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Catastrophic tailings dam failures and disaster risk disclosure

J.R. Owen [a], D. Kemp [a,*], É. Lèbre [a], K. Svobodova [a], G. Pérez Murillo [b]

[a] Centre for Social Responsibility in Mining, Sustainable Minerals Institute, Sir James Foots Building (47a), The University of Queensland, St Lucia Campus, QLD, 4072, Australia

[b] Centre for Water in the Minerals Industry, Sustainable Minerals Institute, Sir James Foots Building (47a), The University of Queensland, St Lucia Campus, QLD, 4072, Australia

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ABSTRACT

The global mining industry produces billions of tonnes of mine tailings each year. This slurry of waste material is often contained in dams, which are among some of the world's largest engineered structures. Several recent and catastrophic tailings dam disasters bring the complex interaction between a mine and its local operating context into plain sight. The absence of public, timely, multi-scalar information about the multiple dimensions of this interaction is a normalised feature in the management of tailings dams. This article highlights the importance of establishing and sharing diverse knowledge about tailings dam disaster risk. We argue that the assessment and disclosure of "situated" disaster risk ought to be prioritised; that is, the combined risk of a hazard bearing structure situated within a local context with inherent vulnerabilities. We present a method for examining situated disaster risk of tailings dams by utilising Environmental, Social and Governance (ESG) indicators to screen for risk across eight categories: waste, water, biodiversity, land uses, indigenous peoples' lands, social vulnerability, political fragility, and approval and permitting. Applied to a global sample of operating mines, the method shows disaster risk potential of existing tailings dams globally. Future application could be used to generate a more complete inventory that includes both established and newly constructed facilities.

1. Introduction

Industrial installations can be both disruptive and disastrous. As with natural disasters, industrial disasters involve serious disruption to the functioning of a community or a society due to hazardous events interacting with conditions of exposure, vulnerability and capacity leading to human, material, economic and/or environmental losses and impacts [57]. Iconic industrial disasters such as Union Carbide in Bhopal, India, in 1984; the failure of the Chernobyl nuclear reactor in the Ukraine in 1986; the Exxon Valdez oil spill in Prince William Sound, Alaska, in 1989; and the Fukushima Daiichi nuclear accident in 2011 wrought disaster in communities and local environments [38]. These disasters each involved a complex set of interactions between the installation and the host context. Recent, high profile and catastrophic tailings dam disasters likewise brings the complex interactions between mining and its local context into view.

Most large-scale mines produce significantly more waste than economic minerals. Tailings are a by-product of separating valuable minerals from uneconomic material, and comprise ground-up rock, process water, and chemical reagents [27]. The global mining industry produces billions of tonnes of tailings each year, with an estimated 14 billion tonnes produced in 2010 [1]. This waste material is contained in tailings dams and other storage facilities.[1] These facilities are among some of the world's largest engineered structures, and a source of disaster risk for nearby localities [23,34,48]. In mining, geotechnical engineers and other related specialists have practical carriage of risk reduction strategies using an approach that is primarily focused on the facility as a potential source of hazard exposure.

There are many examples where the consequences of tailings dam failures have been dire. The catastrophic collapse in January 2019 of the tailings dam at the Córrego do Feijão iron ore mine in the town of Brumadinho in the Brazilian state of Minas Gerais is one of the most recent. By April 2019, more than 230 people had been confirmed dead and large sections of agricultural land totally destroyed [41]. Only four years earlier, the failure of the Bento Rodrigues tailings dam at the Samarco mine, in the same state, and with the same mine owner,

* Corresponding author.
E-mail address: d.kemp@smi.uq.edu.au (D. Kemp).

[1] A tailings storage facility is a broader term that includes means other than a dam for storing tailings. These other means can include deposition in completed open pits, natural depressions or a dry stack method. More controversial approaches include riverine and deep sea disposal.

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wreaked havoc on surrounding communities and ecosystems [49]. Following tailings dam failures in Brazil and elsewhere, including the aluminium sludge spill at the Ajka mine in Hungary in 2010, Philex Padcal in the Philippines in 2012, the Mount Polley mine in Canada in 2014, and the Cadia mine in Australia in 2018, there is a renewed sense of urgency from industry, civil society, and the investor community to understand the types of risks posed by tailings facilities and their potential for failure.

Disaster studies scholar, Oliver-Smith [50], has observed that "the increasing frequency and severity of natural and technological disasters particularly, but not exclusively, in the developing world place them in the center of debates on human-environment relations and issues". The contextual risks associated with specific interactions between society, technology, and the environment are fundamental to understanding the occurrence of industrial disasters. Local context vulnerabilities have a direct bearing on the likelihood, intensity and extent of disaster impacts. According to Alexander [2], there is a strand of research arguing that "vulnerability is a more important cause of disaster than is hazard" seeing the hazard as "a mere trigger, bringing vulnerability to the fore as a self-reinforcing condition fed by positive feedback loops". The mining industry's approach to disaster risk reduction (DRR) focuses on a narrow set of external vulnerability factors in understanding the cause of dam disasters. For our purposes, debates over whether contextual vulnerability or project hazards should take priority in DRR only serve to reinforce the importance of "situating" risks, so as to hold the interaction between hazard bearing activities and contextual factors clearly in frame.

Global frameworks appear to recognise the importance of generating broad-based knowledge for DRR, and through that, an understanding of situated risk. Instruments such as the Sendai Framework for Disaster Risk Reduction 2015–2030 have for the first time recognised the role for the private sector in DRR [58]. For example, recent guidance to support the implementation of the Sendai Framework includes a focus on tailings facilities and their disaster risk potential [59]. However, the application of guidance to support these aspirational goals centres on the risk characteristics of the "facility", rather than bringing into frame the conditions of local context vulnerability within which these facilities are being operated, and will be built into the future.

The absence of public, timely, multi-scalar information about the interaction between social, political, environmental and technological factors is a normalised feature in the management of disaster risks in the mining industry. Low-levels of effort in discerning and disclosing disaster risk provide companies with a source of proprietary advantage over host populations in the development and operation of hazardous facilities, such as tailings dams. This proprietary advantage is exercised when companies avoid generating, or even withhold, information about the likelihood and consequence of tailings dam failures. The disclosure of this information could assist local people in their decisions about how, or whether, to live within a potential disaster footprint of a tailings dam. Disclosure could also assist the state in determining project approvals, applying conditions, and regulating the facility itself.

This article highlights the central importance of examining and sharing diverse knowledge about tailings dam disaster risk. The article is organised into five (5) sections. The following section presents a brief overview of global mining tailings disasters and the response by international organisations, including the industry itself, to those disasters. One notable observation is the industry's focus on the integrity of tailings dam structures and the management systems in place during operation. Little effort has been expended on demonstrating the significance of local context vulnerabilities and their influence on what we are referring to as "situated" disaster risk or the interface between local context vulnerability and operational hazards.

In section three, we present a method for examining situated disaster risk for the catastrophic failure of mine tailings dams. Based on the work of Valenta et al. [60] and Lebre et al. [29], the method utilises Environmental, Social and Governance (ESG) indicators to screen for risk across eight categories including: waste, water, biodiversity, land uses, indigenous peoples, social vulnerability, political fragility, and approval and permitting. These represent known local 'external' factors that can affect the overall design and operational safety of mine tailings dams, and the receiving context in the event of a disaster. We approach these factors as having both causal and consequential potential in mine tailings disasters. This differs from the dominant industry approach, which ties causality to the facility and only a limited number of factors in the host environment, such as extreme weather and seismic events. Applied to a global sample of operating mines, the method shows disaster risk potential of existing tailings facilities. It also highlights critical information gaps in two key areas: operator performance in managing facilities, and the proximity of downstream communities to catastrophic disaster risk. In the absence of corporate disclosure of this information, we use spatial "checks" to determine proximity and elevation as a means of identifying situations where the potential for disaster risk appears to be severe.

In section four, we present our discussion. Following several catastrophic tailings dam failures, the industry's approach to the design and operation of hazard bearing facilities has come into question. We argue that in responding to these questions, the assessment and disclosure of the situated disaster risk ought to be prioritised; that is, the combined risk of a hazard bearing structure situated within a local context with inherent vulnerabilities. Section five offers concluding remarks on the role of disclosure in DRR and its relevance for current debates about the catastrophic potential of global tailings dams.

2. Tailings dam failures and the problem of proprietary advantage

In the past 50 years, 63 major tailings dam failures have been reported worldwide [32], with an upward trend in high-consequence failure events since 1990 [9]. According to Vogel [63], the failure rate after 2000 has increased to a frequency of five to six significant tailings dam failures annually. Each failure event causes extensive damage to the local environment and in catastrophic cases has resulted in the loss of human life. The WISE Uranium project [65] estimated that between 1961 and 2019 at least 2375 people lost their lives from tailings dam disasters globally. In the context of increasing global demand for metals, declining ore grades, and associated increases in mine waste, high volume-high risk mine tailings dams will continue to be built into the future [39]. Unlike water supply reservoirs, mine tailings dams are typically constructed in sequential "lifts" over time. This mode of construction contributes to the incremental expansion of project footprints, and the higher failure rate of tailings facilities [11].

Research that examines tailings dam failure is primarily focused on the integrity of the engineered structure, and the properties of impounded materials. While an official global register of tailings dams does not exist, multiple databases capture disclosed information about tailings disasters, including location, causes of failure, volumes discharged and social and environmental consequences. Studies use these databases [4,47,55] or a selection of case studies [22, 54, 62, 64] to analyse possible causes and preventive actions. Findings suggest that a range of concurrent factors are causal to most failure events, including: uncontrollable external factors (unusual weather, seismic events); technical factors (slope instability, foundation subsidence, static liquefaction of the tailings); and management or other human factors. The focus of these studies is largely the failure mechanism, and decisions relating to the design, construction and operation of facilities themselves [4,6,10,12,22,47,54,55,62,64].

Catastrophic failures at Samarco and Brumadinho have thrust industrial scale mine tailings disasters onto the global stage in unprecedented ways. Graphic images and live footage of death and destruction provided unrestricted public access to these disasters as they unfolded. Headline news across many of the world's media outlets confirm public interest and concern about the nature, speed and scale of devastation.

The Samarco dam failure has been the subject of litigation and settlements involving the operator and parent companies, while for Brumadinho, a settlement is yet to be agreed [46]. Criminal and civil proceedings are underway in both cases [42].[2] The rise in scrutiny following Samarco and Brumadinho is preceded by decades of research, civil society campaigns, and sustained calls for greater transparency into the inherent risks and liabilities of tailings storage facilities globally.

In 1999, a group of the world's largest mining and metals companies initiated the Global Mining Initiative (GMI) in response to a groundswell of public distrust of the mining industry. Led by the World Business Council on Sustainable Development (WBCSD), the initiative commissioned a global inquiry into the industry's reputational crisis. This study, known as the Mining Minerals and Sustainable Development (MMSD) project, produced 175 research papers and reports on agreed priority issues [26]. MMSD Working Paper No. 20 [35], *Stewardship of Tailings Facilities,* positions tailings management as one of the industry's "most significant" challenges.

MMSD Paper No. 20 focused on describing the development and implementation of the responsible stewardship of mine tailings facilities in the areas of management, tailings handling and treatment technologies, and mineral processing technologies and alternatives. While the authors encourage learning from failure, performance standards and public scrutiny, they suggest that the vast majority of operators "deserve praise for their efforts" and advise the public to "avoid supporting non-government organisations that endorse action against corporations who are committed to good practice" [35, p.33]. A public disclosure agenda did not feature in the recommendations. Twenty years later, Vale and BHP, two of the world's largest mining companies, with bold public commitments to sustainable development and responsible tailings management, destroyed hundreds of lives and the livelihoods of thousands of people in two of the worst environmental disasters in Brazil's history.

It was not until after the Samarco disaster that the world's largest mining companies began responding to the issue of tailings dam disasters on a collective basis. In early 2016, the International Council of Mining and Metals (ICMM) led a review of tailings standards, guidelines and risk controls among its member companies. The review report concludes that while high quality guidance about the management and physical stability of tailings dams is widely available, poor implementation is the overarching concern. In December 2016, the ICMM released a binding Position Statement on *Preventing Catastrophic Failure of Tailings Storage Facilities* [24]. The statement commits members to "continuous improvement in design, construction and operations of tailings dams within a robust governance framework". Social considerations were not an explicit focus of the review, nor the ICMM's position statement [45]. No requirement to publicly disclose information about tailings risks was made at this time.

Demands for corporate disclosure about tailings facility risk peaked after Brumadinho. In April 2019, a group of institutional investors, governed through a steering committee chaired by the Church of England Pension Board and the Swedish Council of Ethics of the AP Funds, established the Investor Mining and Tailings Safety Initiative [53]. The initiative called for an international standard. In response, and in collaboration with the United Nations Environment Program (UNEP) and the Principles for Responsible Investment (PRI), the ICMM subsequently commissioned a second tailings review, this time led by an independent chair with an expert panel and a multi-stakeholder advisory panel [25]. The Chair is charged with establishing an international standard that includes a consequence-based classification scheme, a system for independent assurance, and requirements for emergency response.

The institutional investor initiative, on behalf of 96 institutional investors representing $10.3 trillion in assets under management, also issued an open letter to 658 mining companies requesting public disclosure on 20 specific questions about tailings dams. Questions included confirmation as to whether, and if so when, a formal analysis of downstream impacts of catastrophic failure on local communities, ecosystems and critical infrastructure had been conducted. There was no requirement for the disaster analysis to be disclosed, although the letter urged companies to "communicate with communities that may be affected by tailings footprints". On the basis of this information, the investor group, which subsequently attracted more signatories, representing $12 trillion in assets under management, has stated its intent to develop a register of companies that publicly disclose, along with their responses. In the intervening period, some companies have pre-emptively increased public disclosures about their stock of tailings dams.

3. Examining situated disaster risk for mine tailings dams

This section provides an overview of the methodological approach used to determine "situated" disaster risk across a global sample of mine tailings dams. Our approach provides a way of identifying high-risk facilities with respect to the vulnerability of their external context. A series of eight steps were followed, which are elaborated and visualised in Fig. 1. The eight steps are grouped according to sample selection, ESG risk screening and local conditions. In the sample selection process, candidates with sufficient disclosed data to assume the presence of large, active and aging tailings dams are selected. A process of risk screening then provides a multi-factor characterisation of the local context vulnerability of the sample. The final step is a visual validation of the potential for disaster based on specific spatial parameters.

3.1. Sample selection and ESG risk screening

This section details the sample selection and the risk screening processes to test a methodology for situating disaster risk for mine tailings dams globally. Step 1 extracts an initial global sample of projects from the S&P Global Market Intelligence database (2019) [52]; a commercial database with a comprehensive repository of metals and mining properties. This first step selects records for gold, copper, iron and bauxite. These commodities are largest in terms of tonnage (iron, bauxite and copper) and number of mines (gold) that produce tailings. As of March 2019, the S&P database contained 22,971 records based on these four commodities. This includes 17,921 records of gold mining properties, 9195 copper records, 2635 iron ore records, and 249 bauxite records.[3]

In step 2, we excluded projects reported as inactive or not in the operational phase of mine life. This ensured that the sample includes a set of operating projects, where the ownership and management of the mine can be determined. Using these parameters, a sample of 1927 projects for bauxite, iron, gold and copper was generated.

Step 3 limits the sample to mining projects with a start-up date prior to 1999. In doing so, we sought to focus on mines that pre-date the GMI and MMSD study process described in Section 2 above. This places the emphasis on facilities that precede the industry's focus on sustainable development. This step returned 532 records. Many of the parameters applied in this step can be adjusted, for example, the date criteria could be reset to identify projects with tailings facilities built after 1999, or any other time period that different parties are interested in examining.

[2] Parent companies Vale and BHP Billiton reached a settlement for a multi-billion dollar lawsuit over the Samarco dam failure [43]. The operator Samarco announced a multi-billion dollar deal to restore the damaged environment and indemnify affected communities [8]. For the Brumadinho case, a ruling by state court judge Elton Pupo Nogueira in July 2019 makes Vale financially liable for the disaster, while $2.89 billion in the company's assets remain frozen [44].

[3] Due to some metals being mined together (i.e. companion metals) there is an overlap in the records.

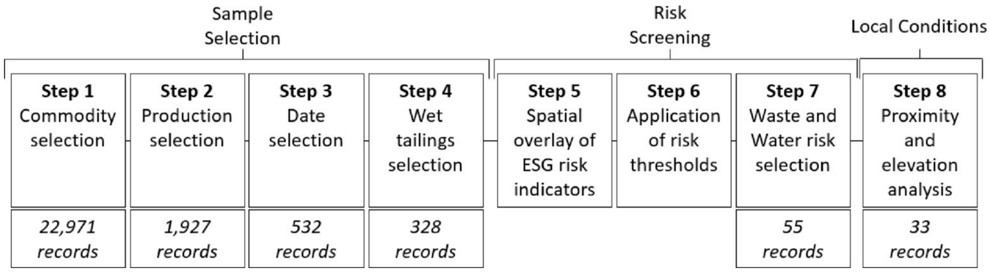

Fig. 1. Sample selection, risk screening and local conditions.

The fourth step involved reviewing the mineral processing methods used at each mine site, including only those records that described processing methods that generate wet tailings, namely flotation, carbon in leach, carbon in pulp and cyanide leaching. The presence of high water content in tailings and the resulting water action (erosion, seepage, overtopping) is a primary factor of tailings dam failure [19]. Because the existence of a tailings facility is not reported in the S&P database, this step uses processing methods as a proxy for the presence of wet tailings facilities.[4] From this sample selection process, Steps 1 to 4 were used to generate a "working sample" of 328 mining projects in four major commodity groups, built prior to 1999 and with wet tailings. Fig. 2 shows their spatial distribution.

The sample of 328 projects was then examined through the ESG risk screening process. This process applies a set of eight ESG risk indicators, including two primary indicators – 'Waste' and 'Water' – that are critical to tailings containment and stability, and six secondary indicators (see Fig. 3). Each indicator relies on one or two publicly available global datasets. For each dataset, a high-risk threshold was defined (see Table 1). The ESG risk context for each project was determined by overlaying the coordinates of the sampled mining projects with the risk indicators (step 5) and assessing which risks exceed the defined threshold (step 6). Using these risk screening steps, we are able to identify mining projects located in "high" ESG risk contexts, meaning they face multiple risks that exceed the threshold.

Primary risk indicators. The 'Waste' and 'Water' environmental indicators cover external natural factors that have influence on major tailings dam failures as well as containment issues that result in chronic pollution. The 'Waste' indicator includes two spatial variables. The first variable, terrain ruggedness, contributes to slope instability, erosion and challenging structural and foundation conditions, which are some of the main identified sources of past tailings dam failures [28,55]. High terrain ruggedness signifies topographic variations and heterogeneity of landslide formations that make tailings dam design more challenging. The second spatial variable in the 'Waste' indicator is the seismic risk, as earthquakes constitute one of the most common external causes of tailings dam failures [28,61].

As mentioned above, water is intrinsically linked to tailings risk [19]. Tailings deposition methods usually involve large volumes of water [19]. Causes for past tailings dam failures have been attributed to water-related events, e.g. unusual rainfall [47]. Seasonal variability, drought and flood occurrence have a strong influence on waste containment and voids stability [55, 65]. The 'Water' indicator comprises these aspects.

Secondary risk indicators. The other indicators included constitute the ESG risk context and either create conditions for sub-optimal tailings management practices, or worsening the social and environmental consequences of a potential tailings dam failure. The 'Biodiversity', 'Land Uses', 'Indigenous Peoples', 'Social Vulnerability', 'Political Fragility' and 'Approval and Permitting' indicators each reflect the fragility of the host environment. The consequences of a potential tailings dam accident may be exacerbated by a high ESG risk context where several of the above indicators are above the high-risk threshold [37]. These risk factors rarely feature in research examining tailings risk.

Environmental and social risk indicators: 'Biodiversity' detects proximity to vulnerable locations in terms of global biodiversity and ecological stability and can serve as a proxy for environmental fragility. The 'Land Uses' indicator represents the concentration of agricultural land and population density around the mining projects. Understanding land disturbance and competing land uses is critical to evaluating the social impacts of mine waste facilities [45]. The 'Indigenous Peoples' indicator evaluates the proximity of mining operations to terrestrial lands managed or owned by indigenous peoples. Indigenous peoples often experience higher levels of poverty, marginalisation, dispossession and discrimination than other peoples [18]. In a mining context, indigenous peoples are particularly at risk due to disruption to their land and culture [20]. The 'Social Vulnerability' indicator includes multiple, national indicators such as demographic pressures, poverty and other inequalities [36]. This indicator expresses the fact that vulnerable societies are less likely to cope with the consequences of a tailings dam failure and that amongst all other factors, the poor are consistently more vulnerable at all stages of the disaster lifecycle [16,17].

Governance risk indicators: The two Governance indicators, 'Political Fragility' and 'Approval and Permitting', reflect the political and regulatory environment within which tailings dams accidents would take place. 'Political Fragility' includes considerations of the political and institutional context of resource governance. Previous research indicates that tailings dam failures correlate to substandard mineral resource governance [47].'Approval and Permitting' relates to the regulatory environment that surrounds large-scale mining developments and operations. The important role of national regulation and legislation in forbidding unsafe tailing deposition methods has been highlighted in case studies [5,64].

Step 7 selects projects that exceed the high-risk threshold on multiple ESG indicators, including the two primary risk indicators. This ESG risk screening resulted in a sub-set of 55 projects (17% of 328) in high risk contexts, with both the 'Waste' and 'Water' risk indicators exceeding the high-risk threshold. These 55 mining projects also recorded high levels of risk amongst the secondary risk indicators. Only one mine in the sub-set returned 'Waste' and 'Water' as high primary risks with no significant secondary risks present. Fifteen (15) mines in the sub-set of 55 exceeded the high-risk threshold for all eight risk indicators. This sub-set presents a broad range of complexities that may influence mining operations, and tailings dam management in particular (see Fig. 4).

3.2. *Testing local conditions for disaster potential*

In the final step 8, further analysis was conducted on the sub-set of 55 projects to assess the local conditions for disaster potential. A spatial analysis established the distance between the mines with high risk scores and surface water streams, as these offer preferential corridors in the case of a tailings spill. The analysis was performed using the near

[4] At the time of writing, the corporate disclosures in response to the investor initiative were not aggregated or systematised to enable engagement by the research community.

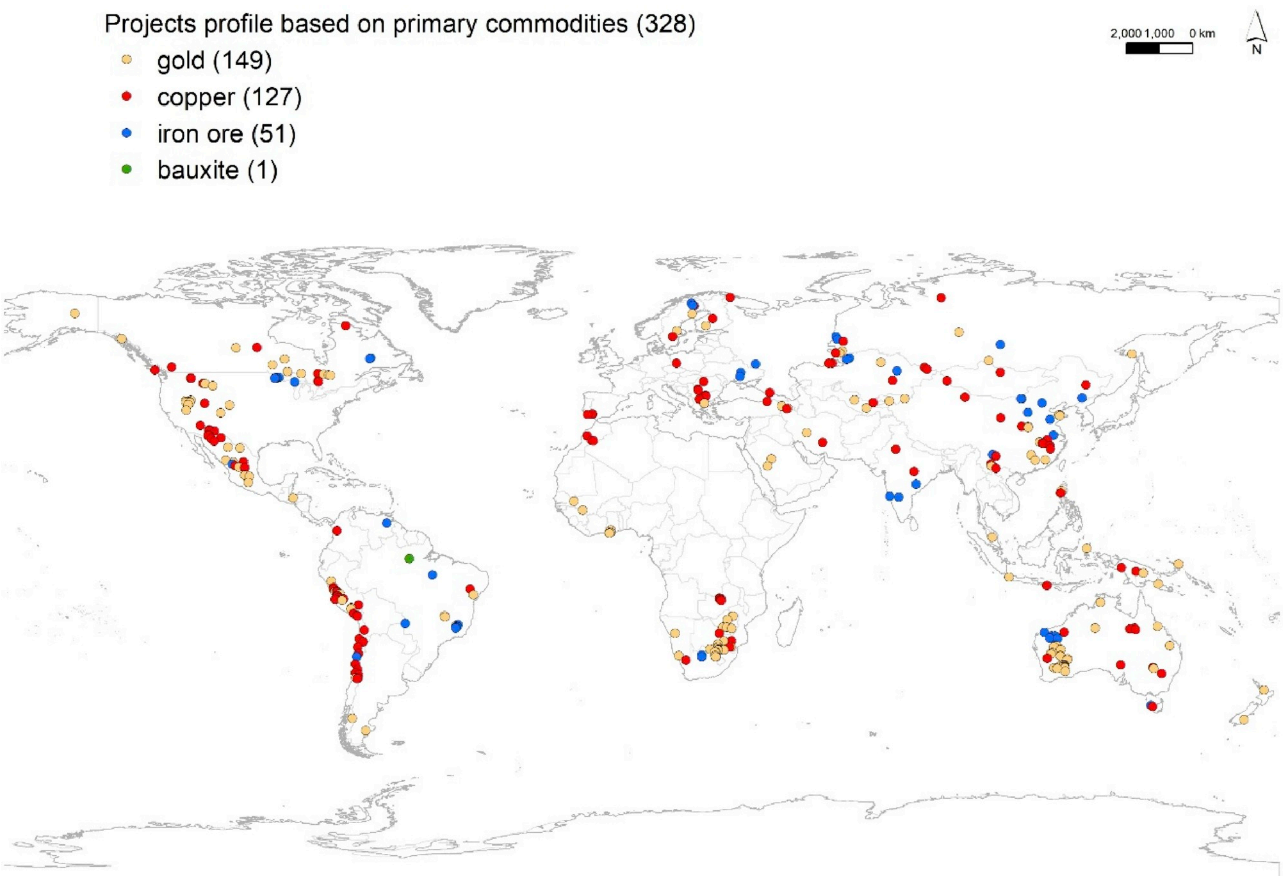

Fig. 2. The sample of 328 mining projects.

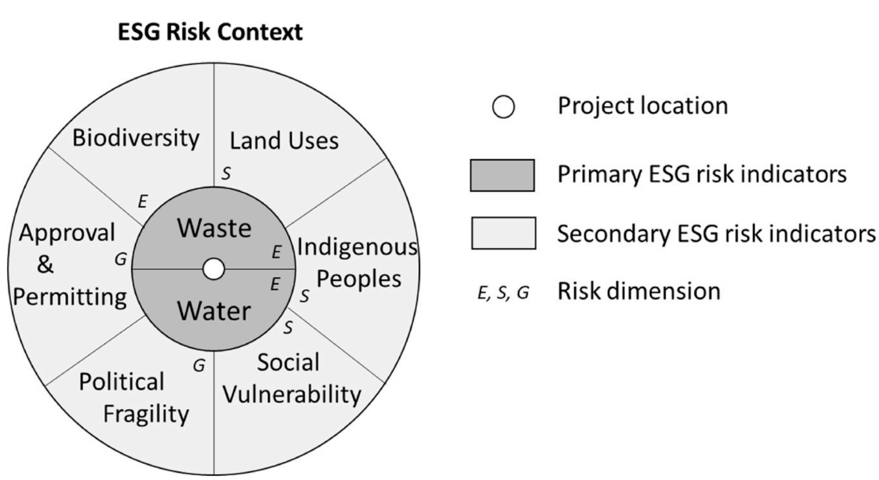

Fig. 3. The ESG risk screening framework.

proximity tool in ArcGIS, based on the HydroSHEDS dataset [31]. The results showed that all 55 mines have a water stream within a 5 km (km) radius.

To attempt to verify the proximity of tailings facilities relative to human settlements, a visual analysis of the satellite images was undertaken using ArcGIS. This resulted in the exclusion of nine projects due to either a tailings facility being indiscernible or no human settlement being located nearby. For the remaining 46 mining projects, further analysis was conducted to determine whether nearby human settlements were located downstream or upstream from the tailings dam. Using the path elevation profile tool in Google Earth Pro, the slope, elevation and direction were measured, based on multiple run-out path options.

A distance of 10 km between the tailings dam and the nearest downstream settlement was used to determine cases where a human population may be in immediate danger following a catastrophic tailings dam failure. Values of average flow velocity indicate a range between 1 km/h and 40 km/h [7,13,33]. A tailings flow speed of 5 km per hour was used as a conservative measure. These parameters imply that government agencies and company personnel have no greater than 2 h to complete a full evacuation to avoid fatalities in inundated communities.

For the 33 mining projects with communities located nearby and downstream from a tailings dam, the average distance between tailings

Table 1
ESG risk indicators and associated indicators of risk.

Risk dimension	ESG risk indicator	Indicators of risk	High-risk threshold
E	Waste	Global Seismic Hazard Map [51]	Peak ground acceleration above 3.2 m/s^2
		Terrain Ruggedness Index [3]	Terrain Ruggedness above 45
E	Water	Aqueduct Water Risk, World Resources Institute [21]	Overall water risk above 0.4
E	Biodiversity	Key Biodiversity Areas [5]	Mining project location within 20 km of a KBA
		World Database on Protected Areas [56]	Mining project location within 20 km of a protected area
S	Land Uses	Human Footprint [61]	Cropland, pasture land or population density indicator above 4.
S	Indigenous Peoples	Indigenous Peoples Land [20]	Mining project location within 20 km of IPL
S	Social Vulnerability	Fragile State Index, social indicators, the Fund for Peace [36]	Country score above 0.5 for social indicators
G	Political Fragility	Fragile State Index, political indicators the Fund for Peace [36]	Country score above 0.5 for political indicators
		Resource Governance Index, Natural Resource Governance Institute [40]	Country score below 60
G	Approval & Permitting	Policy Perception Index, Fraser Institute [49]	Country/region score below 70
		Ease of Doing Business Index, World Bank [14]	Country rank below 76

dam facilities and closest nearby communities was 3.2 km (~40 min for full evacuation), with the shortest distance 0.6 km (~7 min for full evacuation). All identified tailings facilities were located within 5 km of a water stream (maximum = 4.6 km; mean = 2.0 km) (see Fig. 5).

Of these 33 mines, 21 of the parent companies are listed on a stock exchange, 10 are located in OECD countries and 7 are owned by ICMM members. With further research, additional profiling information of these mines and their associated corporate listings, memberships, and lenders could be established.

4. Discussion: disclosure and industrial risk taking

Our method emphasises accepted factors that indicate vulnerabilities in the local context for tailings dam disasters. In the context of the corporate disclosure vacuum, the use of "proximity" and "elevation" as markers of risk was applied with caution understanding that the flow rate of tailings materials can far exceed the figure used in our estimates. These results show the prevalence of factors that indicate situated disaster risk, taking account of the local context and the potential severity of consequence stemming from a potential catastrophic tailings failure. To examine these factors requires extensive knowledge of the local context vulnerability, with similar knowledge and access to information about the design and management of the tailings facility by individual companies. Our method highlights the potential for severe disaster risk, and the need for a more comprehensive approach to disaster risk disclosure.

Conceptualising situated disaster risk is a difficult exercise because of the relationship between facility-based factors and local context vulnerability. In principle, disclosures should ease the difficulty associated with discerning disaster risk levels by making comprehensive information available and subject to public scrutiny. At the same time, disclosure is often thought of as a type of levelling mechanism that lessens the effect of corporate advantage and reduces the extent to which companies are able to silently risk-take on behalf of an unknowing public [45]. These levelling mechanisms lie at the heart of the transformative systems change required for effective DRR.

However, the risk profile of mining projects are dynamic, meaning that even the most extensive front-end disclosure will be inadequate in future years. In this industry, risk disclosure at the design stage of a mining project is a complex proposition. Unlike other industrial installations, mining footprints have the distinct tendency of expanding over time. There are multiple drivers: the influence of near mine exploration, the link between commodity prices and production rates, and the exponential accumulation of waste over the life of mine [30]. These changes can increase exposure to industrial hazards for people nearby. This exposure can materialise either through direct impacts to land and water resources that erode quality of life, or by decreasing the physical demarcation that separates projects from communities. The commercial risk exposure for operators, by contrast, can diminish once the mine is productive, and clear once the initial investment has been recovered. Mine plans are designed to expedite the period of return on investment in order to minimise the commercial risk exposure for company shareholders. This dynamic necessarily affects the financial incentives for operators in identifying and managing multi-dimensional and multi-scalar risk dynamics over time.

This reflects an observation made by Downing [15] on the pattern of incremental growth in mining developments and their effect on surrounding communities. Downing argues that mines will often expand at a gradual rate while avoiding responsibility for direct or indirect build-up of social risk; that is, risk to off-site parties. His work suggests that mining companies intentionally drive social risks upwards to the point that displacement becomes a seemingly "responsible" course of action. By driving risks to the point where inaction is no longer acceptable to the community and the state, companies are able to justify resettlement to safeguard a local population from situated risk; including, in some instances, invoking state responsibility for land use planning, re-zoning and population control. In cases involving tailings disasters, a similar pattern can be discerned [9]; that is, companies drive up the risk profile of projects to the point where displacement becomes a seemingly logical safeguard for local populations, or a disastrous "unplanned" outcome.

The structural patterns surrounding tailings dam disasters, and the extent of liability left in their wake, raises important questions about the foundations of the most basic forms of corporate responsibility. For instance, on what premise are companies entitled to create and carry these levels of risk "on behalf" of other parties? And, perhaps more importantly, what is the justification for disaster risks not being analysed, conveyed, understood, and agreed to by those parties who will be exposed to these risks? How far beyond their own facilities should companies venture in order to understand the situated risk of their activities? To what degree should companies consider the local operating context as potentially causal to tailings dam disasters? The extent to which companies are willing to generate a broader base of knowledge is pivotal, including the generation of knowledge that may weaken their propriety advantage.

To date, the mining industry has given little attention to defining what a community, facing disaster risk, has a 'right to know'. Industry policy largely focuses on planned development in the pre-approval phase of the mine lifecycle, and emergency response to disaster scenarios. In this literature, terms like "free prior informed consent" or (FPIC) are not prominent; either as a means for countering knowledge imbalances between corporations and communities, or as a safeguard against projects proceeding when local communities consider the disaster risk too great to support. The emphasis in discussions about consent largely relates to the conditions that developers must create in order to obtain consent to proceed with production, not the production of disaster risk. Disclosure about project components and the anticipated

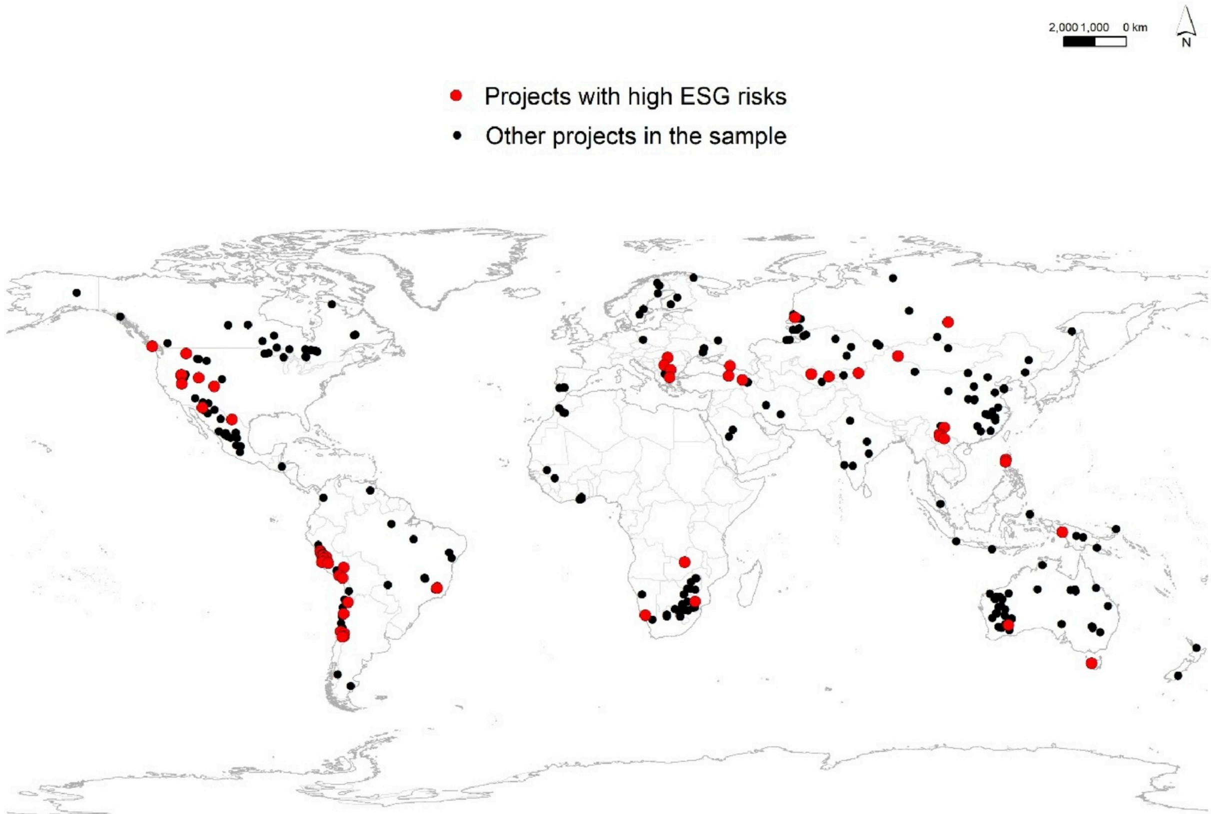

Fig. 4. Sub-set of 55 mining projects that are located in high ESG risk contexts.

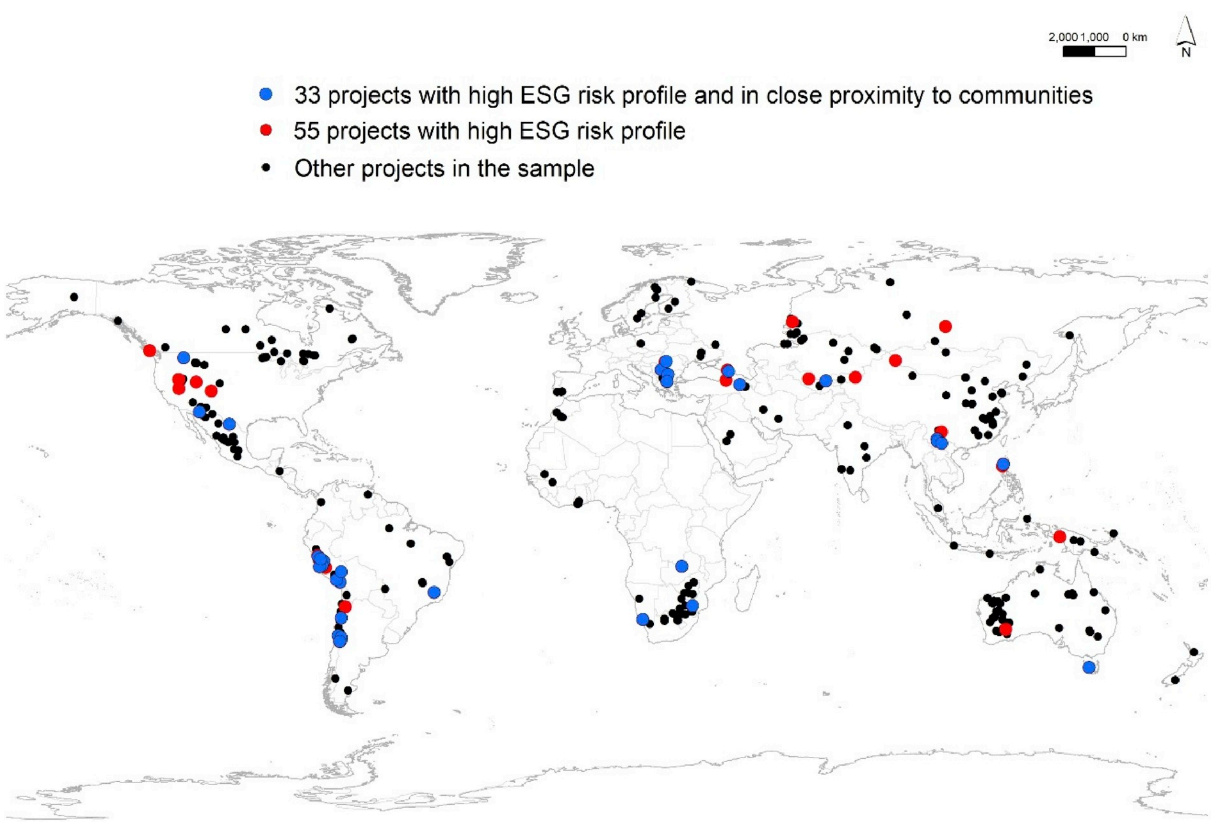

Fig. 5. A set of 33 projects where tailings facilities are located in 10 km downstream proximity to communities.

scope and severity of their effects should be a major component in ensuring that consent is given on an informed basis. Considering the dynamic nature of mining footprints, and the incremental construction of tailings dams, there is a need to re-think existing industry standards relating to risk disclosure and consent.

Likewise, the relationship between disclosure and proprietary advantage warrants further exploration. Companies have multiple points of advantage over local communities in disaster scenarios. The most obvious advantage being that developers, and developer representatives such as lenders and insurers, are usually free of the burden of having to reside in the aftermath themselves. Corporate liability invariably fails to cover either the temporary or permanent damage caused to natural resources and other community assets. Disaster response and recovery will typically align with the company's willingness to voluntarily carry long-term restoration costs. This issue of proprietary advantage guarantees that most communities living in near proximity to mine tailings dams cannot exercise informed judgement about cost and liability, or coordinate public accountability efforts in order to assess, minimise, or prevent, the types of industrial risk taking that occurs in the operation of these facilities.

Curtailing the assumed right of corporations to disclose at their convenience is one means through which to diminish the disaster risk potential associated with tailings dam facilities. Calls for a public register of all tailings facilities with details describing their design and operating specifications will make *some* information more readily available to *some* stakeholders. Investors, governments, academics and non-government agencies, with institutional access to online information repositories will be better informed should a register of coherent meaningful information materialise in future. What benefit, however, will this push for disclosure have for local communities already downstream and in close proximity to a high-risk facility in a vulnerable operating context? Unlike investors, insurers or academics who can easily mobilise their interests elsewhere, communities residing in these locations are typically not in a position to simply re-mobilise their assets, relationships, and entitlements somewhere else.

5. Conclusion

The seemingly upward trend in high-consequence tailings dam disasters has brought the issue of disaster risk disclosure into sharp relief. Demands from investor groups for disclosure on the risk status of mining tailings facilities highlights a rapidly growing interest in corporate and public accountability on potentially hazardous activities. A cursory review of the literature on mine tailings disasters reveals a heightened awareness about risk levels, with strong indications that the underlying drivers of risk will increase in future. Rising consumer demand, coupled with declining ore grades suggests that larger, high volume mine tailings dams based on the 'incremental build' model will be a factor in future global supply scenarios. Without radical changes to the technologies for managing mine waste, including mine tailings, these risks will accumulate well into the future.

Our analytical framework highlights the potential for broadening our understanding disaster risk of mine tailings dams, and the consequences for nearby communities. We applied preliminary ESG criteria to identify risks in the external context of a defined set of projects. Conservative parameters were used to select a sample of active projects in four commodities likely to produce wet tailings, constructed prior to 1999, against which ESG risks were assessed. Likewise, conservative criteria were used to examine local factors. These parameters served to significantly reduce the overall sample size and limit the number of projects with communities located inside a 2 hour emergency response timeframe. In future, these parameters could be relaxed to generate a more complete inventory of both established and recently constructed facilities.

A major constraint of the research is the absence of company-supplied information about facility location, type and internal risk controls. While our methodology provides a basis for understanding ESG risk conditions for mining tailings facilities at a global level, the datasets used cannot explain the effect that company-led controls have on reducing, managing or exacerbating these conditions.

Calls for corporate disclosure rightly focus on drawing industrial risk-taking practices into plain sight. We argue for a more holistic form of disaster risk disclosure that reinforces the importance of "situating" risks, so as to hold the interaction between hazard bearing activities and contextual factors clearly in frame. Corporate disclosures that focus solely on facility risk will not provide the type of broad-based knowledge generation and information disclosure required to make informed decisions about disaster risk and risk reduction. Until such disclosures are normalised, there can be no basis for non-corporate actors determining actual levels of disaster risk and appropriate response strategies. For communities residing in the immediate vicinity of these projects, the 'right to know' should be interpreted as an extension of a more extensive bundle of rights covering the protection of livelihoods, property, and freedom from harm.

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