

Communication

# Mining Waste Challenges: Environmental Risks of Gigatons of Mud, Dust and Sediment in Megadiverse Regions in Brazil

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**Abstract:** The management of long-lived mining wastes is a complex environmental challenge, but the subject is little discussed among the public, scientific community, and policymakers. The negative environmental impacts caused by mining wastes are severe and cause damage to human health and the loss and degradation of natural ecosystems. With the objective of stimulating discussion to advance the development of measures to contain threats to biodiversity and to mitigate negative impacts, we present an overview of total volumes of mining waste disposal in tailings dams and dump piles, discriminating them by ore type and biome. We highlight the major environmental risks and challenges associated with tropical forests, savannas, and freshwater ecosystems and possible limitations and advances in public policies and governance. The scale of this challenge is global, as some data show, for example, Brazil generated 3.6 billion tons of solid mining waste in dump piles in the period between 2008 and 2019. The volume is equivalent to 62% of the global mass of nonfuel minerals removed from the planet's crust in 2006. Numerous socio-environmental disasters are caused by catastrophic mining dam failures, and over the last 34 years, an average of one failure has occurred every three years in Brazil.

**Keywords:** megadiversity; large-scale mining industry; environmental governance

## 1. Introduction

Waste management is a major environmental challenge on a global scale. It has been estimated that in 2016, humankind generated two billion tons of municipal solid waste—residential, institutional, and commercial [1]. However, the largest global waste producer is the mineral industry [2]. The generation of mining waste is estimated to be 50 times higher in terms of annual volume [3], representing immense environmental risks and liability. However, despite the volume and the possibility of mining wastes containing hazardous substances, the discussion around proper and sustainable management of mining wastes has received relatively little attention from the general public, the scientific community, and decision-makers [4–6].

Large-scale mining is an activity that generates intense and prolonged environmental impacts, modifying entire landscapes by removing and processing billions of tons of rocky materials every year [7,8]. Socio-environmental conflicts related to mineral ore exploration is the second most frequent category across the world, only behind conflicts triggered by land acquisition [9]. The production of ore results in the accumulation of two main types of mining waste: (1) Mud, chemical residues, and sandy material generated during the industrial process used to concentrate ores, which are primarily deposited behind tailings dams by hydraulic methods [10–12], and (2) Solid heterogeneous

materials (rocks, soil, and/or sediment) removed to access the ore in mining, which are disposed of in structures known as dump piles (also identified as waste dumps, stockpiles, or spoil piles).

The negative environmental impacts caused by mining waste are severe because they promote, for example, the loss and degradation of natural areas or damage the health of the population exposed to toxic metals resuspended as dust. Freshwater ecosystems are particularly degraded, both because they receive sediment loads—including chemical compounds used in processing—and because they are impacted by tailings dam failure events. In these cases, thousands of kilometers of rivers and streams have been devastated by millions of tons of mud and toxic wastes [2,11,13,14]. Another underrecognized impact is groundwater contamination, which occurs when rainwater infiltrates the waste and transports high amounts of metals and other contaminants to groundwater bodies. All these problems exert influence on social awareness to reduce environmental risk and liability [3] and are relevant and should be faced, in particular, by countries that have the largest mineral reserves, such as the United States, Australia, India, Russia, China, and Brazil.

One factor that further complicates mining waste management is the location of mineral reserves in regions where the world's biological diversity is concentrated [6,14,15]. In this circumstance, Brazil is probably the nation with one of the greatest challenges as it ranks first among the 18 megadiverse countries and, at the same time, is one of the largest global producers of iron, bauxite, niobium, graphite, vanadium, tin, and manganese [16,17]. In this context, the objectives of this study are to (1) present the current panorama of two main types of mining waste in Brazil, one of the world's largest mineral producers, identifying the locations with the highest waste disposal in each biome, (2) highlight the greatest socio-environmental risks, damage and management challenges associated with tropical forests, savannas, freshwater ecosystems, and priority areas for conservation, and (3) discuss possible limitations and advances in public policies, good practice, and governance.

## 2. Materials and Methods

The methodological procedures were accomplished in two stages. In the first stage, we used official databases to obtain the following data to support our analyses. All datasets cited in the manuscript are made publicly available by the Brazilian government according to the 2011 Information Access Law [18]. We consulted federal and state public databases to identify the current panorama of disposal of mining waste in Brazil. We gathered information on volume, type of ore, and disposal material (mud, hazardous chemical residue, and sandy material) from the Integrated System for Safety Management of Mining Dams (SIGBM, its abbreviation in Portuguese) [19]. Georeferenced data on tailings dams were extracted from SIGBM [19], and Brazilian biomes (Amazonia, Caatinga, Cerrado, Atlantic Forest, Pampa and Pantanal) were extracted from the Brazilian Institute of Geography and Statistics (IBGE, its abbreviation in Portuguese) [20]. We validated the coordinates for tailings dams based on interpreting high-resolution imagery (spatial resolution usually finer than 2 m) available in Google Earth [21] by randomly sampling 80% of point locations. It was necessary to assess overlapping point locations with regional data for precision (biome data). We used all georeferenced data available as a shapefile extension (©ESRI vector representation file format) with a geographic projection and the SIRGAS 2000 Datum. The results were calculated using the geographic information system (GIS) software package ArcGis 10.6, by spatially joining data between attribute tables "Brazilian biomes" and "tailings dams".

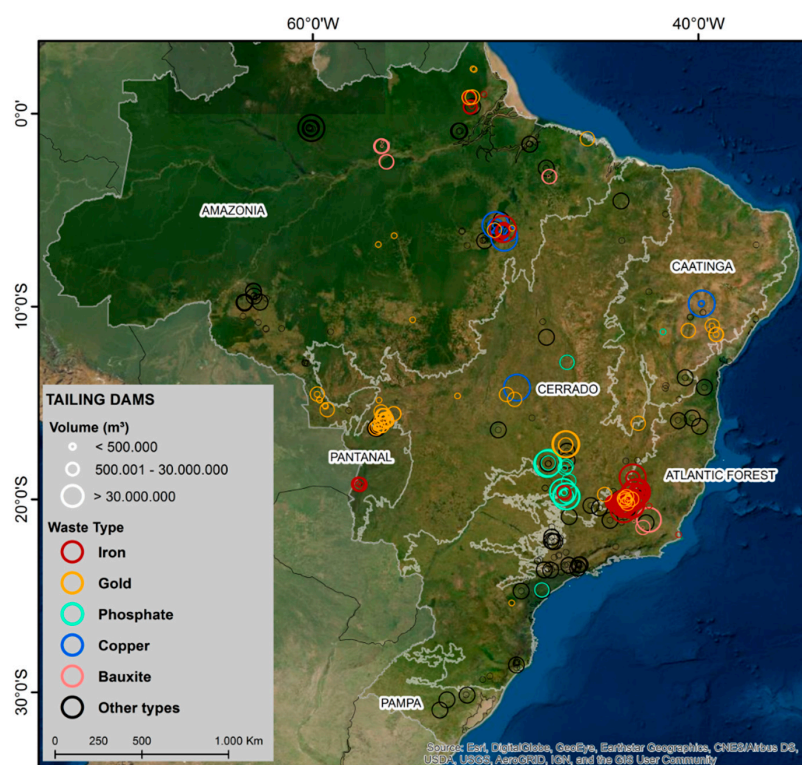
We investigated official inventories of solid mining waste in dump piles from federal and state agencies, made available by the instruments of the National Solid Waste Policy (PNRS, its abbreviation in Portuguese) [22], National Solid Waste Management Information System (SINIR, its abbreviation in Portuguese) [23], Institute of Applied Economic Research (IPEA, its abbreviation in Portuguese) [24], and Environmental Foundation of Minas Gerais State (FEAM, its abbreviation in Portuguese) [25]. We examined information on height and type of disposal material (rock, soil, and sediment) and historical data on volume of material disposed of in dump piles, organized from 2008 to 2018.

In the second stage, the greatest socio-environmental risks and damage caused by mining wastes were compiled from a global chronology of major tailings dam failures [26], the Brazilian Dam Committee (CBDB, its abbreviation in Portuguese) [27], and literature. We utilized the compilation of events of damage caused by mining waste to investigate in a GIS environment, on a local scale, whether the disasters caused damage in protected areas established by the National System of Protected Areas (SNUC, its abbreviation in Portuguese) [28], State Forestry Institute (IEF, its abbreviation in Portuguese) [29], and in priority areas for conservation [30]. Finally, we discuss possible limitations and advances in public policies and governance, based on the PNRS [31] and international good practices, guidance, and standards.

### 3. Results and Discussion

#### 3.1. Tailings Dams: Mud, Chemical Residues and Sandy Material

The federal database allows open access to each of the 839 tailings dams entered in the national register, which is a result of the implementation of the National Dam Safety Policy (PNSB, its abbreviation in Portuguese) [32]. Currently, Brazil has accumulated a total of over 3.76 billion m<sup>3</sup> of mud, hazardous chemical residue (such as cyanide and caustic soda), and sandy materials, resulting from the production of more than 40 ore types [19]. Wastes derived from iron mining predominate, accounting for 38% of the total volume accumulated in the country, followed by gold (22%), phosphate and copper (12% each), and bauxite (6%) waste. Considering the distribution by biome (Figure 1), almost 40% (1.42 billion m<sup>3</sup>) of the volume of all types of waste deposited behind dams is located in the Atlantic Forest, the world's most threatened tropical forest and a global biodiversity hotspot [33]. In the Cerrado (Brazilian savanna), another global biodiversity hotspot, 37% (1.38 billion m<sup>3</sup>) has accumulated. The Amazon Rainforest contains 21% (800 Mm<sup>3</sup>) of all Brazilian waste deposited at tailings dams.



**Figure 1.** Overlap between biomes [20] and 839 tailings dams classified by waste volume and ore type, according to official data from the National Mining Agency [19] in Brazil. Satellite images and map were built and exported using the GIS software package ArcGis 10.6. ©ESRI and its licensors, all rights reserved. This image is not distributed under the terms of the Creative Commons license of this publication. For permission to reuse, please contact the rights holder.

### 3.2. Dump Piles: Rock, Soil and Loose Sediment Disposal in Dump Piles

In Brazil, there is still no official national database of the types, location, and volume of materials historically deposited in dump piles [24]. This lack of good governance instruments remains 10 years after the establishment of the National Solid Waste Policy (PNRS, its abbreviation in Portuguese) [31]. At the regional scale, Minas Gerais is an exception among the 26 Brazilian states for maintaining an official inventory of solid mining waste disposal in dump piles. However, the data available for public consultation are outdated, since inventories were conducted for the years between 2008 and 2018 [25], and do not provide, for example, the name of the mining company, risk classification, environmental damage potential, volume deposited, or location for each dump pile. Despite this bias, it has been found that the total disposal volume in dump piles is approximately 70% of the mass of solid waste generated by mining activity [24]. Specifically, regarding iron mining, Minas Gerais disposed of almost 140 million tons of waste in dump piles just in 2008 [25].

For Brazil, it is estimated that just between 2008 and 2019, 3.6 billion tons of solid mining waste were disposed of in dump piles [34], a volume representing 62% of the global mass of nonfuel minerals removed from the planet's crust in 2006 [10]. Therefore, for the case of iron mining, the Brazilian volume of material accumulated in dump piles may be even higher than the volume of tailings deposited behind mining dams.

### 3.3. Socio-Environmental Risks and Damage

Numerous socio-environmental disasters worldwide are caused by catastrophic mining dam failures [26]. In Brazil, over the last 34 years, there has been an average of one failure every three years, releasing nearly 60 Mm<sup>3</sup> of mud into freshwater bodies, tropical forests and critical ecosystems (Table 1). The scale of the environmental degradation and the intensity of the damage to ecosystems and rural and urban communities caused by those disasters have not yet been fully measured. However, some numbers point to costs in the billions, since the initial cost of only two of those disasters (collapse of the Fundão and B1/Brumadinho dams in 2015 and 2019, respectively) is estimated to total almost US \$2 billion (US \$1: R\$ 5.30) for expenses related to the construction of emergency works, lawsuits for environmental damage, and compensation to public agencies [35,36]. However, most of the waste leakage events downstream of Brazilian dams are not associated with failures or disasters. Rather, the events that frequently cause pollution and silting in freshwater ecosystems occur within the properties of mining companies, and few are adequately reported to control and surveillance agencies [27].

**Table 1.** Major socio-environmental disasters caused by mining tailings dams reported in Brazil. Source: [26,27].

Year	Location	Company	Ore Type	Cause of Disaster	Release	Biome	Impacts/Damage
1986	Itabirito, MG	Itaminas Com. Min. S/A	iron	dam wall rupture	0.35 Mm <sup>3</sup>	Atlantic Forest	Tailings flowed 12 km downstream, killing seven persons.
2001	Nova Lima, MG	Mineração Rio Verde Ltd.a	iron	failure	?	Atlantic Forest	The slurry flowed > 8 km downstream, killing five mine workers. Damage to protected area (Environmental Protection Area South of the Metropolitan Region of Belo Horizonte)
2006	Mirai, MG	Mineração Rio Pomba Cataguases Ltd.a	bauxite	failure	0.4 Mm <sup>3</sup>	Atlantic Forest	Mud mixed with iron oxide and aluminum sulfate flowed downstream.
2007	Mirai, MG	Mineração Rio Pomba Cataguases Ltd.a	bauxite	failure after heavy rain	2 Mm <sup>3</sup>	Atlantic Forest	The mud flow left approximately 6000 residents homeless and flowed >100 km downstream. Damage to protected area (Environmental Protection Area of the Mirai). See details in Mineral Technology Center (CETEM, its abbreviation in Portuguese) [37].
2009	Barcarena, PA	Hydro Alunorte	bauxite	overflow red mud after heavy rain	?	Amazonia	?
2014	Itabirito, MG	Herculano Mineração Ltd.a	iron	failure	?	Atlantic Forest	Two workers killed and one missing, tailings flowed downstream. Damage to a Priority Area for the Conservation of Brazilian Biodiversity and UNESCO Espinhaço Mountains and Atlantic Forest Biosphere Reserves. See details in Mineral Technology Center (CETEM, its abbreviation in Portuguese) [38].
2015	Mariana, MG	Samarco S/A	iron	failure	43 Mm <sup>3</sup>	Atlantic Forest	Severe and multiple damage. Tailings flowed 668 km downstream, impacting 294 small creeks; 19 people were killed. Damage to protected areas: Environmental Protection Area Barra Longa, Special Protection Area Ouro Preto and Mariana, UNESCO Espinhaço Mountains and Atlantic Forest Biosphere Reserves, including protected coastal zones: Comboios Biological Reserve, an important place for spawning of sea turtles, Santa Cruz Wildlife Refuge, and Environmental Protection Area Costa das Algas. Damage to key areas for the conservation of six rare Brazilian plants. See details in [11].
2018	Barcarena, PA	Hydro Alunorte	bauxite	Overflow of red mud basin after heavy rain?	?	Amazonia	Red mud flowed, rendering the water supply nonpotable.
2019	Machadinho D'oeste, RO	Metalmig Min. Ind. Com. S/A	tin	failure	?	Amazonia	Tailings spill damaged seven bridges, leaving 100 families isolated.
2019	Brumadinho, MG	Vale S/A	iron	failure	12 Mm <sup>3</sup>	AtlanticForest	Severe and multiple damage. Tailings flowed 120 km downstream, 259 people were killed, and 11 are still reported as missing. Damage to a Priority Area for the Conservation of Fish Biodiversity and UNESCO Espinhaço Mountains and Atlantic Forest Biosphere Reserves. See details in Vergilio et al. [11].
2019	N.S. Livramento, MT	VM Mineração e Construção	gold	failure	?	Pantanal/Cerrado	Tailings flowed 1–2 km, disrupting a power line.

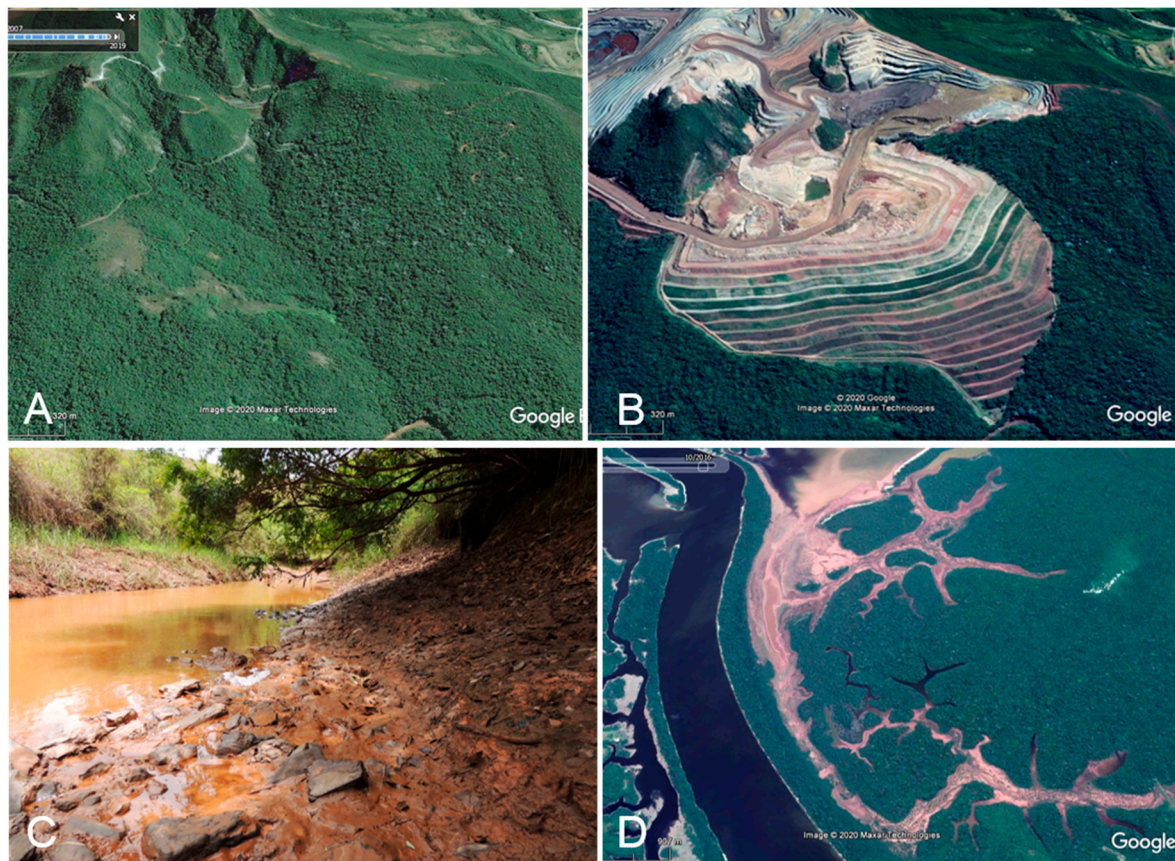


Due to the high potential for environmental damage from waste dams, in the last decade, Brazilian public policies were implemented focusing on the creation of a national register and definition of monitoring and risk management requirements for these structures [6,39]. The national register helps improve governance because it contains a complete database. Information exists for each registered mining dam, for example, the name of the mining company, volume and type of tailings, risk classification, potential for environmental damage, and location. All information is updated in real time and is available for public consultation in the Integrated Mining Dam Management System [19]. However, much of the information provided to the state agencies is controlled by the mining companies, and the government does not have sufficient resources (human or technical) to adequately supervise all mining projects. Despite the great progress that has been made in the last decade, there is still a long way to go, including the passage of legislation affording greater protection to the resident populations downstream of tailings dams and an increase in inspection rigor.

Legislation passed in the state of Minas Gerais, such as Law 23.291/2019 and the state dam safety policy [40], and the regulations at the national level, such as Resolution 13/2019 on stability of mining dams built by the upstream method [41], have been important in establishing more restrictive rules for mining waste disposal at tailing dams and for balancing economic growth and environmental preservation. However, the restrictions on the construction of tailing dams are only one of the many challenges that need to be overcome in order to stop the series of environmental disasters that have plagued Brazil over the past decade. As an example, it is fundamental to understand that, as many mining companies migrate from waste disposal at dams to dump piles, the impacts of the latter also need to be better understood and mitigated through the creation of public policies and regulations, including the less evident impacts, such as the pollution of underground waters.

Regarding dump piles, there is no federal open-access database on with geotechnical risk or environmental damage potential classification, at least in the manner established by dam safety public policy [42]. However, this discussion should be encouraged, considering that some piles exceed more than 300 m in height and have individual capacity for the disposal of tens of millions of m<sup>3</sup> of wastes. Furthermore, some large dump piles are associated with a watercourse and exist in locations with average annual rainfall between 1300–2500 mm [43], for example, see Figure 2A,B. This association reinforces the potential for environmental damage because water is the main transport agent of sediments and contaminants leached from these structures [10]. Some materials, such as sulfides, deposited in piles, are recognized for their geochemical reactivity and high potential for environmental contamination. Even when the materials are considered “inert”, the polluting potential is considerable due to the enormous volumes of sediments and dust [10]. In Brazil, this contamination is extremely problematic because few states have groundwater monitoring networks, therefore, this impact cannot be perceived in other regions [44]. Poulsen et al. [45] discussed cases of dump pile failures and the consequences for loss of life and negative impacts. Under certain conditions, metals resuspended as dust originating in mine sites can cause respiratory and cardiovascular diseases in the exposed urban population [46].

In Brazil, there is a spatial correlation between the largest mine sites and biodiverse areas [47], for example, iron mining occurs on mountaintops and causes irreversible losses in forests and rare metalliferous ecosystems, known as *canga*, located in the Atlantic Forest and Amazon Rainforest. Other examples are bauxite and copper mines, which are concentrated in the Amazon Rainforest, phosphate mines, which generate the largest production volumes in the Cerrado, and gold mines, which generate the largest production volumes in the Cerrado and Atlantic Forest.



**Figure 2.** Impacts caused by mining wastes in Brazilian forests and freshwater ecosystems. Atlantic Forest: (A,B) Stream and forest loss due to the establishment of dump piles from mountaintop iron mining (images from 2006 and 2018, respectively), (C) pollution and silting of the watercourse downstream of mining dams and piles. (Photo: Instituto Prístino, 2019), Amazon Rainforest: (D) Pollution and silting of the Caranã Stream (Batata Lake) by discharge of bauxite mining waste (image from 2016).

The mining sites, when analyzed individually, i.e., per enterprise, are located in relatively restricted areas (on the order of tens to thousands of hectares), but the footprint required to dispose of mining waste can be very large [2]. Even so, even at the local scale, most of the mining waste volume is deposited in biodiverse areas, forest fragments, critical habitats, and freshwater ecosystems. Studies indicate that mining activities generate impacts and represent considerable risk, specifically for sites with high concentrations of endemic species of vascular plants, cave invertebrates, anurans, and birds [48–50]. Examples of this situation occur with dams and dump piles (Figure 2C) located in a matrix of Atlantic Forest fragments in the Quadrilátero Ferrífero region, a mosaic of 29 protected areas, and in two UNESCO Biosphere Reserves, “Serra do Espinhaço” and “Atlantic Forest” [6].

In the Amazon Rainforest, mine wastes are concentrated in the Carajás region, a mosaic of six protected areas, and in the Saracá-Taquera National Forest, a protected area affected by the discharge of residues and fine sediments from bauxite mining and beneficiation. Pollution events that occurred between 1979 and 1989, reaching the Caranã Stream (Batata Lake), were, at the time, some of the most publicized environmental problems in Brazil [51]. After 30 years, it is still possible to observe the silting caused by mining wastes in Batata Lake (Figure 2D). Sonter et al. [52] identified extensive mining-induced deforestation in the Amazon forest, which has extended more than 70 km from the source area due to the opening of roads and expansion of urban centers to support growing supply chains.

Most of the reported impacts and damage are associated with projects that have environmental licenses. However, a situation that we want to highlight is even broader than discussions about the licensing process and can be represented by a simple and direct question: Why convert biodiversity areas, such as tropical forests, freshwater ecosystems, and other critical points of biodiversity, into sites for the disposal of mining waste?

### 3.4. Public Policies and Good Practices

A National Solid Waste Policy (PNRS, its abbreviation in Portuguese), which includes regulation of mining waste, was established only in 2010 [31]. Despite catalyzing some general advances, the major obstacles to the implementation of the PNRS include the lack of financial resources and the difficulty of coordinating different government agencies [53]. In addition to the challenge per se of obtaining the financial and technological resources required for the management of gigatons of mining waste over decades or centuries, the high socio-environmental risk (and its corresponding long-term costs) of spatial association between megadiversity areas and mining sites should also be considered [6,54]. This scenario is also worrisome due to the gaps in knowledge on the volume of material deposited in dump piles and on the biogeochemical behavior of many toxic elements present in mining wastes [11,55].

A decade after the publication of the PNRS, very little progress has been made in the management of solid mining wastes when compared with the management of tailings dams. An example of this stagnation is the situation of the regional public policies of the three states with the largest volume of wastes deposited at both types of structures, dump piles and tailings dams: Minas Gerais (with 64% of the volume of tailings in Brazil) has not yet completed its State Plan, the state of Pará (16%) completed its State Plan, but data on mining waste were not reported, and a similar situation is observed for the state of Goiás (with 8% of the Brazilian tailings volume), where the State Plan did not include data on dump piles, and the determined volume of tailings at dams did not cover all the main mining companies (details in MMA [22]). In addition, at least one legislative project [56] that aims to make use of materials derived from mining tailings for the construction of social housing and for the recovery of public roads has been awaiting debate in the legislative chamber of Minas Gerais since 2015. This situation contrasts with that noted by Donadelli [57], who emphasized the need to integrate environmental policies and political leaders' responsibility as important elements for overcoming complex environmental difficulties.

In recent decades, multi-institutional good practices, guidance, and standards for the management of mining waste have established dozens of principles, key components, and guidelines, some of technical nature, such as plans and criteria for design, construction, operation and monitoring, and others addressing governance and environmental management [2,58,59]. For example, the Mining Principles of the International Council on Mining and Metals (ICMM) [15] define performance expectations for responsible mining in terms of environmental, social, and governance practices. One of those principles strives, consistent with internationally recognized good practices, to effectively manage the design, construction, operation, monitoring, and decommissioning of tailings dams and dump piles to minimize the risk of catastrophic failures. Another principle requires assessing risks and impacts on biological diversity and ecosystem services with the ambition of achieving no net loss of biodiversity, applying to new projects and major expansions. Achieving no net loss is especially relevant at sites where biological diversity is concentrated and contributes to ethical business practices that support sustainable development [15]. The mining industry would thereby establish criteria to prevent the development of new mine waste disposal sites in natural areas of threatened tropical forests or other biodiversity hotspots. In Brazil, implementing this action could considerably reduce the extinction risk for the fauna and flora endemic to the Atlantic Forest and avoid the deforestation of hundreds of hectares of forest fragments and impacts on freshwater ecosystems.

The use of technically recognized international procedures for determining the geochemical reactivity of materials and their potential risk is recommended by the Brazilian Mine Association



(IBRAM its abbreviation in Portuguese) in cases of a lack of or insufficient national normative references [60]. This proposal is a good practice, considering that in most cases of waste discharge and pollution, including some dam failure events, the companies have had official environmental licenses to operate mining activities. This scenario highlights a weakness in environmental regulation in Brazil and in the monitoring and inspection practices identified in the scientific literature [14,61,62].

In response to frequent tailing dam disasters, 15 additional principles and 77 auditable requirements to set up a global industry standard on tailings management [63]. This global standard aims to avoid “any damage to people and the environment (zero damage), with zero tolerance for human fatalities”. The Brazilian Mine Association [60] published a Commitment Letter recognizing and taking responsibility for the tailings dam failures that caused immense socio-environmental disasters. Several commitments made have adhered to those principles and requirements for the management of mining waste. In turn, good practices, guidance, and standards addressing the management of mining waste disposal in dump piles are still rare in the literature. However, mining regulatory standards in Brazil established in 2001 already directed actions linked to the rational use of minerals, the minimization of environmental impacts, the improvement of health and safety conditions, in addition to considering the need for improvement and use of new technologies [64]. Therefore, federal regulations had, in a sense, already established some principles and guidelines for the management of mining waste.

Management of mine waste and environmental governance in Brazil should also be made more effective, specifically by strengthening the connection/interaction between the actions established in the national public policies for solid waste (PNRS), dam safety (established in 2010), water resources (established in 1997), and protected areas (established in 2000). Such actions concern the prevention and management of geotechnical risk, monitoring, reduction of waste generation, management of environmental liabilities, conservation of natural resources and ecosystem services, and integration of databases. The main cases of dam failure reported in Brazil (Table 1) support the argument about the need for good governance and integrated public policies. Two of these cases of failure are among the largest global disasters, causing terrible socio-environmental damage, including more than 300 deaths, and severely impacting two of the major hydrographic basins in eastern Brazil (details in [11,39,65]). However, information about the volume of tailings that spilled into the environment is available for fewer than 45% of the cases of dam failure.

#### 4. Conclusions

Our results demonstrate that the current panorama of two main types of mining waste in Brazil represents enormous environmental challenges and requires significant improvements in public and private governance. It is clear, from what has been demonstrated, that the public policy advances which have occurred in Brazil have been insufficient to prevent adverse impacts from mining activities, especially those concerning waste disposal. Governments, control and inspection agencies, companies, academia, conservation organizations, and the communities involved, therefore, need, urgently and with an interdisciplinary perspective, to intensify the debate on the challenges of mining waste management. We identified a lack of an integrated knowledge base, especially for mining waste disposal in dump piles.

We argue that mining waste governance implies initiatives promoting transparency, such as a federal public and integrated mining waste database (dump piles and tailing dams), including information about georeferenced location, storage volume, ore waste types, hazardous substances, geotechnical risk, and environmental damage potential classification. The regulatory agencies must have sufficient resources (human and technological resources) to adequately supervise hundreds of mining projects and thousands of waste disposal structures. The Brazilian mining industry also definitely needs to take proactive actions for sustainability and implement the dozens of principles and auditable requirements developed by its own associations and international councils. There is no doubt that society, responsible businesses, and investors will demand increasingly rational management

of mineral resources and establish increasingly restrictive limits for the generation and disposal of mining waste.

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