplitude or individually non-decisive deviation that becomes decision-relevant when

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

evaluated against a stable baseline, persistence and direction of trend, rate of change, measurement uncertainty, agreement among independent instruments or observations, and consistency with a predefined failure mechanism. A single outlier should normally trigger validation rather than automatic operational intervention unless an established threshold is exceeded. TARPs should therefore define confirmatory checks, treatment of missing or discordant data, escalation when independent evidence converges, and the consequences of false-positive and false-negative decisions. This operational definition preserves sensitivity without turning anomaly detection into indiscriminate alarm generation (Clarkson & Williams, 2020; Hui et al., 2018; Li et al., 2020; Zare et al., 2024).

Figure 5 summarizes a monitoring-to-decision architecture. Its central message is that sensors are only the first stage. Data quality, interpretation, uncertainty, escalation thresholds, accountable decision rights, and pre-agreed actions are equally important. A trigger-action-response plan should define what happens when one instrument fails, when multiple weak signals disagree, and when model predictions conflict with field observations.

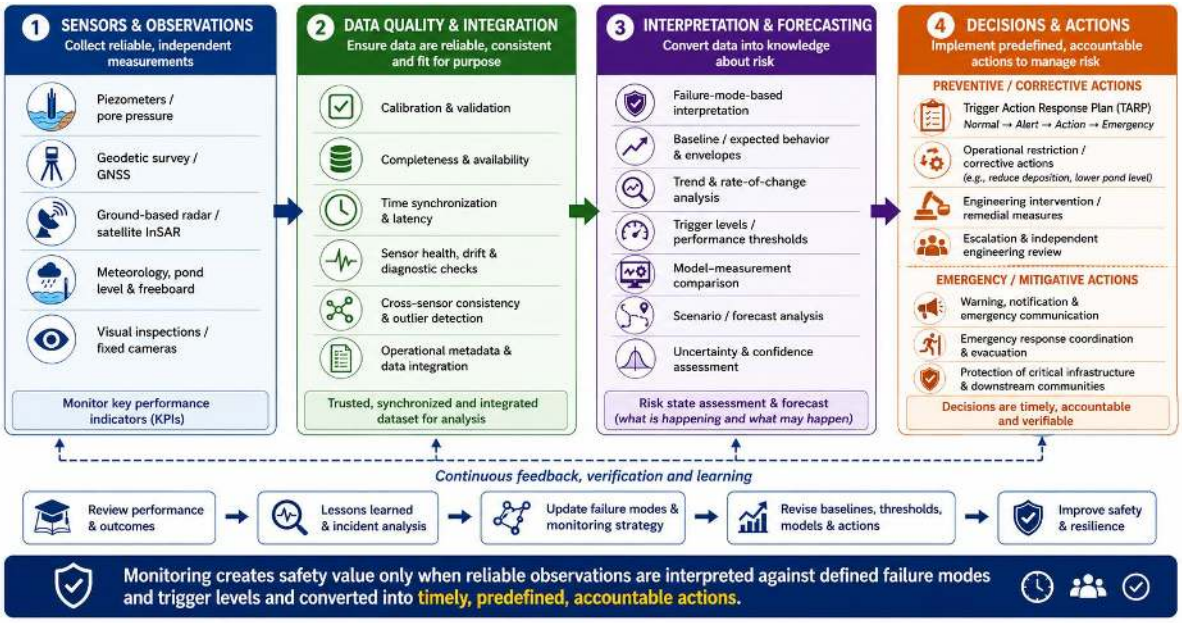


Figure 5. ***Monitoring-to-decision architecture for a failure-mode-based tailings surveillance system.***
Note. Author synthesis based on Clarkson and Williams (2020), Hui et al. (2018), Li et al. (2020), and Zare et al. (2024).

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

The architecture also provides a practical audit question: if a significant trend appears today, can the organization demonstrate who validates it, who interprets it, which threshold applies, who can stop or change operations, and how rapidly that decision is implemented?

Table 6 summarizes complementary monitoring technologies. Redundancy is most valuable when measurements provide partly independent physical information and do not share the same dominant data, communication, or interpretation failure mode.

Table 6. Selected monitoring technologies and their role in a failure-mode-based surveillance system.

Method	Primary variable	Strength	Key limitation
Piezometers	Pore pressure / phreatic condition	Direct geotechnical relevance	Point measurement; installation and interpretation dependence
Survey / GNSS	Surface displacement	High precision at controlled points	Sparse spatial coverage unless network is dense
Ground radar	Surface velocity/acceleration	High-frequency spatial deformation	Line-of-sight and atmospheric/geometry effects
Satellite InSAR	Wide-area deformation	Extensive spatial coverage and historical series	Revisit interval, coherence, line-of-sight sensitivity
Flow/seepage monitoring	Drain and seepage response	Direct evidence of hydraulic change	Requires baseline and context
Weather/pond monitoring	Hydrological loading and freeboard	Essential for overtopping prevention	Forecast and measurement uncertainty

Note. Author synthesis based on Clarkson and Williams (2020), Hui et al. (2018), Li et al. (2020), Stefaniak and Wróżyńska (2018), and Zare et al. (2024).

10. Critical synthesis: the case-to-control architecture and recurring systemic patterns

Evidence from the case histories and mechanism studies supports a first recurring pattern: accumulation rather than surprise. Catastrophic failure commonly requires a predisposing state—such as weak saturated tailings, adverse foundation conditions, limited freeboard, or deficient drainage—followed by a trigger or progressive change (Davies, 2002; Hudson-Edwards et al., 2024; Williams, 2021). This review interprets long-lived predisposing states as a governance challenge because normal operation can normalize adverse conditions. The control implication is that the lack of a previous failure cannot be used as evidence of an adequate margin.

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

A second evidence-based pattern is coupling: hydrology changes pore pressure and erosion potential; deformation changes drainage and geometry; deposition changes material state and beach length; and climatic loading changes water-balance uncertainty (Eze et al., 2025; Ma et al., 2026; Xie et al., 2023). This review interprets these interactions as reasons to test pathways jointly rather than assign a single causal label. The control implication is to stress-test water-related and geotechnical margins against plausible combinations of changing boundary conditions without attributing every event to climate change.

A third pattern is asymmetry in the treatment of uncertainty. The reviewed literature carefully quantifies many material and model uncertainties, whereas construction history, drain condition, pond location, data validity, and decision timing are often less explicitly represented (Chen et al., 2024; Chen, 2022; Elacoste et al., 2026; Halabi et al., 2022). This review interprets those omissions as epistemic gaps in the safety case. The control implication is to propagate uncertainty through both the physical model chain and the organizational decision chain rather than reset it at disciplinary boundaries.

A fourth pattern concerns challenge and independence. The literature supports independent technical review as a means of testing the ground model, failure-mode completeness, material-state interpretation, water balance, parameter uncertainty, and consequence assumptions (Wilson, 2021; Yu et al., 2025). The case-to-control synthesis extends this concept: independence should also be examined across data sources, interpretation, and decision authority, because common-cause dependencies can render several nominal controls ineffective at once.

A fifth pattern concerns the escalation of consequences and responses. Some tailings failures accelerate so rapidly that warning and evacuation time may be much shorter than assumed in generic plans (Silva & Eleutério, 2023). The reviewed evidence separates physical hazard from exposure, vulnerability, and response capacity; the synthesis then links those dimensions to mitigative barriers. Where credible arrival times are shorter than executable warning and evacuation times, the control implication is to strengthen prevention and reduce exposure rather than rely solely on emergency response.

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Taken together, these patterns support the case-to-control architecture: each credible pathway should be traced from predisposing state and trigger to physical mechanism, breach/runout hazard, exposure and vulnerability, and then to the preventive, detective, and mitigative barriers intended to interrupt escalation. Multiple barriers are desirable, but their value depends on demonstrated effectiveness, functional/data/organizational independence, and resistance to common-cause failure. Table 7 consolidates the functions previously distributed across separate mechanism and lifecycle tables and makes both barrier-degradation factors and evidence boundaries explicit.

Table 7. Case-to-control failure-pathway, barrier-degradation, and evidence matrix

Failure pathway/lifecycle focus	Predisposing state, trigger & decision-relevant weak signals	Barrier set: preventive / detective / mitigative	Barrier degradation / common-cause factors	Evidence nature and confidence boundary
Liquefaction/flow instability	Contractive saturated state; static/cyclic loading. Weak signals: pore-pressure/deformation trends, unfavorable state, loss of margin	Prevent: state characterization, drainage, deposition control, conservative stability assessment. Detect/mitigate: validated piezometry + deformation → TARP, operating change, exposure reduction/evacuation	Invalid baseline; sparse sensors; common model/calibration; drain degradation; normalization of adverse trends; same team validates and decides	Physical linkage: strong laboratory, critical-state, numerical, and case evidence. Organizational response: generally moderate/contextual unless event records are explicit
Overtopping/erosion	High pond, reduced freeboard, extreme rainfall, inadequate water balance. Weak signals: pond rise, beach retreat, forecast change, shrinking freeboard	Prevent: water balance, spillway capacity, beach management, storm readiness. Detect/mitigate: pond/rainfall surveillance → water removal, restrictions, warning/evacuation	Common water-balance assumption; invalid level data; blocked drainage/spillway; forecast error; delayed operating response	Physical linkage: strong experimental/numerical evidence. Control implication: synthesis supported by risk and monitoring literature
Internal erosion/piping	Hydraulic gradients, defects, filter incompatibility, preferential seepage. Weak signals: wet spots, turbidity, seepage/pore-pressure change, sinkholes	Prevent: filter compatibility, drains, interface QA, seepage control. Detect/mitigate: seepage/turbidity surveillance → investigation/intervention; emergency action if progression credible	Uninstrumented local pathway; shared seepage model; drain blockage; inspection blind spots; delayed investigation	Physical linkage: moderate-to-strong experimental/risk evidence; event-specific causal confidence depends on geometry and records
Foundation /	Weak layers;	Prevent: site	Entrenched	Physical linkage:

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Failure pathway/lifecycle focus	Predisposing state, trigger & decision-relevant weak signals	Barrier set: preventive / detective / mitigative	Barrier degradation / common-cause factors	Evidence nature and confidence boundary
structural instability	geometry/loading changes; invalidated ground model. Weak signals: unexpected settlement/lateral movement, changed deformation pattern	characterization, staged verification, independent review. Detect/mitigate: deformation monitoring → re-analysis, operational stop/change, consequence planning	ground model; correlated reviewers/data; undocumented as-built changes; change-management failure	high in well-documented cases such as Mount Polley; organizational attribution usually lower unless decision records are available
Seismic / operational coupling	Cyclic demand, rapid loading, altered deposition, major operating change. Weak signals: post-event deformation/pore pressure, changed state/geometry	Prevent: seismic assessment, change management, conservative operating limits. Detect/mitigate: post-event inspection/instrument validation → restrictions, engineering review, emergency response	Sensor damage; pre-event model bias; unassessed operational change; common decision bottleneck	Physical linkage: high where dedicated event data exist; transfer to governance remains contextual

Note. The matrix is a synthesis architecture rather than a universal instrumentation prescription. "Weak signals" become decision-relevant only after validation against baseline, trend/rate, uncertainty, corroboration, and mechanistic plausibility. Evidence confidence refers to the linkage summarized, not to the existence of the nominal control.

11. Research gaps, future agenda, and review limitations

11.1 Research gaps and future agenda

The future agenda is organized by the unresolved stages of the case-to-control architecture rather than by disciplinary topic alone. First, predisposing-state uncertainty remains substantial where in-situ state, construction history, drainage condition, and water balance are incompletely constrained. Research should test how uncertainty in these inputs changes the credibility of a failure pathway and the operating margin required for safe decisions (Liu et al., 2024; Rógenes et al., 2025; Silva et al., 2024).

Second, trigger attribution and propagation through the model chain require stronger separation between what is observed and what is inferred. Laboratory and constitutive models, breach models, and runout models should propagate parameter and scenario

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

uncertainty from initiation to hazard extent and arrival time, rather than resetting uncertainty at each stage (Ng et al., 2023; Sordo et al., 2025; Sreekumar et al., 2024).

Third, barrier-degradation detection needs to be made an explicit research focus. Studies should evaluate how changing geometry, nonstationary rainfall, drain aging, data loss, model drift, and operational change degrade preventive and detective controls, including the possibility that several controls share a common failure cause (Atakhanova et al., 2026; Eze et al., 2025; Ma et al., 2026; Massignan et al., 2025).

Fourth, decision performance requires auditable measures of validation latency, escalation latency, information handoffs, authority, and action under uncertainty. Such indicators should be linked to specific failure modes and control performance rather than reduced to generic compliance scores (Jefferies, 2022; Kemp et al., 2021; Marais et al., 2024; Owen et al., 2020).

Fifth, response effectiveness should be tested against scenario-specific arrival time, downstream exposure, vulnerability, communication feasibility, and the operational consequences of false-positive and false-negative alerts. This is the stage at which consequence modeling, monitoring, and emergency management must be evaluated as one decision system rather than as separate products (Silva & Eleutério, 2023; Zare et al., 2024).

Finally, data systems should be evaluated for independence as well as accuracy. New remote sensing, automation, and data-driven methods are valuable when they add a genuinely independent line of evidence, improve warning lead time, and remain robust to missing data and changed operating conditions. Prediction accuracy alone is insufficient if the method shares the same dominant data or model failure mode as the controls it is intended to back up (Clarkson & Williams, 2020; Hui et al., 2018; Li et al., 2020; Menezes et al., 2026; Stefaniak & Wróżyńska, 2018; Zare et al., 2024). Table 8 translates the unresolved stages of the case-to-control architecture into decision-oriented research priorities.

Table 8. Research priorities derived from unresolved stages of the case-to-control architecture

Architecture stage	Knowledge gap	Decision-oriented research question	Desired output
Predisposing state	State, geometry, drainage, construction history, and water balance incompletely constrained	Which uncertainties materially change pathway credibility and operating margin?	Traceable uncertainty bounds tied to operating criteria

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

Architecture stage	Knowledge gap	Decision-oriented research question	Desired output
Trigger attribution	Observed trigger and modeled trigger may be non-unique	Which independent evidence can discriminate competing triggers?	Multi-method trigger tests with explicit residual uncertainty
Barrier degradation	Controls can age, drift, be bypassed, or fail from common causes	How can loss of barrier effectiveness be detected before the top event?	Performance indicators for barrier health and shared dependencies
Breach/runout propagation	Initiation, breach, rheology, and topography uncertainties compound	How should uncertainty be propagated to hazard extent and arrival time?	Scenario envelopes with end-to-end uncertainty traceability
Decision performance	Validation, interpretation, escalation, and authority can introduce latency	Which decision-chain characteristics preserve action time under uncertainty?	Auditable decision-latency and escalation metrics
Response effectiveness	Hazard, exposure, vulnerability, and evacuation capacity are not equivalent	When is warning/evacuation executable within credible arrival time?	Scenario-tested response performance and exposure-reduction criteria
Evidence independence	Nominally redundant controls may share data/model/organizational failure modes	Which combinations provide functional, data, and organizational independence?	Common-cause analysis and independence benchmarks

Note. Priorities are derived from the evidence gaps exposed by the revised case-to-control framework, rather than intended as a general ranking of all tailings research needs.

11.2 Limitations of the present review

The review has limitations that constrain claims of completeness, representativeness, and causal certainty. First, the evidence base was pre-curated rather than generated by a de novo systematic database search; the discovery stage therefore cannot be reproduced or audited as a systematic search, and selection, language, and publication biases cannot be quantified. The source-level coding in Supplementary Table S1 makes the analytical use of the available corpus transparent but does not convert the study into a systematic review. Second, geographic representation is uneven and global TSF inventories remain incomplete, so regional or construction-method failure rates cannot be inferred from the corpus. Third, primary evidence types are epistemically heterogeneous: laboratory, numerical, forensic, environmental, social, monitoring, and governance studies address different questions and

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

cannot be treated as interchangeable forms of confirmation (Hudson-Edwards et al., 2024; Massignan & Sánchez, 2024; Mpanza, 2024; Piciullo et al., 2022).

Fourth, case metrics such as released volume, timing, and long-term consequences are reported inconsistently, precluding a harmonized quantitative meta-analysis. Fifth, retrospective reconstruction is vulnerable to hindsight bias, parameter non-uniqueness, and model equifinality; reproducing an observed outcome does not uniquely identify the trigger or barrier failure. Sixth, proprietary engineering records and official investigation records not represented in the supplied scientific corpus were not systematically assessed. This limitation is especially consequential for organizational attribution, so governance/control confidence is intentionally reported separately and is often lower than confidence in the physical mechanism. Finally, the author-coded domains and confidence categories are qualitative analytical devices; they improve traceability but do not imply statistical reliability or inter-rater reproducibility (Kheirkhah Gildeh et al., 2021; Sreekumar et al., 2024).

12. Conclusions

The case-to-control synthesis shows that the most transferable unit of learning from a major tailings failure is neither the event name nor a single "root cause," but the complete pathway by which a predisposing state progresses through trigger, physical mechanism, breach/runout hazard, exposure and vulnerability, and barrier degradation to consequence. Across regions and mechanisms, the decisive analytical question is therefore which evidence supports each link and which control can interrupt it before escalation becomes irreversible.

Physical-mechanism confidence and organizational/control confidence must be kept separate. Liquefaction, overtopping, internal erosion, foundation weakness, and seismic or operational coupling can be strongly supported by experimental, observational, numerical, or forensic evidence while the associated organizational decision chain remains only partly documented. The revised framework makes that epistemic boundary explicit and treats uncertainty as information to be propagated rather than hidden by a single causal label.

Prevention consequently depends on barrier performance, not barrier count. Preventive, detective, and mitigative controls should be auditable, linked to failure-mode-specific weak signals and TARPs, and tested for functional, data, and organizational independence because

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

common-cause failures can defeat multiple nominal safeguards simultaneously. The case-to-control architecture provides a compact basis for connecting geotechnical diagnosis, water management, monitoring, governance, emergency planning, and closure while preserving the distinction between reviewed evidence, integrative interpretation, and normative control implication.

Declarations

Funding: No external funding was declared for this review.

Conflicts of interest: No competing interests are declared.

Data availability: No new experimental dataset was generated. The evidence base comprises the cited literature and standards; the author-coded traceability matrix is provided as Supplementary Table S1.

Author contributions: Withheld for double-blind review and to be restored after acceptance.

References

1. Adamo, N., Al-Ansari, N., Sissakian, V., Laue, J., & Knutsson, S. (2021). Dam safety: The question of tailings dams. *Journal of Earth Sciences and Geotechnical Engineering, 11*(1), 1–26. https://doi.org/10.47260/jesge/1111
2. Agurto-Detzel, H., Bianchi, M., Assumpção, M., Schimmel, M., Collaço, B., Ciardelli, C., Barbosa, J. R., & Calhau, J. (2016). The tailings dam failure of 5 November 2015 in SE Brazil and its preceding seismic sequence. *Geophysical Research Letters, 43*(10), 4929–4936. https://doi.org/10.1002/2016GL069257
3. Aires, U. R. V., Santos, B. S. M., Coelho, C. D., da Silva, D. D., & Calijuri, M. L. (2018). Changes in land use and land cover as a result of the failure of a mining tailings dam in Mariana, MG, Brazil. *Land Use Policy, 70*, 63–70. https://doi.org/10.1016/j.landusepol.2017.10.026.
4. Alizadeh, P., Hekmatnejad, A., Ramezani, A., & Pena, A. (2026). Rainfall-induced hydrological triggers and static liquefaction: A case study of the Brumadinho tailings dam failure. *Journal of Engineering and Applied Science, 73*, Article 176. https://doi.org/10.1186/s44147-026-01003-9
5. Armstrong, M., Petter, R., & Petter, C. (2019). Why have so many tailings dams failed in recent years? *Resources Policy, 63*, Article 101412. https://doi.org/10.1016/j.resourpol.2019.101412

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

6. Atakhanova, Z., Baigaliyeva, M., & Kairat, A. (2026). Mine tailings facilities in Kazakhstan: Public databases, management practices, and extreme weather events. *Sustainability, 18*(13), Article 6479. https://doi.org/10.3390/su18136479
7. Azam, S., & Li, Q. (2010). Tailings dam failures: A review of the last one hundred years. *Geotechnical News, 28*(4), 50–53. https://ksmproject.com/wp-content/uploads/2017/08/Tailings-Dam-Failures-Last-100-years-Azam2010.pdf
8. Bird, G., Brewer, P. A., Macklin, M. G., Balteanu, D., Serban, M., Driga, B., & Zaharia, S. (2008). River system recovery following the Novaţ-Roşu tailings dam failure, Maramureş County, Romania. *Applied Geochemistry, 23*(12), 3498–3518. https://doi.org/10.1016/j.apgeochem.2008.08.010
9. Buch, A. C., Sims, D. B., de Ramos, L. M., Marques, E. D., Ritcher, S., Abdullah, M. M. S., & Silva-Filho, E. V. (2024). Assessment of environmental pollution and human health risks of mine tailings in soil: After dam failure of the Córrego do Feijão Mine (in Brumadinho, Brazil). *Environmental Geochemistry and Health, 46*, Article 72. https://doi.org/10.1007/s10653-024-01870-2
10. Chapman, P., & Cummins, B. (2025). A framework for assigning noncredible failure modes in tailings storage facility risk assessments. *Journal of Performance of Constructed Facilities, 39*(4), Article 04025036. https://doi.org/10.1061/JPCFEV.CFENG-4606
11. Chen, C. (2022). Hazards identification and characterisation of the tailings storage facility dam failure and engineering applications. *International Journal of Mining, Reclamation and Environment, 36*(6), 399–418. https://doi.org/10.1080/17480930.2022.2051136
12. Chen, C., Ma, B., & Li, Z. (2022). A mining tailings storage facility failure analysis model using bow-tie representation. *Journal of Failure Analysis and Prevention, 22*(3), 983–999. https://doi.org/10.1007/s11668-022-01375-z
13. Chen, C., Zhao, Y., & Ma, B. (2024). Three-dimensional risk matrix for risk assessment of tailings storage facility failure: Theory and a case study. *Geotechnical and Geological Engineering, 42*, 1811–1833. https://doi.org/10.1007/s10706-023-02647-7
14. Cheng, D., Cui, Y., Li, Z., & Iqbal, J. (2021). Watch out for the tailings pond, a sharp edge hanging over our heads: Lessons learned and perceptions from the Brumadinho tailings dam failure disaster. *Remote Sensing, 13*(9), Article 1775. https://doi.org/10.3390/rs13091775
15. Clarkson, L., & Williams, D. J. (2020). Critical review of tailings dam monitoring best practice. *International Journal of Mining, Reclamation and Environment, 34*(2), 119–148. https://doi.org/10.1080/17480930.2019.1625172
16. Clarkson, L., & Williams, D. J. (2021). An overview of conventional tailings dam geotechnical failure mechanisms. *Mining, Metallurgy & Exploration, 38*(3), 1305–1328. https://doi.org/10.1007/s42461-021-00381-3

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

17. Coutinho, R. S., Silva, R. S. A., Almeida, M. S. S., Cavalcanti, M. C. R., Nagula, S. S., & Delgado, B. G. (2025). Static liquefaction susceptibility of a Brazilian iron ore tailings dam: A combined laboratory testing and numerical modeling approach. *International Journal of Geomechanics, 25*(8), Article 04025167. https://doi.org/10.1061/IJGNAI.GMENG-11018

18. Davies, M. P. (2002). Tailings impoundment failures: Are geotechnical engineers listening? *Geotechnical News, 20*(3), 31–36. https://miningquiz.com/pdf/Impoundments/Dam_failuresDavies2002.pdf

19. Dong, L., Deng, S., & Wang, F. (2020). Some developments and new insights for environmental sustainability and disaster control of tailings dam. *Journal of Cleaner Production, 269*, Article 122270. https://doi.org/10.1016/j.jclepro.2020.122270

20. Duan, Z., Chen, J., Xie, J., Li, Q., Zhang, H., & Chen, C. (2024). Study on the evolution characteristics of dam failure due to flood overtopping of tailings ponds. *Water, 16*(17), Article 2406. https://doi.org/10.3390/w16172406

21. D'Hyppolito, L. C. S., Sayão, A. J., & Nunes, A. L. L. (2024). A simple method for assessing the probability of liquefaction of tailings dams. *Soils and Rocks, 47*(4), Article e2024000924. https://doi.org/10.28927/SR.2024.000924

22. Eghbali, A., Shayan, P., Darvishi, M., Javan, M., & Mohseni, O. (2025). Flood hydrograph analysis of tailings dam failure. *Environmental Earth Sciences, 84*, Article 704. https://doi.org/10.1007/s12665-025-12704-4

23. Elacoste, T. S., Silva, G., Porto, T. B., & Ruchkys de Azevedo, Ú. (2026). An approach to variable prioritization in tailings dam failure susceptibility analysis. *The Extractive Industries and Society, 25*, Article 101759. https://doi.org/10.1016/j.exis.2025.101759

24. Eze, K. N., Shorunke, M. O., Ilesanmi, O. O., Anosike, C. U., Ezeanowai, U. H., & Adekunle, O. H. (2025). Sustainability in management for unsaturated mine tailings dams amidst climate change. *Discover Geoscience, 3*, Article 112. https://doi.org/10.1007/s44288-025-00222-6

25. Fernandes, G. W., Goulart, F. F., Ranieri, B. D., Coelho, M. S., Dales, K., Bösche, N., Bustamante, M., Carvalho, F. A., Carvalho, D. C., Dirzo, R., Fernandes, S., Galetti, P. M., Millan, V. E. G., Mielke, C., Ramirez, J. L., Neves, A., Rogaß, C., Ribeiro, S. P., Scariot, A., & Soares-Filho, B. (2016). Deep into the mud: Ecological and socio-economic impacts of the dam breach in Mariana, Brazil. *Natureza & Conservação, 14*(2), 35–45. https://doi.org/10.1016/j.ncon.2016.10.003.

26. Fourie, A. (2009). Preventing catastrophic failures and mitigating environmental impacts of tailings storage facilities. *Procedia Earth and Planetary Science, 1*(1), 1067–1071. https://doi.org/10.1016/j.proeps.2009.09.164

27. Fourie, A. B., Blight, G. E., & Papageorgiou, G. (2001). Static liquefaction as a possible explanation for the Merriespruit tailings dam failure. *Canadian Geotechnical Journal, 38*(4), 707–719. https://doi.org/10.1139/t00-112

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

28. Franks, D. M., Stringer, M., Torres-Cruz, L. A., Baker, E., Valenta, R., Thygesen, K., Matthews, A., Howchin, J., & Barrie, S. (2021). Tailings facility disclosures reveal stability risks. *Scientific Reports, 11*, Article 5353. https://doi.org/10.1038/s41598-021-84897-0

29. Gao, T., Qin, Z., Yang, R., Li, Q., Geng, C., Zhang, J., & Chen, Z. (2025). Study on risk assessment and risk prevention of dam failure during the operation period of tailings pond. *Buildings, 15*(16), Article 2833. https://doi.org/10.3390/buildings15162833

30. Garcia, F. F., Camilo Cotrim, C. F., Caramori, S. S., Bailão, E. F. L. C., Nabout, J. C., Gitirana Junior, G. F. N., & Almeida, L. M. (2025). Mine tailings dams' failures: Serious environmental impacts, remote solutions. *Environment, Development and Sustainability, 27*(8), 18179–18201. https://doi.org/10.1007/s10668-024-04628-z

31. Glotov, V. E., Chlachula, J., Glotova, L. P., & Little, E. C. (2018). Causes and environmental impact of the gold-tailings dam failure at Karamken, the Russian Far East. *Engineering Geology, 245*, 236–247. https://doi.org/10.1016/j.enggeo.2018.08.012

32. Guimarães, R. N., Moreira, V. R., Cruz, J. R. A., Saliba, A. P. M., & Amaral, M. C. S. (2022). History of tailings dam failure: Impacts on access to safe water and influence on the legislative framework. *Science of the Total Environment, 852*, Article 158536. https://doi.org/10.1016/j.scitotenv.2022.158536

33. Halabi, A. L. M., Siacara, A. T., Sakano, V. K., Pileggi, R. G., & Futai, M. M. (2022). Tailings dam failures: A historical analysis of the risk. *Journal of Failure Analysis and Prevention, 22*(2), 464–477. https://doi.org/10.1007/s11668-022-01355-3

34. Hancock, G. R. (2021). A method for assessing the long-term integrity of tailings dams. *Science of the Total Environment, 779*, Article 146083. https://doi.org/10.1016/j.scitotenv.2021.146083

35. Hancock, G. R., & Coulthard, T. J. (2022). Tailings dams: Assessing the long-term erosional stability of valley fill designs. *Science of the Total Environment, 849*, Article 157692. https://doi.org/10.1016/j.scitotenv.2022.157692

36. Hudson-Edwards, K. A., Kemp, D., Torres-Cruz, L. A., Macklin, M. G., Brewer, P. A., Owen, J. R., Franks, D. M., Marquis, E., & Thomas, C. J. (2024). Tailings storage facilities, failures and disaster risk. *Nature Reviews Earth & Environment, 5*(9), 612–630. https://doi.org/10.1038/s43017-024-00576-4

37. Hui, S., Charlebois, L., & Sun, C. (2018). Real-time monitoring for structural health, public safety, and risk management of mine tailings dams. *Canadian Journal of Earth Sciences, 55*(3), 221–229. https://doi.org/10.1139/cjes-2017-0186

38. International Commission on Large Dams. (2022). *Tailings dam safety* (Bulletin No. 194). https://www.icold-cigb.org/GB/publications/bulletins.asp

39. International Council on Mining and Metals, United Nations Environment Programme, & Principles for Responsible Investment. (2020). *Global industry standard on tailings*

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

management. Global Tailings Review. https://globaltailingsreview.org/global-industry-standard/.

40. Ishihara, K., Ueno, K., Yamada, S., Yasuda, S., & Yoneoka, T. (2015). Breach of a tailings dam in the 2011 earthquake in Japan. *Soil Dynamics and Earthquake Engineering, 68*, 3–22. https://doi.org/10.1016/j.soildyn.2014.10.010
41. Islam, K., & Murakami, S. (2021). Global-scale impact analysis of mine tailings dam failures: 1915–2020. *Global Environmental Change, 70*, Article 102361. https://doi.org/10.1016/j.gloenvcha.2021.102361
42. Jefferies, M. (2022). Improving governance will not be sufficient to avoid dam failures. *Proceedings of the Institution of Civil Engineers – Geotechnical Engineering, 175*(2), 166–180. https://doi.org/10.1680/jgeen.21.00105
43. Jeyapalan, J. K., Duncan, J. M., & Seed, H. B. (1983). Investigation of flow failures of tailings dams. *Journal of Geotechnical Engineering, 109*(2), 172–189. https://doi.org/10.1061/(ASCE)0733-9410(1983)109:2(172)
44. Jing, X., Chen, Y., Williams, D. J., Serna, M. L., & Zheng, H. (2019). Overtopping failure of a reinforced tailings dam: Laboratory investigation and forecasting model of dam failure. *Water, 11*(2), Article 315. https://doi.org/10.3390/w11020315
45. Kemp, D., Owen, J. R., & Lèbre, É. (2021). Tailings facility failures in the global mining industry: Will a 'transparency turn' drive change? *Business Strategy and the Environment, 30*(1), 122–134. https://doi.org/10.1002/bse.2613
46. Kheirkhah Gildeh, H., Halliday, A., Arenas, A., & Zhang, H. (2021). Tailings dam breach analysis: A review of methods, practices, and uncertainties. *Mine Water and the Environment, 40*(1), 128–150. https://doi.org/10.1007/s10230-020-00718-2
47. Kütter, V. T., Martins, G. S., Brandini, N., Cordeiro, R. C., Almeida, J. P. A., & Marques, E. D. (2023). Impacts of a tailings dam failure on water quality in the Doce River: The largest environmental disaster in Brazil. *Journal of Trace Elements and Minerals, 5*, Article 100084. https://doi.org/10.1016/j.jtemin.2023.100084
48. Ledesma, O., Sfriso, A., & Manzanal, D. (2022). Procedure for assessing the liquefaction vulnerability of tailings dams. *Computers and Geotechnics, 144*, Article 104632. https://doi.org/10.1016/j.compgeo.2022.104632
49. Li, S., Yuan, L., Yang, H., An, H., & Wang, G. (2020). Tailings dam safety monitoring and early warning based on spatial evolution process of mud-sand flow. *Safety Science, 124*, Article 104579. https://doi.org/10.1016/j.ssci.2019.104579
50. Lin, S.-Q., Wang, G.-J., Liu, W.-L., Zhao, B., Shen, Y.-M., Wang, M.-L., & Li, X.-S. (2022). Regional distribution and causes of global mine tailings dam failures. *Metals, 12*(6), Article 905. https://doi.org/10.3390/met12060905
51. Liu, H., Nagula, S., Jostad, H. P., Piciullo, L., & Nadim, F. (2024). Considerations for using critical state soil mechanics based constitutive models for capturing static

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

liquefaction failure of tailings dams. *Computers and Geotechnics, 167*, Article 106089. https://doi.org/10.1016/j.compgeo.2024.106089

52. Luo, C., Li, D., & Xu, B. (2023). Study on the evolution of tailings dam break disaster under complex environment. *Sustainability, 15*(20), Article 14728. https://doi.org/10.3390/su152014728
53. Luo, Y., Zhou, M., Wang, M., Feng, Y., Luo, H., Ou, J., Wu, S., & Jing, X. (2025). Study on lateral erosion failure behavior of reinforced fine-grained tailings dam due to overtopping breach. *Water, 17*(14), Article 2088. https://doi.org/10.3390/w17142088
54. Lyu, Z., Chai, J., Xu, Z., Qin, Y., & Cao, J. (2019). A comprehensive review on reasons for tailings dam failures based on case history. *Advances in Civil Engineering, 2019*, Article 4159306. https://doi.org/10.1155/2019/4159306
55. Lü, X., Zeng, S., Liu, X., Weng, M., Shao, Y., & Li, Y. (2024). Enhanced method of slices with experimental evidence for predicting static liquefaction on tailings dams. *Bulletin of Engineering Geology and the Environment, 83*, Article 227. https://doi.org/10.1007/s10064-024-03735-5
56. Ma, W.-B., Chen, Y.-C., Li, H.-D., Bian, Z.-F., Lei, S.-G., & Zhang, Z.-X. (2026). Safeguarding tailings dams at the climate brink. *Science, 391*(6783), 360–361. https://doi.org/10.1126/science.aee4079
57. Macklin, M. G., Brewer, P. A., Balteanu, D., Coulthard, T. J., Driga, B., Howard, A. J., & Zaharia, S. (2003). The long term fate and environmental significance of contaminant metals released by the January and March 2000 mining tailings dam failures in Maramureş County, upper Tisa Basin, Romania. *Applied Geochemistry, 18*(2), 241–257. https://doi.org/10.1016/S0883-2927(02)00123-3
58. Marais, L., Kemp, D., van der Watt, P., Matebesi, S., Cloete, J., Harris, J., Ang, M. L. E., & Owen, J. R. (2024). The catastrophic failure of the Jagersfontein tailings dam: An industrial disaster 150 years in the making. *International Journal of Disaster Risk Reduction, 109*, Article 104585. https://doi.org/10.1016/j.ijdrr.2024.104585.
59. Massignan, R. S., & Sánchez, L. E. (2024). Public databases of tailings storage facilities fall short of full risk disclosure. *The Extractive Industries and Society, 17*, Article 101420. https://doi.org/10.1016/j.exis.2024.101420
60. Massignan, R. S., Siqueira-Gay, J., & Sánchez, L. E. (2025). Setting a comprehensive bow-tie framework for disaster risk analysis of mine tailings storage facilities. *Risk Analysis, 45*(12), 4604–4618. https://doi.org/10.1111/risa.70137
61. Menezes, D. A. de, Lima, H. M. de, & Santos, T. B. dos. (2025). Risk mitigation in tailings storage facilities: A comprehensive approach of the Risk Control Management System (RCMS). *Territorium, 32*(II), 53–70. https://doi.org/10.14195/1647-7723_32-2_4
62. Menezes, D. A. de, Matos, J. M. V., Lima, H. M. de, & Santos, T. B. dos. (2026). A data-driven approach linking the credible failure modes for tailings storage facilities risk

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

assessment supported by decision tree assessment. *Soils and Rocks, 49*(2), Article e2026011825. https://doi.org/10.28927/SR.2026.011825

63. Mpanza, M. (2024). Establishing a tailings storage facility database in Gauteng. *The Extractive Industries and Society, 20*, Article 101547. https://doi.org/10.1016/j.exis.2024.101547
64. Mánica, M. A., Arroyo, M., Gens, A., & Monforte, L. (2022). Application of a critical state model to the Merriespruit tailings dam failure. *Proceedings of the Institution of Civil Engineers – Geotechnical Engineering, 175*(2), 151–165. https://doi.org/10.1680/jgeen.21.00001
65. Ng, C. W. W., Crous, P. A., & Jacobsz, S. W. (2023). Centrifuge and numerical modeling of liquefied flow and nonliquefied slide failures of tailings dams. *Journal of Geotechnical and Geoenvironmental Engineering, 149*(9), Article 04023075. https://doi.org/10.1061/JGGEFK.GTENG-10800
66. Nišić, D., Aleksić, N., Živanović, B., Pantelić, U., & Rupar, V. (2024). Review of the failure at the flotation tailings storage facility of the "Stolice" Mine (Serbia). *Applied Sciences, 14*(22), Article 10163. https://doi.org/10.3390/app142210163
67. Nišić, D., Knežević, D., & Lilić, N. (2018). Assessment of risks associated with the operation of the tailings storage facility Veliki Krivelj, Bor (Serbia). *Archives of Mining Sciences, 63*(1), 165–181. https://doi.org/10.24425/118893
68. Otieno, F., & Shukla, S. K. (2023). An insight into failure of iron ore mine tailings dams. *International Journal of Mining, Reclamation and Environment, 37*(2), 127–147. https://doi.org/10.1080/17480930.2022.2159295
69. Owen, J. R., Kemp, D., Lèbre, É., Svobodova, K., & Pérez Murillo, G. (2020). Catastrophic tailings dam failures and disaster risk disclosure. *International Journal of Disaster Risk Reduction, 42*, Article 101361. https://doi.org/10.1016/j.ijdrr.2019.101361
70. Pacheco, F. A. L., Pissarra, T. C. T., Valera, C. A., Carvalho de Melo, M., & Sanches Fernandes, L. F. (2025). Tailings dam failures in Brazil: River contamination, ecosystem recovery, and institutional responses to the Mariana and Brumadinho disasters. *Current Opinion in Environmental Science & Health, 47*, Article 100654. https://doi.org/10.1016/j.coesh.2025.100654
71. Pereira, A. C. (2025). Tailings liquefaction and dam stability: Advances in diagnosis, monitoring, standards and mitigation—A critical review. *REMUNOM, 21*(02), 1–55. https://doi.org/10.61164/erfqjg05
72. Pereira, A. C. (2026). Comparative global review of dam failures: Mining tailings versus hydro, industrial, and civil dams—Causes, mechanisms, and lessons learned. *RECIMA21 – Revista Científica Multidisciplinar, 7*(1), Article e717147. https://doi.org/10.47820/recima21.v7i1.7147

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

73. Piciullo, L., Storrøsten, E. B., Liu, Z., Nadim, F., & Lacasse, S. (2022). A new look at the statistics of tailings dam failures. *Engineering Geology, 303*, Article 106657. https://doi.org/10.1016/j.enggeo.2022.106657

74. Rico, M., Benito, G., & Díez-Herrero, A. (2008). Floods from tailings dam failures. *Journal of Hazardous Materials, 154*(1–3), 79–87. https://doi.org/10.1016/j.jhazmat.2007.09.110

75. Rico, M., Benito, G., Salgueiro, A. R., Díez-Herrero, A., & Pereira, H. G. (2008). Reported tailings dam failures: A review of the European incidents in the worldwide context. *Journal of Hazardous Materials, 152*(2), 846–852. https://doi.org/10.1016/j.jhazmat.2007.07.050

76. Riveros, G. A., & Sadrekarimi, A. (2021). Static liquefaction behaviour of gold mine tailings. *Canadian Geotechnical Journal, 58*(6), 889–901. https://doi.org/10.1139/cgj-2020-0209

77. Rodríguez, R., Muñoz-Moreno, A., Caparrós, A. V., García-García, C., Brime-Barrios, Á., Arranz-González, J. C., Rodríguez-Gómez, V., Fernández-Naranjo, F. J., & Alcolea, A. (2021). How to prevent flow failures in tailings dams. *Mine Water and the Environment, 40*(1), 83–112. https://doi.org/10.1007/s10230-021-00752-8

78. Rodríguez-Pacheco, R., Caparrós, A. V., Alcolea, A., Martínez-Pagán, P., Martínez-Segura, M. A., García-García, C., Faz, Á., Corral, I., Roque, C., & Zarroca, M. (2022). Static liquefaction causes the flow failure of a tailings dam: A case study of El Descargador, Cartagena–La Unión mining region, SE Spain (October 1963). *Minerals, 12*(12), Article 1488. https://doi.org/10.3390/min12121488

79. Rógenes, E., Paes, I. T., Delgado, B. G., Bittar, R. J., Gomes, A. dos S., Cirone, A., Fávero Neto, A. H., & Rasmussen, L. L. (2025). Assessing static liquefaction triggers in tailings dams using the critical state constitutive models CASM and NorSand. *International Journal for Numerical and Analytical Methods in Geomechanics, 49*(4), 1092–1112. https://doi.org/10.1002/nag.3914.

80. Sadrekarimi, A., & Riveros, G. A. (2020). Static liquefaction analysis of the Fundão dam failure. *Geotechnical and Geological Engineering, 38*(6), 6431–6446. https://doi.org/10.1007/s10706-020-01446-8

81. Schoenberger, E. (2016). Environmentally sustainable mining: The case of tailings storage facilities. *Resources Policy, 49*, 119–128. https://doi.org/10.1016/j.resourpol.2016.04.009

82. Shandro, J., Jokinen, L., Stockwell, A., Mazzei, F., & Winkler, M. S. (2017). Risks and impacts to First Nation health and the Mount Polley Mine tailings dam failure. *International Journal of Indigenous Health, 12*(2), 84–102. https://doi.org/10.18357/ijih122201717786

83. Silva, A. F. R., & Eleutério, J. C. (2023). Analysis of flood warning and evacuation efficiency by comparing damage and life-loss estimates with real consequences related to

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

the São Francisco tailings dam failure in Brazil. *Natural Hazards and Earth System Sciences, 23*, 3095–3110. https://doi.org/10.5194/nhess-23-3095-2023

84. Silva, A. V., Gomes, G. J. C., Huertas, J. R. C., & Cândido, E. S. (2024). Exploring tailings dam stability considering uncertainties in the critical state parameters of the NorSand model. *Geotechnical and Geological Engineering, 42*(6), 4721–4741. https://doi.org/10.1007/s10706-024-02809-1
85. Sordo, B., Rathje, E., & Kumar, K. (2025). Runout of liquefaction-induced tailings dam failure: Influence of earthquake motions and residual strength. *Soil Dynamics and Earthquake Engineering, 194*, Article 109371. https://doi.org/10.1016/j.soildyn.2025.109371
86. Sreekumar, U., Kheirkhah Gildeh, H., Mohammadian, A., Rennie, C., & Nistor, I. (2024). Tailings dam breach outflow modelling: A review. *Mine Water and the Environment, 43*(4), 563–587. https://doi.org/10.1007/s10230-024-01015-y
87. Stark, T. D., Moya, L., & Lin, J. (2022). Rates and causes of tailings dam failures. *Advances in Civil Engineering, 2022*, Article 7895880. https://doi.org/10.1155/2022/7895880
88. Stefaniak, K., & Wróżyńska, M. (2018). On possibilities of using global monitoring in effective prevention of tailings storage facilities failures. *Environmental Science and Pollution Research, 25*(6), 5280–5297. https://doi.org/10.1007/s11356-017-0995-x
89. Su, C., Rana, N. M., Evans, S. G., Wang, B., & Zhang, S. (2024). Tailings storage facilities in China: Historical failure incidents, existing status, and database-driven quantitative risk assessment. *International Journal of Disaster Risk Reduction, 114*, Article 104973. https://doi.org/10.1016/j.ijdrr.2024.104973
90. Sugiyama, T., Zhang, Z., Zeng, X., & Matsubae, K. (2025). Induced social responsibility in global mineral supply chains: Fatalities from tailings dam failures. *Journal of Cleaner Production, 519*, Article 145983. https://doi.org/10.1016/j.jclepro.2025.145983
91. Sun, E., Zhang, X., Li, Z., & Wang, Y. (2012). Tailings dam flood overtopping failure evolution pattern. *Procedia Engineering, 28*, 356–362. https://doi.org/10.1016/j.proeng.2012.01.733
92. Tian, S., Dai, X., Wang, G., Lu, Y., & Chen, J. (2021). Formation and evolution characteristics of dam breach and tailings flow from dam failure: An experimental study. *Natural Hazards, 107*(2), 1621–1638. https://doi.org/10.1007/s11069-021-04649-1
93. Van Niekerk, H. J., & Viljoen, M. J. (2005). Causes and consequences of the Merriespruit and other tailings-dam failures. *Land Degradation & Development, 16*(2), 201–212. https://doi.org/10.1002/ldr.681
94. Verdugo, R. (2024). Static liquefaction in the context of steady state/critical state and its application in the stability of tailings dams. *Soil Dynamics and Earthquake Engineering, 176*, Article 108270. https://doi.org/10.1016/j.soildyn.2023.108270

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies
Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

95. Wang, C., Wang, Y., Qin, W., He, H., Wang, H., Wang, H., Leng, X., Chang, M., & Fang, K. (2025). Pore water pressure surge and piping failure characteristics in tailings dam: Evidence from large-scale physical modelling. *Bulletin of Engineering Geology and the Environment, 84*, Article 509. https://doi.org/10.1007/s10064-025-04588-2.

96. Wang, F., Li, W., Yu, P., & He, C. (2024). Research on the static liquefaction failure of upstream tailings dams under continuous discharge conditions. *Computers and Geotechnics, 176*, Article 106785. https://doi.org/10.1016/j.compgeo.2024.106785

97. Wang, G., Zhao, B., Lan, R., Liu, D., Wu, B., Li, Y., Li, Q., Zhou, H., Liu, M., Liu, W., & Liu, X. (2022). Experimental study on failure model of tailing dam overtopping under heavy rainfall. *Lithosphere, 2022*(Special 10), Article 5922501. https://doi.org/10.2113/2022/5922501

98. Wang, K., Yang, P., Hudson-Edwards, K. A., Lü, W.-S., & Bu, L. (2018). Status and development for the prevention and management of tailings dam failure accidents. *Chinese Journal of Engineering, 40*(5), 526–539. https://doi.org/10.13374/j.issn2095-9389.2018.05.002

99. Williams, D. J. (2021). Lessons from tailings dam failures—Where to go from here? *Minerals, 11*(8), Article 853. https://doi.org/10.3390/min11080853

100. Wilson, G. W. (2021). The new expertise required for designing safe tailings storage facilities. *Soils and Rocks, 44*(3), Article e2021067521. https://doi.org/10.28927/SR.2021.067521

101. Wu, T., & Qin, J. (2018). Experimental study of a tailings impoundment dam failure due to overtopping. *Mine Water and the Environment, 37*(2), 272–280. https://doi.org/10.1007/s10230-018-0529-x

102. Xie, C., Chen, Z., Xiong, G., Yang, B., & Shen, J. (2023). Study on the evolutionary mechanisms driving deformation damage of dry tailing stack earth–rock dam under short-term extreme rainfall conditions. *Natural Hazards, 119*(3), 1913–1939. https://doi.org/10.1007/s11069-023-06190-9

103. Yao, C., Wu, L., Yang, J., Xiao, L., Liu, X., Jiang, Q., & Zhou, C. (2021). Influences of tailings particle size on overtopping tailings dam failures. *Mine Water and the Environment, 40*(1), 174–188. https://doi.org/10.1007/s10230-020-00725-3

104. Yin, G., Li, G., Wei, Z., Wan, L., Shui, G., & Jing, X. (2011). Stability analysis of a copper tailings dam via laboratory model tests: A Chinese case study. *Minerals Engineering, 24*(2), 122–130. https://doi.org/10.1016/j.mineng.2010.10.014

105. Yu, H., Zahidi, I., Fai, C. M., Liang, D., & Madsen, D. Ø. (2025). Tailings dam failures: A critical evaluation of current policies and practices. *Results in Engineering, 25*, Article 103973. https://doi.org/10.1016/j.rineng.2025.103973

106. Yuan, L., Chen, D., Li, S., Wang, G., Li, Y., Li, B., & Chen, M. (2024). Coupled analysis of risk factor for tailing pond dam failure accident based on N–K model and SNA. *Sustainability, 16*(19), Article 8686. https://doi.org/10.3390/su16198686

CC BY 4.0
Attribution 4.0 International
Deed

JIRRS
Journal International Review of Research Studies

Received: 22/07/2026 - **Accepted:** 21/08/2026
Vol: 1.09 - September (2026)
DOI: 10.66104/xtdeed56
Pages: 1-45

107. Zabolotnii, E., Morgenstern, N. R., & Wilson, G. W. (2022). Mechanism of failure of the Mount Polley Tailings Storage Facility. *Canadian Geotechnical Journal, 59*(8), 1503–1518. https://doi.org/10.1139/cgj-2021-0036

108. Zare, M., Nasategay, F., Gomez, J. A., Moayedi Far, A., & Sattarvand, J. (2024). A review of tailings dam safety monitoring guidelines and systems. *Minerals, 14*(6), Article 551. https://doi.org/10.3390/min14060551

109. Zhao, K., Deng, Z., Chen, S., Zhong, Q., Chao, Y., & Jiang, J. (2025). Effects of flow velocity and concentration on the overtopping failure mechanism of tailings dams. *Environmental Earth Sciences, 84*, Article 480. https://doi.org/10.1007/s12665-025-12483-y

110. Zhen, Z., Ma, X., & Ma, B. (2021). Exploration and research on the propagation law of seepage risk network in tailings storage facility. *Discrete Dynamics in Nature and Society, 2021*, Article 8704259. https://doi.org/10.1155/2021/8704259

111. Zhen, Z., Wu, X., Ma, B., Zhao, H., & Zhang, Y. (2022). Propagation network of tailings-dam failure risk and identification of key hazards. *Scientific Reports, 12*, Article 5580. https://doi.org/10.1038/s41598-022-08282-1

112. Zheng, B., Wang, J., Feng, T., Wang, W., Zhou, Y., Cao, G., & Wang, Y. (2022). Risk evolution study of tailings dam failure disasters based on DEMATEL-MISM. *Frontiers in Earth Science, 10*, Article 906486. https://doi.org/10.3389/feart.2022.906486.

CC BY 4.0
Attribution 4.0 International
Deed