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Original article

Public databases of tailings storage facilities fall short of full risk disclosure

Rafaela Shinobe Massignan *, Luis Enrique Sánchez

Department of Mining and Petroleum Engineering, University of São Paulo, Av. Prof. Mello Moraes, 2373, Butantã. Zip code 05508-030, São Paulo, SP, Brazil

A R T I C L E I N F O

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A B S T R A C T

Major disasters involving tailings storage facilities (TSFs) in Canada (2014) and Brazil (2015 and 2019) shed light on the absence of disclosure of risk information of such structures. Subsequently, the conveners of the Global Tailings Review developed the Global Industry Standard for Tailings Management, that encouraged ample dissemination of information, and launched the first international database of TSFs, the Global Tailings Portal (GTP). To investigate the current state of TSF's public databases, a search was made in 36 mining countries, finding ten open-access inventories. Those databases, the GTP and an inventory cited in the literature were analyzed in terms of 22 categories of information organized in four groups: scope, format, frequency of update, and content. Five databases were launched after the Brumadinho failure, indicating that recent major TSF disasters enhanced the perception of their risks. However, inventories are incomplete, as not all types of facilities and operational status are included. Only four databases inform about hazard-prone areas, although they all disclose information related to TSFs' stability. The database of the National Mining Agency of Brazil, SIGBM, displays the highest score, featuring 16 categories of information. We highlight the importance of public databases and show that most fall short of comprehensively presenting relevant, accurate, timely, and understandable information for a range of stakeholders. We also call on governments, industry associations, and others to develop and continuously improve the disclosure of TSF risk information.

1. Introduction

After the catastrophic failure of a tailings dam in Brumadinho, Brazil, in 2019, mining companies have been called to disclose information about their tailings storage facilities (TSFs) whose risks became an important topic in their agenda (Sánchez and Franks, 2022). This disaster followed the failures in Mount Polley, Canada, in 2014, and Mariana, also in Brazil, in 2015, boosting a "credibility crisis" for the mining industry (Hopkins and Kemp, 2021). Those major disasters shed light on the anodyne TSFs risk communication, as insufficient information is disclosed (Owen et al., 2020; Sarker et al. 2022).

Early warning systems can prevent hazards from becoming disasters (Lumbroso et al., 2021), although risk communication is usually neglected (Fakhruddin et al., 2020). People in hazard-prone areas have the right to know to which risks they are subjected (Tzioutzios et al., 2022; Baker et al, 2020). Yet, TSF failures continue and the exposed communities are still impacted without proper risk information. Since the Brumadinho disaster, and up to November 2023, 22 TSF failures have been reported in Angola, Bolivia, Brazil, Canada, China, India, Mexico, Myanmar, Peru, South Africa, Tanzania, and Turkey (WISE-Uranium Project, 2023).

There were no warning sirens in the hazard-prone area in both Mount Polley (Morgenstern et al., 2015) and Mariana (Phillips and Brasileiro, 2018). The failure of the Fundão tailings dam in Mariana resulted in 19 fatalities and spread 39.2 Mm^3 of iron ore tailings. Extensive damage was caused to ecosystems and livelihoods over 630 km of the Rio Doce and its adjoining coastal area (Sánchez et al., 2018). The lack of information was evidenced as a vulnerability of exposed communities, whose root cause is related to the manner of disclosure of critical information (Kemp, 2020). This vulnerability is also extended to the recovery process (Milanez et al., 2021).

Similarly, in Brumadinho, the sirens of the Córrego do Feijão mine were hit by the wave of tailings before they could be triggered (Jamasmie, 2019). The failure spilled 12 Mm^3 of tailings, caused 270 deaths, and, still, three are reported missing (Andrade and Mansur, 2022). A computational modeling study concluded that if the sirens had sounded as the dam failed, between 100 to 150 lives could have been saved (Lumbroso et al., 2021).

Not only the media and lawmakers were called the attention, but also investors (Innis and Kunz, 2020), already aware of other mine tailings

* Corresponding author.
E-mail address: rafa.s.m@usp.br (R.S. Massignan).

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disasters around the world (Azam and Li, 2010). In the aftermath of the Brumadinho disaster, international investors requested that publicly listed mining companies disclose information on their facilities. More than 100 companies responded, resulting in the first international public database of TSFs (Franks et al., 2021) - the Global Tailings Portal[1] (herein GTP).

Such initiatives of 'publicly accessible databases (…) about the safety and integrity of tailings facilities' are encouraged by the Global Industry Standard on Tailings Managements (GISTM), established by the Global Tailings Review (GTR, 2020)[2]. GTR was set up to shed light on corporate practices, finding that access to information on TSFs is very limited (Franks et al., 2021). GISTM contains 77 Requirements, demanding an unprecedented range of TSF information disclosure (Kemp et al., 2021). However, it lacks recommendations or guidance on the minimal content and updating frequency.

Here, we undertake a global survey of public databases of TSFs and shed light on their scope (type of facilities and operational status), format, frequency of updates, and content. We also identify strengths and shortcomings and make recommendations. Following this introduction, in Section 2, we expose the importance and difficulties of risk communication throughout risk disaster management. In Section 3, we categorize aspects that influence TSFs risk of failure. Section 4 explains the methodology applied in the search and analysis of TSFs public databases, while Section 5 exposes our main findings and discussion. In Section 6, we conclude by reflecting on the role of such databases in TSFs management transparency.

2. Community right-to-know and disaster risk communication

Providing information that assists in 'understanding the problem, alternatives, opportunities and/or solutions' is the first step in community engagement (IAP2, 2018). In fact, according to Principle 10 of the 1992 UN Conference on Environment and Development's Rio Declaration (UN, 1992; Sánchez and Croal, 2012), States should widely disclose environmental information held by public authorities, including those related to hazardous activities and materials. Moreover, the UN Human Rights Office of the High Commissioner (OHCHR) states that companies whose activities impose risks on human rights should report externally how they respond to these risks. Reporting should be in a form that is adequate to the intended audience. Its content and frequency must be sufficient to inform the adequacy of companies' measures to respond to the risks imposed on human rights (OHCHR, 2011).

Risk communication is an interactive process of exchanging risk information and opinions among individuals, groups, and institutions (Xue et al., 2022). Its content (Tzioutzios et al., 2022), format (Xiao et al., 2011), and frequency (Xue et al., 2022) must consider how the public responds to risk information (Nelkin, 1989), rather than only disclosing technical data. Understanding the societal perception of the risk, concerns, and values (Frewer, 2004) and considering cognitive and political dimensions (Berger-Sabbatel and Journé, 2018) are important to develop the disclosed content.

Risk communication is crucial for effective risk management (Xiao et al., 2011; Sartain et al., 2015) and it is used throughout the disaster risk management cycle: before (information for awareness and promotion), during (emergency response) and after the disaster (recovery and reconstruction) (Kondo et al., 2019). Information after the disaster aims to support disaster victims and disaster-stricken areas (Kondo et al., 2019). When a disaster strikes, early warnings containing easy and understandable information should be used to prevent and minimize impacts, for example, through evacuation orders (Kondo et al., 2019). However, without risk communication before a disaster, people would not be prepared for emergencies (Coppola, 2020). Providing information about the size of the risk and how to properly respond to it (Kondo et al., 2019) is an important part of emergency preparedness (Coppola, 2020).

Therefore, risk communication is a long process that should be planned as a dialogue and avoid confrontation (Sartain et al., 2015). Frequent interaction between stakeholders increase trust (Sartain et al., 2015), which is of paramount importance to reach a common understanding (Kondo et al., 2019). Furthermore, the use of appropriate terms and physical units may reduce inaccurate reporting and misconception (Sartain et al., 2015). The relevance of comprehensive, well-structured and up-to-date public databases for disclosure of TSF risk information will be discussed in the following sections.

3. Selection of information to be disclosed

TSFs are complex engineered facilities (MAC, 2021), whose risk of failure depend on multiple factors and correlations (Chen et al., 2022). These risks could lead to a disaster, i.e. 'serious disruption of the functioning of a community or a society at any scale', causing 'human, material, economic and environmental losses and impacts' (UNGA, 2016). A disaster is a consequence of the interaction of hazardous events, conditions of exposure, capacity, and vulnerability (UNGA, 2016). Therefore, public databases of TSFs should contain information, not only associated with hazards, but also with hazard-prone areas as both embody risk management (Kemp, 2020).

Burgherr et al. (2022) proposed a classification of facilities to guide investors using 13 indexes in three groups (environment, social, and governance). Valerius and Carvalho (2020) developed a TSF risk management index using a combination of parameters about characteristics of the facility, maintenance and monitoring information, engineering records, and exposure conditions, information potentially important for public disclosure.

Ferreira et al. (2020) built a dataset of Brazilian TSFs using satellite images and machine learning to identify tailings dams, their coordinates, ore classification, and risk category. However, they struggled with identifying constructive method and potential damage. Similarly, Sarker et al. (2022) interpreted satellite images to identify TSFs in Australia, obtaining their coordinates, operating status and ore classification. Nevertheless, their database was constrained by the limitations of visual interpretation.

We posit that the selection of desirable content of databases should be structured around the risk factors, i.e. causes and consequences of TSF failures, including preventive barriers. Chen et al. (2022) applied a bow-tie model to systemize these factors, which vary throughout the life cycle. Causes are classified in Table 1 regarding human, site condition, facility, and tailings characteristics. Some of these factors also influence inundation areas, e.g. TSF's volume and water content (Fourie, 2006; Martin et al, 2019). Moreover, immediate consequences (Table 1) are aggravated depending on tailings toxicity, exposure conditions (Kemp, 2020; Owen et al., 2020). and mitigation barriers, e. g. emergency preparedness (GTR, 2020; MAC, 2021).

4. Methods

4.1. Search of public databases of TSFs

In order to investigate existent public databases of TSFs, a search was conducted in countries known for producing mineral commodities, where tailings production is also high and, therefore, TSFs databases are more likely. The search was conducted in 36 countries (listed in

[1] https://tailing.grida.no/

[2] GTR was co-convened by the International Council on Mining and Metal (ICMM), the United Nations Environment Programme (UNEP) and the Principles for Responsible Investment (PRI).

Table 1
Key risk factors associated with TSF failure of interest for public disclosure.

Risk of failure	Classification	Risk factors
Causes	Human (resources and decisions)	Design criteria Vick (1990) Engineering records GTR (2020), MAC (2021) Operational procedure Vick (1990), Baker et al (2020) Monitoring and maintenance procedures GTR (2020), MAC (2021) Qualified employees GTR (2020), MAC (2021)
	Site condition	Geotechnical, hydrological and geological conditions, such as seismic activity, heavy rain and wind Vick (1990), Azam and Li (2010), Franks et al. (2021), foundation Baker et al. (2020)
	Facility	Construction method and materials Vick (1990), Franks et al. (2021) Water management Fourie (2006) Year of construction Operational status Franks et al. (2021) Dimensions Vick (1990), Franks (2021)
	Tailings	Geochemistry; grain size; water content Fourie (2006), Martin et al. (2019)
Consequences	Exposure conditions	People; infrastructure; social, economic, and ecological valorized areas and assets GTR (2020), MAC (2021).
	Emergency Preparedness	Emergency simulation, escape routes, evacuation centers, early warnings, and emergency plan disclosure GTR (2020), MAC (2021).

Source: classification adapted from Chen et al. (2022).

Supplementary Material A) included in the SNL Metals & Mining[3] database of S&P Global Market Intelligence (2023), which covers data from over 35,000 mines. In addition, due to the subnational competence in regulating mining and environmental matters, searches were also conducted for states or provinces of four federal countries listed in S&P: USA, Australia, Brazil, Canada and USA.

The searches were conducted in February 2023, using the search engine DuckDuckGo[4], which emphasizes the privacy of users' data. Consequently, the user's geographical location does not interfere with the results of the search. Moreover, it provides a tool, used in this research, to select the country of the search. When a country was not listed in the DuckDuckGo settings, the option 'all regions' was selected.

Therefore, the search process was composed by four steps for each country: search of the (I) name of the country in addition to the terms 'tailings dam' and 'data' in the respective national language; (II) mining and environmental government agencies or organizations; (III) national geological survey; and (IV) industry mining organizations or associations. For countries whose national idiom differs from Portuguese, English, and Spanish, Google Translate[5] was used to translate webpages. In addition, GTP and a Peruvian database - not found in the search, but cited by Emerman (2022) - were selected for analysis.

Inclusion criteria comprised open access databases of facilities of mining waste - tailings and rock waste. Information may be visualized online or through download. Data presentation was considered in table, individual files, or map format, as long as the map includes more information than only the location of TSFs. Exclusion criteria encompassed water dams repositories and databases developed by single mining companies. However, an inventory of an industry association was considered for analysis.

4.2. Analysis of the databases

In order to standardize and select information for analysis, we listed the complete data of 12 databases (last updates until November 2023), resulting in 207 categories. These were classified into four groups: Scope of the database, Format, Frequency of updates, and Content. Categories of analysis were defined considering the literature on risk communication and TSF risk of failure (sections 2 and 3). Justification for inclusion of each category is provided in Table 2. Information considered to be complementary to a category already selected was disregarded (Supplementary Material B). An example is the municipality where TSF is localized, because coordinates were selected. Moreover, for each group, exclusion criteria were considered, as follows.

The group "Scope" refers to which TSFs are included in the database, according to (i) type of structure and (ii) operational status. The latter refers to active, inactive, closed, and abandoned, while the first to tailings dams, in-pit disposal and dry stacks. Tailings classification in terms of water content (slurry, thickened, paste) was also considered.

The group "Format" is related to the manner of information disclosure, i.e. a table, map, or files, and whether it is online. Format influences people's risk perception and reaction (Xiao et al., 2011), readiness, and retrieval of information by any interested person. This group therefore assesses database retention of informational material about tailings and TSFs, including contact details for inquiries. However, database description, graphics production, access sketches, and photos were disregarded, as they were considered extra items.

The group "Frequency" of update describes how often information is updated. It regards the dynamism of TSFs' risks (Hopkins and Kemp, 2021; MAC, 2021) and the reliability of up-to-date information (Sartain et al., 2015, Xue et al., 2022). Therefore, this group restricts scope and content information.

The group "Content" describes disclosed information regarding: (i) identification, characteristics that influence (ii) the probability of failure, and (iii) its consequences. This group presents data about risk magnitude and how to properly respond to it (Kondo et al., 2019). In order to select information for analysis, database content was divided into 18 classes (Supplementary Material B): identification, location, classification, and risk factors listed in Table 1. The environmental impacts of TSFs (e.g. dust emission, water contamination) was also identified, but disregarded, since this research focused on failure risk. Likewise, disaster recovery information and data specific to local legislation were not considered. Engineering records and qualified employees (human causes of failure) were neglected, because the *existence* of a document, or employee, was considered less preferable than its disclosure. Regarding TSF's dimension, only volume was considered, because it represents the maximum quantity of tailings released in case of an outflow.

5. Findings and discussion

5.1. Ten databases identified

The search found ten public databases of TSFs in six countries: Brazil, Chile, Canada (British Columbia), Mexico, Portugal, and Spain. One Chilean database was cited by Araya et al. (2021), Campos-Medina et al. (2023) and Emerman (2022), who cited three other inventories also found by the present search. Table 3 lists these databases - in addition to the GTP and a Peruvian database -, their main information, and the abbreviations adopted here, while Supplementary Material C holds their full reference.

Many stakeholders were involved in the inventories establishment. Apart from GTP, all databases were created by an organization of a particular jurisdiction (country, state, or province). Eight of twelve databases were developed either by national or provincial/state governments, which legally require information from companies and hold privileged data, enhancing the development of databases. Nonetheless,

[3] https://www.marketplace.spglobal.com/en/datasets/snl-metals-mining-(19)
[4] https://duckduckgo.com/about
[5] https://chrome.google.com/webstore/detail/google-translate/aapbdbdomjkkjkaonfhkkikfgjllcleb?hl=pt

Table 2
Categories of information selected to analyze public databases of TSFs.

Group	Category	Justification	
Scope of the database	1	Multiple types of facilities	The probability of failure depends on the type of TSF Vick (1990), Azam and Li (2010), Franks et al. (2021). Structures other than dams are also hazardous. Examples: Tailings dams, in-pit storage, and dry stacks.
	2	Operational status	The operational status may influence the probability of failure Franks et al. (2021). Examples: Active, inactive, closed, and abandoned.
Format	3	Informational material about tailings and TSFs	The provision of easily accessible information enables people to make better use and may reduce inaccurate reporting and misconception Sartain et al. (2015). Examples: Glossaries, use of plain language, images, videos.
	4	Contact channel	A communication channel that enables answering questions and enhances dialogue between stakeholders, as risk communication should be double way Sartain et al. (2015).
	5	Data available in multiple supports	It is related to the manner of disclosure, such as a table with all TSFs of the database, individual files for each TSF, an interactive map with all TSFs of the database – i.e. maps where zoom is possible and in each TSF, information regarding a table of content is visualized.
	6	Data retrieval	Whether data is available online only or available for download, which enhances information analysis.
	7	Link to access external material	Exemplifies how databases can disclose materials external to the inventory, or at least their access way. This could be a model for disclosing emergency preparedness plans and inundation areas, as they should be widely disclosed Coppola (2020), GTR (2020), MAC (2021).
Frequency of update	8	Informed frequency of update	Up-to-date information is crucial to understand the risks imposed by TSFs. Risks change during the operation of a TSF Owen et al. (2020) Hopkins and Kemp (2021) MAC (2021).
	9	Informed last update available	
Content	10	Geographical coordinates	Location is essential information and empowers people outside the mining company to understand the risks to which they are exposed Franks et al. (2021).
	11	Company owner	Regards TSF's identification and enables the user to make contact with the company and to make complaints directly to the company.
	12	Name of the TSF and mine	Regards TSF's identification, as company owner alone may not be sufficient to identify a specific facility.
	13	Site condition	Inadequate foundation Baker et al. (2020), seismic activity, and heavy rain influence TSF's stability Vick (1990), Azam and Li (2010), Franks et al. (2021).
	14	Construction method	Influences risk stability (Vick, 1990; Franks et al., 2021). Examples: Upstream, centerline, downstream, and single-stage tailings dams.
	15	Water management	Poor water management is related to the main causes of failure Vick (1990), Fourie (2006) – overtopping, piping Baker et al. (2020), and liquefaction. Examples: drainage system, freeboard, supernatant water.
	16	Monitoring	Regards physical issues to control, which reveals TSF's maintenance and stability, and monitoring methods. Examples: erosion, seepage.
	17	Construction year	Reports of stability issues increase with the age of the facility Franks et al. (2021)
	18	Current TSF volume	Influences the volume released in a failure Piciullo et al. (2022). If the last update is not informed, the database did not punctuate this category.
	19	Ore classification or geochemical tailings information	Elucidates the consequences of a possible failure, as toxic substances will aggravate tailings contamination.
	20	Consequence classification	TSFs with high consequence classification impose severe probable consequences. Therefore, the decision-making of companies should be based-on consequence information alone, rather than risk information (which also includes the probability of failure) (Hopkins and Kemp, 2022).

(*continued on next page*)

Table 2 (*continued*)

Group	Category	Justification	
	21	Exposure in hazard-prone areas	Informs about 'situating' risks, - the interaction between hazard and vulnerability Owen et al. (2020) Examples: how many people, public infrastructures, or environmental hot spots are exposed.
	22	Disclosure of emergency procedures or delimitation of hazard-prone area in case of failure	Emergency procedures should reach exposed communities and local authorities in hazard-prone areas before an emergency Coppola (2020), GTR (2020), MAC (2021). Maps of inundation areas enable the identification of exposed communities, infrastructure, cultural resources and ecosystems. People in hazard-prone areas have the right to know the risks they are subjected to Tzioutzios et al. (2022), Baker et al. (2020).

investors also used their influence to request information, as evidenced by GTP. Likewise, the Chilean Mining Council (CM), an association of mining companies, developed an inventory to inform about the TSFs of its member companies (CM, 2023). Nevertheless, the non-profit network BC Mining Law Reform and SkeenaWild Conservation Trust were responsible for the BC Mine Tailings Map, as 'risk factors at TSFs in B.C. is hard to find' (BC Mining Law Reform and SkeenaWild Conservation Trust, 2023). The Peruvian NGO *CooperAcción* also developed a geoportal with mining residues information.

Consulted by email, the owners of CL-SERNAGEOMIN, CL-CM, and PT-DGEG did not inform us when their database was launched. Five databases were established after the disasters in British Columbia (2014) and Minas Gerais (2015 and 2019), as illustrated in Fig. 1. The development of GTP (2020), BR-ANM (2020), PE-CA (2020), MX-SENR (2021), and CA-BCMLR (2022) evidence that those disasters enhanced global perception of TSF's risks and the need to disclose risk information. It confirms that people's risk perception is raised after a recent disaster (Fourie, 2006; Owen et al., 2020).

The inventories PT-DGEG and ES-MITECO contain only closed or abandoned facilities, which is required for European Union (EU) members, according to the Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006[6]. However, a single inventory for the EU was not found, and in the other two EU country members selected for search - Ireland and Poland (Supplementary Material A) - no TSFs database were detected. In Ireland, a map with 'solid waste heaps' was found[7], but was not included in the analysis because there is no table of contents available. In Poland, such inventory was not found, probably because of the language barrier.

Due to the language barrier, we also encountered difficulties when searching databases from Kazakhstan, Turkey, and China. Regarding the latter, an article was found claiming that a database of tailings dams was developed (Xie et al., 2008). Nonetheless, it might not be public, as we did not identify it after an extensive internet search.

Among other countries considered for search, we did not find databases of TSFs. In the Canadian province of Alberta, TSF's annual reports are available for download by the provincial corporation Alberta Energy Regulator[8]. Yet a repository of reports is not a database. Furthermore, exceptionally for Australia, an article reassured the nonexistence of such inventory (Sarker et al., 2022).

Water dam inventories were found in Mexico, Peru, Angola,

Table 3
Databases analyzed.

Database	Owner	Geographical scope	Abbreviation adopted in this article[a]
Global Tailings Portal	GRID-Arendal*, Investor Mining and Tailings Initiative**	Global	GTP
Integrated System of Mining Dams Management (SIGBM)	National Mining Agency (ANM) of Brazil***	Brazil	BR-ANM
Dam inventory	Environmental Foundation (FEAM) of the Brazilian state of Minas Gerais (MG) ***	Minas Gerais	BR-MG
Public data on tailings facilities	Chilean National Service of Geology and Mining (SERNAGEOMIN) ***	Chile	CL-SERNAGEOMIN
Tailings facilities of companies members of Consejo Minero	Mining Council (CM) *	Chile	CL-CM
Mining residue	CooperAcción*	Peru	PE-CA
Preliminary inventory of tailings dams	Secretary of Environment and Natural Resources***	Mexico	MX-SENR
Summary Table of DSI Reports for Permitted Metal and Coal Mines	Mines and Mineral Resources Division of Canadian province of British Columbia (BC) ***	BC	CA-BC
British Columbia Mine Tailings Map	BC Mining Law Reform Network and SkeenaWild Conservation Trust*	BC	CA-BCMLR
National Inventory of Structures of Tailings Disposal	Geological and Mineral Institute of Spain (IGME)***	Spain	ES-IGME
Inventory of closed and dangerous closed facilities for mining waste disposal in Spain	Ministry of Ecological Transition and Demographic Challenge of Spain (MITECO)***	Spain	ES-MITECO
Inventory of closed waste facilities	Energy and Geology General-Direction (DGEG) of Portugal***1	Portugal	PT-DGEG

*Non-governmental organization; **Group of investors; ***Government agency
[a]The abbreviation is composed of the 2-letter code of the country of origin, according to ISO 3166, followed by a specification of the owner. Exceptionally, the Global Tailings Portal was abbreviated for GTP.

[6] This Directive aims to establish measures to prevent or reduce adverse effects on the environment, and risks to human health, that may be caused by the management of mining wastes. Available on: https://eur-lex.europa.eu/resource.html?uri=cellar:c370006a-063e-4dc7-9b05-52c37720740c.0005.02/DOC_1&format=PDF

[7] https://data.gov.ie/dataset/mines-solid-waste-heaps?package_type=dataset

[8] 2021 Company Tailings Management Reports [183MB ZIP]. Available on: https://www.aer.ca/providing-information/by-topic/tailings/tailings-management

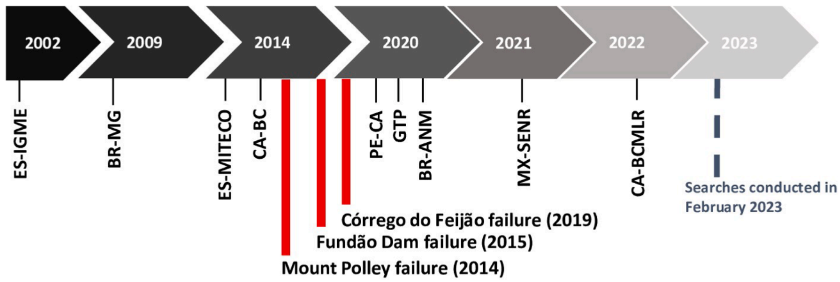

Fig. 1. Timeline of databases' launch and recent catastrophic TSFs failures. Until February 2023. CL-SERNAGEOMIN, CL-CM, and PT-DGEG were not included, because their publication date was not found.

provinces of Canada, the USA (federal and states), and Bolivia (Supplementary Material D). Databases of these two latter also contain mining dams, representing *1.3% of US National Dams; 1% of the National Inventory of Dams,* both from the USA*;* and 3.1% of Bolivia's inventory. However, only databases of facilities for mining waste disposal were considered in this research.

5.2. Analysis of public databases

ES-IGME and BR-ANM are the databases that contain most categories of information (16 each). Nevertheless, both do not inform updating frequency and the latter does not share informational material of TSFs. They were followed by CL-CM and CA-BCMLR (Fig 2).

The smallest number of categories is 5, by DGEGES-MITECO, an inventory of closed and abandoned TSFs that only informs the tailings chemistry classification, among "Content" categories. Frequency of update (category 8) is not informed by any of the databases. The results for each group of categories are presented in the sequence, while Supplementary Material E holds the complete analysis.

5.2.1. Scope

Except for PE-CA, which does not inform types of TSFs, all databases include tailings dams (Fig 3). GTP, BR-ANM, and PT-DGEG are the most comprehensive, as they include in-pit disposal and dry stacking. BR-ANM however only includes tailings piles 'subjected to liquefaction' (ANM, 2022), therefore not all tailings dry stacks in Brazil are included in the database. In-pit disposal is also included in ES-IGME, and dry stack in both Chilean databases and CA-BCMLR.

In addition to tailings dams, in-pit disposal, and dry stacks should also have their data disclosed. Although their reported probability of failure is lower (Franks et al. 2021; Piciullo et al., 2022), accidents are still probable to happen, such as the rupture of a dry stack in the Pau Branco Mine, Minas Gerais, in January 2022. Its mud wave blocked an important highway near the capital city of Belo Horizonte (WISE--Uranium Project, 2023). However, this type of facility is not included neither in BR-ANM nor in BR-MG.

Tailings' solids content is informed only by CL-SERNAGEOMIN and CL-CM. Since Chile has an arid climate and seismic activity

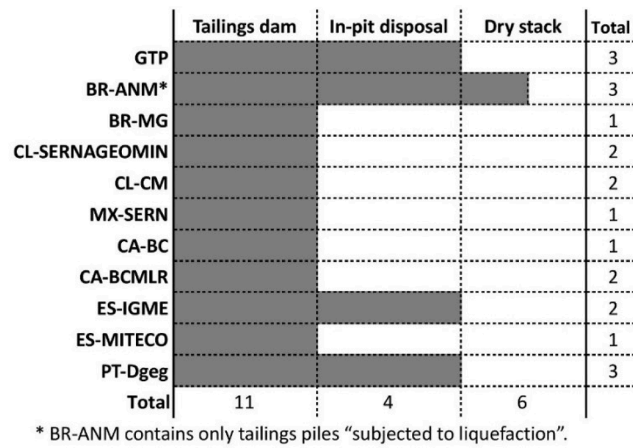

Fig. 3. Types of facilities registered by each database.

(Campos-Medina et al., 2023), which could trigger liquefaction (Vick, 1990), water reuse is important. Likewise, thickening and filtering technologies are encouraged by GTR (2020), and MAC (2021), as they minimize the volume of water. Hence, the likelihood and the consequences of a failure are reduced (Fourie, 2006; Martin et al, 2019).

Concerning operational status (Fig. 4), each database applies different criteria for the classification of TSFs' life cycles. However, most inventories include active TSFs, whose identification is facilitated by legal obligations of company owners to the government. Likewise, no database disclose illegal facilities, and only six consider abandoned. DGEG Satellite image monitoring was proposed to address the challenge governments face in identifying illegal and abandoned dams (Lumbroso et al., 2020).

Although governments usually have closed TSFs records, four databases do not include these facilities. As the probability of failure increases with age (Franks, 2021), the inclusion of closed status is of paramount importance. Furthermore, the absence of maintenance and control could cause an unmanaged failure risk.

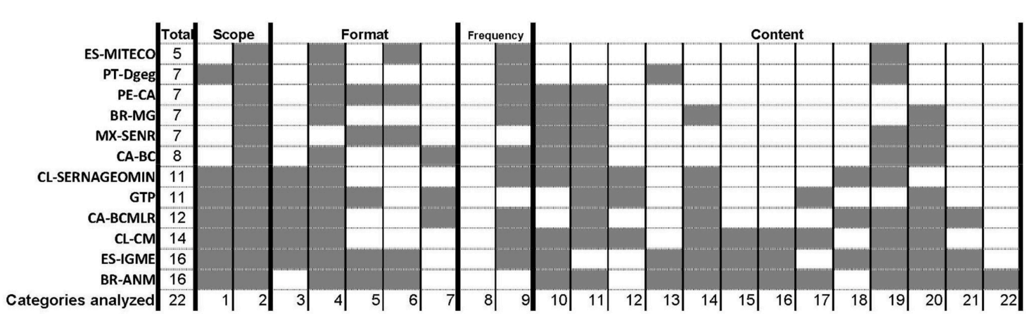

Fig. 2. Categories of information featured in each database.

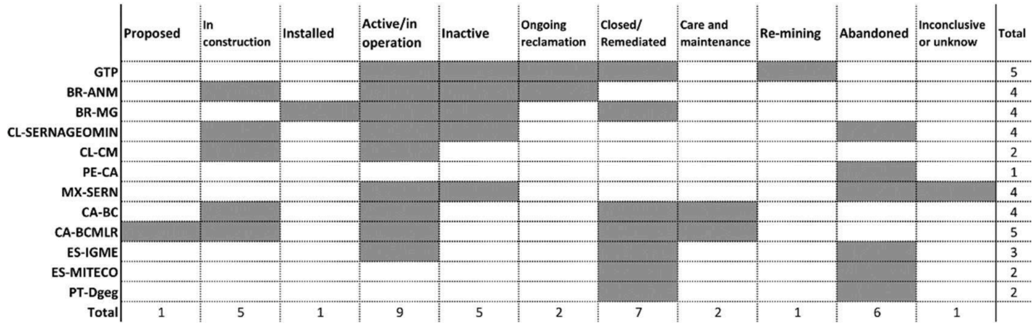

Fig. 4. Operational status applied by each database.

5.2.2. Format

Only five databases have informational material explaining tailings and disposal facilities. It could enable better use of the information by the public. GTP features a short section of 'definitions', while CL-CM includes a long glossary and videos about tailings. CL-SERNAGEOMIN contains Frequently Asked Questions (FAQ) about TSFs, and BC-BCMLR and ES-IGME hold sections explaining their data. The lack of explanatory material, found in six databases, and the consequent use of inappropriate terms, causes inaccurate reporting and misconception (Sartain et al., 2015). BR-ANM, for example, discloses information on drainage systems, yet it does not explain related terms.

Except for MX-SENR[9], all databases inform an e-mail or telephone for contact, although only BR-ANM and CL-SERNAGEOMIN disclose a contact explicitly for 'complaints'. The possibility of contact is of paramount importance to answer questions and to enhance dialogue, increasing trust (Sartain et al., 2015) and common understanding (Kondo et al., 2019) between stakeholders. Timely responses are important to fulfill any request (GTR, 2020).

Regarding the manner of disclosure (Fig. 5), nine databases are presented in tables, six in interactive maps, and three in individual files for each TSF. Five inventories are available in multiple supports: BR-ANM and ES-IGME are the only ones with the three possibilities, and GTP, PE-CA, and MX-SENR hold a table and an interactive map. Furthermore, eight inventories are available online and eight for download[10], as only five are available in both forms.

We have not been able to elect the best format, nevertheless different advantages of each were observed. Interactive maps enhance the visualization of hazard-prone areas and the precise location of TSFs. Moreover, it empowers people outside the mining company to understand the risks to which TSFs are exposed (Franks et al., 2021). Maps and individual files hamper TSFs and databases comparison, in contrast to a table containing all TSFs of the database. However, individual files of BR-ANM, CL-CM, and ES-IGME inform deeper details, rather than their tables. Downloadable data also enhances analysis, as they may be visualized in offline mode. Therefore, multiple formats databases fulfill a large range of data visualization.

Moreover, three databases provide web links to access external material. GTP regarding reports of TSF's company owners; CA-BC, Dam Safety Reports; and CA-BCMLR, database methodology. These are examples that databases can disclose materials external to the inventory, or at least their access way. This could be a manner of disclosing emergency preparedness plans and inundation areas.

5.2.3. Frequency of update

Any database discloses its frequency of update clearly. However, BR-MG and CL-CM have been updating annually since, at least, 2002 and 2021, respectively. Nine databases inform when they were last updated, except GTP, MX-SENR, and BR-ANM. Nevertheless, their last updates were found in different sources, such as on the webpage of the Church of England Pension Fund, Mexican Secretary of Environment and Natural Resources (2021), and personal communication with ANM staff, respectively. ES-IGME has never been updated since its release in 2002, while CA-BC and PT-DGEG were last updated in 2014 and 2020, respectively, as illustrated in Fig. 6. By November 2023, BR-MG and BR-ANM had the most recent updates. The latter is continuously updated according to the auditing of ANM or the inclusion of information by companies (Souza, 2021).

Out-of-date information decreases credibility, as TSF risks are dynamic (Hopkins and Kemp, 2021; MAC, 2021). Therefore, information not frequently updated does not correspond to current facilities' characteristics. CA-BC, for example, last updated in 2014, discloses weblinks to access the dam's safety reports, however, the websites direct to an error page. Although high frequency of updates is more reliable, the date of the last update should also be informed in the database.

5.2.4. TSF's identification

Eight databases disclose TSFs' geographical coordinates, which were selected to analyze location disclosure. Nevertheless, they can only be plotted on maps if map tools (e.g. Google Maps or QGis) are known by the user. Although GTP and BC-BCMLR do not disclose coordinates, they offer interactive maps, enhancing the visualization of location and possible risk interaction among facilities. DGEG. However, ES-MITECO and PT-DGEG do not disclose in either way.

Identification of a TSF may also be made through its name, mine, or company owner. Six inventories inform the name of the TSF and six, the mine. Only PE-CA, ES-MITECO, and ES-IGME disclose either way. Moreover, nine databases provide the facility's owner, except PT-DGEG, ES-IGME, and ES-MITECO. Such information enables the user to identify a specific facility of interest, to contact the company, and to make complaints.

5.2.5. Characteristics that influence TSF's stability

Site selection must consider environmental aspects (Vick, 1990). Three databases inform about the foundation, seismic activity, or mining method of the mine – which may induce ground movements. However, no inventory disclose rain and wind data.

Additionally, environmental aspects should restrict the construction method. Upstream method, for example, is inadequate for sites with heavy rain and seismic activity (Vick, 1990), featuring a higher frequency of failure and instability (Franks et al., 2021; Piciullo et al., 2022). Such aspects explain why this method is the most disclosed, featuring in the seven databases that inform the construction method (Fig. 7).

Moreover, poor water management affects TSF's stability (Vick,

[9] The database website was considered, but Mexican Secretary of Environment and Natural Resources website includes a contact e-mail: https://www.gob.mx/semarnat/prensa/integra-gobierno-de-mexico-inventario-homologado-preliminar-de-presas-de-jales

[10] GTP offers a download option only for sketches made by the database user in the online map. However, the database was not considered downloadable, because TSF information are not available for download.

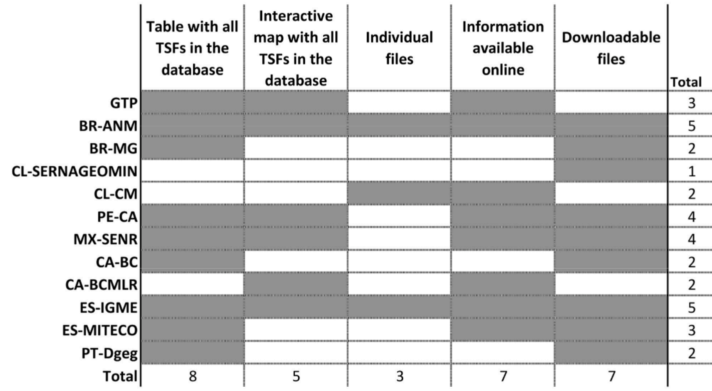

Fig. 5. Manners of presenting disclosed data.

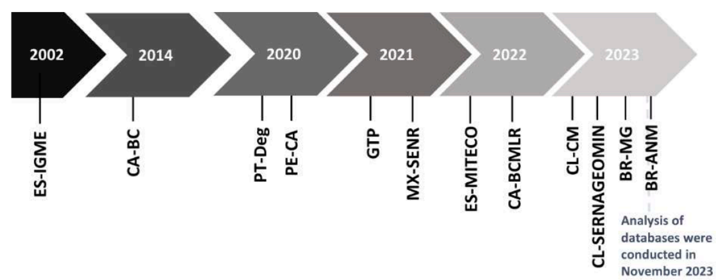

Fig. 6. Timeline of the last updates.

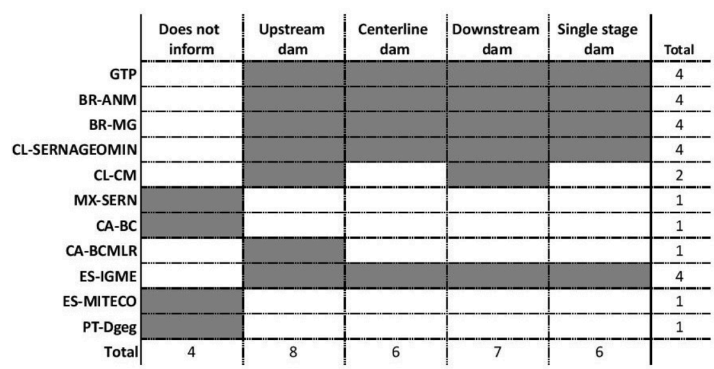

Fig. 7. Raise methods registered by each database. PE-CA do not inform construction method.

1990; Fourie, 2006). Nevertheless, only three databases disclose related information, e. g. drainage system, supernatant water, and water recycling. Similarly, the same three inventories inform physical issues observed in monitoring inspections. Such information illustrates TSF's maintenance and monitoring control, hence facility's stability conditions.

Facility age also influences the probability of failure, as older TSFs reported a higher frequency of instabilities (Franks et al., 2021). However, only three inventories inform the construction year. Likewise, three databases disclose the current volume, although their last update was in 2022 and 2002. Ore classification or geochemical tailings information, whose specific gravity directly impacts the load borne by the TSF (Vick, 1990), is disclosed by ten databases, except GTP and PE-CA. Furthermore, this information influence economic feasibility of tailings reprocessing, which could be a recovery option, reducing landfill areas (Araya et al., 2021).

5.2.6. *Characteristics of hazard-prone area*

Consequence classification, which should be established upon credible failure scenarios (GTR, 2020), is available in seven databases. However, only BC-BCMLR and CL-CM inform the criteria used for consequence classification, which enables the user to better understand this information. Besides, TSFs with high consequences should be highlighted, as they impose severe probable consequences.

In addition, only four databases disclose information about hazard-prone areas. Exposure of people, infrastructure, and nature reserves is informed. However, the precise identification of hazard-prone areas is made through inundation maps. Only BR-ANM provides it, in a geospatial file (.kmz). Furthermore, it allows the database user to fulfill their right to know to which TSF risks they are exposed (Tzioutzios et al., 2022; Baker et al, 2020).

Nevertheless, none of the databases inform emergency procedures, which should be widely spread during the facility life cycle. Exposed communities and local authorities (GTR, 2020; MAC, 2021) should have access to the contingency plan and emergency simulations - before an emergency (Coppola, 2020). With this in mind, the cell phone application Prox[11], launched in 2022, informs emergency routes and evacuation centers of tailings dams in Minas Gerais.

5.3. Limitations and strengths of the study

Although guidelines for public databases of TSFs have not been agreed upon internationally, recommendations were made by researchers. Regarding scope, the broader operational status and facilities type included, the better. Multiple format of disclosure enhances data use. The last date of update should be informed. Moreover, content should inform TSF's identification, factors that influence its stability, exposure conditions and emergency preparedness information. Nonetheless, future studies may define further specifications.

Similarly, as guidelines do not exist, the 22 categories selected for analysis were based on TSF failure risk and risk communication literature. Therefore, different categories could lead to divergent results. It is important to emphasize that we did not intend to elect the "best" databases, but to study improvements needed. Furthermore, Supplementary Material B discloses the complete content of the 12 databases and explains exclusion reasons.

In addition, the source of the data featured in each database was not studied. We only analyzed information reliability regarding frequency of update. Satellite image monitoring was proposed for auditing data informed by miners (Lumbroso et al., 2020). BR-ANM, for example, was criticized for not verifying the data provided by company's owners, which have caused flaws in the national dam safety auditing (Lumbroso et al., 2020; Lanchotti, 2023).

6. Conclusion

Major disasters in Canada and Brazil shed light on the absence of TSFs risk disclosure. Searching public databases of TSFs, we found ten open-access inventories in Brazil, British Columbia (Canada), Chile, Portugal, Mexico and Spain, in addition to the Global Tailings Portal and another in Peru. The twelve databases were analyzed for 22 categories of information about their scope, format, frequency of update, and content.

We found gaps that require improvements. All databases are incomplete, as they do not disclose all types of facilities. In addition to dams, only four inventories include in-pit disposal and six include dry stacks – which are being used as an alternative to dam disposal, and also constitute hazards. Closed and abandoned facilities are ignored by four and five databases, respectively, which could reveal unreported risks. Only five databases contain informational material to facilitate the understanding of laypeople. Furthermore, the last update is informed in nine databases, nevertheless, only three were updated in 2023. Out-of-date information discredits the entire effort of disclosure.

Some factors that influence the stability of a TSF are disclosed in all databases. However, regarding hazard-prone areas, only four contain descriptions of exposed areas and communities. Moreover, no database discloses information about emergency preparedness, such as emergency routes. Inundation maps are provided only by BR-ANM. This database displays the highest score, featuring 16 categories of information, out of 22 selected as essential, perhaps unsurprising, given the two recent major dam failures in Brazil. However, it does not share informational material of TSFs, neither updating frequency.

As TSFs are constructed for perpetuity and failures still occur, the key takeaways from this research are: (1) databases must be improved to provide relevant, accurate, timely, and understandable information for a range of stakeholders; (2) jurisdictions that do not have TSFs public databases should be encouraged to develop their own; (3) we recommend that current and future databases minimally display the categories of information presented here.

[11] https://segurancaprox.com.br/

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CRediT authorship contribution statement

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Declaration of competing interest

None.

Supplementary materials

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