SPECIAL ARTICLE

Received: 03/11/2019
Accepted: 03/12/2019
Funding: National Council of Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq).

Work accidents which become disasters: mine tailing dam failures in Brazil

Acidentes de trabalho que se tornam desastres: os casos dos rompimentos em barragens de mineração no Brasil

Carlos Machado Freitas[1,2], Mariano Andrade da Silva[1,2]

ABSTRACT | The recent Vale S.A. dam failure in 2019 is one of the most serious work accidents ever in Brazil and is becoming a milestone for mining risk management systems in the country. It is characterized as an incident with irreversible and hard-to-manage intensive and direct impacts on workers and extensive impacts in space and time. Despite their low frequency, dam failures are not rare, but represent an open fracture in an universe in which abnormalities become the normal state of affairs in the everyday routine of corporations. Work accidents like this one and that involving the Samarco dam in 2015 undermine the trust in the entire mine tailings dam failure risk prevention and control system. We need to learn from these incidents to change the ideas and methods in vigor in an intersectoral and participatory manner.

Keywords | accidents, occupational; industrial disaster; occupational health.

RESUMO | O recente rompimento da barragem da mineradora Vale S.A., em 2019, figura entre os mais graves acidentes de trabalho já registrados no Brasil e caminha para se tornar um marco no sistema de gerenciamento de riscos dessas atividades no país. Ele caracteriza-se como um evento que envolve desde impactos intensivos e diretos sobre trabalhadores e comunidades a efeitos extensivos no espaço e tempo, irreversíveis e de difícil gestão. Rompimentos de barragens não são eventos raros, porém, apesar da baixa frequência, configuram uma fratura exposta de um universo de anormalidades transformadas em normalidades no cotidiano das corporações. Acidentes de trabalho como esse e o da Samarco em 2015 abalam a confiança em todo o sistema de prevenção e controle de riscos de acidentes e desastres em barragens de mineração. Devemos extrair lições dos mesmos com o sentido de mudar as lógicas vigentes de modo intersetorial e participativo.

Palavras-chave | acidentes de trabalho; desastre industrial; saúde do trabalhador.

[1]Fundação Oswaldo Cruz, Health Emergencies and Disasters Study and Research Center – Rio de Janeiro (RJ), Brazil.
[2]National Public Health School – Rio de Janeiro (RJ), Brazil.
DOI: 10.5327/Z1679443520190405

INTRODUCTION

The two most serious incidents involving mining dams in the 21st century took place in Brazil in the end of 2015 and beginning of 2019, respectively. For deriving from mining production and waste disposal processes, they can be primarily categorized as work accidents (WA) with impacts extending in space (hundreds of kilometers away from the event site) and time (i.e. ecological changes and contaminations which effects might last years and even decades). For these reasons they are also known as major accidents (MA). Moreover, for disrupting everyday life — with considerable (material, economic and environmental) damage, losses and impact on the health of the local populations inasmuch as they surpass the response capacity of the directly involved communities, counties and regions — this type of accidents are also rated disasters.

In the present article we employed the abbreviation WA/disasters to emphasize the fact that these incidents are primarily WA which become MA, or disasters more in particular. With this, we do not only seek to broaden the view on this type of accidents, but also to call the attention to the need for intersectoral dialogue, proposals and actions involving workers, the labor, health, environment, mining and social service sectors, as well as social movements launched by victims, as e.g. the Dam Victims Movement (Movimento dos Atingidos por Barragens — MAB).

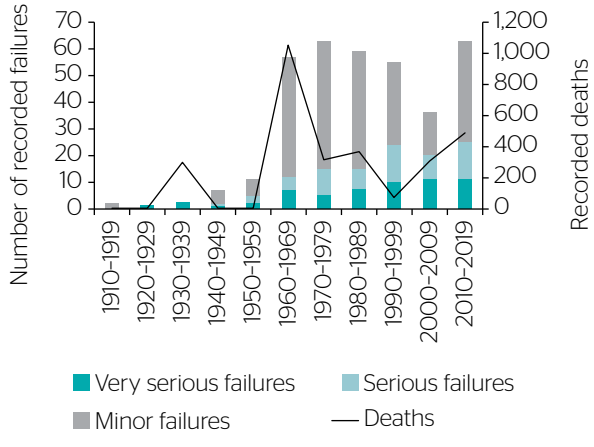
The Samarco (a subsidiary of Vale S.A.) WA/disaster, in 2015, caused 19 deaths, including 14 (74%) workers, and released 50 million m^3 of tailings which extended over 36 municipalities to a total of 650 km along the Doce River[1]. In turn, the Vale S.A. WA/disaster, which took place in 2019, had more than 300 victims, including deaths and missing people (who will hardly be found after one month of intensive searches). One hundred and thirty-one victims (42%) were Vale S.A. employees and the other 177 outsourced/community residents. In this incident, 13 million m^3 of tailings were released, which extended to 18 municipalities at least along 250 kilometers. Both incidents had enormous impacts on the Doce and Paraopeba Rivers basins, including huge amounts of waste and high levels of contamination with heavy metals, which interfere with the living and working conditions of millions of people along the course of both rivers and threaten ecosystem services and the livelihood of the future generations[2,3].

Based on an analysis of both WA/disasters and global data, we sought to characterize some aspects common to mining tailing dam disasters and current trends. Characteristics and trends which can be extremely dangerous when they become the normal state of affairs and the basis for artificial risk management and abstract trust systems. Our intention is to provide grounds to the discussion on the prevention of such incidents and to contribute to reduce risks and their consequences for the life and health of labor health and the overall population from an intersectoral, and thus interdisciplinary, perspective.

DAM FAILURES ARE NOT SO RARE, BUT THEY BECAME NORMAL IN BRAZIL

While serious WA/disasters involving mining dams seem to be exceptional — because this is what it is expected we come to believe — they are more frequent than what one might imagine. The World Mine Tailings Failures (WMTF) database, which includes data for a little more than 100 years (1915 to 2019), comprises 356 records. Graphic 1 depicts the most serious incidents distributed according to their degree of severity. As is shown, the frequency of incidents in general is increasing, particularly since the 1960s, and that of serious and very serious failures since the 1980s. The number of deaths increased along the 1960s to then decrease in the following decades until the 1990s, when it began increasing again.

Chart 1 describes incidents we selected from the WMTF database as the most serious from the perspective of human



Source: World Mine Tailings Failures[4].

Graphic 1. Dam failures along the period from 1915 to 2019

impacts (more than 10 deaths). Analysis showed that such type of incidents became relatively frequent in recent years, to a total of 27 very serious WA/disasters. The country with the largest number of events is China starting in the 1960s. There are records of more than one incident for two countries only, to wit, South Africa, in 1970 and 1990, and Brazil, in 2015 and 2019. It is worth noticing that the latter was the most serious in the last forty years in terms of immediate fatal victims. Only two WA/disasters involved central countries (the United Kingdom and the United States) in

Chart 1. Major mine tailing dam failures along the period from 1915 to 2019.

Mining company/location	Country	Ore extracted	Construction method	Recorded deaths	Year
Corrego do Feijao, dam I, Vale, Minas Gerais	Brazil	Fe	Upstream	308	2019
Hpakant, Kachin	Myanmar	Jade	N/I	115	2015
Fundao dam, Samarco (Vale & BHP), Minas Gerais	Brazil	Fe	Upstream	19	2015
Zijin Mining, Xinyi Yinyan tin mine, Guangdong	China	Sn	N/I	22	2010
Ajka alumina plant, Kolontar (MAL Magyar Aluminum) #2	Hungary	Al	Downstream	10	2010
Lixi tailings dam, Taoshi, Linfen City, Shanxi (Tahsan Mining Co.)	China	Fe	Upstream	254	2008
Miliang, Zhen'an County, Shangluo, Shaanxi	China	Au	N/I	17	2006
Nandan tin mine, Dachang, Guangxi	China	Sn	N/I	28	2000
Surigao del Norte, Placer (Manila Mining Corporation) 2nd event	Philippines	Au	Water retention	12	1995
Longjiaoshan, Daye iron ore mine, Hubei	China	Fe	N/I	31	1994
Merriespruit, Virginia, (Harmony), no 4A tailings complex	South Africa	Au	Upstream	17	1994
Jinduicheng, Shaanxi	China	Mo	Upstream	20	1988
Huangmeishan	China	Fe	N/I	19	1986
Prestavel mine, Stava	Italy	Fe	Upstream	269	1985
Niujiaolong, Shizhuyuan Nonferrous Metals Co., Hunan	China	P	N/I	49	1985
Bafokeng, Merensky tailings dam	South Africa	Pt	Upstream	13	1974
Buffalo Creek, West Virginia, USA (Pittston Coal Co.)	United States	Coal	N/I	125	1972
Certej Mine	Romania	Au	N/I	89	1971
Mufulira, Roan Consolidated Copper Mines	Zambia	Cu	N/I	89	1970
Iwiny tailings dam	Poland	Cu	N/I	18	1967
Mir mine (Placalnica) Zgorigrad	Bulgaria	Pb, Zn	Upstream	488	1966
Aberfan, South Wales Colliery	United Kingdom	Coal	N/I	144	1966
El Cobre old dam	Chile	Cu	Upstream	200	1965
Huogudu, Yunnan Tin Group Company, Yunnan	China	Sn	Upstream	171	1962
Jupille	Belgium	Coal	N/I	11	1961
Luciana Tailings Failure Satanna	Spain	N/I	N/I	18	1960
Los Cedros, Tlalpujahua, Michoacan	Mexico	Au, Ag	Upstream	300	1937

N/I: not informed.
Source: World Mine Tailings Failures[4].

the 1960s and 1970s. All the others correspond to countries rated peripheral and semi-peripheral from the perspective of the global economy.

According to the Internal Commission on Large Dams (ICOLD) all 221 dam failures along the period from 1915 to 2001 were preventable: "there was technical knowledge to build and maintain tailing storage facilities safely, however, deposition above the permitted volume combined with inadequate management was reported as the main cause of failures"[5].

Bowker and Chambers[6] analyzed 214 tailings storage facility failures between 1940 and 2010. Sixty-seven (31%) serious (>100,000 m^3 and/or loss of life) or very serious (at least 1 million m^3 and/or release that travelled 20 km or more and/or ≥ 20 deaths) failures occurred along the analyzed period. A total of 52 incidents occurred from 1990 to 2010, being 17 rated serious and 16 very serious, i.e., 63% (33/52). The data described in this study evidence an increase in the proportion of serious and very serious failures in the latest decades, which suggests that the incidence of this type of incidents is increasing.

Rico et al.[7] analyzed 145 tailings dam disasters and found that 55.9% of the incidents involved dams with over 15 meters of height and 22% over 30 meters. About 83% of the failures occurred when the dam was active, 15% in inactive and abandoned dams and only 2% in inactive but maintained dams. The method of dam construction that accounted for the highest number of events incidents was associated with the upstream raised method, representing 76% of the cases; downstream and centerline raised tailings dams represented 15 and 5% of the global cases, respectively.

The Vale S.A. B1 dam failure is one of the most serious among several which took place in Brazil between 2001 and 2019[8]. Relative to Samarco (2015) and Vale S.A. (2019) incidents, the dams had been classified as with low risk criterion (RC; documentation complied with the legal requirements and allegedly indicated adequate administration and low probability of accidents) and high associated potential risk (APR; close population concentration and ecological integrity, with consequences in the case of serious failures). The technological method for dam construction was the upstream raised method in both cases, which is the least expensive but also the least safe, as was mentioned above. On the day it broke, the storage capacity of the Samarco dam was about 50 million m^3 [9] and had 106 to 108 meters of height. In turn, Brumadinho dam I measured 86 meters of height and stored almost 13 million m^3 of tailings[10].

The monitoring and alert systems failed in both cases. To make the situation worse, at the Vale S.A. dam in Brumadinho, the company restaurant (with a seating capacity of 200) and management building were located in an industrial area about 1 km away from the dam and could be directly hit in just one minute with no possibility of evacuation whatsoever. On the one hand, the incidents were the outcome of a combination of serious project and operational flaws, managerial and organizational shortsightedness and corporate neglect vis-à-vis the lives of workers and the exposed population and the environment. On the other hand, starting in the 1990s, the government forwent its role in the regulation and supervision of risks in industrial extraction and production. One further factor to consider are the characteristics of the process of privatization of the Doce River Valley in the end of the 1990s. To summarize, the combination of all these factors seemingly contributed to increase the frequency of WA/disasters involving mining dams in Brazil to the point they became almost normal, in addition to resulting in the most serious WA ever in Brazil[11].

RISK ARTIFICIAL MANAGEMENT MAKES THE ABNORMAL BECOME THE NORMAL

WA/disasters do not happen in a void. While they are not rare, they seem to become the routine state of affairs only when they occur within an corporate and governmental context that makes the abnormal become the normal. Thus they represent an instance of what Freitas et al.[12] called "artificial risk management." This is an approach to safety and risk management characterized by actions and processes deployed whenever government agencies and companies want to persuade the population that effective accident control and prevention is assured, at the same time they make their universe less transparent and silence the dissonant voices of workers and trade unions who stubbornly insist that something is wrong.

According to Brazilian legislation for dams (Law no. 12,334, from 20 September 2010), companies are responsible for the safety of constructions and the National Mining Agency and state environmental licensing agencies are charged together of inspecting mining activities. To apply, companies should supply the required information. The problem is that the risk statements provide by

mining companies thus also serve to define the priorities for inspection, which practice affords ideal conditions for companies seeking to evade inspection to distort facts[13].

The audit performed by the Ministry of Labor following the failure of Samarco Fundao dam brought to light an abnormal history of flaws starting at the time of the concession governamental licence and continuing all along the stages of construction, operation and management, resulting a sequence of flaws that conspired to make the structure fragile, eventually leading to its collapse.

Samarco had developed an aggressive policy of production expansion involving shady mechanisms to make the regulatory and concession processes more flexible, increase productivity and a decision to reduce the investment in safety by 44% from 2015 to 2016[14]. The process of environmental licensing for the Fundao dam was extraordinarily rapid: while it started in 2005, the first operation permit was issued in 2008 — it is worth observing that the permit renewal was being reviewed when the dam broke. Several changes in the dam structure had been made from the time the first permit was issued to the time of the incident. Indeed, modifications were made twice, in 2008 and 2015, on each occasion after just a brief licensing process, which, for instance, did not include public hearings. In September 2014, the engineer responsible for the dam project called the attention to a crack that had appeared following the aforementioned changes. In June 2015, Samarco was granted authorization to enlarge the dam to then connect it to the Germano dam, which was also undergoing modifications[15,16].

Following the dam failure, which can be compared to an open fracture in the company, an invisible universe became visible and thus it was revealed that the Fundao dam had a "clandestine" tailings deposition system not described in the licensing documents. This was the result of the activity of its neighbor, Vale S.A. (Alegria Mine), in Mariana, which in 2014 contributed with 28% of the liquid effluents released into the Fundao dam[1]. The investigation by the Ministry of Labor[17] evidenced a variety of problems neglected over a long period of time, including: accelerated growth of 11 meters/year, on average, the highest rates corresponding to 2011 (20 meters/year) and 2014 (14.6 meters/year) while the safe raising range is 4.57 to 9.14 meters/year; high tailings saturation due to deposition above the permitted volume; flaws in the water level monitoring system; insufficient auscultation equipment (set of instruments and methods for observation and control of the safety conditions of dams); flaws in the equipment and draining system.

Four months before the Fundao dam failure, the VOGBR Hydric Resources and Geotechnics engineer responsible for issuing the dam stability report — as required by the National Policy of Dam Safety (Law no. 12,334) — delivered this document after a brief inspection. The report provided guarantees that the dam structure was safe and requested the execution of safety procedures. Yet the report was issued without the due verification of the piezometers (devices used for dam auscultation) in the left abutment, where several anomalies had been detected. These instruments are essential to monitor the conditions of dams. In addition, the equipment map must be included in a risk chart, which companies must keep up-to-date, including records of any changes in structure and height. For no apparent reason, this document was last updated in August 2013 and thus did not include the measurement mechanisms recommended in 2014 by the project engineer after cracks were found in the left abutment[13].

In his statement to the civil police, the VOGBR engineer said he had collected data and the fact he had not analyzed all the available documents had not interfered with the accuracy of his work. Yet upon issuing the report, he observed "Samarco must update the risk chart, [the dam] height is constantly being raised, to a rate of 15 meters in 2014 in up to 11 consecutive stages"[13]. The Federal Public Prosecutor Office (FPPO) considered this report misleading for having been based on an outdated risk chart and the full set of instruments had not been inspected[1].

The Corrego do Feijao mine entered in operation in 1956, being first managed by Companhia de Mineração Ferro e Carvao, starting 1973 by Ferteco Mineração and since 2003 by Vale S.A. The mining plant comprises mineral extraction and processing infrastructure and seven dams, in addition to support and administrative buildings. The B1 dam was classified as with low RC and high APR. In December 2018, Vale S.A. obtained authorization for ore fine recovery from dams I and VI and to increase the mine production capacity. With this, the useful life of the mine could be extended until 2032[18].

The Vale S.A. B1 dam had not received any tailings since 2014 and TÜV SÜD Brasil had issued physical and hydraulic stability reports. According to the consultants, in none of the inspections they had been able to detect any

abnormality in the state of conservation of the dam structure[19]. However, the first investigations pointed to the existence of several cracks, in addition to insistent complaints by the employees'[20]. It was revealed that the management had, indeed, been aware of the ongoing risk and that the TÜV SÜD engineers had received pressure from the Vale S.A. management to issue the aforementioned stability reports.

Both WA/disasters represent as if it were open fractures which afford a glimpse into a universe of abnormalities which became the normal routine in the management of the dam failure risk. A universe in which all governmental regulations notwithstanding, very little or nothing was actually regulated, but the risk assessment companies (VOGBR and TÜV SÜD) — hired by the very originators of such risks (Samarco and Vale S.A.) — attested the latter were "safe." This was the context for the emergence of risk artificial management, according to the aforementioned notion[12].

ABSTRACT TRUST SYSTEMS WITH PLANS AND SIRENS WHICH DO NOT WORK AND SAVE NO ONE

As Giddens[21] observed, modern institutions are deeply intertwined with abstract, or expert, trust systems, which connect local practices to globalized social relations in regard to crucial aspects, such as safety, risk and danger. These abstract trust systems are mediated, made possible and operationalized by public (mining, water, environment and safety and health, among others) and private (national and global consulting firms which provide reports) organizations — and their experts — which role is to make workers and communities at high-risk for disasters feel safe. Within the universe of such abstract systems — which focus is more on promoting trust than on ensuring safety — although most dams should to be classified as with medium-to-high potential risk, the vast majority are actually attributed low RC, whence everybody is made to believe that everything is under control.

One among the legal obligations of companies is to prepare and update a Dam Safety Plan (DSP), as stated in the National Mining Agency Administrative Ruling no. 70,389/2017. As was just said, implementing the DSP is mandatory and it must be prepared before the first filling, when it should be available to the safety staff and public and supervisory agencies. The aim of the DSP is to contribute to the management of the dam safety and must include overall information, plans and procedures, inspection reports, periodic safety reviews and an emergency action plan (EAP) — actually only mandatory for dam structures with high APR or when required by supervisory agencies.

In the case of Samarco, although the environment agency had demanded alert systems as a condition to grant the license, the company continued its operations with full disregard for this requirement. It stated it had developed a plan for continuous monitoring and an EAP, including simulations with the workers and communities[22]. According to the FPPO, the EAP was not activated on the day of the accident, but was flawed, merely intended to meet bureaucratic regulations and just indicated the need for landline telephones to report incidents in areas with poor mobile phone signal[1]. The company had not made simple devices, such as sirens or warning lights, available nor any other means to spread emergency alerts to the permanent or outsourced employees and the downstream communities. There was no effective channel of communication whatsoever and proper training on how to behave in emergencies had not been provided to the people at risk. The number of fatal victims was not larger thanks to the solidarity of workers and local residents alone: were they not to have given the alert through independent means, the number of deaths would have been much higher. Even communities quite far from the dam — the tailings having arriving only 10 hours later, as e.g. in Barra Longa — were not duly alerted.

For its Brumadinho dam, Vale S.A. had formulated a formal EAP and according to the company, training involving emergency simulations, coordinated by the civil defense, had been provided to the community and public safety agencies in June 2018. According to the EAP, in case of an emergency the plan coordinator ought to contact the company's emergency and communication control center (ECCC) which was in charge of sounding the six sirens installed in the neighboring communities to alert the residents to immediately go to preset meeting points[23].

The day of the dam failure in Brumadinho, Minas Gerais, the sirens in the Corrego do Feijao mine were not activated. According to the company, the reason was the "speed of the incident." The siren in question was hit before it could be activated, said the Vale S.A. CEO, after a meeting with the Attorney General[24]. Neither the ECCC was alerted, because at least one of the employees charged

of communication had been killed. A part of the residents complained of lack of precise information on safe and unsafe locations in case of dam failure. In addition, the list with the telephone numbers of the authorities to be contacted in case of dam failure was not up-to-date and the few ones which were, such as the municipal government secretary, were not called.

Artificial risk management goes together with abstract trust systems, especially in the case of expert systems, which involve lay people unaware of the actual risk of dam failure. This corresponds to a large number of permanent and outsourced employees and communities likely to be hit by tailings, who are made to believe that companies do have emergency plans which will be activated in case of disasters and that warning systems will alert all, that companies do report to municipal authorities and that the latter include active civil defense systems working harmoniously with the mining companies, that they are safe and will protected by companies and the government if something goes wrong[21].

Following these WA/disasters, the previously safe system of risk classification used by the supervisory agencies became unsafe and the reports system began to be seen with mistrust by the Public Prosecutor Office. The many and successive episodes requiring evacuation and activation of alert systems after the Vale S.A. WA/disaster at Brumadinho brought into light an open fracture in a risk management approach that seemed, and was, artificial, whence the trust in abstract systems was broken. In Ouro Preto, Nova Lima and Barao de Cocais, among other mining towns, families were suddenly removed from areas which could no longer be held to be safe as a function of the high likelihood of new dam failures.

FINAL CONSIDERATIONS

As we attempted to show in the present article, dam failures are not rare and in Brazil they seem to have become normal, thus bringing into light a universe in which everything that seemed to be under control and safe vanished into thin air. That which seemed to be normal in reporting, licensing and the supervision practice of companies, the shelved emergency plans and the silent sirens, became abnormal. The actual risk management practices failed together with the dams, revealing a world in which risk artificial management — that even allowed for company restaurants to be intentionally built and operate in locations which would not enable saving the life of one single employee — was considered "normal." More than just a dam, the failure encompassed the trust in the entire risk prevention and control system for WA and disasters involving mining dams.

Beyond the 19 or more than 300 deaths in the examples described here, the effects of this type of WA/disasters have long-term impacts on workers and communities over an indefinite time (months or years ahead). In addition to the permanent or outsourced employees who might have been exposed to tailings and their contaminants, hundreds of firefighters participated in rescue operations and there are countless agricultural workers and fishermen who depend on the now contaminated water for their livelihood, to the point it became difficult to distinguish between workers and "the community." They are further exposed to the dust from the dry slimes, which increases the number of cases of respiratory and skin diseases, as in Barra Longa after the Samarco disaster, which should be added to the higher incidence of parasitic diseases, diarrhea and gastroenteritis, anxiety, alcohol consumption, mental health impacts, diabetes, high blood pressure and stroke. Further problems are accidents during reconstruction, violence arising from social disaggregation, arbovirus- and other vector-borne diseases arising from major ecological changes. Beyond the immediate effects, other hazards, harms and diseases emerge over time[25,26].

We hope the lessons learned from these WA/disasters will result in deep changes in our extractivism-based model of development; that environmental and human costs will be effectively taken into account rather than externalized; plans and actions to reduce risks consider the real risks of the process; the environmental injustice and the violations of the workers and communities' rights will no longer be tolerated; incongruence and contradictions in the government and companies' policies and actions will be denounced and faced with effective transparency and the participation of society at large.

Such changes require modifying the current models for the understanding and governance of risks, which involve strengthening government agencies (with the due human, technical and financial resources) and increasing the participation of society through representatives of the exposed

and affected communities, non-governmental organizations, academic institutions and trade unions. From the perspective of the changes required to reduce the risk of WA/disasters in mining dams we suggest:

- Preventing future risk derived from outdated and dangerous technologies in the construction of new dams;
- Reduce the present risk through a broad scoped supervisory task-force and audits of the existing dams;
- Developing effective and safe intersectoral plans with wide participation of workers and communities;
- Developing alert and warning systems which effectively contribute to save lives, including regular training;
- Reinforcing the state of preparation and the response capacity at locations vulnerable to dam-related risks, involving the civil defense, environment, health and social services agencies;
- Ensuring that environmental and health recovery actions are combined with better and safer living and working conditions at the time of reconstruction.

All these processes should include the labor, health, social services, environment, water and mining sectors, full transparency and participation of representatives of workers and dam victim movements.

REFERENCES

1. Brasil. Ministério Público Federal. Força-tarefa Avaliação dos efeitos e desdobramentos do rompimento da barragem de Fundão em Mariana-MG. Belo Horizonte: Secretaria de Estado de Desenvolvimento Regional, Política Urbana e Gestão Metropolitana-Governo de Minas Gerais; 2016. 273 p.
2. Instituto Mineiro de Gestão das Águas. Encarte especial sobre a qualidade das águas do rio doce após 3 anos do rompimento da barragem de fundão 2015-2018. Belo Horizonte: Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável; 2018.
3. Instituto Mineiro de Gestão das Águas. Informativo diário dos parâmetros de qualidade das águas nos locais monitorados ao longo do Rio Paraopeba, após o desastre na barragem B1 no complexo da Mina Córrego Feijão da Mineradora Vale/SA no município de Brumadinho - Minas Gerais. Belo Horizonte: Instituto Mineiro de Gestão das Águas; 2019. 128 p.
4. World Mine Tailings Failures. World mine tailings failures-from 1915 [Internet]. World Mine Tailings Failures; 2019 [cited on Feb. 25, 2019]. Available at: https://worldminetailingsfailures.org/
5. International Commission on Large Dams. Tailings dams: risk of dangerous occurrences: lessons learnt from practical experiences. New York: United Nations Publications; 2001.
6. Bowker L, Chambers D. The risk, public liability & economics of tailings. Stonington; 2015.
7. Rico M, Benito G, Salgueiro AR, Díez-Herrero A, Pereira HG. Reported tailings dam failures: A review of the European incidents in the worldwide context 2008. J Hazard Mater. 2008;152(2):846-52. https://doi.org/10.1016/j.jhazmat.2007.07.050
8. Santos RSP, Wanderley LJ. Dependência de barragem, alternativas tecnológicas e a inação do Estado: repercussões sobre o monitoramento de barragens e o licenciamento do Fundão. Antes fosse mais leve a carga: reflexões sobre o desastre da Samarco/Vale/BHP Billiton. Marabá: iGuana; 2016. p.87-139.
9. Brasil. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Laudo Técnico Preliminar: Impactos ambientais decorrentes do desastre envolvendo o rompimento da barragem de Fundão, em Mariana, Minas Gerais. Brasília: Ministério do Meio Ambiente; 2015.
10. BBC Brasil. Brumadinho: Brasil tem mais de 300 barragens de mineração que ainda não foram fiscalizadas e 200 com alto potencial de estrago. London: BBC News Brasil; 2019.
11. Freitas CMD, Rocha V, Silva EL, Alpino TDMA, Silva MAD, Mazoto ML. Conquistas, limites e obstáculos à redução de riscos ambientais à saúde nos 30 anos do Sistema Único de Saúde. Ciênc Saúde Coletiva. 2018;23(6):1981-96. http://dx.doi.org/10.1590/1413-81232018236.04702018
12. Freitas CM, Porto FM, Machado JMH. Acidentes industriais ampliados: desafios e perspectivas para o controle e a prevenção. Rio de Janeiro: FIOCRUZ; 2000.
13. Serra C. Tragédia em Mariana: a história do maior desastre ambiental do Brasil. Rio de Janeiro: Record; 2018.
14. Prazeres L. Após tragédia em Mariana, Vale reduziu em 44% os gastos em segurança... Uol Notícias [Internet]. 2019 [cited on April. 10, 2019]. Available at: https://noticias.uol.com.br/cotidiano/ultimas-noticias/2019/02/01/tragedia-em-mariana-vale-corta-gastos-seguranca.htm?cmpid=copiaecola
15. Mansur MS, Wanderley LJ, Milanez B, Santos RSPD, Giffoni PR, Gonçalves RJDAF, et al. Antes fosse mais leve a carga: reflexões sobre o desastre da Samarco/Vale/BHP Billiton. Marabá: iGuana; 2016.
16. Freitas CM, Silva MA, Menezes FC. O desastre na barragem de mineração da Samarco: fratura exposta dos limites do Brasil na redução de risco de desastres. Ciênc Cult. 2016;68(3):25-30. http://dx.doi.org/10.21800/2317-66602016000300010
17. Brasil. Ministério do Trabalho e Previdência Social. Relatório de análise de acidente rompimento da barragem de rejeitos fundão em Mariana - MG. Brasília: Ministério do Trabalho e Previdência Social; 2016. 138 p.
18. Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável. Subsecretaria de Regularização Ambiental. Parecer Único nº 0786757/2018. Belo Horizonte: Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável / Subsecretaria de Regularização Ambiental; 2018. 112 p.

19. BBC Brasil. Brumadinho: O que se sabe sobre o rompimento de barragem que matou ao menos 115 pessoas em MG. BBC Brasil; 2019.
20. Movimento dos Atingidos por Barragens. A privatização mata: Análise do MAB sobre o crime da Vale em Brumadinho MG. São Paulo: Movimento dos Atingidos por Barragens; 2019. 25 p.
21. Giddens A. As consequências da modernidade. 5ª ed. São Paulo: Editora da Unesp; 1991.
22. Marshall J. Rompimentos de barragens de rejeitos no Brasil e no Canadá: uma análise do comportamento corporativo. Caderno Eletrônico de Ciências Sociais. 2017;5(1):27-46. https://doi.org/10.24305/cadecs.v5i1.2017.17793
23. Lobel F, Barbon J. Sirenes em Brumadinho estão intactas, ao contrário de discurso inicial da Vale. Folha de S.Paulo [Internet]. 2019 [cited on Mar. 6, 2019]. Available at: https://www1.folha.uol.com.br/cotidiano/2019/02/sirenes-em-brumadinho-estao-intactas-ao-contrario-de-discurso-inicial-da-vale.shtml
24. Rossi A. Tragédia em Brumadinho: Vale diz que sirenes não foram acionadas por "velocidade" do deslizamento. BBC Brasil [Internet]. 2019 [cited on Mar. 6, 2019]. Available at: https://www.bbc.com/portuguese/brasil-47063312
25. Brasil. Ministério da Saúde. Secretaria de Vigilância em Saúde. Relatório final - Estudo sobre o perfil epidemiológico da população de Barra Longa-MG, pós-desastre, 2016. Brasília: Ministério da Saúde/Secretaria de Vigilância em Saúde; 2017.
26. Instituto Saúde e Sustentabilidade, Greenpeace. Avaliação dos riscos em saúde da população afetada pelo desastre de Mariana. São Paulo: Instituto Saúde e Sustentabilidade; 2018.

Correspondence address: Carlos Machado Freitas – Rua General Cristovão Barcelos, 208, apto. 402 – Laranjeiras – CEP: 22245-210 – Rio de Janeiro (RJ), Brazil – E-mail: carlosmf@ensp.fiocruz.br