TEXTE
114/2023

Tailings Management Facilities (TMF) Safety Methodology

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publisher:
German Environment Agency

TEXTE 114/2023

Advisory Assistance Programme (AAP) of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

Project No. 154973

Project: “Improving the safety of tailings management facilities in Kyrgyzstan”

Projekt running time: April 2021 – December 2021

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Imprint

Publisher
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Report performed by:
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Kalinova street,12-13
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Report completed in:
December 2021

Edited by:
Section III 2.3 Safety of Installations
Winkelmann-Oei, Gehard (Fachbegleitung)

Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4804

Dessau-Roßlau, September 2023

This project was financed by the German Federal Environment Ministry's Advisory Assistance Programme (AAP) for environmental protection in the countries of Central and Eastern Europe, the Caucasus and Central Asia and other countries neighbouring the EU. It was supervised by the German Environment Agency.
The responsibility for the content of this publication lies with the authors.

Umwelt Bundesamt

Federal Ministry
for the Environment, Nature Conservation,
Nuclear Safety and Consumer Protection

Abstract: Tailings Management Facilities (TMF) Safety Methodology

The Tailings Management Facility Safety Methodology (hereinafter TMF Safety Methodology) is mainly based on the requirements and principles declared in “Safety guidelines and good practices for tailings management facilities” endorsed by the Conference of the Parties to the UNECE Convention on the Transboundary Effects of Industrial Accidents as well as other comparable international TMF standards. The TMF Safety Methodology is a powerful tool for the process of harmonizing technical standards for the entire life cycle of TMFs throughout the UNECE region. The Tailings Management Facility Safety Methodology, which consists of a Checklist for verifying the actual safety situation of tailings management facilities and the Tailings Management Facility Hazard and Risk Indexes (THI or TRI) for assessment of TMFs on regional, national and international basis.

Based on a strategy of the German Federal Environment Agency (UBA) the TMF Safety Methodology was developed since 2013 within the following projects

- "Improving the safety of industrial tailings management facilities based on the example of Ukrainian facilities" (2013-2015), Report No. (UBA-FB) 002317/ENG, ANH2
- "Raising Knowledge among Students and Teachers on Tailings Safety and its Legislative Review in Ukraine" (2016-2017) on the results of trainings conducted at National Mining University (Dnipro, Ukraine). Report No. (UBA-FB) 002638/E.
- "Assistance in safety improvement of tailings management facilities (TMF) in Armenia and Georgia" (Project No. 83392), according a follow up activity at TMFs in Armenia and Georgia the Methodology has been improved in 2018-2019.
- "Capacity development to improve safety conditions of tailings management facilities in the Danube River Basin – Phase I: North-Eastern Danube countries " (Project No. 118221) 2019-2020.
- Improving the safety of tailings management facilities in Kyrgyzstan (Project No. 154973) 2021-2022.

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BAT	Best Available Techniques
CRF	Credibility Factor
CA	Competent authorities
DRB	Danube River Basin
DRPC	Danube River Protection Convention
EC	European Commission
EU	European Union
FD	Floods Directive
FoS	Factor of Safety
GIS	Geographic Information System
ICMM	International Council on Mining and Metals
ICOLD	International Commission on Large Dams
ICPDR	International Commission for the Protection of the Danube River
IED	Industrial Emissions Directive
JEG	Joint Expert Group
MS	Member States
MSRF	Meeting Safety Requirements Factor
MWD	Mining Waste Directive
PAR	Population At Risk
PGA	Peak Ground Acceleration
PRI	Principles for Responsible Investment
TEI	Tailings Exposure Index
TEIA	Transboundary Effects of Industrial Accidents
THI	Tailing Hazard Index
TMF	Tailings Management Facility
TRI	Tailings Risk Index
UBA	German Environment Agency
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
WFD	Water Framework Directive
WHC	Water Hazard Class

1 INTRODUCTION

Mining is one of the most traditional and historically relevant industrial sectors in the world, providing valuable ores and minerals for further processing. Nowadays it is becoming even more important, as with the spread of smart and advanced technologies, a steep rise of connected mining activities is expected to supply the necessary battery storages with the specific metals needed. However, mining also represents a significant waste stream generated by its operations. One of the many types of the mining waste is the tailings, the fine-grained waste material derived from a mining processing plant and frequently transported by hydraulic methods to and deposited and handled at Tailings Management Facilities (TMFs). Tailings Management Facility is intended to encompass the whole set of structures required for the handling of tailings including the tailings storage facility, tailings dam(s), tailings impoundment, clarification ponds, delivery pipelines, etc.

Different studies estimate the number of industrial mines worldwide as up to 18,000 (Azam and Li, 2010) or even 30,000 (SNL, 2016; Roche, 2017). While there is no publicly accessible global inventory of tailings dams, one reliable estimate has put the number of tailings dams worldwide at about 3,500 (Davies and Martin, 2000).

Ideally, TMFs should ensure the safe long-term storage of fine-grained mineral processing waste. However, TMFs can leak or collapse due to unfavourable natural conditions, design and construction deficiencies and inappropriate operation and management practices. Due to the physical characters and/or chemical nature of substances that can be found in the tailings, but also due to the significant amounts of stored mining waste, TMFs pose a risk to the environment and population. Such risks may be present at all kind of TMFs, including active, temporarily or permanently closed, abandoned or even rehabilitated sites (e.g. long-term chemical pollution).

Over the last two decades, there has been a growing concern about the environmental degradation caused by unintended large-scale movement of hazardous materials related to failures of TMFs. Failures may result in uncontrolled spills and releases of hazardous tailings materials to the environment. These accidental pollution events may have serious acute impacts and direct damages on human health, built infrastructure, economic activities and environmental and natural resources. Pollution of waterbodies very often has a negative large-scale or transboundary effect on environmental resources. Moreover, accidents at TMFs may lead to long-term water and soil pollution and have negative chronic and accumulative effects on human health and the environment. Unintended release of the tailings imposes substantial associated costs on society. The economic cost associated with cleaning up the contamination after a TMF failure can reach hundreds of millions of Euros (UNEP, 1998).

According to Davies (2002), the failure rate of TMFs over the last 100 years is estimated to be more than two orders of magnitude higher than the failure rate of conventional water retention dams (reported as 0.01 %). Important factors that make the probability of TMFs failure higher than that of other earth structures or dams include lack of understanding of behaviour of tailing materials, inappropriate site monitoring and geotechnical investigations (Berghe et al., 2011) and low availability of financial resources. Worldwide, almost 60 major tailings dam failures that caused significant human fatalities and pollution were reported in the period of 2010–2019. The management of TMF safety has not improved significantly and remains a serious problem throughout the world. Major TMF disasters followed by serious consequences still occur quite often and the problem of TMF failures will even further rise if no consistent strategies and measures to improve the TMF safety level are implemented.

One of the most recent examples that included human fatalities was an accident at the TMF in Minas Gerais State, Brazil on 26 January 2019. The incident has become one of Latin America's worst ever mining disasters. This disaster killed 259 people and other 11 remain reported missing. The financial costs are estimated up to 40 Billion of $ the Brasilian State is reclaiming from the operator. It is the second incident of its kind in less than four years as on 5 November 2015, another TMF accident occurred in the same area, killing 19 people. About 60 million cubic meters of iron-rich mud flowed down through several rivers towards the Atlantic Ocean (WISE, 2020).

In China, the Ministry of Environmental Protection responded directly to 56 reported tailings-related pollution accidents in the period of 2006–2014 (Liu et al., 2015). Other major accidents in China include the Zhen'an gold tailings spill in Shaanxi Province in 2006, the Wulong tailings leakage in Liaoning Province in 2008, the Minjiang tailings spill in Sichuan Province in 2011 and the Wantai manganese tailings leakage in Guizhou Province in 2012 (Liu et al., 2015).

The severe environmental damage caused by TMF dam breaching at the Baia Mare gold processing facility in Romania in 2000 is a well-known example of mining disasters. On the night of 30 January 2000, a dam holding contaminated waters burst at the mining works in Baia Mare, and 100,000 m^3 of cyanide-contaminated water spilled into the Someş River (EC, 2000). The polluted water eventually reached the Tisza River and then the Danube River, killing large quantities of fish in Hungary and Serbia and seriously damaging the aquatic ecosystem of the Tisza and the Danube. The lessons learnt from this accident significantly contributed to the improvement of the EU mining waste regulation.

On 4 October 2010, the dam of a TMF of an alumina processing plant located near Ajka collapsed and a huge amount of caustic red mud (almost 1 million cubic metres of liquid waste) was released. The red mud reached via local creeks the municipalities of Devecser, Kolontár, Somlóvásárhely, Somlójenő, Tüskevár, Apácatorna and Kisberzseny and caused significant devastation. In the following days, the red mud contaminated the Torna creek and the valley of River Marcal and River Rába. Through the Torna, Marcal, Rába and the Mosoni branch of the Danube, the alkaline slurry entered the Danube, causing destruction to some extent in all the waters affected. The disaster killed 10 people and almost 150 others slightly or severely injured by the caustic exposure, including both local residents and participants in the rescue operations (Mecsi, 2013). These two TMF accidents were recorded as the most serious failures in the DRB.

Recognising the importance of the TMF accidents, in 2001 the International Commission on Large Dams (ICOLD) announced its conclusion that the frequency and severity of tailings failures were increasing globally (ICOLD, 2001). To keep that recognition in the spotlight, they created a global failures compilation (ICOLD, 2001, 2007).

Many efforts have been undertaken recently by the international expert community to improve TMF safety through the strengthening of the safety requirements, for instance, by putting into practice advanced remediation technologies and modern techniques in mining practices. Achievements in Earth sciences within the field of geological, seismic, hydrological and climate risks have also been considered for the design and operation of TMFs. For example, at the Baia Mare gold processing facility measures were implemented to improve the TMF safety, such us enhancing the planning activities for waste management, assessment and inspection of activities, including the permit/licence issuing process, investment to increase dam safety around the TMF and treatment of mine waters. Although the facility is currently inactive, it has licence for functioning under safe conditions. Nevertheless, TMFs in many countries of Central and Eastern Europe and the former Soviet Union urgently need measures to improve their safety.

Recent accidents clearly demonstrate the necessity of taking actions to improve the safety level of TMFs in order to avoid a high number of serious accidents. Putting in place additional and appropriate preventive and contingency measures at TMFs - at least according to international safety standards - will help and support minimizing of risks and the adverse impacts of accidents to avoid loss of human life and severe environmental impacts. This was also stressed by Santamarina et al. (2019), urging to gain better understanding of the mechanisms of tailings dam failures and to use this knowledge to improve management practices and to make regulations more effective.

Over the medium- to long-term, many more deaths may occur as a result of long-term toxicity in relation to soil or sediment pollution caused by TMF spills, but no direct links to tailings dam failures have been made yet. Also, the financial consequences of TMF failures are incredibly high. Post-accident costs range from a few hundred million of Euros for remediation and clean-up costs to several billion of US Dollars (e.g. the Brazilian Government claimed 40 billion of US Dollars from the Vale mining company after the TMF accident in Minas Gerais State).

Taking into account all of the above, the Federal Environment Agency of the Federal Republic of Germany (UBA), together with the Secretariat of the UNECE Convention on Transboundary Effects of Industrial Accidents, has developed the so-called "Guidelines and Good Practices for Tailings Management Facilities". To support implementation of the document, UBA has developed a Tailings Management Facility Safety Methodology, which consists of a Checklist for verifying the actual safety situation of tailings management facilities and the Tailings Management Facility Hazard and Risk Indexes (THI or TRI) for assessment of TMFs on regional, national and international basis.

About 1,000 tailings management facilities located in the UNECE region are possible object to be checked using this Methodology; training in the TMF Safety Methodology has been conducted in a number of countries, including Ukraine, Armenia, Georgia, DRB, and in Central Asia region – Kyrgyzstan, Kazakhstan, Tajikistan, Uzbekistan.

The TMF checklist is adapted to the legislation, licensing and permitting system, regulatory and technical documents of a particular country, the actual conditions of the location of facilities, other specific conditions and features. Questions of the checklists are differentiated for active and inactive tailings facilities.

1.1 Policy context

On the European level, EU Member States (MS) are obliged to implement the Seveso Directive (EC, 2012) to prevent major accidents involving dangerous substances and to limit the consequences of such accidents. Operators of dangerous facilities storing or processing dangerous substances in quantities above certain thresholds (given for lower and upper tier) have to develop a major accident prevention policy, to implement this policy by a safety management system, to provide safety reports and information on accidents and to elaborate emergency intervention plans for the internal areas of the establishments. Moreover, competent authorities of EU MS are obliged to develop external emergency plans for the surrounding areas of the dangerous plants, to provide the public with necessary information regarding the risks posed by the respective plants, to ensure that appropriate remediation measures are taken in case of accidents and to conduct periodic inspections to check whether technical requirements are fulfilled.

Regarding mining activities, EU MS have to implement the Extractive Waste Directive (EWD, EC, 2006), which aims to prevent or reduce any adverse effects on the environment and any resultant risks to human health as a result of the management of waste from the extractive industries including mineral processing. Operators shall draw up a waste management plan for the minimisation, treatment, recovery and disposal of extractive waste and shall have a permit from the competent authority. Similar obligations to those of the Seveso Directive (safety reports, accident prevention policy, on-site emergency plans, information for the public) shall also be complied with for Category A mining waste facilities.

To ensure enhanced industrial technologies, EU MS have to comply with the Industrial Emissions Directive (IED, EC, 2010). The IED prescribes that authorities need to ensure that pollution prevention and control measures at the relevant industrial units are up-to-date with the latest Best Available Techniques (BAT) developments. The industrial plants covered by the IED must have an environmental permit with emission limit values for polluting substances to ensure that certain environmental conditions and technical standards are met.

In accordance with the EWD and IED, a revised EU BAT Reference Document for the Management of Waste from Extractive Industries was published, presenting updated data and information on the management of waste from extractive industries, including information on BAT, associated monitoring, and developments in them (JRC, 2018). Moreover, the European Commission (EC) recently adopted technical guidelines for inspections of waste facilities in accordance with the MWD (EC, 2020). The guidelines are to be carried out by competent authorities. The inspections are aimed at ensuring that any waste facility has obtained the required permit and complies with the relevant permit conditions. The inspections relate to the different life-phases of the waste facilities.

At large regional scale, Parties to the Convention on the Transboundary Effects of Industrial Accidents (TEIA Convention, UNECE, 2008) of United Nations Economic Commission for Europe (UNECE) have to fulfil obligations related to industrial hazards similar to those of the Seveso Directive. The TEIA Convention aims at preventing accidents that can have transboundary effects and at helping countries to prepare for and respond to accidents if they occur. It also promotes active international cooperation regarding accident risk mitigation. To further support the countries, the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention, UNECE, 2008) and the TEIA Convention established a specific Joint Expert Group (JEG) focusing in particular on transboundary water pollution issues, which are related to industrial accidents. The JEG supports the elaboration of guidelines and checklists and organises seminars and trainings to help countries to develop, improve and harmonise their national procedures and requirements related to safety measures and contingency planning.

To address the rising concerns about TMF safety, the UNECE published the Safety Guidelines and Good Practices for Tailings Management Facilities (Safety Guidelines, UNECE, 2014). These include both recommendations to operators for the safe design of TMFs and to authorities for the legal basis to cover issuing permits for the safe operation of TMFs. The UNECE called on governments of its countries and TMF operators to include and implement these safety guidelines into national regulations and technical standards. In subsequent years however, it became clear that the implementation of the safety guidelines is fraught with difficulties since safety standards are outlined only in general terms.

In response to the need to improve cooperation and coordination between land-use planning and industrial safety procedures, the UNECE decided to develop guidance on land-use planning and the related safety aspects under three UNECE instruments: the TEIA Convention, the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention, UNECE, 1991) and its Protocol on Strategic Environmental Assessment (Protocol on SEA, UNECE, 2003). The Guidance on Land-Use Planning, the Siting of Hazardous Activities and related Safety Aspects was published in 2017 (UNECE, 2017). This document also noticed that the UNECE TMF Safety Guidelines address the need for land-use planning considerations to be considered when evaluating optimum siting of new TMFs, and the need to carry out an environmental impact assessment prior to construction as well as a risk assessment.

Furthermore, following the Brumadinho TMF accident in Brazil, in January 2019, the International Council on Mining and Metals (ICMM), the Principles for Responsible Investment (PRI) and the United Nations Environmental Program (UNEP) initiated a Global Tailings Review to review existing good practices and develop on that basis an international standard for the industry (GTR, 2020).

1.2 Methodology application scope and key definitions

The TMF Safety Methodology is applicable to tailings management facilities (ash storages, sludge storages, slag storages, pools for waste products accumulation including fly ash, slag, sludge and other types), which are moved hydraulically from places of their formation. Such wastes are generated at extraction and enrichment of mineral ores and coal, at large chemical industry (plants), metallurgical enterprises, coke plants, thermal power plants (coal-fired), etc.

The basic terms indicated below are used in this Methodology with the following meaning:

Abandoned TMF site is an area formerly used for mine waste storage operations (an idle/inactive site) that is neglected and whose legal owners still exist and can be located.

TMF **Accident** is a dangerous man-made accident that threatens human life and health, leads to the destruction of buildings, structures, equipment and transportation facilities, disruption of the production and transportation, and affects the environment.

TMF **Closure** is a whole of TMF life process that typically culminates in tenement relinquishment (generally, after a legally binding sign-off of liability). Closure (generally) is deemed to be complete at the end of decommissioning and rehabilitation and where and all current appropriate regulatory obligations have been satisfied.

TMF **conservation** includes the complex of mining, engineering, construction, and reclamation works that ensure safe storage of wastes in the TMF for a certain period.

Primary **dam** is an embankment of soil or overburden intended for space-filling during the first stage of the storage tank to be used for staring liquid waste (tailings, slurries).

Protective **dam** is a dam built within the danger zone to protect the area that may be affected in case of a failure of retaining structures of the storage tank.

Separating **dam** is a dam dividing the tailings pond into separate compartments.

TMF **Decommissioning** is the process that begins near, or at, the cessation of mineral production. This term refers to a transition period and activities between cessation of operations and final closure.

Dewatering is removal of water from water-saturated materials to reach the moisture content, which allows processing dewatered materials by dry excavation/drilling equipment and transportation by mechanical transport.

Drainage system includes the complex of hydraulic structures, equipment and facilities designed for controllable diversion of seepage water through the dam.

Emergency reservoir/tank is a periodically emptied reservoir intended for receiving slurry during a short-term failure of the main hydraulic transportation system or an emergency at the main reservoir/storage.

Emergency situation (Emergency) is a situation formed in a certain territory as a result of a TMF accident, which may lead or led to human casualties, damage to human health or the environment, significant economic losses, and disruption of life activity.

Factor of Safety (FoS) is the ratio of the shear strength (or, alternatively, an equivalent measure of shear resistance or capacity) to the shear stress (or other equivalent measure) required for dam slope equilibrium. If FoS is less than 1.0, the slope is unstable.

Harm is any damage to people, property, or the biophysical, social, or cultural environment.

Hazard is a source of potential harm or a situation with a potential for harm, thus a potential cause of harm. Hazard is a property or situation that, in particular circumstances, could lead to harm.

Hazard class of waste is a characteristic of waste quantifying its potential hazard to the environment and humans due to toxicity.

Hydraulic protection system includes the complex of hydraulic structures (ditches, channels, ponds, etc.) intended for capturing and diversion of surface runoff from the catchment area of the tailings pond.

Hydraulic transportation is the technological process of moving materials by water flow. Depending on how slurry is transported through the pipeline, hydraulic transportation may be driven by gravity only, pressure and gravity, and pressure only.

Hydro-technical structures (HTS) are dikes, the dams protecting storage tanks and reservoirs, low-permeable screens, spillways, water drainage and water discharge facilities, channels, pumping stations for delivery of slurry and circulating water, and other facilities intended for water storage and prevention from harmful effects of liquid waste.

Impoundment bed is the surface of the bottom, natural slopes and upper slopes of the enclosing structures of the TMF below the design mark of their crest.

Injection/filling method is the method to release tailings material through the distributing pipelines to different sections of the tailings pond.

In-situ observations are observations conducted at the TMF to control its parameters; in-situ observations include visual inspection and instrumental measurements.

Lagoon is the area of surface sediments above the water level limited by the dam slope and the water edge in the settling pond.

Level of filling is the average elevation of the surface of tailings materials within the tailings pond.

Liquid waste storage is a reservoir intended for storing industrial wastes delivered by hydraulic transportation, which includes a complex of technologically interconnected structures, equipped and operated in accordance with the design. Depending on waste type and the intended purpose liquid waste storages, include tailings, slurry (slime) storages, industrial wastewater storages, sedimentation tanks, evaporation ponds, fly-ash storages, piles, sludge collectors.

Low-permeable screen is a layer of low permeable materials installed by the placement of appropriate materials (low-permeable clays, sludge etc.) in the impoundment bed.

Maximum water level is the maximum permissible water level at the design mark of the crest of enclosing structures. For stage-by-stage construction of TMFs maximum water level is defined for each stage or the layer of filling the tailings pond.

Monitoring of TMF safety is a set of continuous observations of the TMF state and its environmental impact.

Neglected TMF site is an idle or inactive site that has **not** been closed and has no clear and **obvious** owner but that **may** still be held under some form of title and where all current appropriate regulatory obligations have **not** been satisfied (Fig. 1). **Orphaned** TMF site is abandoned TMF operations or facilities for which the responsible party no longer exists or cannot be located (Fig. 1).

Progressive Rehabilitation is a process referring to the on-going rehabilitation of TMF sites and mineral related facilities **during the operational life** of a facility. Progressive rehabilitation may include works such as re-vegetation of areas disturbed during project development and operations, re-vegetation of abandoned or filled mine waste areas including tailings impoundment areas; removal and/or disposal of any obsolete structures and materials as per a final rehabilitation and closure plan; backfilling of approved underground or surface excavations using mill tailings to reduce tailings impoundment areas; methods to reduce or eliminate soil erosion and stabilization of the site which will facilitate re-vegetation and reclamation; placement of waste rock in the underground workings or open pits, or by covering the waste rock with till or topsoil and then re-vegetating in an acceptable manner, and so forth.

Recycled water supply system is the complex of equipment and facilities for supply of recycled process water within the TMF area.

Rehabilitation (Reclamation) is the return of the disturbed land to a stable, productive and/or self-sustaining condition, taking into account beneficial uses of the site and surrounding land.

Risk is a probability of a defined hazard or damage, and the magnitude of the consequences of the occurrence.

Risk assessment includes risk estimation and risk evaluation.

Risk estimation is concerned with the outcome or consequences of an event/action taking account of the probability of occurrence,

Risk management is the process of implementing decisions about accepted or alternating risks.

Safety level is the index quantifying the probability that harm can become actual. Safety level can be defined as a relative level of risk reduction provided by implementation of technical or organizational safety measures. Safety level serves as the criterion to check the effectiveness of safety measures at the TMF site.

Safety measure is a measure taken to improve inconsistencies with safety requirements revealed by the inspection of the TMF site.

Safety of the TMF is the state of the tailings management facilities, which allows protecting the life, health and legitimate interests of people, the environment, the safe functioning of infrastructure and economic entities.

Settling pond is the pond within the impoundment intended for clarification, accumulation and withdrawal of circulating water.

Sludge is disperse liquid waste generated in technological processes of chemical, metallurgical and other industries.

Slurry is a turbulized mixture of solid particles of tailings materials with water.

Slurry pipeline is the pipeline, channel or tray for slurry transportation. Depending on the intended use there may be main or distribution slurry pipelines.

Coastal **spillway** is a channel-type structure installed in the coastal abutment of the tailings pond or the storage tank to discharge water from a settling pond.

Discharge **spillway** is a structure designed to discharge water from a settling pond.

Starter dam serves as the starting point for embankment construction. The starter dam design specifies the internal and external geometry of the structure, and should include specifications for drainage, seepage control, and in some cases liner systems required to maintain embankment stability and control releases to the environment.

Tailings materials are the fine-grained waste material remaining after the metals and minerals recoverable with the technical processes applied have been extracted. The material is rejected at the "tail end" of the process with a particle size normally ranging from 10 μm to 1.0 mm.

A **Tailings dam (bund wall)** is a tailings embankment or a tailings disposal dam. The term "tailings dam" encompasses embankments, dam walls or other impounding structures, designed to enable the tailings to settle and to retain tailings and process water, which are constructed in a controlled manner.

A **Tailings Impoundment** is the storage space/volume created by the tailings dam or dams where tailings are deposited and stored. The boundaries of the impoundment are given by the tailings dams and/or natural boundaries.

Tailings Management Facility is intended to encompass the whole set of structures required for the handling of tailings including the tailings storage facility, tailings dam(s), tailings impoundment, clarification ponds, delivery pipelines, etc.

Temporary Closure (An **Idle/Inactive** TMF site under **Care and Maintenance**) is the phase following temporary cessation of operations when infrastructure remains intact and the site continues to be managed. The site is still held under some form of title and all current appropriate regulatory obligations for closure have **not** been satisfied. When being maintained in some way with a view to future resumption of operations, such sites are frequently referred to as being under care and maintenance (Fig. 1).

TMF capacity is the amount of waste (tailings materials, sludge) that can be stored in the tailings pond/storage according to the technology accepted in the TMF design. (Another definition: **TMF capacity** is the total volume of the impoundment within the design elevation of the enclosing dam crest).

TMF life cycle is a regular sequential change in the stages of TMF existence; TMF life cycle includes the stages of design, construction, operation, closure and rehabilitation, and after-care.

TMF operator (TMF operating company) is a state, private, or municipal company or other entity/organization legally responsible for the TMF.

TMF owner is the state or private or any other legal form entity, which has the rights to own, use, and dispose of the TMF. The owner of the tailings dump is in most cases the TMF operator (TMF operating organization).

TMF total area is the area of the TMF site within the boundaries of the land lease for storage of tailings materials.

TMF used area is the area limited by the horizontal projection of the tailings pond contours within the area filled in tailings materials.

TMF used capacity is the amount of waste (tailings materials, sludge) that are actually stored in the tailings pond/storage.

Transboundary emergency is an emergency with the damaging factors going beyond the state borders, or an emergency that occurred abroad and affects the territory of the state.

Inundation **zone** is the zone within which flow formed after dam failure moves.

Dangerous **zone** is the zone adjacent to the downstream area of retaining structures; flooding of this zone may lead to catastrophic consequences.

Secured **zone** is an area around the TMF and along the pipelines for slurry and water delivery, within which working, staying people and mechanisms not related to TMF operation is prohibited.

Sanitary-protection **zone** is the area between the borders of the TMF site including the storages of materials and reagents and residential areas.

2 TMF SAFETY METHODOLOGY

As was mentioned above, UBA has developed a so-called TMF Safety Methodology, which is mainly based on the UNECE Safety Guidelines. This Methodology contains three main parts that can help to fight actual TMF safety problems. The first tool that is designed to assess the hazard potential of a TMF is the so-called Tailings Hazard Index (THI). By evaluating TMFs using this index, countries can receive a fast overview on the number of TMFs with the highest hazard potential so that additional safety measures needed at the respective TMFs can be implemented subsequently. It is recommended to use this index to rank TMFs at regional, national and international level. In 2020 - 2021, this THI has been improved by integrating land-use planning aspects into the calculation, and in especially the potential impact of TMF failures to men and environment.

The new index, the so-called the Tailings Risk Index (TRI), therefore provides a basis for Risk Assessment to the population and environment downstream a TMF. Moreover, the risk assessments also have obvious benefits for individual countries to target their limited financial and personnel resources to TMFs according to their risk level. It allows assessment of the risk of a large number of TMFs to prioritize safety measures and land use planning, and is also a good tool for building up a TMF Mining Cadastre system and facilitating an alert-system for contingency measures on the national and international scale.

The third tool of the TMF Safety Methodology is the TMF Checklist, which can be used to assess the safety of individual TMFs. The deficiencies can be compared with a potential measure catalogue and based on recommended short-, medium- and long-term additional safety measures competent authorities might obligate TMF operators to implement. In addition, operators might also use the results for their own safety checks and future investment planning at the site. Proper control of TMF safety requires regular inspections of these objects to be performed according to national regulations, considering international safety requirements and the BAT and offering engineering solutions for sustainable mining and environmental restoration.

More detailed information about each tool can be found in Chapters 3-5.

3 TMF CHECKLIST

As indicated above, one of the main elements of the TMF Safety Methodology is a Checklist for examinations of a minimum set of TMF technical safety requirements, combined with potential technical measures to implement international standards for the safe operation of TMFs (Measure Catalogue). The Checklist allows a detailed evaluation of the TMF safety level to be performed and recommends protective and preventive measures based on BAT.

The Checklist method as the core of the TMF Safety Methodology is based on the requirements and principles declared in the UNECE Safety Guidelines as well as other comparable international TMF standards. Thus, the method is a powerful tool for the process of harmonizing technical standards for the entire life cycle of TMFs throughout the UNECE region. However, it has to be noted that application of the methodology itself can be seen only as one of the first steps that has to be taken to improve the safety of TMFs. Additional steps have to be implemented, as recommended by the Measure Catalogue for short-, medium- and long-term time period.

The Measure Catalogue provides recommendations and measures for all stages of the TMF life cycle largely based on expert recommendations and the revised EU BAT Reference Document for the Management of Waste from Extractive Industries (JRC, 2018). It helps to safely manage TMFs with optimized efforts of competent authorities and operators. It is also a benchmark for the UNECE countries fighting TMF failures and strengthening their mining standard procedures and legislation.

The benefits of application of the Checklist are:

- all interested competent users (competent authorities, inspectors and operators) may work along the same assessment procedure allowing a consistent safety evaluation;
- TMF operators can detect non-compliances with minimum set of the safety requirements as a self-assessment at the TMF;
- all users work with the same Measure Catalogue that is accumulating best available technologies in sustainable mining;
- the checklist methodology is robust in the sense that it returns evaluation results with good reproducibility applied for the same TMF by different competent users.

The Checklist is a practical tool that includes three sub-elements:

- a **Questionnaire** with three groups of questions;
- a **Safety Evaluation Tool** for assessing the TMF safety level and expressing the results of the Questionnaire evaluation in aggregated indicator values;
- **a Measure Catalogue** recommending actions to improve TMF safety.

The questions of the Questionnaire are formulated in such way to encompass the minimum set of the requirements critical for TMF safety, which allows evaluating the TMF conditions. Questions in all groups of the Checklist are sorted by the TMF life cycle and each subsection contains relevant questions applied to the specific stage. Globally accepted stages of the TMF life cycle include site selection and design; construction; operation and management; decommissioning, closure and maintenance (see e.g. UNECE Guidelines).

The Safety Evaluation Tool gives the assessment of TMFs in compliance with applicable safety requirements, generating aggregated indicator values. The Evaluation Matrix evaluates the answers to the questions from the Questionnaire based on a simple scoring system; it includes both **overall** and **categorical evaluation** using specific categories, which allows thorough checking all TMF elements. Besides, the Matrix enables evaluation of uncertainties caused by the lack of data on the inspected TMF.

The application of the TMF Checklist is supported by a Measure Catalogue with short-, medium- and long-term safety measures. The short- and medium-term measures should be based mostly on economic aspects whereas the long-term measures should meet high international safety standards (e.g. ICOLD Guidelines, EU Extractive Waste Directive).

The Checklist is available in Excel format to facilitate its practical use via automatic calculation of the safety level and simple identification of appropriate safety measures.

Separate evaluation tools were developed for three question groups as follows:

- For active sites in one of their life-cycle stage, operating under an approved TOP:
  - "Basic Check" (Section A);
  - "Detailed Check" (Section B);
- For inactive sites which are currently do not have a valid TOP: "Check of Inactive Sites" (Section C).

Questions in each Section (A; B; C) are split in two Groups: the **Group 1** is intended for **visual inspection**, while the **Group 2** is used to **work with documentation**. Visual inspection is mandatory for all three groups.

The "Basic Check" group (Section A) is intended to be used by competent state authorities. The evaluation can be performed based on the analysis of available operator's documentation (TOP, EIA, protocols, and reports of operation etc.) and site visit results within a short period. It provides a general assessment of the TMF safety level and helps to determine the need for more detailed evaluation by using the "Detailed Check" (Section B).

The "Detailed Check" group (Section B) is recommended to be applied by state inspectors and TMF operators in order to evaluate the safety level based on a detailed assessment of the TMF's constituents and conditions. Evaluation can be performed based on the analysis of available design and construction information as well as operation records, supported by additional studies and tests clarifying all TMF parameters and using information via interviews with TMF staff received during site visit.

The objectives of the "Detailed Check" section are:

- assessment of all TMF systems and technical components;
- assessment of all risks/hazards, impacts and potential impacts, linked with TMF construction, operation, closure, and rehabilitation;
- determination of the needs and priorities for taking short-, medium, and long-term measures aiming to improve the TMF safety level.

The safety evaluation with the "Detailed Check" section requires appropriate professional expertise to assess the technical implementation of the executed measures. A Measure Catalogue is attached to "Detailed Check" section to identify recommended measures to be implemented.

The section “Check of Inactive Sites” (Section C) is intended to be used for evaluation of non-active TMFs also including abandoned and orphaned ones. Its aims are to assess inactive sites, set inspection priorities and improve the management at inactive sites. The reason of the separate Section C questionnaire is that abandoned and orphaned TMFs without regular or any kind of inspection and intervention may cause long-term pollution to the surrounding environment (surface- and groundwater courses, habitats, soil).

Within the frame of the Kyrgyz project, the Section B questions have been revised and better adjusted to conditions of the Kyrgyz mining industry, considering geomorphological, seismic constrains, specialties of mining waste types (e.g. high share of radioactive wastes). In addition, structural changes were recommended by the training participants, and it was suggested to amend the evaluation tool regarding the acceptability of the results and to make it more articulated. In response to these requested changes, the site visit part (Group 1) of the “Detailed Check” section (Section B) has been fully revised and updated along with an amended evaluation tool.

Detailed documentation on the “Basic Check” (Section A) and “Check of Inactive Sites” (Section C) can be found in former project reports (UBA 2018, UBA 2020a). The revised and updated “Detailed Check” section (Section B), as a standalone tool for TMF safety assessment, is described in the following chapters.

3.1 Detailed Checklist for operating TMFs

The objective of the “Detailed Check” section (Section B) is to assess the status of the TMF through the answers according to specific categories and criteria. Thorough and comprehensive analysis of TMF safety is to be made through answering the questions of. The “Detailed Check” section should be used along with a thorough documentation check and site visit and implies further deskwork on computer by filling out the TMF Checklist. Based on the assessment submitted, the authorities can make a counter check if required.

The “Detailed Check” section should be used by experienced inspectors and personnel. It can also be used for advanced training programs. It is recommended to use this checklist primarily for operating TMFs with higher THI or TRI scores to improve safety conditions, but also in response to changes of regulatory requirements, implementation of new technical processes, construction upgrading. Moreover, it can be useful for assessing safety level in the light of after-effects and lessons of accidents occurred at similar facilities.

As indicated above, the Checklist tool has three technical components: a Questionnaire, a Safety Evaluation Tool, and a Measure Catalogue. The Checklist has been composed in MS Excel (see the file "Checklist Tool.xlsx" attached to this report) in order to facilitate simple data processing and an automatized evaluation procedure.

3.1.1 Questionnaire

The "Detailed Check" section includes the groups "Detailed Visual Inspection" (Group 1) and "Detailed Document Check" (Group 2). The application of both groups is required for complete and reliable evaluation of the TMF safety level.

Group 1 contains 38 questions while Group 2 comprises of 223 questions. Both groups cover the three main phases of the TMF’s entire life cycle from design & construction phase through operation & management to closure & maintenance. Each of the main phases is further subdivided into several categories allowing the assessment of TMF safety according to different planning, technical and operational aspects besides the overall safety evaluation. The categories and the number of questions falling into them for both groups are presented in Table 1.

All Checklist questions are to be answered by choosing one of five alternative options:

1. “Yes” is applied if there are enough data or sufficient information to give the positive answer.
2. “No” is applied if there are enough data or sufficient information to give the negative answer or if there is no information at all to answer the question.
3. “Mostly yes” is applied if there are no enough data or sufficient information to give the definitive answer (“yes” or “no”) but there are more arguments to accept the positive answer “yes” rather than “no”.
4. “Mostly no” is applied if there are not enough data or sufficient information to give the definitive answer (“yes” or “no”) but there are more arguments to accept the negative answer “no” rather than “yes”.
5. “Not applicable” is chosen if the question is not relevant for the assessed TMF or situation.

Table 1. Structure of the "Detailed Check" questionnaire.

TMF life cycle phase/category	Group 1	Group 2
Design and Construction phase		
Hazard Identification and Risk Assessment		26
Environmental Impact Assessment and Land-use Planning	3	21
Emergency Planning		6
Design Documentation and Permitting	3	30
Organisational and Corporate Management		6
Operation and Management phase		
Dam Raising Operations and Tailings Control	9	5
Water Management	8	13
Transportation and Infrastructure	5	6
Training and Personnel		18
Organizational and Corporate Management		17
Emergency Planning	3	26
Monitoring of Infrastructure Elements and Processes	5	12
Monitoring of Environmental Elements	2	13

TMF life cycle phase/category	Group 1	Group 2
Closure and Maintenance phase		
Closure and Rehabilitation Plan		12
Organizational and Corporate Management		8
Monitoring of Infrastructure Elements and Processes		2
Monitoring of Environmental Elements		2
Total	**38**	**223**

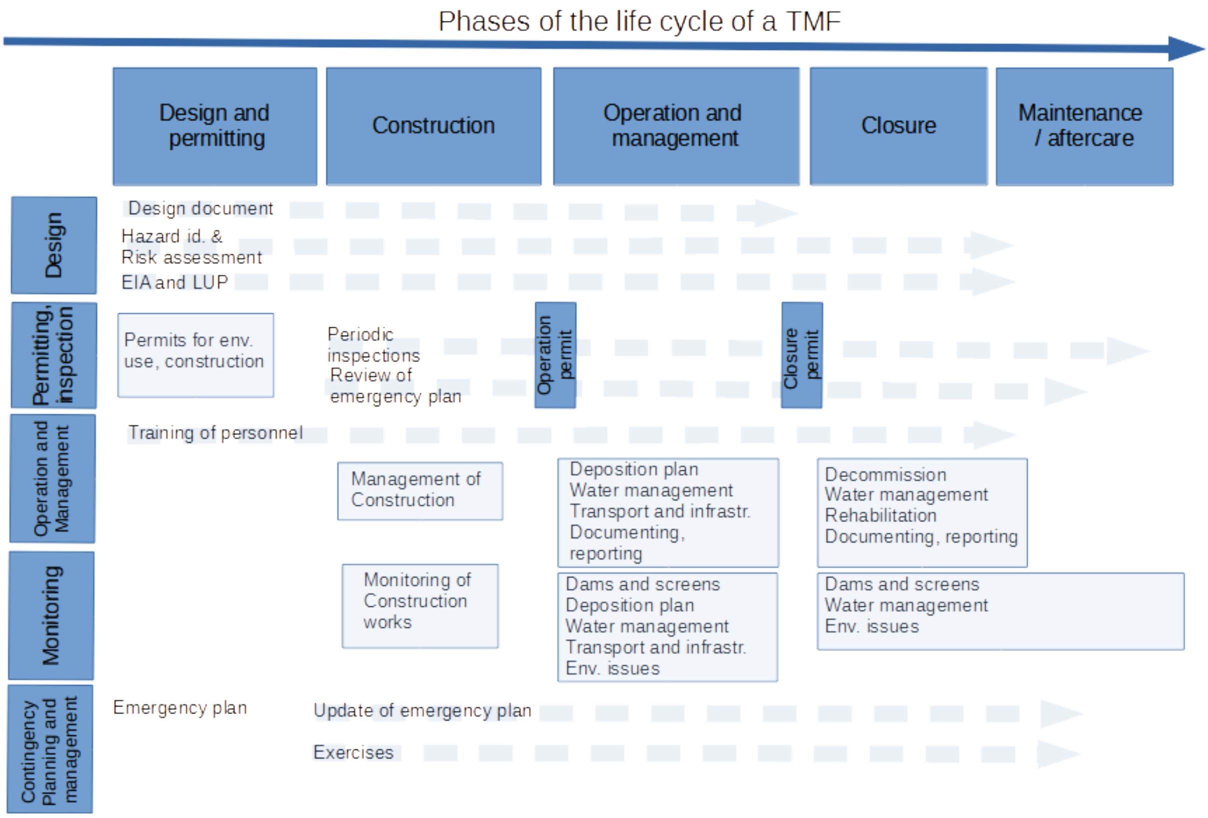
Each question is formulated in a way that the positive answer “yes” is interpreted as the maximum level of TMF safety, whereas the negative answer “no” is considered as the minimum level of TMF safety for the given question. The ambiguous answers “mostly yes” and “mostly no” allow the Checklist user to be flexible in evaluation, considering availability and credibility of data sources.

Group 1 questions have to be answered based on a site visit covering all critical components of the TMF. Consultation with the TMF operators during the visit is highly recommended, for answering several questions it is necessary. Areas, which cannot be visited personally shall be investigated by drone recording.

Answering Group 2 questions need to have access to the TMF design documentation, operational manual, emergency plans and regular monitoring and safety inspection reports.

It is important to mention that during different phases of the life cycle of a TMF, the set of applicable questions will change according to the tasks, documents and TMF components relevant to the given phase. This relationship is shown in figure 1.

Figure 1. Tasks, documents and elements of a TMF relevant for assessment in the different phases of the TMF life cycle



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3.1.2 Safety Evaluation Tool

Quality assessment of the TMF safety level is performed with the Safety Evaluation Tool, which is found in the worksheets adjacent to the Questionnaire worksheets. For both Group 1 and Group 2 as well as for the entire questionnaire **an overall** and **a categorical safety level evaluation** is performed automatically, based on aggregated numerical values from the answers to the Checklists.

The overall evaluation of the TMF safety level summarizes the numerical aggregated values of all answers to the Checklist questions. It identifies the TMF state and quantifies the priority of recommended interventions and remedial actions.

The categorical evaluation is additional to the overall evaluation, it demonstrates the TMF safety from different aspects – tasks managed by staff and condition of major TMF components – and provides details of TMF performance and conditions.

In the first step, each answer is numerically evaluated using the same scoring system. The numerical evaluation is based on the answer given to the question, converted to values presented in worksheets „Group 1 Questions“; „Group 2 Questions“. Conversion of answers to numeric values is given as explained in Table 2.

Table 2. Numerical evaluation of the answers.

Answer	Numerical value
"Yes"	4
"Mostly yes"	3
"Mostly no"	2
"No"	1
"Not applicable"	0

The score for a question is determined with the following weighting function:

$$S = A \cdot f_w \tag{1}$$

where S is the score of the answer, A is the numerical value of the answer based on visual inspection or document check and f_w is the question weight.

Questions considered more critical on technical safety requirements of the TMF operation are which may lead to an emergency situation in case they are not met. Critical questions are assumed to have double the significance compared to a general question, so the question weight is 1 for general questions and 2 for critical questions.

3.1.2.1 Overall evaluation

In the second step, the TMF safety performance is evaluated by using two factors that are quantified from the answer scores of the individual questions. The factor "Meeting Safety Requirements (MSR)" is the index quantifying how many components and parameters of the inspected TMF meet the minimum set of requirements of environmental and industrial safety. The factor "Credibility (CR)" is the index quantifying the robustness of answers – based on sufficiency and consistency of data – used for the performance evaluation (Checklist).

The MSR is calculated by summing up the scores of the quantitative answers and relating it to the sum of the maximum scores for both groups:

$$MSR_{tot} = \frac{MSR_1 + MSR_2}{2} = \left(\frac{\sum_{i=1}^{N_1} S_i}{\sum_{i=1}^{N_1} S_{i,max}} + \frac{\sum_{j=1}^{N_2} S_j}{\sum_{j=1}^{N_2} S_{j,max}} \right) \cdot 0.5 \tag{2}$$

where MSR_{tot} is the overall MSR factor, MSR_1 and MSR_2 are the MSR factors for Group 1 and 2, N_1 and N_2 are the number of questions of Group 1 and 2, S_i and S_j are the answer scores for question i and j, $S_{i,max}$ and $S_{j,max}$ are the maximum answer score for question i and j (value 4 is to be applied for general questions, value 8 for critical questions), i and j are the indexes of the questions in Group 1 (i) and 2 (j). Questions answered "not applicable" are not considered in the MSR calculation.

Giving definitely positive answer ("yes") to all questions makes the MSR value equal to 100%. Answers with "no" will decrease the overall score proportionally. Theoretically, answering all questions with "no" will result 0% MSR value. If an ambiguous answer ("mostly yes" or "mostly no") is given to some (but not all) questions, then the value of the MSR will also be less than 100% indicating deficiency in comparison to the expected technical standards.

The CR is calculated by summing up the number of the definitive answers ("yes" or "no"), which is then divided by the number of relevant questions (total number of questions minus not applicable questions) for both subgroups:

$$CR_{tot} = \frac{CR_{tot,1}+CR_{tot,2}}{2} = \left(\frac{N_{def,1}}{N_{rel,1}} + \frac{N_{def,2}}{N_{rel,2}}\right) \cdot 0.5 \qquad (3)$$

where CR_{tot} is the overall CR factor, $CR_{tot.1}$ and $CR_{tot.2}$ are the CR factors for Group 1 and 2, $N_{def,1}$ and $N_{def,2}$ are the number of definitive answers ("yes" or "no") in Group 1 and 2, $N_{rel,1}$ and $N_{rel,2}$ are the number of relevant questions (all answered except "not applicable" ones) in Group 1 and 2.

The more definitive answers are received, the higher the CR becomes and thus, ambiguous answers decrease this factor. A CR value of less than 100% means that there are ambiguous answers for some Checklist questions. Answering either only positively or only negatively to all questions makes the CR value equal to 100% for both cases, although the MSR values would be different (100% and 0%, respectively). Theoretically, if all answers are ambiguous ("mostly yes" or "mostly no") the value of the CR will be 0%.

The overall evaluation primarily considers the TMFs' safety status based on the factor "MSR". The MSR has to be 100% to reach the full compliance with standards, meeting the "Acceptable" safety level. In case the MSRF is less than 100% but only "yes" or "mostly yes" answers were given, the assessment will be "Acceptable with conditions", indicating that some of the questions with ambiguous answers need to be further investigated. In all other cases, the assessment will result in "Non-compliant" safety level indicating that some of the standards are not met and the reliability of the information sources needs to be improved.

Answers to four dedicated questions from the Group 1, namely Q21, Q23, Q27 and Q30 should have definitely positive ("yes") answer to avoid the "Non-compliant" qualification status. These four "killing questions" have specific importance to dam stability and cannot be answered as not relevant. Therefore, if any of these questions does not receive the "yes" answer, the status of the TMF safety shall be considered as "Non-compliant".

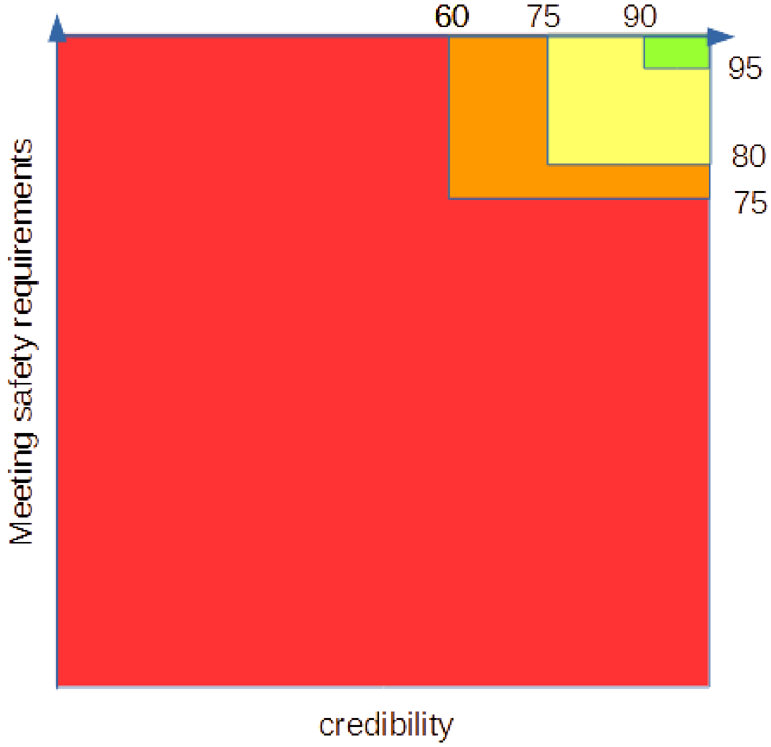
On the other hand, low CR values indicate the lack of appropriate data or signs of minor deterioration which by the time could led to more serious problems affecting the TMF safety level.

In cases where the TMF safety level is evaluated as "Acceptable with conditions" or "Non-compliant" it is recommended to develop an action plan along with a financial plan to improve TMF safety based on the appropriate measures listed in Measure Catalogue. The evaluation report along with the action plan may be valuable information for the TMF operators and the competent authorities in terms of measure implementation in line with the respective national legislation and the required financial resources.

Recommended categories of acceptability and action plans based on MSR and CR values are as follows (see also Figure 2.):

- Green: MSR>95%; credibility > 90%: Acceptable with conditions, improvements recommended,
- Yellow: MSR>80%; credibility > 75%: Acceptable with conditions, short-term improvements recommended, mid-term action plan should be developed or revised,
- Orange: MSR>75%; credibility > 60%: Acceptable with conditions, short-term improvements strongly recommended, mid-term action plan should be developed or improved,
- Red: MSR<75%; credibility < 60%: Non-compliant, short-term actions are required.

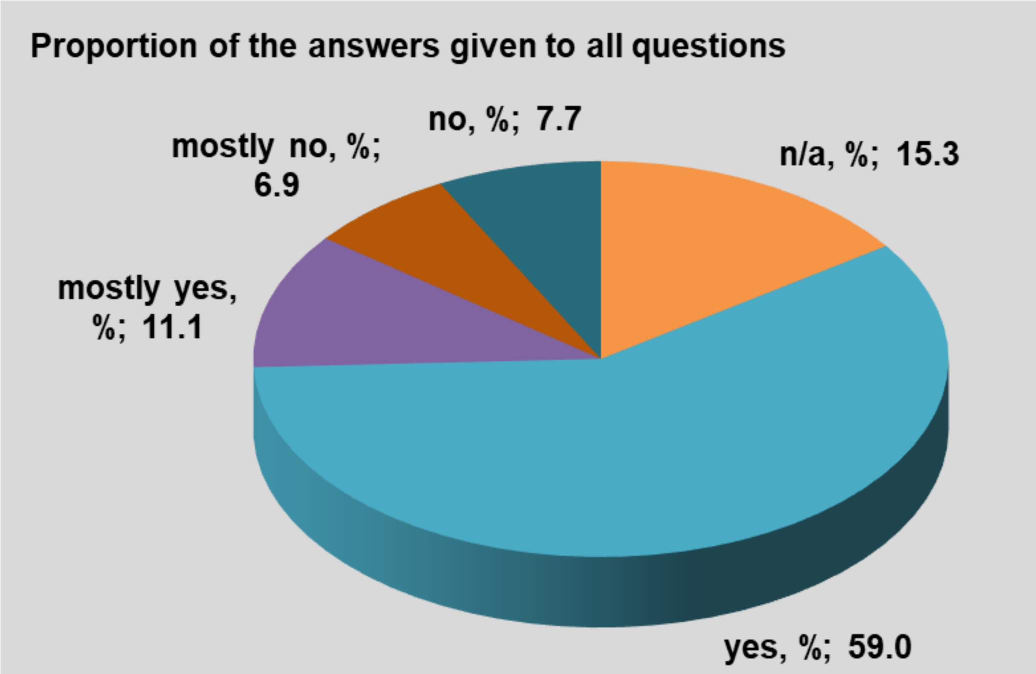
Figure 2. Categories of intervention based on the results of MSR and CR values (%)

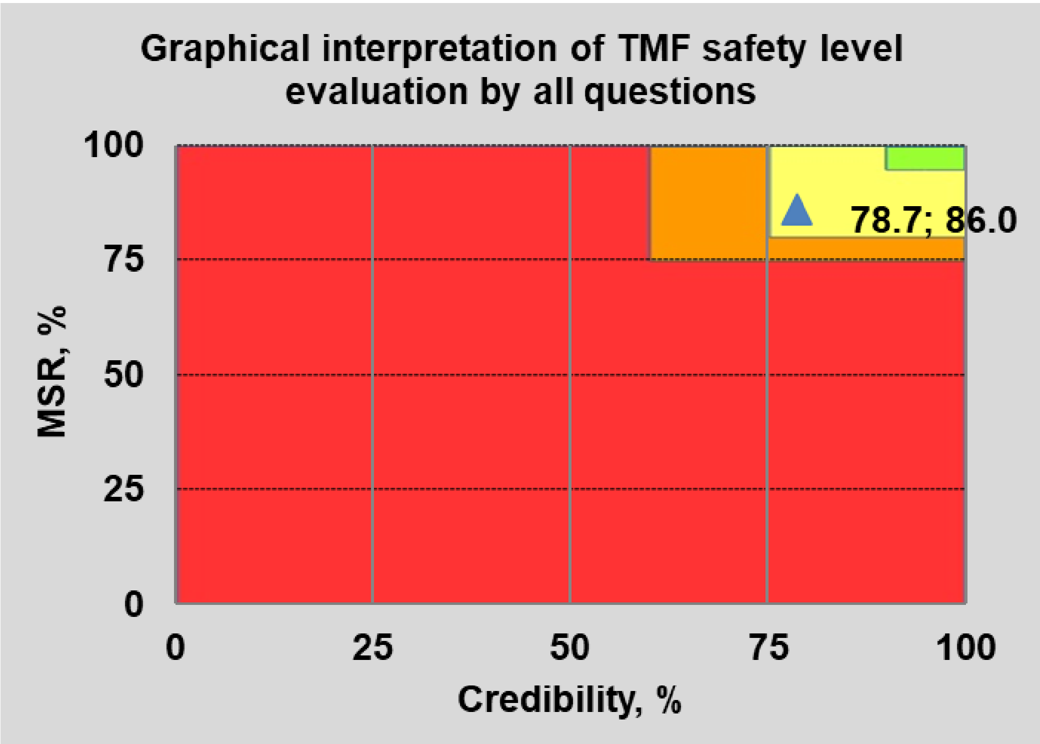


Source: own illustration

Assessment results (distribution of the answers, MSR and CR values for the Groups and the overall questionnaire) are automatically presented in summary tables and diagrams in the checklist tool (see Figure 3). They are automatically generated once all questions are answered.

Figure 3. Overall evaluation of the Checklist answers





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3.1.2.2 Categorical evaluation

Evaluation of the TMF safety level using the questions of the Group “Detailed Check” is based also on independent assessment of question subsets falling into several categories. Questions in Group 1 and 2 originally categorized according to the life cycle of the TMF are redistributed in the categorical assessment relevant to different tasks and TMF components (see also Figure 1.) The categories listed in Table 3 cover all major aspects of TMF performance, management, technical properties, and site conditions. In total, 8 categories are defined for Group 1 and 12 for Group 2.

Table 3. Question categories according to various TMF management aspects

Categories	Abbreviation	Group 1	Group 2
Hazard Identification and Risk Assessment	HRA		26
Environmental Impact Assessment and Land-use Planning	EIA-LUP	3	21
Emergency Planning	EMP	3	32
Design Documentation and Permitting	DDP	3	30
Organisational and Corporate Management	OCM		31
Dam Raising Operations and Tailings Control	DRO	9	5
Water Management	WTM	8	13
Transportation and Infrastructure	TRI	5	6
Training and Personnel	TP		18
Monitoring of Infrastructure Elements and Processes	MIP	5	14
Monitoring of Environmental Elements	MEE	2	15
Closure and Rehabilitation Plan	CRP		12
Total		**38**	**223**

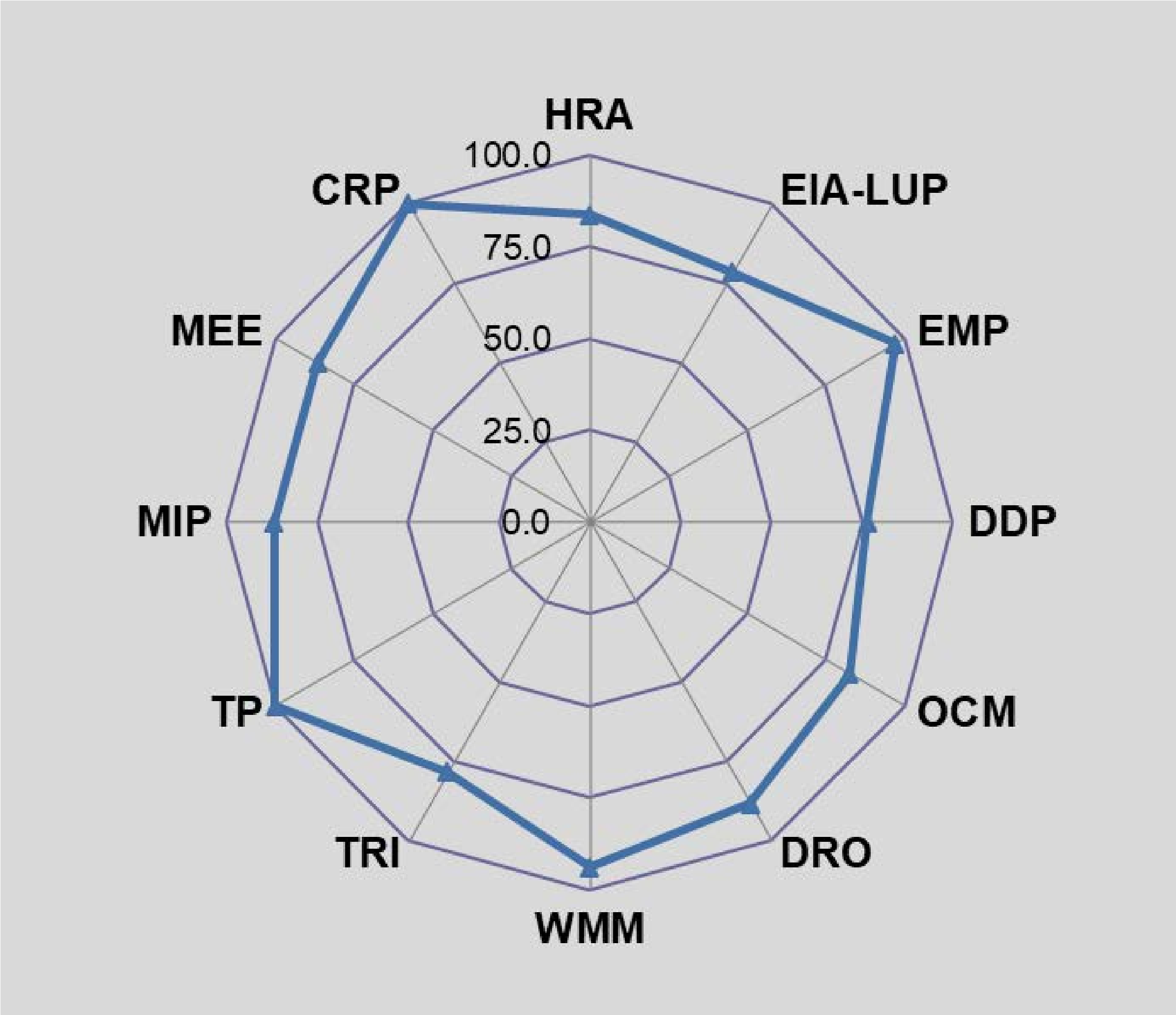
Categorical evaluation of the TMF safety level is performed by calculating the MSR for each categories separately with Equation (4), where k refers to the defined category (see Table 3), N_1 and N_2 refer to quantity of questions falling into the defined category in Group 1 and 2, respectively. For those categories, which have questions only for Group 2, the MSR value calculated for Group 2 ($MSR_{2(k)}$) is used.

$$MSR_{cat(k)} = \frac{MSR_{1(k)} + MSR_{2(k)}}{2} = \left(\frac{\sum_{i=1}^{N_1} s_{i(k)}}{\sum_{i=1}^{N_1} s_{i(k),max}} + \frac{\sum_{j=1}^{N_2} s_{j(k)}}{\sum_{j=1}^{N_2} s_{j(k),max}} \right) \cdot 0.5 \quad (4)$$

Assessment results (MSR values by categories for the Group 1 and 2 and the overall questionnaire) are presented in summary tables and spider diagrams in the checklist tool. They are automatically generated once all questions are answered.

Evaluation worksheets for Group 1 and 2 contain a pivot table which collects data from the questions summary table (raw data, columns O-W) and redistributes data to category evaluation and overall evaluation tables. The pivot table should be refreshed after each modification in the Questions worksheets, otherwise the overall and categorial evaluation tables as well as the diagrams will show false values.

Figure 4. Categorical evaluation of the Checklist answers



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3.1.3 Measure Catalogue

The Measure Catalogue includes a list of actions recommended to be taken in cases where non-compliance of TMF conditions with current safety requirements or regulations has been identified. Experts should determine the appropriate actions for each problem detected at the TMF.

The Measure Catalogue is based on expert recommendations in sustainable extractive waste management and modern and advanced safety standards, in particular the respective BAT Reference Document (JRC, 2018), guidelines and recommendations provided by Cambridge (2018) and the EU technical guidelines for inspections (EC, 2020). The list of measures is recommended to be updated permanently in line with the advanced technologies, reviewed standards and application experiences.

The measures cover all phases of a TMF's life cycle, and they are grouped to solve specific problems (non-compliances) detected during TMF evaluation. The measures are further specified according to their priority and time horizon (short-, mid- and long-term).

The detected problems are certain non-compliances between applicable safety requirements and the actual state of TMF components or parameters. Each question of the questionnaire refers to a certain problem in the Measure Catalogue to which some solutions are proposed.

Actions are recommended for all questions that are not answered 100% positively (answers “no”, “mostly no”, or “mostly yes”). The proposed measures are one or more actions aiming to improve the TMF safety level. There can be several measures proposed to solve or mitigate the same problem. The user can select the most appropriate measures for the specific case considering TMF and site-specific features.

Each measure is specified in the Measure Catalogue by the number of the problem detected and by a capital letter indicating the recommended action, such as 3A, 21D, etc. The questionnaire makes clear references to these measures so that the questions are explicitly linked to measures to be implemented in cases where non-compliance is identified. The measure priority depends on the urgency and costs of the proposed actions and can be defined as short-, mid-, and long-term interventions. These measures are classified in Table 4.

Table 4. Measure priorities.

Duration	Aim and standards applicable	Resources	Recommended terms[1]
Short-term measures	Urgently reconcile inconsistencies with safety requirements at the TMF according to national[2] technical standards	Available resources of the TMF operator; sufficient to provide low-cost measures or actions	To be completed not later than 3 months after prescription
Mid-term measures	Reconcile the inconsistencies with safety requirements that need some months for geotechnical or technological implementation according to national[2] technical standards	Available resources of the TMF operator and external sources; the measures shall be justified by “cost-effectiveness” criteria	To be completed not later than 1 year after prescription
Long-term measures	Technical upgrade of the inspected TMF to meet the safety requirements or recommendations regarding the implementation of modern international standards for industrial and environmental safety	Available resources of the TMF operator and external sources including governmental sources; the measures shall be justified by “cost-effectiveness” criteria	To be completed no later than 5 years after prescription

[1] This limitation can be changed in case of emergencies, accidents and for other important reasons.

[2] International standards are applied if no national standards to a specific issue are available.

3.2 Evaluation procedure

The Checklist should primarily – but not exclusively – be used for those TMFs considered unsafe based on preliminary hazard or risk assessments (e.g. the THI or TRI methods). These high priority sites should be first investigated by applying the Detailed Checklist (Section B) to assess the TMF safety level.

In order to accomplish the evaluation procedure, the Checklist user should first develop a TMF Evaluation Program. Checklist user can be a legal or natural person who must meet the criteria laid down by national law for being competent to perform the TMF Evaluation Program. The Program should cover all work-phases resulting in the evaluation of the TMF safety level and should include a well-defined and realistic timeline.

The Program should involve the following work-phases:

1. Preliminary check of the availability and accessibility of all relevant information on the TMF,
2. Visiting the TMF site for visual check (Group 1),
3. Checking the TMF documentation (Group 2),
4. Evaluation of the Checklist and reporting on the results.

3.2.1 Preliminary information check

Prior to start applying the Checklist, the user must be familiar with the company and the TMF being evaluated. For this reason, a request should be sent to the TMF operator with a template to be filled in to indicate what information is available about the TMF and its operation. The operators should provide a summary for each item of the template along with a list of available documentation. The template should include the categories indicated in the Table 5.

Table 5. Categories for preliminary information check.

No	Requested information (categories)
1	Technical information and design documentation: flowcharts, description of the production process used at the enterprise, specification of input raw materials, chemical composition and physical properties of tails, tailings deposition technology in details.
2	Geographical site information: climate conditions, including weather extremes, precipitation and flood statistics
3	TMF Deposition Plan: maps, schemes, cadastral boundaries, adjacent infrastructures
4	Geological and hydrogeological conditions: seismic activity, landslides, faults, karst areas, soil properties, groundwater regime, etc.
5	Ecology and environment: flora, fauna, water and land ecosystems
6	Social environment: location, condition and size of communities and settlements; land use, access to the TMF territory
7	Risks to: surface water bodies, groundwater, air, soils, and biota
8	Stored material: hazardous substances and materials stored in the TMF
9	TMF history: construction and operation periods, contractor(s), accidents occurred.
10	TMF management system and bodies/persons responsible for TMF operation/maintenance

If any part of this information is not provided without written justification of the TMF operators, the Checklist user should assume the worst-case scenario and evaluate the TMF safety level as "Unacceptable conditions" due to lack of necessary data. The Checklist user must submit an appropriate report to the competent authorities drawing attention to the following conditions:

1. the TMF site was preliminarily evaluated to have a high level of accident hazard (THI or TRI indexes are high relative to country or international average), therefore a detailed investigation is urgently needed;
2. the recommended detailed investigations cannot be performed because of limited information accessible from the operator;
3. danger of an accident event with possible dramatic consequences may exist due to potentially missing safety measures;
4. an authority inspection has to be urgently executed followed by taking immediate actions where necessary.

3.2.2 Site visit

Visual inspection and the related safety evaluation should be carried out according to a site visit plan that includes the necessary steps for using the Checklist methodology. The site visit plan should be based on studying the preliminary information provided by the TMF operator, should include a work plan on the site and should indicate a preliminary list of documents requested for evaluation. Site visit plan can be done on the aerial photo (e.g. high-resolution satellite image) of the site. The person or group doing the inspection should define the places where the observations regarding the given question form Group 1 questions can be completed and whether consultation with the competent representative of the operator is required to answer this question. Preparation of a simple table with questions, how to observe and where, indication of observation points is very useful to the site visit plan.

Before the visit, the elaborated site visit plan should be discussed with the competent representative of the operator to secure the accessibility, technical and personnel support.

During the site visit, the Checklist user can immediately fill in the Group 1 questionnaire as much as possible. Building a close and open dialogue with the operators is highly recommended to ensure transparency and to avoid any misunderstanding or hiding unfavourable operation conditions. The better they understand the aim of the site visit and are involved into the evaluation, the higher the acceptance of the evaluation results is. Bilateral discussions, meetings, staff interviews can support the smooth information exchange.

Using drones with high-resolution cameras, photo shooting, and appropriate remote-control equipment are strongly recommended for visual inspection of hard-to-reach parts of the TMF but being critical to its safety. The video and pictures recorded should be used as evidence in the evaluation of visual inspection results.

If the inspection is actively prohibited by the operator through hindering discussions with TMF personnel, groundless denial of inspecting any of TMF parts (especially those are critical for safety) or by prohibiting the use of drone, the Checklist user has to suspect a serious problem, which could result in a TMF failure. In this case the Checklist user should assume the worst-case scenario and evaluate the TMF safety level as "Unacceptable conditions" due to insufficient site visit conditions. Similar to the preliminary check, an authority inspection has to be urgently executed.

3.2.3 Document check

Answering the Group 2 questionnaire requires comprehensive deskwork based on the available TMF documentation and additional information received from the company (e.g. interviewing, photos). The document check can be either combined with the site visit if the operators can accept a longer stay for the Checklist user visitors at the TMF or can be accomplished after the site visit using copies of the documents made available by the TMF personnel.

The following documents are required at least:

- Licensed design documentation;
- Environmental impact assessment and risk assessment;
- Operational manual, waste management plan;
- Monitoring reports or logs on technological, ecological and environmental parameters;
- Certificates of qualification and staff training;
- Management documents;
- Internal and external emergency plans where relevant.

3.2.4 Evaluation and reporting

The filled in Checklist is automatically evaluated resulting in overall and categorical evaluation parameters and a selection of necessary measures for improving the TMF safety level. Based on evaluation results, the Checklist user should compile a report on the work performed and the safety conditions of the investigated TMF. The report should summarize the results of the TMF safety level evaluation, the problematic aspects/TMF areas detected by the evaluation, all decisions on further actions required to implement the recommended measures (timing, resources, efforts) and the procedures for controlling the actions/measures to be implemented (resources, timing). Supporting documentation (maps, photos, video records, meeting summaries) should also be attached to the report.

3.3 Practical test at the Altynken TMF in Kyrgyzstan

In the framework of the Kyrgyz TMF project, a regional demonstration training event was organised in 27-29 September 2021 in Bishkek and at the Altynken TMF site for invited national and international TMF operators and environmental inspectors. The training event included theoretical lectures on the TMF Safety Methodology in Bishkek, site visit and field exercises at the Altynken TMF site (Taldybulak Levoberezhniy deposit) and desk exercises to test, discuss and amend a detailed checklist (again in Bishkek). In total, 35 trainees from Kyrgyzstan and Kazakhstan, and 5 trainers, international experts and project partners participated in the training event.

The major objective of the training was to demonstrate the applicability of the Checklist to the trainees, understand the qualifiers based on visual assessment, use of the Measure catalogue and assess the safety conditions of the TMF, applying Group B section of the checklist. For these objectives, the Altynken TMF commenced in 2015 became a feasible site with high-level safety standards, equipped and designed to meet BAT requirements.

On the first day, a comprehensive programme of lectures was provided to familiarise the participants with the Checklist as well as with examples of signs of deterioration of TMP components. In addition, a site visit was organised to the Altynken site on the second day to test the Group 1 part of the checklist designed for visual inspection. During the site visit, participants were divided into two groups and each group performed a separate inspection on the facility. The trainees had their own checklist and answered the questions independently. Each group was accompanied by two trainers and local TMF operators who provided explanations of the questions. Finally, a practical evaluation exercise on the third day completed the training programme. The site visit work was supported by an itinerary indicating the issues and number of questions which can be observed at the current stop. On the third day of the training, participants evaluated the overall and categorical safety conditions of the TMF, compared the results of the visual inspections, exchanged their impressions on the site visit and provided recommendations on how to improve the Checklist. The outcomes of the training event significantly contributed to the revision and update of the Checklist, in particular the questionnaire and the measure catalogue.

Evaluation of the results showed the robustness of the Checklist as aggregated indicators obtained by the two groups differ within 5% (Table 6).

Table 6. Evaluation key indicators received by the two training groups on detailed visual inspection, visiting the Altynken TMF site.

Key indicators	Results from Group 1	Results from Group 2
Meeting Safety requirements, MSR (%)	92.9	95.2
Credibility (%)	70.6	72.7
Share of answers „Yes” (%)	63.2	63.2
Share of answers „Mostly yes” (%)	26.3	23.7
Share of answers „Mostly no” (%)	0.0	0.0
Share of answers „No” (%)	0.0	0.0
Share of answers „Not applicable” (%)	10.5	13.2

Based on the feedback from the trainees, seven questions (Q3, Q11, Q14, Q17, Q34, Q36, Q38) have been improved in the Group 1 part of the checklist.

3.4 Benefits of TMF Checklist application

The Checklist was conceived as a toolkit to improve TMF safety level and to ensure public safety in the areas potentially affected by tailings spills. On the top of enhancing technical quality and safety, it may also bring many organizational and managerial benefits listed below:

- The TMF Checklist imposes standardised, unified qualification requirements both to TMF operators and state inspectors. Thus, systematic application of TMF the Checklist can permanently enhance the skills and qualification of both, TMF operators and state inspectors.
- The TMF Checklist unifies the procedure to evaluate the safety of various TMFs, which ensures a consistent assessment and complies with the relevant international standards.

- The Checklist covers the entire life cycle of the TMFs so that it can reveal design deficiencies and inappropriate operation conditions, can improve emergency preparedness, and can support implementing an adequate closure and rehabilitation plan.
- Regular training for the TMF personnel can enhance staff knowledge on preventive measures and their preparedness to emergencies.
- Systematic application of the Checklist to various TMFs in different countries will contribute to better understanding the risks posed by TMFs across geographic regions or river basins.
- Reproducibility of the evaluation results approves the robustness of the Checklist methodology.

Communicating the TMF Checklist results to the public – both the directly affected and the wider society – and discussing safety issues with local communities in the form of public hearings can help raise awareness in society of TMF safety, accident prevention and emergency management. On the other hand, openness and communication of the Checklist results can demonstrate the high level of management, environmental protection and safety of the site and thus improve the public acceptance of the resources industry.

4 TMF HAZARD ASSESSMENT

The TMF Safety Methodology offers an index-based assessment of the hazard potential of a number of TMFs, the so-called THI method (UBA, 2016). With this simple index method, a large number of TMFs can be sorted and prioritised according to the calculated hazard potential. The approach already proved its usefulness in directing limited country resources (financial and personnel) to TMFs representing the highest hazard potential. The underlying criteria of the *THI* were worked out and agreed by international experts and have been improved taking up the results of a historical TMF failure analysis. Also, it is very useful in the graphical mapping of TMFs in countries or international regions (i.e. UNECE, river basins).

The original THI method was slightly modified by revising and adjusting several parameters. The overall calculation procedure was not changed.

4.1 The Tailings Hazard Index method

The THI method takes the following parameters into account that have been identified as being most crucial:

- total capacity of TMFs,
- toxicity of substances of the stored tailings,
- TMF management status,
- natural conditions specific to the TMF site,
- and dam safety parameters.

4.1.1 Calculation of the THI

According to the above-mentioned parameters, the calculation procedure of the *THI* includes five steps. In case values of some parameters are unavailable or impossible to identify, the maximum values have to be used (worst-case scenario). Thus, the hazard related to an unavailable TMF parameter (for example toxicity) is expected to be the highest.

4.1.1.1 Tailings capacity

The parameter "Tailings capacity" (THI_{Cap}) is related to the volume of stored tailings materials in the facility (m^3). The parameter is assumed to increase with growing volume by logarithmic relation with the base of 10. Thus, increasing the volume of tailings materials by 10 times (one order) will increase the index by 1. The parameter is calculated by the formula:

$$THI_{Cap} = \mathrm{Log}_{10}\,[V_t] \tag{4}$$

where V_t is the total volume of tailings materials in the TMF (m^3).

4.1.1.2 Tailings toxicity

The parameter "Tailings toxicity" (THI_{Tox}) is evaluated based on the Water Hazard Class (WHC) of the materials in the tailings according to the German national classification (UBA, 2017). For integrated toxicity characterization, it is crucial to have a parameter representing all potential threats to the aquatic ecosystem in the short and longer term. The WHC is considered as a validated methodology integrating all potential threats to aquatic ecosystems, including acute and chronic toxicity as well as bioaccumulation and accumulates dangers for different organism (fish, crustacean, bacteria). The data are online available for around 7,000 substances.

Alternatively, a self-classification is possible according to the United Nations Globally Harmonized System of Classification and Labelling of Chemicals. 7 shows the WHC classification and the respective toxicity index to be used.

Table 7. Evaluation of the tailings toxicity.

Water Hazard Class, WHC[1]	THI_{Tox}
no hazard	0
low hazard	1
medium hazard	2
high hazard	3

[1] According to the German classification

A specific problem is related to radioactive waste, as radioactivity is not integrated into the WHC classification. However, there is a need for considering it since many TMFs contain materials resulted from mining of radioactive substances (e.g. in Central Asia). Therefore, it is suggested to apply $THI_{Tox} = 4$ in case radioactive substances are stored in TMFs and their radioactivity exceeds the doubled value of the local background radioactivity.

4.1.1.3 Management conditions

The parameter "Management conditions" (THI_{Man}) is the TMF status that should be identified from four options shown in Table 7 (revised in comparison to the original method). The TMF accident statistics (Rico et al., 2008a, 2008b) show that closed and rehabilitated TMFs are safer in terms of accident frequency. No accidents were recorded at these TMFs. For this reason, the parameter related to TMF management is assumed to be lower for the closed or rehabilitated facilities compared to the active TMFs. As closed TMFs might still miss necessary safety measures, their hazard potential might be higher than that of the fully rehabilitated ones. On the other hand, abandoned or orphaned TMFs may have at least the same hazard potential as active TMFs due to the missing operation, management and controlled surveillance on the spot. Therefore, and because of precautionary aspects the hazard potential for abandoned facilities is rated by the same value as that of the active sites. At the same time, the THI_{Man} should also take into account the management status for transient suspended TMFs which can pose a greater danger than closed ones, but less than active and abandoned ones.

The value of THI_{Man} is determined according to Table 8.

Table 8. Evaluation of the management conditions.

Management status	THI_{Man}
Rehabilitated	0
Closed	1

Management status	THI_{Man}
Suspended	2
Abandoned, orphaned	3
Active	3

4.1.1.4 Natural conditions

The parameter "Natural conditions" (THI_{Nat}) is related to environmental risks, which are very often involved in TMF failures. Especially earthquakes, heavy rainfalls and floods have been many times classified as causes for TMF accidents.

Accordingly, the respective hazard potential is calculated by the following equation:

$$THI_{Nat} = THI_{Seism} + THI_{Flood} \quad (5)$$

where THI_{Seism} is the hazard index for seismic activity and THI_{Flood} is the hazard index for flooding based on the geological and hydrological conditions of the TMF site.

The value of THI_{Seism} is calculated based on the data on reference peak ground acceleration (PGA) corresponding to a specified reference probability of exceedance or a reference return period (JRC, 2008). The parameter Reference PGA can be taken from freely available data sources (e.g. GFZ, 2011). It allows harmonizing different scales of national classifications. The seismic hazard is defined as "Low" if the Reference PGA is below or equal to 0.1, and "Moderate or High" if the Reference PGA is above 0.1.

Accordingly, the earthquake hazard (THI_{Seism}) is described based on the following assumption in Table 9.

Table 9. Evaluation of the seismic hazard.

Reference PGA[1]	THI_{Seism}
≤ 0.1	0
> 0.1	1

[1] as recommended in EUROCODE 8 (JRC, 2008).

The influence of floods (THI_{Flood}) is related to the flood prone areas with a statistical parameter of HQ-500 that quantifies flood event frequency with a five-hundred-year return period (floods with a probability of 1 in 500 years). The flood-induced hazard at the TMF location area is determined according to Table 10. The flood prone areas according to the values of HQ-500 can be obtained from open sources (e.g. JRC, 2016).

Table 10. Evaluation of the flood hazard.

TMF location	THI_{Flood}
In the flood prone area of HQ-500	1

TMF location	THI_{Flood}
Beyond the flood prone area of HQ-500	0

4.1.1.5 Dam safety

Dam stability is probably the most critical parameter within the hazard evaluation. The parameter “Dam conditions” (THI_{Dam}) is considered to be related to the dam design parameter “Factor of Safety” (FoS) that has to be calculated already at the TMF design stage and it refers to dam slope stability (Coduto, 1998; Cruz et al., 2008; Fredlund et al., 2012). The term FoS is commonly used to express the safety margin of slopes on embankment dams. The influence on the TMF hazard potential of this parameter is assessed according to Table 11, based on Cambridge (2018).

Table 11. Evaluation of the dam safety.

Factor of safety (FoS)	$THI_{\cancel{Dam}}$
> 1.5	0
≤ 1.5 (or not available)	1

In a former THI methodology (UBA, 2016), the age of TMFs was also taken into account. Older TMFs were classified as more dangerous than newer ones. However, no satisfactory proof was found for this assumption in the historical analysis and therefore the age was left out. In fact, there are even some hints that it might be vice versa. Especially new TMFs seem to be very much involved in TMF failures. One explanation could lie with poor management and lack of experience at new sites or even on the other hand a consolidated geological stability at old TMFs. For future studies, this aspect should be considered more closely.

4.1.1.6 THI

The overall THI is calculated by the following formula taking all individual critical parameters into account that influence TMF hazard, i.e. the volume of tailings stored in TMF, the toxicity of substances contained in tailings, the hazard related to the actual management of the facility, the specific natural (geological and hydrological) conditions at the TMF site and the dam functionality:

$$THI = THI_{Cap} + THI_{Tox} + THI_{Man} + THI_{Nat} + THI_{Dam} \quad (6)$$

The THI is to be understood on logarithmic scale, meaning that an increase of the THI value with one indicates 10 times higher hazard. An example calculation for the THI can be found in Annex E.

The THI provides a simple tool to roughly assess the accident hazard of a number of TMFs in a region. More detailed assessment tools may be used at national or sub-regional level. Moreover, parameters shown in this report may be subject to fine-tuning according to national conditions (e.g. taking the type and conditions of the deposited materials into account, adjusting several parameter values).

The developed THI methodology is primarily designed to assess the danger level of TMFs and prioritize hazard hotspots. No quantified risks for specific areas downstream of a TMF can be outlined by applying the THI and it does not take any potential direct impacts on people or environment into account.

However, in case of detailed land-use planning activities, which should be performed in the frame of TMF design and licensing, potential risks to people and the environment have to be taken into account.

5 TMF RISK ASSESSMENT

Bearing in mind that the TMFs pose significant risks to peoples' lives, the environment and economic goods that are located downstream, potential failures have to be already taken into consideration during licensing of a TMF. In this regard taking susceptible people and the environment within the vicinity of TMFs into account is one of the priority tasks of land-use planning in order to minimize losses in case of an accident.

Disaster risk originates from the complex interaction between development processes that determine conditions of exposure, vulnerability and hazard (UNISDR, 2015). Disaster risk is therefore considered as the combination of the severity and frequency of a hazard, the number of people and assets exposed to the hazard and their vulnerability to damages.

The THI approach does not consider important land-use planning criteria such as the distance to waterbodies and settlements downstream, as well as the landscape of the downstream territory. Consequently, there might be significant differences in terms of accident risk between TMFs with the same THI but located in different vulnerable areas.

There are different formal definitions of land-use planning but all of them have the common understanding, that it is defined as a process where land is allocated and regulated for different social and economic activities such as agriculture, industry, recreation, housing and commerce issues. In order to manage the appropriate siting of activities and prevent land-use conflicts, land-use planning decisions must account for all sources of land-use related risk, both natural and manmade, which include potential threats to human health, property and the environment arising from hazardous facilities, some of which are TMFs.

As already mentioned, the TMF Safety Methodology was designed to implement the Safety Guidelines into a living document, but this Methodology does not include any land-use planning aspects or risk assessment measures yet. Therefore, and as a first step, it is important to design an amended methodology by taking into consideration the risks to human health and environment in relation to any TMF accident.

For doing so, risk assessment and risk mapping are an important part of land-use planning for TMFs. Moreover, the risk assessments also have obvious benefits for individual countries to target their limited financial and personnel resources to TMFs according to their risk level.

In order to support land-use planning activities, the Tailings Risk Index (TRI) methodology has been developed to assess the risks of potential accidents on different receptors.

5.1 The Tailings Risk Index method

The THI (already described in Chapter 4) describes and quantifies the potential accidental hazard of TMFs based on the volume and hazardousness of the stored substances and their management, natural site and dam stability conditions. However, it does not consider the socio-economic and environmental values located nearby the TMF, which may be at risk. Therefore, an advanced methodology assessing these additional risks is needed. The TRI has been developed to address these aspects, particularly considering risks to people and environment.

The TRI method can be used:

- To provide a preliminary generalized semi-quantitative overview of the different risks in a large area (e.g. transboundary river basins or several countries) or to indicate the most dangerous TMFs on national level (territory of the whole country or some regions);

- To enable the prioritization of the different types of risk (to environment and population) for further detailed analysis.

The TRI assessment takes into account the total hazard potential plus the population and water bodies downstream as potential receptors at risk of exposure in case of an accident. As the socio-economic values at risk and vulnerability of the potential receptors can be estimated only by a detailed assessment, the TRI approach does not include these aspects. Any further detailed risk assessment for individual TMFs to support contingency planning or specific safety assessments needs to integrate more specific aspects and information directly at and around the site (e.g. further receptors to be potentially exposed, vulnerability of the receptors).

5.1.1 Data collection and processing

To assess the risk of a TMF, first of all the population and water bodies in the vicinity downstream of the TMF dam are considered. The subsequent TRI can then be determined taking into account different potentially affected downstream zones for population and environment.

Past accidents show that the usual runout length of the released tailings in the field (before reaching surface waters) is up to 10 km from the concerned TMFs (see Annex A). Therefore, a zone with 10 km radius is considered as a potential risk zone for the TRI methodology.

The respective data collection and processing consists of the following steps:

1. Definition of a circular area (risk zone) around the TMF with a specified radius that represents the potential spreading distance of the probable effect of a failure downstream of the TMF (10 km).
2. Identification of the settlements and waterbodies located downstream of the TMF and inside the potential risk zone and therefore may be affected in case of a TMF failure. The downstream settlements and water bodies can be identified using Geographic Information System (GIS) techniques (e.g. determining flow routes based on a topographic map and intersecting them with a land use map). In case the user of this methodology does not have a license to use or proper knowledge in GIS, the estimation of the risk zone and downstream settlements/waterbodies can be made by visual inspection of any available digital or hard copy maps (e.g. satellite, terrain).
3. Obtaining population data and summing up the population of the downstream settlements for the potential risk zone (Population At Risk, PAR).
4. Obtaining the mean discharge rate/water surface area of the closest stream/lake water body downstream in the potential risk zone.

5.1.2 Risk assessment

The TRI method first assesses the potential direct exposure on population and environment by calculating Tailings Exposure Index (TEI) values for both receptors. The overall TEI is then combined with the THI resulting in the TRI.

5.1.2.1 Calculation of the TEI

The calculation of the TEI is a simplified (basic) approach based on the total population and the size of nearest water body within 10 km distance.

5.1.2.1.1 Impact on population

The parameter TEI_{Pop} is a factor taking into account the downstream population located up to 10 km from the TMF (PAR). The TEI_{Pop} factor is determined by a simple classification shown in Table 12.

Table 12. Population exposure index.

PAR in 10 km zone	TEI_{Pop}
< 100	2
100 - 1000	3
1000 - 10000	4
10000 - 100000	5
≥ 100000	6

5.1.2.1.2 Impact on the environment

The TEI_{Env} is a factor that considers the size of the nearest waterbody to the TMF located downstream within 10 km distance of the TMF and may be polluted by a TMF accident. The TEI_{Env} factor is determined based on the mean river discharge value or the lake surface area presented in Table 13. The size classification for rivers refers to the ICPDR scheme used for the Danube Accident Emergency Warning System (ICPDR, 2018). For pragmatic reasons, instead of a mathematical equation (e.g. a logarithmic function of the mean river flow rate) a simple classification is set, as accurate flow/water surface area data are very often not available.

Table 13. Environment exposure index.

Stream flow rate, m^3/s or lake surface area, km^2	TEI_{Env}
< 100	2
100 - 1000	3
> 1000	4

5.1.2.1.3 The overall TEI

The total TEI is calculated by the following formula:

$$TEI = TEI_{Pop} + TEI_{Env} \tag{7}$$

5.1.2.2 Calculation of the TRI

The TRI is calculated based on the THI and TEI values by the following formula:

$$TRI = THI + TEI \tag{8}$$

Similarly to the THI, the TEI and the TRI are also to be evaluated on the logarithmic scale. An example calculation for TRI can be found in Annex E.

TRI index can be easily integrated to the Cadastre system of the country that will help competent authorities to evaluate the risk of the TMFs much easier.

However, in the case of detailed land-use planning, which must be carried out as part of the design and licensing of a TMFs, the potential risks to humans and the environment must be taken into account.

5.2 Land use planning aspects

The UNECE TMF Safety Guidelines address the need for land-use planning considerations to be considered when evaluating optimum siting of new TMFs, and the need to carry out an environmental impact assessment prior to construction as well as a risk assessment.

In order to fulfill this condition, when constructing new TMFs, it is recommended to assess the presence of buildings and water bodies around the vicinity of the future TMF For this, it is recommended to take into account land-use aspects such as areas of possible vulnerability zones. Considering the results of historical analysis, a radius of 10 km can be taken as a boundary zone for restrictions.

It is necessary to define risk zones also nearer to a TMF as the potential hazard is rising exponentially with decreasing distance to the TMF.

It is advisable to zone the area in vicinity of the tailings, within which a number of restrictions would apply:

Zone A - up to 1 km

Zone B - 1 to 5 km

Zone C - 5 to 10 km

Zone D - beyond 10 km

These zones should be considered as potentially affected by possible accidents at the tailings management facility. When determining the zones it is necessary to take into consideration the terrain relief, gorges, river beds, forests, the site topography below the marks. According to specific conditions, some adjustment of zone sizes is possible.

Zoning restrictions are proposed for the construction of new tailings facilities (Table 14) and additional precautionary measures for existing tailings facilities as well (Table 15).

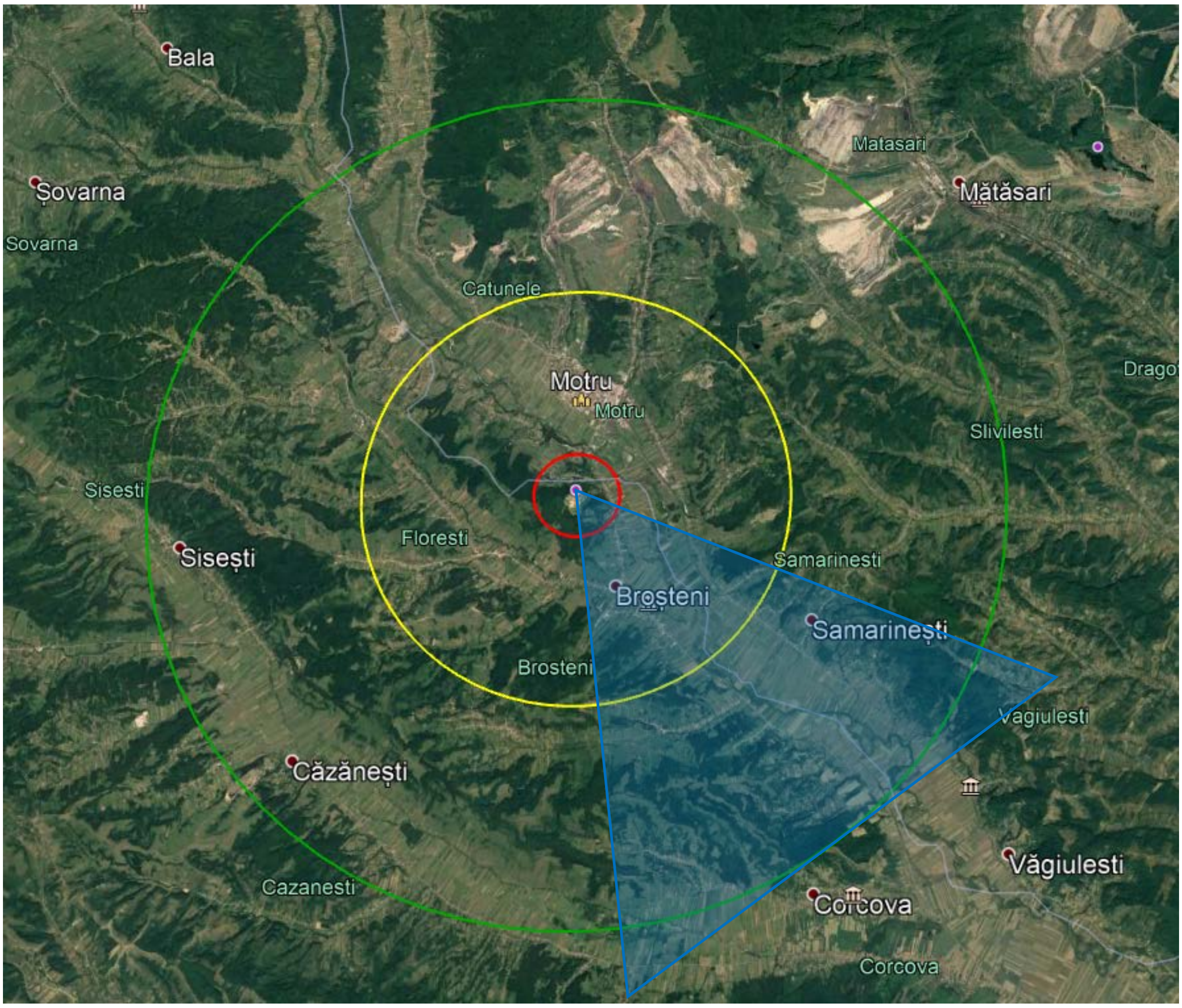
Similar precautions are required for inactive tailings facilities, abandoned, mothballed, or reclaimed in the event of unsatisfactory operations.

Table 14: Proposed restrictions for new tailings facilities

Zone	Distance, m	Recommendation on restrictions
A	< 1000	No waterbodies, to build infrastructure facilities used by people is not allowed
B	1000 - 5000	No waterbodies, not allowed to build residential educational or medical institutions, placement of recreational centres, tent camps, parking for hunters, fishermen and tourists

Zone	Distance, m	Recommendation on restrictions
C	5000 - 10000	placement of stadiums, national parks and airports, shopping centers, other objects with a mass presence of people is not allowed
D	>10000	No restrictions

Figure 5. Definition of different risk (zone of vulnerability) downstream of the new planned TMF



© Google

The red circle outlines the risk zone A (0-1 km), the yellow circle outlines the risk zone B (1-5 km), the green circle outlines the risk zone D (5-10 km) and the blue zone shows the downstream territory that can be potentially affected within the risk zones in case of an accident.

Table 15: Proposed restrictions for existing tailings facilities.

Zone	Distance, m	Recommendation on restrictions
A	No waterbodies, buildings with infrastructure (except technical buildings) used by people are not allowed	For waterbody: build additional protection dams. An alert system is required. For buildings: develop a plan to move them to a safer area. The territory of the TMF should be fenced off with barbed wire and identification signs and illuminated billboards should be placed in the risk zone, notifying of the possible grave and immediate danger.
B	No waterbodies, not allowed to build residential educational or medical institutions, placement of recreational centres, tent camps, parking for hunters, fishermen and tourists	For waterbodies: automatic monitoring stations are needed, dependent to protective measures For buildings: the construction of a protective wall or a ditch is required, which can protect the population, and especially children, in the case of an accident at TMF.
C	placement of stadiums, national parks and airports, shopping centers, other objects with a mass presence of people is not allowed	develop an emergency evacuation plan, establish a communication system between operators and representatives of the airport, stadium or park

This is a proposal which can be adjusted according to individual risk assessment, to established safety measures or other individual factors.

At the same time, the size of these zones can be adapted to the conditions of the country, the topographic and climatic conditions of the area.

Also, taking into account the legislative and regulatory framework of countries, these risk zones can be integrated into local regulations. For example, Kyrgyzstan is adapting risk areas for use in the Sanitary-Epidemiological Rules and Standards.

5.3 Example of application of risk zones

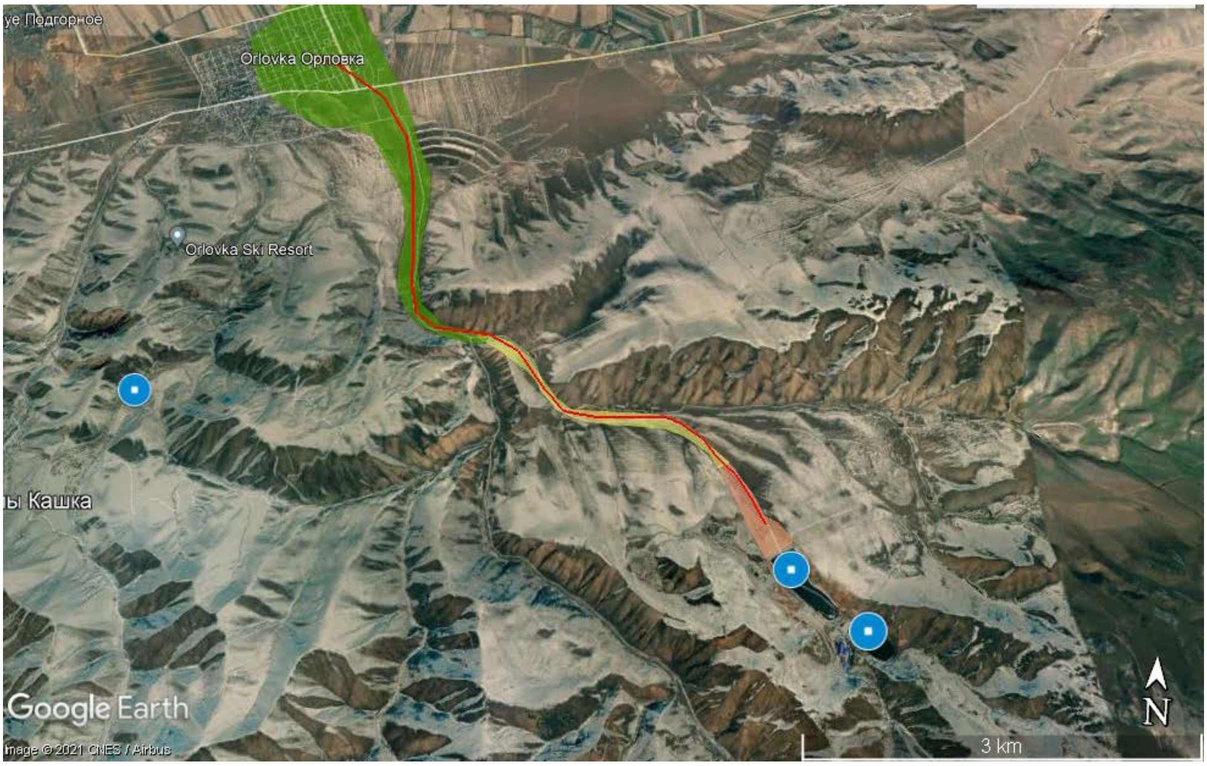
For demonstrating the risk zones' application, the "Altyn-Ken" TMF at the Taldybulak Levoberezhny gold deposit was chosen. Deposit Taldybulak Levoberezhny is located in the southeastern side of the Chui Valley, in the valley of the Taldybulak River. It contains two tailings management facilities. The calculated distance downstream of 10 km considers topography of the territory (Figure 6) and shows the potential spill of tailings in the case of the accident.

In zone A (5 km zone, the Tadibulak river is located. The city Orlovka with population of 6260 people is in zone C (10 km). In the same one, a school, kindergarten and hospital are located. According to the recommendations the following restrictions should be considered:

- For Tadibulak river: build additional protection dam. To develop a warning system in the case of an accident

► For the Hospital, school and kindergarten– develop an evacuation plan in case of an accident

Figure 6: The distance downstream of "Altyn-Ken" TMF



source: own illustration and Google Earth

The red zone outlines the risk zone A (0-1 km), the yellow zone outlines the risk zone B (1-5 km), the green zone outlines the risk zone D (5-10 km) downstream territory which can be potentially affected within the risk zones in case of an accident.

5.4 Risk mapping considerations

Mapping is a necessary part of land-use planning to clearly illustrate existing environmental conditions, the location of urban areas, land use types, potential sources of risks and potential consequences. For land-use planning and risk assessment of hazardous TMFs, a set of maps is recommended to be collated that demonstrates the concerned area and its conditions:

1. Land uses in areas surrounding the TMF;
2. Urban developments and industrial facilities downstream;
3. Topographical and landscape conditions (e.g. slope, landscape elements)
4. Hydrological and environmental features (e.g. surface water and groundwater bodies, floodplains, nature protection areas).

By using modern risk assessment tools (based on geographical information systems), all georeferenced maps and spatial hazard and risk data can be overlapped to clearly present the situation. The result is a spatial risk map, in which the potential exposure of hazardous activities to other land uses and developments can be evaluated.

For the evaluation of consequences on people, society, economy and the aquatic resources, the following parameters are recommended to be integrated and assessed by responsible authorities:

1. location of the TMFs
2. volume of the tailings and capacity of the TMF,
3. list of hazardous materials and their toxicity,
4. operational conditions of the TMF,
5. natural hazards at the TMF location (seismicity, floods, rainfall, snowmelt, landslides, wind),
6. dam stability parameters,
7. risk zone downstream with a defined radius,
8. population downstream in defined risk zones,
9. water bodies downstream in defined risk zones,
10. landscape and topographic properties around (potentially),
11. socio-economic and ecological values downstream in defined risk zones (potentially),
12. distance to other TMFs or hazardous installations (potentially),
13. distance to country or state borders (potentially).

This selection allows to consider also land-use planning aspects. Besides, visualization is very important for proper risk assessment and resulting strategies for contingency planning. Moreover, in case of a dam failure, the affected areas including soil, settlements and polluted water can be easily seen thanks to visual inspection and analysis of images collected from different satellites that show the territory nearby the failed TMF before and after the disaster.

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ANNEXES

A Analysis of historical tailings dam failures

A substantial number of TMF accidents occurred in the past decades, which could have been avoided or partly controlled if adequate safety measures had been put in place and land-use planning aspects taken into account. A comprehensive analysis on the past TMF accidents was carried out to better understand the severity and dimensions of these TMF disasters, including the potential number of casualties and spreading distance of the tailings downstream of the TMF in case of an accident. Moreover, satellite images taken before and after some selected TMF accidents were analysed to investigate the potential runout distances before reaching water bodies. More detailed information can be found in the report (UBA, 2020b)

A.1 Data collection

A database of historical TMF failures was compiled using bibliographic sources as well as open source information. In the first step, the existing inventories on past TMF failures were explored. Currently, various investigations and comprehensive reviews have attempted to summarize the causes of TMF failures throughout the world using historical TMF failure data (e.g. USCOLD, 1994; Davies, 2002; ICOLD, 2007; Rico et al., 2008a; Rico, et. al, 2008b; Bowker and Chambers, 2015; Bowker and Chambers, 2016; Bowker and Chambers, 2017; WMTF, 2020; CSP2, 2020; WISE, 2020). For this report, the data of Bowker and Chambers (WMTF, 2020) were used as core database.

Although the published data are undoubtedly very valuable, they are certainly incomplete, as smaller incidents are very common (e.g. Villarroel et al., 2006) and remain underreported in both scientific literature and public media. It is also considered that many incidents are unreported because of fears of bad publicity and legal ramifications (Davies, 2000), particularly in China, Russia and other emerging and developing countries. Therefore, the selected database may be subject to further fine tuning and update.

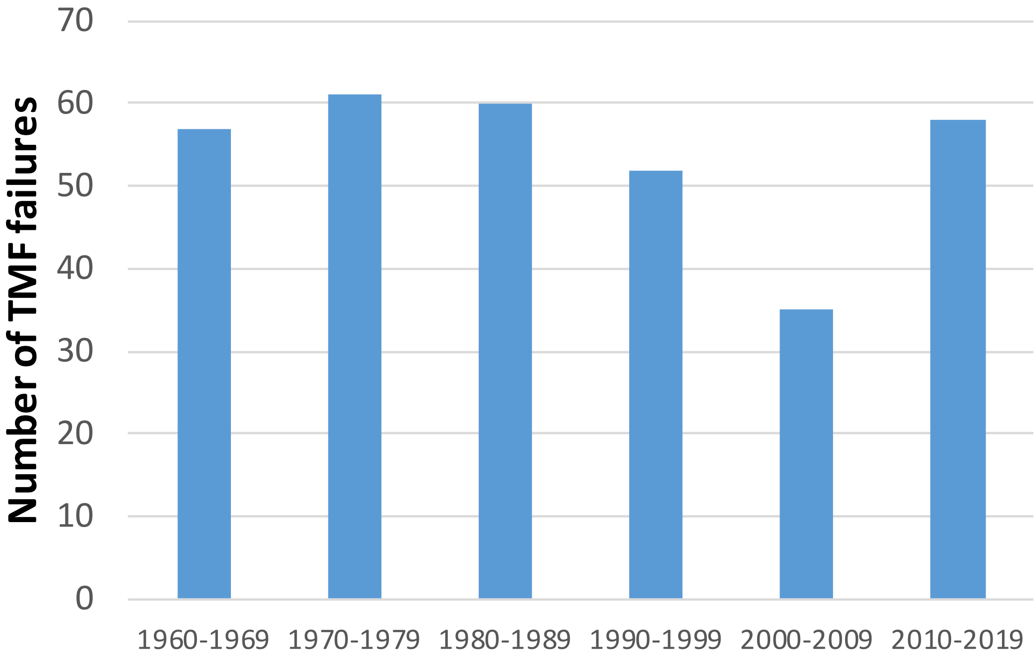
A.2 Assessment results

A.2.1 Number and severity of TMF failures

Data records over 350 failures of TMFs in the world are available since 1915. However, data sets on failures occurred before the 1960s are rather incomplete. Moreover, there are only a few reports about these failures, because the total number of TMFs was small and the operation of the TMFs was not properly documented. Therefore, only the accidents in the last 60 years were considered for the assessments (Figure 7 and Annex B).

During the last 60 years, 323 accidents were reported in total. The number of failures was stagnant in the first three decades then decreased after 1990 over two decades (1990-1999 and 2000-2009), presumably reflecting to reduced mining activities between 1990 and 2009, in particular in the former Soviet Union countries. However, over the last decade the number of failures returned back to the level of the 1970ies. In 2019 alone, there were 7 TMF failures, two of which were very serious with multiple deaths. The failure trend is rising, therefore actions need to be taken to avoid a high number of serious accidents. Nevertheless, modern surveillance techniques and visual recording have become widespread in the last decade which provide sound evidence and reliable data on accidents but these tools were not available in the past therefore historic records may be uncertain. Besides this, the effects of climate change (increasing frequency and intensity of heavy rainfall, thunderstorm and flash flood events, rapid snow melt) may also contribute to this increasing tendency.

Figure 7. Number of TMF dam failures by decades from 1960 to 2019.



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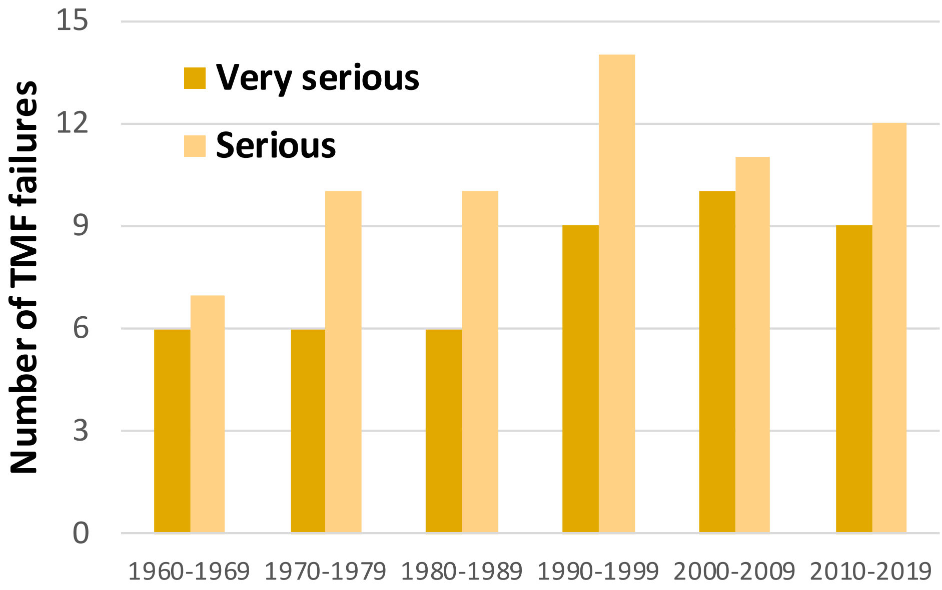
Categorizing the impacts of TMF failures is a difficult - and to some extent subjective - task. Also the line between a serious failure and a very serious failure is not clearly defined. Bowker and Chambers (2015) defined serious failures as ‘having a release of greater than 100,000 m^3 and/or loss of life’ and very serious failures as ‘having a release of at least 1 million m^3 and/or a release that travelled 20 km or more and/or multiple deaths’. Both types show increasing tendency since the 1990ies (see Figure 8).

Figure 8. Number of very serious and serious TMF dam failures by decades from 1960 to 2019.



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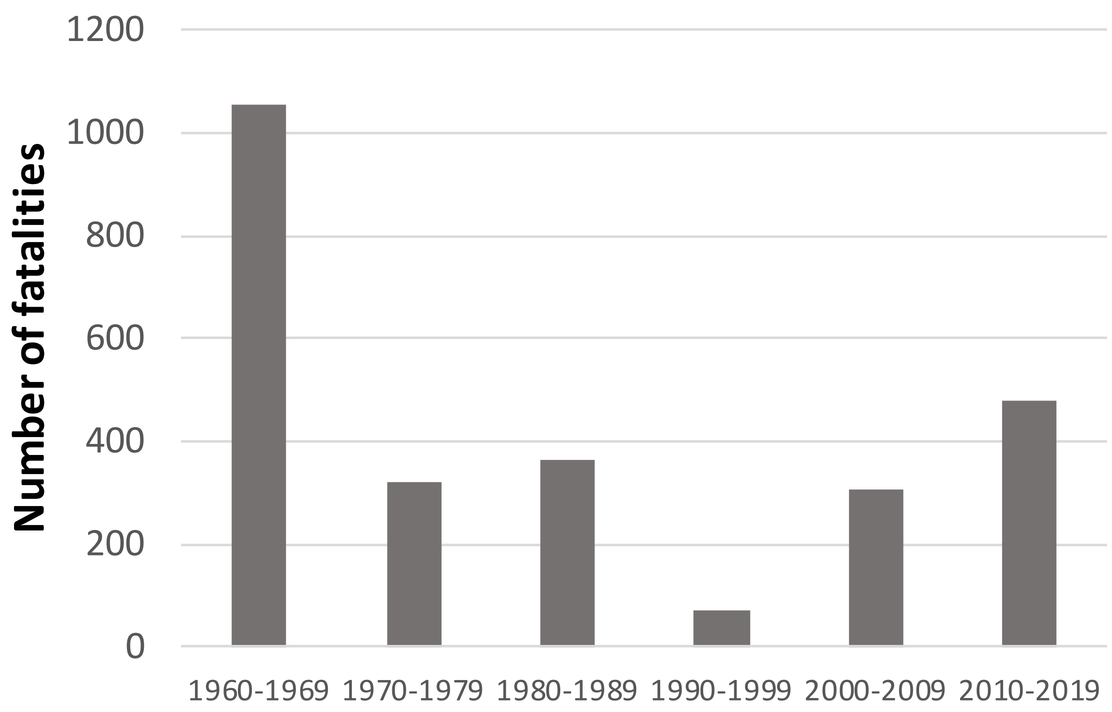
In the last 60 years, 2,599 deaths due to 323 accidents at TMFs have been registered (Figure 9 and Annex B). Across decades, the figures show that the loss of human life has significantly increased in the last 20 years. During the last 10 years, there were 480 deaths stemming from 13 TMF failures. In 2019 alone, 327 people died or are missing because of two accidents (dam failure in Brumadinho, Brazil: 259 people were killed and 11 are reported missing; disaster in Hpakant, Kachin state, Myanmar: 3 workers died and 54 workers are reported missing, (see Figure 9 and Annex B). The figure of cumulated deaths is comparable to the finding of Santamarina et al. (2019), showing almost 3,000 deaths in the last 100 years.

Loss of human life because of TMF dam failures stayed within the range of 300-400 in most decades (from 1990 to 1999 there was a significant decrease). From 1960 to 1969, a very high death number was recorded due to some very dramatic accidents such as the accident on Mir mine, Sgorigrad, Bulgaria in 1966, when half of Zgorigrad village was destroyed, killing 488 people (WISE, 2020).

Figure 9. Reported human life loss because of TMF dam failures by decades from 1960 to 2019.



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On the top of the number of accidents and casualties, the rate of serious accidents and the failure-specific loss of life related to fatal accidents (number of deaths per failures with casualty) and to the overall accidents (number of deaths per total failures) were also analysed. The results of this evaluation are presented in Table 16.

Table 16. Analysis of historical TMF failures.

Decade	Failures	Failures with casualty	Deaths	Rate of fatal failures (%)	Specific loss of life (all accidents)[1]	Specific loss of life (fatal accidents)[2]
1960-1969	57	9	1054	15.8	18	117
1970-1979	61	9	322	14.8	5	36
1980-1989	60	6	365	10.0	6	61
1990-1999	52	6	72	11.5	1	12
2000-2009	35	6	306	17.1	9	51
2010-2019	58	13	480	22.4	8	37
Total (1960-2019)	**323**	**49**	**2599**	**15.2**	**8**	**53**

[1] related to the total number of accidents

[2] related to accidents with loss of life

Over the examination period, 49 accidents out of the total number of 323 TMF failures (15%) were fatal and led to nearly 2,600 deaths (the environmental damages and costs are not counted). Importantly, the number of accidents with fatalities has significantly increased in the last 10 years in comparison to the previous decades. Moreover, while the rate of failures with loss of life over a period of 40 years (from 1960 until 1999) remained almost unchanged with an average of 13%, over the past 20 years the number of fatal accidents began to grow and their rate reached 22% during the last two decades. The reasons behind may include ageing of TMFs, inadequate planning of land-use and urban areas or impacts of climate change. The long-term specific loss of life related to overall accidents and fatal events has a dramatic value of 8 and 53, respectively and they remained significant in the last two decades (on the global average, region or country level data may be different).

In Table 17 statistical data on the "conventional" hazardous industries ("Seveso-sites") for Germany during 2010-2019 are presented (UBA, 2020b) and compared to TMF accident data for the same period. Despite the total number of failures being 4 times higher at conventional hazardous installations in comparison to TMFs, the number of deaths was more than 30 times lower. Moreover, more than 20% of the TMF accidents was fatal, this figure is only 4% for the SEVESO sites. Accordingly, the specific loss of life value related to all and fatal accidents is much higher for TMF failures (two orders of magnitude and 20 times, respectively). It should be noted that no detailed data were available for the EU countries except Germany, therefore these findings should be carefully interpreted and the comparison is not representative. Bearing in mind that Germany is a developed industrial country where safety measures are of a high standard, the differences might be less significant in comparison to regional figures or global numbers.

Table 17. "Seveso-site" accidents in Germany and TMF failures in the last decade (2010-2019).

Decade	Failures	Failures with casualty	Deaths	Rate of fatal failures (%)	Specific loss of life (all accidents)[1]	Specific loss of life (fatal accidents)[2]
SEVESO	232	9	16	3.9	0.07	1.8
TMF	58	13	480	22.4	8	37

[1] related to the total number of accidents

[2] related to accidents with loss of life

These figures clearly demonstrate the necessity of improving the safety level of TMFs. Putting in place additional and appropriate preventive and contingency measures at the TMFs, at least according to international safety standards, will help and support the minimizing of risks and adverse impacts of accidents to avoid human losses and severe environmental impacts.

Nowadays, land-use planning aspects, such us population, natural resources and heritage and socio-economic goods within the vicinity of a TMF that may be potentially affected in case of an accident should also be prominent issues to be considered.

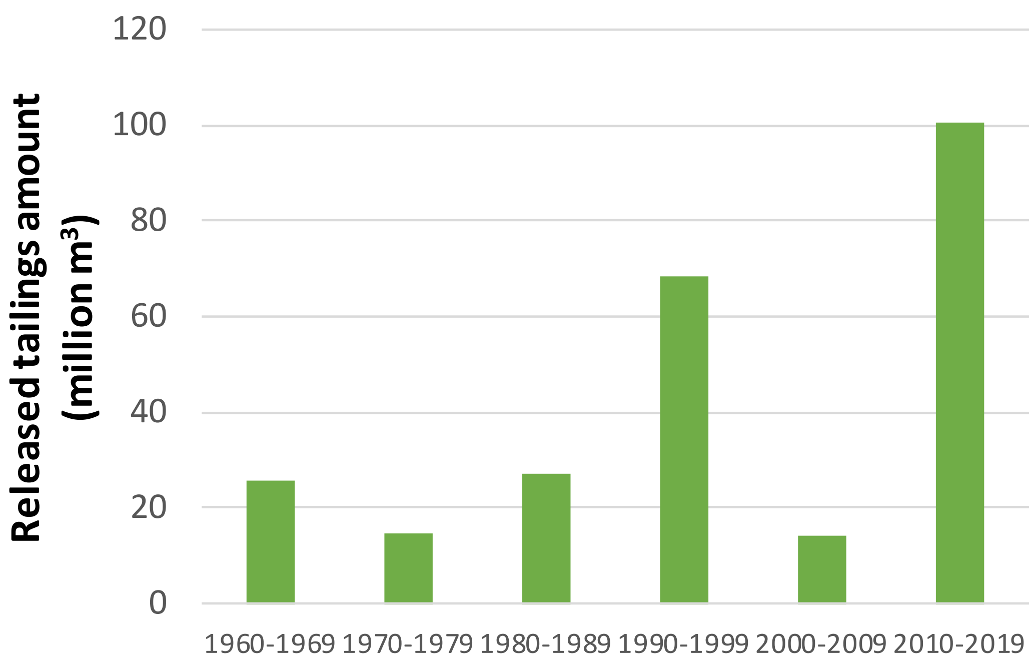
By analysing historic mining metric indicators such as production costs and prices of various metals, Bowker and Chambers (2015) developed a correlation between these indicators and failure severity, enabling an estimation of projected future failures. The results forecast that if the present mining metric "driven by continuously lower grades in identified resources and continuously falling real prices of most metals" continues, serious and very serious failures of tailings dams will also continue to rise as a consequence of limited financial and human resources allocated to safety measures in the past. Despite the ambitious and strict regulations in many countries, a number of "legacy" TMFs exists with low level of safety measures.

A.2.2 Released volumes

Findings of research studies associated with TMF failures made by Rico et al. (2008b) and Concha Larrauri et al. (2018) show that reasonable statistical analysis can also be made for both the volume of tailing materials that could be released from a TMF and the distance downstream, over which the released tailings could move.

Looking at the last 60 years, a total of almost 250 million m³ tailings materials in 323 TMF accidents were released (Figure 10 and Annex B, note that only about half of the accidents have recorded tailings release, the others either had minimal released amount or data are not available). In the last 10 years, the amount of released tailings has significantly increased, 58 TMF dam failures released more than 100 million m³ of tailings into the environment.

Figure 10. Recorded total amount of released tailings by decades from 1960 to 2019.



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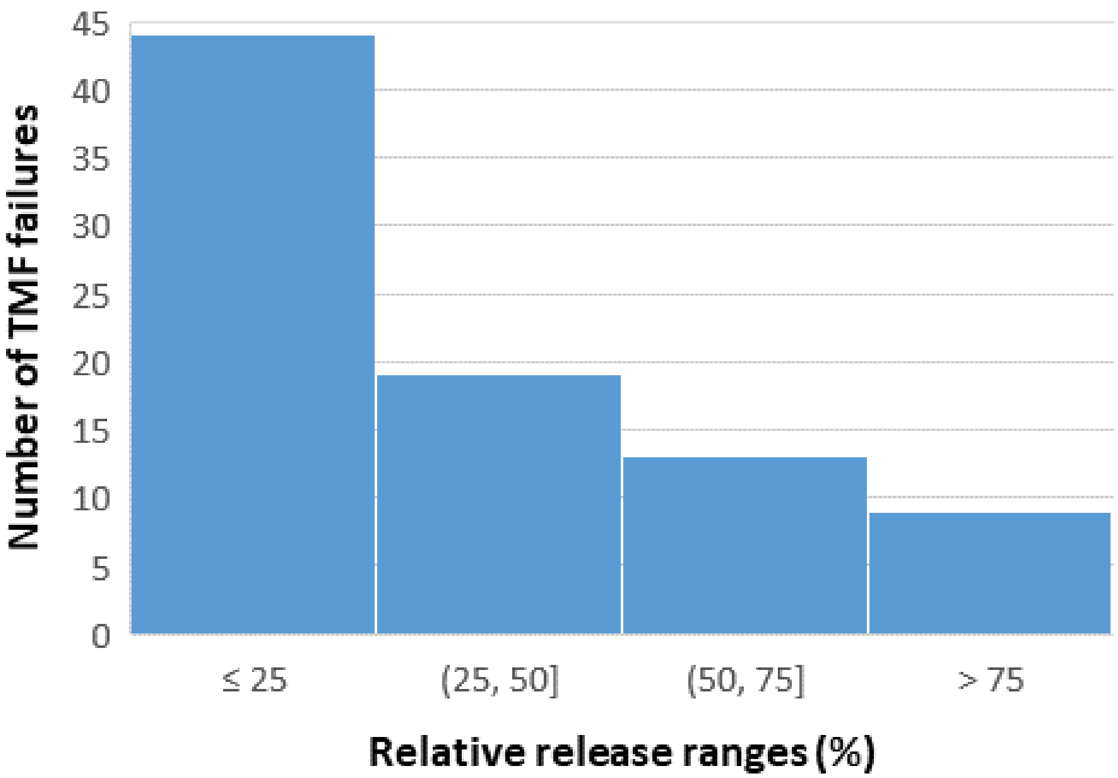
The number of human fatalities may directly depend on the distance between the settlements located downstream and the TMF. The smaller the runout distance to reach a settlement and the higher the volume of the substances released, the higher the number of causalities that may occur in case of TMF failures. Therefore, the amount of released materials related to TMF capacity and the runout distance downstream of a TMF were further analysed for the recorded TMF accidents.

Out of the 323 TMF accidents, for which data were collected (see Annex B), only 85 cases contained data on the total capacity of the collapsed TMF together with information on the released volume of materials (see Annex C). The results of this evaluation are presented on Figure 11.

In most of the cases (44 of 85) the released volume was less than 25% of the total TMF capacity. The number of accidents where the relative volume of released materials ranged from 25 to 50% was more than two times less (19). The number of cases when spilled tailings volume reached a range of 50-75% and 75-100% of the total capacity was around 10 (13 and 9, respectively).

Figure 11. Distribution of TMF failures according to the relative amount of released materials.



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A.2.3 Runout distances downstream

Regarding the runout distance, official data were available for 91 cases (see Annex C). The reported distance values have a large range varying between 0 and 2,000 km. According to the distribution of the runout distances, for majority of the cases (60%) the runout distance did not exceed 10 km (see Annex C). For almost 30% of the cases, the reported transport distance exceeded 20 km indicating different definitions of the runout distance used in various official sources. Some sources indicate only the near-field distance from the TMF to the receiving water (field transport). Some others indicate the far-field distance of the tailings spreading including both, field and in-stream transport. This is well reflected in the large range of reported distance data (4 orders of magnitude). Almost one third of the transport route distances include both field and in-stream transport distances and almost all of these distances are bigger than 20 km (see Annex C).

A.2.4 Investigations on direct runout distances

To more accurately determine the direct runout distance, an additional analysis was performed for those cases, where the official runout distance exceeds 10 km (37 accidents). Additional information on runout distances was collected from open sources. Moreover, it was also checked if any information is available whether the reported runout length includes river transport distance. In case no information was accessible, the possible direct runout distances were estimated based on the location of the TMFs and the closest water bodies by using online satellite maps. Unfortunately, for some historical accidents additional information on the runout distance or the exact TMF location was not available due to limited data records from the past.

The map analysis was carried out by using high-resolution satellite images showing the surrounding area of the selected TMFs before and after the accidents. Three examples are presented in detail.

Case study 1: Córrego de Feijão mine, Brumadinho, Minas Gerais, Brazil

According to WISE (2020), during the disaster on Córrego de Feijão mine (Brazil, 2019), the slurry wave moved downhill and then was transported further downstream by the River Rio Paraopeba. The mud first hit the mine administrative area and a small community about 1 km downstream of the mine. The National Water Agency stated that the tailings had polluted over 500 km of rivers. The image analysis shows that the downhill runout distance was approximately 7 km after that the plume reached the river (Figure 12).

Figure 12.Territory near the Córrego de Feijão dam on 14.01.2019 (left) and 30.01.2019 (right).

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Case study 2: Samarco Mineração S.A Fundão Minas Gerais, Brazil

The failure on the Samarco Mineração S.A Fundão tailings dam on the 5th of November 2015 released tailings, which travelled downstream via a natural waterway. The mud continued to move further about 650 km along the Rio Doce River, reaching the Atlantic coast 17 days later.

However, the image analysis of the accident (13) shows that the distance to the affected main waterbody is less than 1 km.

Figure 13. Territory near the Fundão dam on 21.07.2015 (left) and 11.10.2015 (right).

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Case study 3: Ajka Alumina Plant, Kolontár, Hungary

During a disaster near Ajka, the red mud reached the municipalities of Devecser, Kolontár, Somlóvásárhely, Somlójenő, Tüskevár, Apácatorna and Kisberzseny. An area of about 8 km^2 was flooded. In the following days, the red mud contaminated the Torna creek and the valley of river Marcal, almost reaching the river Rába. Through the Torna, Marcal, Rába and the Moson branch of the Danube, the alkaline red slurry travelled about 80 kilometres downstream and finally entered the Danube River. The image analysis (Figure 14) shows that the distance to the nearest settlement and surface water that were contaminated with the released tailings is about 4 km.

Figure 14. Territory near the Ajka TMF on 07.10.2010 (left) and 22.10.2010 (right).

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Outcomes of the runout analysis

The results of the runout estimation are shown in Annex C. For 17 out of the 37 cases it was possible to find additional information or to identify the location of the TMFs and estimate the potential transport distance. In all these cases, the estimated direct runout distance is much less than the reported value. Moreover, for 15 of them, the runout distance of the tailings did not exceed 10 km.

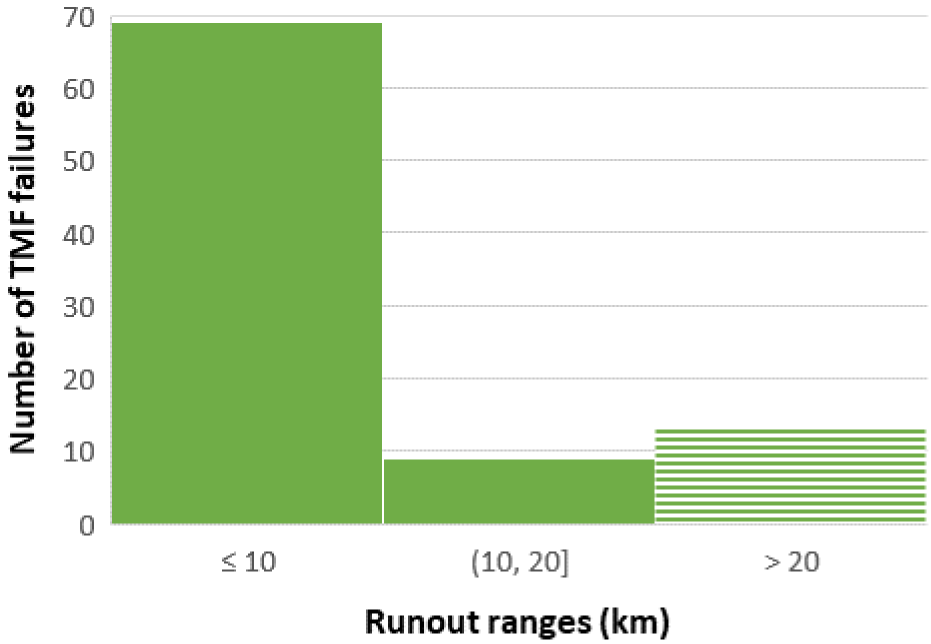
Potential risk zone delineation

As it can be seen from the additional investigations, the difference between the actual runout distance and the distance reported in open sources may be significant. Although large distances are reported, the majority of the investigated accidents show that the direct runout distance to the river/settlement nearby is less than 10 km if only field transport is taken into account.

The reason for this discrepancy is that in many cases official documents report on the maximum travelling distance but do not distinguish between field and river transport routes. However, to understand the dimensions of the potential risk zone in the direct downstream vicinity of a TMF where people and environmental resources may be at risk, the field transport distances need to be known.

Updating the original runout distance data with the investigation results presented in Annex C, the amended overall runout length analysis shows that 69 cases out of the 91 reported accidents have less than 10 km direct runout distance (see Figure 15). Out of the remaining 22 cases, 9 have a runout length between 10 and 20 km, whereas 13 cases show a runout above 20 km. However, for all of these 13 accidents in-stream transport is indicated, thus, the direct runout distance needs to be further investigated. However, it is very likely that in 10 km distance the spill would reach a surface water body or the overland spread would slow down and the released materials would be retained in surface depressions and ponds, over flat areas, in vegetated surfaces or behind landscape objects or terrain barriers. Neglecting the 13 cases with incomplete information, the proportion of runout distances less than 10 km is almost 90% (69 out of 78). This indicates that a distance of 10 km could be a suitable threshold for delineation of a direct risk zone downstream of TMFs.

Figure 15. Distribution of TMF failures according to the runout distance of the tailings.



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The striped column indicates data with uncertainty

The obtained statistical data do not allow for a discrete runout distance threshold to be lined out due to lack of information and merging overland and in-stream runout lengths. However, a solid reference is the Ajka alumina plant accident, being the best recorded and analysed TMF accident in Europe. Based on the impacts experienced with that accident, no deaths or serious acute toxicity occurred in an area beyond 10 km distance (the maximum field runout length was 4.2 km before reaching a surface water body or a terrain barrier). Also, no data on serious health damages out of 10 km zone were found at other TMF accidents within the UNECE region. Therefore, and based on the findings of the investigations on past events, a standard runout distance of 10 km was defined to assess the population at risk within the UNECE region. This may be different in other regions of the world and the exact values are case-specific depending on the site conditions and the accident dimensions. Data on some TMF accidents suggest a larger distance, especially if riverside wetlands and the terrestrial watershed area cannot be clearly distinguished.

A.2.5 Resumé

1. During the last 60 years, more than 320 accidents have been reported in total, resulting in almost 2,600 deaths. A reduction in mining activity between 1989-2009 led to a decrease in incidents, yet the last decade has seen failures peaking at their highest recorded level (58 failures).

2. The number of serious (having release greater than 100,000 m^3 and/or loss of life) and very serious (having release at least 1 million m3 and/or release that travelled 20 km or more and/or multiple deaths) accidents show a clear increasing tendency over the last decades.

3. Of the 250 million m^3 of tailings materials released in the last 60 years, 40% were released during the last decade (100 million m^3).

4. Assessment of the past accidents shows that the proportion of direct runout distances (transport distance of the released surface water body or retained by landscape objects or terrain barriers) less than 10 km is almost 90%. This indicates that a distance of 10 km could be a suitable threshold for delineation of a direct risk zone downstream of TMFs.

B Historical tailings dam failures with reported data

Based on Bowker and Chambers (WMTF, 2020).

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
1	Nossa Senhora do Livramento, Mato Grosso, Brazil (VM Mineração e Construção, Cuiabá)	2019	580,000		2.0	
2	Cobriza mine, San Pedro de Coris district, Churcampa province, Huancavelica region, Peru (Doe Run Perú S.R.L)	2019		67,488	375.0	
3	Hpakant, Kachin state, Myanmar,Shwe Nagar Koe Kaung Gems Co. Ltd., Myanmar Thura Gems Co. Ltd.	2019				3
4	Muri, Jharkhand, India (Hindalco Industries Limited)	2019			0.2	1
5	Machadinho d'Oeste, Oriente Novo, Rondônia, Brazil (Metalmig Mineração Indústria e Comércio S/A)	2019				
6	Brumadinho, Mina Córrego do Feijão, Minas Gerais, Brazil (Vale)	2019	12,000,000	9,570,000	600.0	270
7	Huancapatí, Recuay province, Áncash region, Peru (Compañía Minera Lincuna SA, Grupo Picasso)	2018		80,000		
8	Duke Energy, L.V. Sutton Power Station, Wilmington, North Carolina.	2018	2,100,000			
9	Duke Energy, HF Lee Power Plant, Goldsboro, North Carolina	2018	875,000	2,000		
10	Cieneguita mine, Urique municipality, Chihuahua, Mexico (Minera Rio Tinto and Pan American Goldfields)	2018		439,000	26.0	5
11	Hpakant Jade Mines, Myanmar	2018				20
12	Hector Mine Pit Pond, MN, USA	2018	185,000	123,000		
13	Cadia, New South Wales (Newcrest Mining)	2018		1,330,000		
14	Barcarena, Pará, Brazil , Alunorte (Hydro Alu Norte/Norsk Hydro ASA)	2018				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
15	Hpakant Jade Mines, Myanmar	2018				6
16	Hernic PGM Project, South Africa (Jubilee Metals Group)	2017	4,875,000	-		
17	Kokoya mine, Liberia (MNG Gold-Liberia)	2017	300,000	11,356		
18	Vedanta Aluminium Limited Smelter Ash Pond, Jharsuguda, India	2017		2,625,000		
19	Mishor Rotem, Israel (ICL Rotem)	2017		100,000	20.0	
20	Husab, Namibia (Swakop Uranium (Taurus Minerals))	2017				
21	Highland Valley Copper, British Columbia, Canada (Teck Resources)	2017		850	0.0	0
22	Tonglvshan Mine, Hubei Province, China (China Daye Ltd.)	2017		200,000		2
23	Antamok, Baguio, Philippines (Philex)	2016		50,000		
24	Duke Energy Coal Ash, Goldsboro, North Carolina	2016	415,000			
25	New Wales plant, Polk County, Mulberry, Florida (Mosaic Co)	2016		800,000		
26	Louyang Xiangjiang Wanji Aluminum, China	2016	2,000,000	2,000,000	2.0	
27	Hpakant Jade Mines, Myanmar	2015				115
28	Fundao-Santarem (Germano), Minas Gerais, Brazil (Samarco = Vale & BHP)	2015	56,400,000	43,700,000	668.0	19
29	Gold King Mine, near Silverton, Colorado	2015		11,356		
30	Yellow Giant Mine, Banks Island, British Columbia, Canada	2015		240	1.0	
31	Herculano Iron Mine, Itabirite, Minas Gerais, Brazil	2014	4,500,000			3
32	Buenavista del Cobre mine, Cananea, Sonora, Mexico (Grupo Mexico)	2014		40,000		
33	Imperial Metals, Mt Polley, British Columbia, Canada	2014	74,000,000	23,600,000	7.0	

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
34	Queensland Nickel, Yabulu Refnery, Townsville, Australia	2014		80,000		
35	Dan River Steam Station, North Carolina (Duke Energy)	2014	155,000,000	334,000		
36	Zangezur Copper Molybdenum Combine, Armenia	2013				
37	Obed Mountain Coal Mine Alberta, Canada	2013		670,000	180.0	
38	Coalmont Energy Corporation, Basin Coal Mine	2013		30	30.0	
39	Casa Berardi Mine, La Sarre, Abitibi region, Quebec (Hecla Mining Company)	2013		57,000		
40	Gullbridge Mine Newfoundland	2012		100,000	0.5	
41	Sotkamo, Kainuu Province, Finland (Talvivaara)	2012	5,400,000	240,000		
42	Padcal No 3, Benquet Philippines (Philex)	2012	102,000,000	13,000,000		
43	Hudson Bay (HB) Mine, Salmo, British Columbia (Regional District of Central Kootenay & Teck)	2012	1,800,000			
44	Johson Gold Mining Corporation at Baranggay Bangong-Bayan	2012				
45	Mineracao Serra Grande Tailings Dam, State of Goias, Brazil (Anglo Ashanti)	2012		900		
46	Mianyang City, Songpan County, Sichuan Province, China	2011		10,000		
47	Ray Mine, Hayden, AZ, USA (Asarco)	2011		3,600		
48	Bloom Lake, Newfoundland, Canada (Cleveland Cliffs)	2011		200,000		
49	Ajka Alumina Plant, Kolontár, Hungary (MAL Magyar Aluminum)	2010	30,000,000	1,000,000	80.0	10
50	Zijin Mining, Xinyi Yinyan Tin Mine, Guangdong Province, China	2010				22
51	Zijin Mining, Zijinshan Gold & Copper Mine, (Ting River)	2010		500		

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
52	Zijin Mining, Zijinshan Gold & Copper Mine, (Ting River)	2010		9,100		
53	Huancavelica, Peru, Unidad Minera Caudalosa Chica	2010		100,000	110.0	
54	Las Palmas, Pencahue, VII Region, Maule, Chile (COMINOR)	2010	220,000	170,000	0.5	4
55	Veta del Agua Tranque No. 5, Nogales, V Region, Valparaíso, Chile	2010	80,000	30,000	0.1	
56	Tranque Adosado Planta Alhué, Alhué, Region Metropolitana, Chile	2010				
57	Tranque Planta Chacón, Cachapoal, VI Region, Rancagua, Chile	2010				
58	Tranque Adosado Planta Alhué, Alhué, Region Metropolitana, Chile (Florida Mining)	2010				
59	Karamken, Magadan Region, Russia (cyanide-leach processing facility of gold mines in the region)	2009	4,600,000	1,200,000		2
60	Huayuan County, Xiangxi Autonomous Prefecture, Hunan Province, China	2009		50,000		3
61	Kingston fossil plant, Harriman, Tennessee, USA (TVA)	2008		4,100,000	4.1	
62	Taoshi, Linfen City, Xiangfen county, Shanxi province, China (Tahsan Mining Co.)	2008	290,000	190,000	2.5	254
63	Ekati Mine, Northwest Territories, CA (BHP Billiton)	2008		4,500		
64	Bernburg, Germany (Solvay)	2007		150,000		
65	Glebe Mines, UK	2007		20,000		
66	Mineracao Rio Pomba Cataguases, Mirai, Minas Gerais, Brazil, Mineração (Industrias Quimicas Cataguases)	2007	3,800,000	2,000,000		
67	Fonte Santa ,Freixia De Espado a Cinta, Potugal	2006		231,600	2.5	
68	Nchanga, Chingola, Zambia (Konkola Copper Mines - Vedanta)	2006				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
69	Miliang, Zhen'an County, Shangluo, Shaanxi Province, China	2006			5.0	17
70	Mineracao Rio Pomba Cataguases, Mirai, Minas Gerais, Brazil, Mineração (Industrias Quimicas Cataguases)	2006		400,000		
71	Tailings Dam, USA	2005	500,000	170,000	25.0	
72	Captains Flat Dump No 3, Australia	2005		40,000	12.0	
73	Bangs Lake, Jackson County, Mississippi, USA (Mississippi Phosphates Corp)	2005		64,350		
74	Pinchi Lake, BC, Canada (Teck Cominco Ltd.)	2004		7,000		
75	Riverview, Florida (Cargill)	2004		227,000		
76	Partizansk, Primorski Krai, Russia (Dalenergo)	2004	20,000,000	160,000		
77	Malvési, Aude, France (Comurhex, Cogéma/Areva)	2004		30,000		
78	Cerro Negro, near Santiago, Chile, (5 of 5)	2003		80,000	20.0	
79	Sasa Mine, Macedonia	2003	2,000,000	100,000	12.0	
80	Mineracao Rio Pomba Cataguases, Mirai, Minas Gerais, Brazil, Mineração (Industrias Quimicas Cataguases)	2003		1,200,000		
81	El Cobre, Chile - El Soldado (Exxon)	2002		4,500		
82	El Cobre, Chile, 2, 3, 4, 5 (Exxon)	2002		8,000		
83	San Marcelino Zambales, Philippines, Bayarong dam (Benguet Corp-Dizon Copper-Silver Mines Inc)	2002	47,000,000	1,000,000		
84	San Marcelino Zambales, Philippines, Camalca dam (Benguet Corp-Dizon Copper-Silver Mines)	2002				
85	Thalanga Mine, Queensland Australia	2002	290,000			0

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
86	Tarkwa, Ghana (Goldfields)	2001				
87	Cuajone mine, Torata water supply dam, Peru	2001	16,000,000	-		
88	Sebastião das Águas Claras, Nova Lima district, Minas Gerais, Brazil	2001			8.0	2
89	Nandan Tin mine, Dachang, Guangxi	2000				28
90	Inez, Martin County, Kentucky, USA (Massey Energy subsidiary Martin Co. Coal Corp)	2000		1,068,500	120.0	
91	Aitik mine, near Gällivare, Sweden (Boliden Ltd)	2000	15,000,000	1,800,000	5.2	
92	Borsa, Romania (Remin S.A - govt)	2000		9,140		
93	Baia Mare, Romania	2000	800,000	100,000	2,000.0	
94	Toledo City, Philippines (Atlas Con Mining Corp)	1999		5,700,000		
95	Red Mountain, BC	1999		10,000		
96	Surigao Del Norte Placer, Philippines (3 of 3) Manila Mining Corp	1999		400,000	12.0	4
97	Huelva, Spain (Fertiberia, Foret)	1998		50,000		
98	Zamboanga Del Norte, Sibutad Gold Project (Philex Mining Corp)	1998				
99	Los Frailes, near Seville, Spain (Boliden Ltd.)	1998	15,000,000	6,800,000	41.0	
100	Mulberry Phosphate, Polk County, Florida, USA (Mulberry Phosphate)	1997		200,000		
101	Zamboanga Del Norte, Sibutad Gold Project (Philex Mining Corp)	1997				
102	Pinto Valley, Arizona, USA (BHP Copper)	1997		230,000		
103	Tranque Antiguo Planta La Cocinera, IV Region, Vallenar, Chile	1997		60,000	0.2	
104	Algarrobo, IV Region, Vallenar, Chile	1997				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
105	Algarrobo, IV Region, Vallenar, Chile	1997				
106	Maitén, IV Region, Vallenar, Chile	1997				
107	Amatista, Peru	1996		600,000		
108	Caravelí, Peru	1996				
109	El Porco, Bolivia (Comsur-62%, Rio Tinto-33%)	1996		166,000	300.0	
110	Sgurigrad, Bulgaria	1996	1,520,000	220,000	6.0	
111	Marcopper, Marinduque Island, Philippines (2 of 2) (Placer Dome and President Marcos)	1996		1,600,000	26.0	
112	Laisvall (Boliden), Sweden	1996	20,000,000	-		
113	Negros Occidental, Bulawan Mine Sipalay River, Philippines (Philex Mining Corp)	1995				
114	Golden Cross, Waitekauri Valley, New Zealand (Coeur d'Alène Mines)	1995	3,000,000			
115	Surigao del Norte Placer, Philippines (2 of 3) (Manila Mining Corp)	1995		50,000		12
116	Omai Mine, Tailings dam No 1, 2, Guyana (Cambior)	1995	5,250,000	4,200,000	80.0	
117	Middle Arm, Launceston, Tasmania	1995	25,000	5,000		
118	Riltec, Mathinna, Tasmania	1995	120,000	40,000		
119	Hopewell Mine, Hillsborough County, Florida, USA (IMC-Agrico)	1994		1,900,000		
120	Payne Creek Mine, Polk County, Florida, USA (IMC-Agrico)	1994		6,800,000		
121	Fort Meade Phosphate, Florida, USA (Cargill)	1994		76,000		
122	IMC-Agrico Phosphate, Florida, USA	1994				
123	Merriespruit, near Virginia, South Africa (Harmony) - No 4A Tailings Complex	1994	7,040,000	600,000	4.0	17

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
124	Olympic Dam, Roxby Downs, South Australia	1994		5,000,000		
125	Minera Sera Grande: Crixas, Goias, Brazil	1994	2,250,000	-		
126	Tapo Canyon, Northbridge, California	1994		135,000	0.2	
127	Fort Meade, Florida, Cargill phosphate (3 of 3)	1994		76,000		
128	Longjiaoshan, Daye Iron Ore mine, Hubei	1994				31
129	Marcopper, Marinduque Island, Mogpog Philippines (12/6) (1 of 2) (Placer Dome-President Marcos)	1993				2
130	Gibsonton, Florida, USA (Cargill)	1993				
131	TD 7, Chingola, Zambia	1993		42		
132	Itogon-Suyoc, Baguio gold district, Luzon, Philippines (Benguet Corp)	1993				
133	Saaiplaas, South Africa, failure on south ring dyke (22Mar93)	1993		100		
134	Saaiplaas, South Africa, 2 failures on west ring dyke (18-19Mar93)	1993		100		
135	Magma Copper Company Pinto Valley Division Pinto Valley Operations, Arizona	1993		90,000		
136	Ray Complex, Pinal County, Arizona, AB-BA Impoundment	1993		216,000	18.0	
137	Marsa, Peru (Marsa Mining Corp)	1993				6
138	Kojkovac, Montenegro	1992	3,500,000	-		
139	Maritsa Istok 1, Bulgaria	1992	52,000,000	500,000		
140	Tubu, Benguet, No.2 Tailings Pond, Luzon, Philippines - Padcal (Philex)	1992	102,000,000	32,243,000		
141	Ajka Alumina Plant, Kolontár, Hungary	1991	4,500,000	43,200		
142	Iron Dyke, Sullivan Mine, Kimberley, BC, Canada (Cominco, Inc)	1991		75,000		

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
143	Magma Mine Tailings Dam #3	1991		8,000		
144	Brewer Gold Mine Jefferson South Carolina	1990		41,640	80.0	
145	Matachewan Mines, Kirtland Lake, Ontario	1990		190,000	168.0	
146	Soda Lake, California, USA	1989				
147	Stancil, Maryland, USA	1989	74,000	38,000	0.1	
148	Silver King, Idaho, USA	1989	37,000	100		
149	Southern Clay, Tennessee, USA	1989		300		
150	Little Bay Mine (Atlantic Coast Copper Co), Little Bay, Newfoundland and Labrador, Canada	1989	1,250,000	500,000		
151	Big Four, Florida, USA	1989				
152	Thompson Creek, Idaho, USA (Cyprus)	1989	27,000,000			
153	Unidentified, Hernando, County, Florida, USA #2	1988	3,300,000	4,600		
154	Jinduicheng, Shaanxi Province., China	1988		700,000		20
155	Consolidated Coal No.1, Tennessee, USA,	1988	1,000,000	250,000		
156	Riverview, Hillsborough County, Florida (Gardiner/Cargill)	1988		246		
157	Unidentified, Hernando, County, Florida, USA #1	1988				
158	Rain Starter Dam, Elko, Nevada, USA	1988	1,500,000			
159	Surigao Del Norte Placer, Philippines (1 of 3) (Manila Mining Corp)	1987				
160	Montcoal No.7, Raleigh County, West Virginia, USA	1987		87,000	80.0	
161	Bekovsky, Western Siberia	1987	52,000,000	-		

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
162	Xishimen, China	1987		2,230		
163	Montana Tunnels, MT, USA (Pegasus Gold)	1987	250,000			
164	Marianna Mine #58, PA	1986	300,000			
165	Mankayan District, Luzon, Phillippines, No.3 Tailings Pond (Benguet Corp subsidiary Lepanto Con Mining Co)	1986		100,000		
166	Pico de Sao Luis, Gerais, Brazil	1986				
167	Story's Creek, Tasmania	1986	30,000	100		
168	Rossarden, Tasmania	1986	200,000			
169	Itabirito, Minas Gerais, Brazil (Itaminos Comercio de Minerios)	1986		100,000	12.0	7
170	Mineral King, BC, Canada	1986	Small			
171	Huangmeishan, China	1986				19
172	Spring Creek Plant, Borger, Texas, USA	1986	30,000			
173	Niujiaolong tailings pond, China	1985	1,100,000	730,000	4.2	
174	Bonsal, North Carolina, USA	1985	38,000	11,000	0.8	
175	Prestavel Mine - Stava, North Italy, 2, 3 (Prealpi Mineraria)	1985	400,000	180,000	4.2	269
176	La Belle, Pennsylvania, USA	1985	1,230,000			
177	Cerro Negro No. (4 of 5)	1985	2,000,000	500,000	8.0	
178	Veta de Agua No. 1, Chile	1985	700,000	280,000	5.0	
179	Niujiaolong, Hunan (Shizhuyuan Non-ferrous Metals Co.)	1985	1,100,000	731,000	4.2	49
180	Olinghouse, Nevada, USA	1985	120,000	25,000	1.5	
181	El Cobre No. 4 - El Soldado (Exxon)	1985				
182	Marga, Chile - El Teniente (Codelco)	1985				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
183	Quintette, MaËmot, BC, Canada	1985		2,500,000	2.5	
184	Texasgulf 4B Pond, Beaufort, Co., North Carolina, USA	1984	12,300,000			
185	Mirolubovka, Southern Ukraine	1984	80,000,000	-		
186	Battle Mt. Gold, Nevada,	1984	1,540,000			
187	Virginia Vermiculite, Louisa County, Virginia, USA	1984				
188	Clayton Mine, Idaho, USA	1983	215,000			
189	Golden Sunlight, MT, USA	1983				
190	Vallenar 1 and 2	1983				
191	Grey Eagle, California, USA	1983				
192	Sipalay, Phillippines, No.3 Tailings Pond (Maricalum Mining Corp)	1982	22,000,000	15,000,000		
193	Royster, Florida, USA	1982				
194	Ages, Harlan County, Kentucky, USA	1981		96,000	163.0	1
195	Dixie Mine, Colorado, USA	1981				
196	Balka Chuficheva, Russia	1981	27,000,000	3,500,000	1.3	
197	Texasgulf No. 1 Pond, Beaufort Co., North Carolina, USA	1981	24,700,000			
198	Veta de Aqua A	1981				
199	Veta de Agua B	1981				
200	Tyrone, New Mexico (Phelps Dodge)	1980	2,500,000	2,000,000	8.0	
201	Sweeney Tailings Dam, Longmont, Colorado, USA	1980				
202	Marga, Sewell, VI Region, Rancagua, Chile - El Teniente (Codelco)	1980				
203	Arena, Sewell, VI Region, Rancagua, Chile - El Teniente (Codelco)	1980				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
204	San Nicolas, Peru	1980				
205	Kyanite Mining, Virginia, USA	1980	430,000			
206	Churchill Copper, BC	1979		37,854		
207	Churchrock, New Mexico, United Nuclear	1979	370,000	370,000	110.0	
208	Union Carbide, Uravan, Colorado, USA	1979				
209	Unidentified, British Columbia, Canada	1979		40,000		
210	Suncor E-W Dike, Alberta, Canada	1979				
211	Incident No. 1, Elliot, Ontario, Canada	1979				
212	Arcturus, Zimbabwe	1978	680,000	39,000	0.3	1
213	Mochikoshi No. 2, Japan (2 of 2)	1978	480,000	3,000	0.2	
214	Mochikoshi No. 1, Japan (1 of 2)	1978	480,000	80,000	8.0	1
215	Norosawa, Japan	1978	225,000			
216	Hirayama, Japan	1978	87,000			
217	Syncrude, Alberta, Canada	1978				
218	Madison, Missouri, USA	1977				
219	Grants, Milan, New Mexico, USA mill site (Homestake Mining)	1977		30,000		
220	Western Nuclear, Jeffrey City, Wyoming, USA #2	1977		8,700		
221	Pit No. 2, Western	1977				
222	Unidentified, Hernando, County, Florida, USA	1977				
223	Kerr-McGee, Churchrock, New Mexico, USA	1976				
224	Zlevoto No. 4, Yugoslavia	1976	1,000,000	300,000		

No	Mine	Year	Storage volume (m³)	Release (m³)	Runout (km)	Deaths
225	Dashihe, China	1976				
226	Unidentified, Idaho, USA	1976				
227	Cadet No. 2, Montana,	1975				
228	Silverton, Colorado, USA	1975		72,500		
229	Madjarevo, Bulgaria	1975	3,000,000	250,000	20.0	
230	Carr Fork, Utah, USA (Anaconda)	1975				
231	Mike Horse, Montana, USA (Asarco)	1975	750,000	150,000	24.0	
232	Dresser No. 4, Montana,	1975				
233	Keystone Mine, Crested Butte, Colorado, USA	1975				
234	Heath Steele main dam, Brunswick, Canada (American Metals)	1975				
235	PCS Rocanville, Saskatchewan, Canada	1975				
236	Unidentified, Green River, Wyoming, USA	1975				
237	Bafokeng, South Africa	1974	13,000,000	3,000,000	45.0	12
238	Golden Gilpin Mine, Colorado, USA	1974				
239	Deneen Mica Yancey County, North Carolina, USA	1974	300,000	38,000	0.0	
240	Silver King, Idaho, USA	1974	37,000	13,600		
241	Galena Mine, Idaho, USA (ASARCO) (2 of 2)	1974		3,800	0.6	
242	Berrien, France	1974				
243	GCOS, Alberta, Canada	1974				
244	Unidentified, Mississippi, USA #2	1974				
245	Unidentified, Canaca, Mexico	1974				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
246	Ray Mine, Arizona, USA #2 (Kennecott)	1973				
247	(unidentified), Southwestern USA	1973	500,000	170,000	25.0	
248	Earth Resources, N M,	1973				
249	Ray Mine, Arizona, USA	1972				
250	Brunita Mine, Caragena, Spain (SMM Penaroya)	1972	1,080,000	70,000		1
251	Buffalo Creek, West Virginia, USA (Pittson Coal Co.)	1972	500,000	500,000	64.4	125
252	Galena Mine, Idaho, USA (ASARCO) (1 of 2)	1972				
253	Cities Service, Fort Meade, Florida, phosphate	1971	12,340,000	9,000,000	120.0	
254	Certej gold mine, Romania	1971		300,000		89
255	Chungar, Peru	1971				1
256	Ticapampa, Peru	1971				3
257	Pinchi Lake, BC, Canada	1971				
258	Atacocha, Peru (Compañía Minera Atacocha)	1971				
259	Quiruvilca mine, Almivirca tailings dam, Peru (2 of 2)	1971				
260	Western Nuclear, Jeffrey City, Wyoming, USA	1971				
261	Mufulira, Zambia (Roan Consolidated Mines)	1970	1,000,000	68,000		89
262	Maggie Pye, United Kingdom, clay	1970		15,000	0.0	
263	Park, United Kingdom	1970				
264	Portworthy, United Kingdom	1970				
265	Unidentified, Mississippi, USA	1970				
266	Williamsport Washer, Maury County, Tennessee, USA	1970				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
267	Phoenix Copper, BC	1969		11,356		
268	Bilbao, Spain	1969		115,000	0.0	1
269	Buenaventura, Peru	1969				
270	Monsanto Dike 15, TN,	1969	1,230,000			
271	Stoney Middleton, UK	1968				
272	Yauli-Yacu, Peru	1968				
273	Hokkaido, Japan	1968	300,000	90,000	0.2	
274	Agrico Chemical, Florida, USA	1968				
275	IMC K-2, Saskatchewan, Canada	1968				
276	Iwiny Tailings Dam, Poland	1967	16,000,000	4,600,000	15.0	18
277	Climax, Grand Junction, CO, USA - Mill (Climax Molybdenum Co)	1967		12,000		
278	Mobil Chemical, Fort Meade, Florida, phosphate	1967		2,000,000		
279	Unidentified, United Kingdom	1967				
280	Unidentified, United Kingdom #2	1967				
281	Unidentified, United Kingdom #3	1967				
282	Aberfan, Tip No 7, South Wales Colliery	1966	230,000	162,000	0.6	144
283	Geising/Erzgebirge, German Democratic Republic VEB Zinnerz	1966		70,000		
284	Mir mine, Sgurigrad, Bulgaria	1966	1,520,000	450,000	8.0	488
285	Williamthorpe, UK #2	1966				
286	Gypsum Tailings Dam (Texas, USA)	1966	6,360,000	130,000	0.3	
287	Williamthorpe, UK #1	1966				
288	Derbyshire, United Kingdom	1966		30,000	0.1	

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
289	Tymawr, United Kindom #2	1965			0.7	
290	El Cobre Old Dam	1965	4,250,000	1,900,000	12.0	200
291	El Cobre New Dam	1965	350,000	350,000	12.0	
292	El Cobre Small Dam - El Soldado (Penarroya)	1965	985,000			
293	La Patagua New Dam, Chile (La Patagua - private)	1965		35,000	5.0	
294	Los Maquis No. 3	1965	43,000	21,000	5.0	
295	Bellavista, Chile	1965	450,000	70,000	0.8	
296	Hierro Viejo, Chile	1965		800	1.0	
297	Ramayana No. 1, Chile	1965		150		
298	Cerro Blanco de Polpaico, Chile	1965				
299	El Cerrado, Chile	1965				
300	Los Maquis No. 1	1965	30,000	20,000		
301	Sauce No. 1, Chile	1965				
302	Sauce No. 2, Chile	1965				
303	Sauce No. 3, Chile	1965				
304	Sauce No. 4, Chile	1965				
305	Cerro Negro No. (3 of 5)	1965	500,000	85,000	5.0	
306	Cerro Negro No. (2 of 5)	1965				
307	Cerro Negro No. (1 of 5)	1965				
308	American Cyanamid, Florida #2	1965				
309	N'yukka Creek, USSR	1965				
310	Unidentified, Idaho, USA	1965				

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Runout (km)	Deaths
311	Alcoa, Texas, USA	1964	4,500,000			
312	Castano Viejo Mine, San Juan, Argentina	1964	26,500	17,000	2.2	3
313	Utah Construction, Riverton, Wyoming, USA	1963				
314	Louisville, USA	1963	910,000	667,000	0.1	
315	Huogudu, Yunnan Tin Group Co., Yunnan	1962	5,420,000	3,300,000	4.5	171
316	Mines Development, Edgemont, South Dakota, USA	1962		100	40.0	
317	American Cyanamid, Florida	1962		11,356,230		
318	Quiruvilca mine, Almivirca tailings dam, Peru (1 of 2)	1962				
319	Union Carbide, Maybell, Colorado, USA	1961		280		
320	Tymawr, United Kingdon #1	1961			0.7	
321	Jupille, Belgium	1961	550,000	136,000	0.6	11
322	La Luciana, Reocín (Santander), Cantabria, Spain	1960	1,250,000	100,000	0.5	18
323	Lower Indian Creek, MO, USA	1960				

C Tailings dam failures with reported data on released volume and storage capacity

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Relative amount of released material (%)
1	Brumadinho, Mina Córrego do Feijão, Minas Gerais, Brazil (Vale)	2019	12,000,000	9,570,000	79.8
2	Duke Energy, HF Lee Power Plant, Goldsboro, North Carolina	2018	875,000	2,000	0.2
3	Hector Mine Pit Pond, MN, USA	2018	185,000	123,000	66.5
4	Hernic PGM Project, South Africa (Jubilee Metals Group)	2017	4,875,000	-	-
5	Kokoya mine, Liberia (MNG Gold-Liberia)	2017	300,000	11,356	3.8
6	Louyang Xiangjiang Wanji Aluminum, China	2016	2,000,000	2,000,000	100.0
7	Fundao-Santarem (Germano), Minas Gerais, Brazil (Samarco = Vale & BHP)	2015	56,400,000	43,700,000	77.5
8	Imperial Metals, Mt Polley, British Columbia, Canada	2014	74,000,000	23,600,000	31.9
9	Dan River Steam Station, North Carolina (Duke Energy)	2014	155,000,000	334,000	0.2
10	Sotkamo, Kainuu Province, Finland (Talvivaara)	2012	5,400,000	240,000	4.4
11	Padcal No 3, Benquet Philippines (Philex)	2012	102,000,000	13,000,000	12.7
12	Ajka Alumina Plant, Kolontár, Hungary (MAL Magyar Aluminum)	2010	30,000,000	1,000,000	3.3
13	Las Palmas, Pencahue, VII Region, Maule, Chile (COMINOR)	2010	220,000	170,000	77.3
14	Veta del Agua Tranque No. 5, Nogales, V Region, Valparaíso, Chile	2010	80,000	30,000	37.5
15	Karamken, Magadan Region, Russia (cyanide-leach processing facility of gold mines in the region)	2009	4,600,000	1,200,000	26.1
16	Taoshi, Linfen City, Xiangfen county, Shanxi province, China (Tahsan Mining Co.)	2008	290,000	190,000	65.5
17	Mineracao Rio Pomba Cataguases, Mirai, Minas Gerais, Brazil,	2007	3,800,000	2,000,000	52.6

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Relative amount of released material (%)
	Mineração (Industrias Quimicas Cataguases)				
18	Tailings Dam, USA	2005	500,000	170,000	34.0
19	Partizansk, Primorski Krai, Russia (Dalenergo)	2004	20,000,000	160,000	0.8
20	Sasa Mine, Macedonia	2003	2,000,000	100,000	5.0
21	San Marcelino Zambales, Philippines, Bayarong dam (Benguet Corp-Dizon Copper-Silver Mines Inc)	2002	47,000,000	1,000,000	2.1
22	Cuajone mine, Torata water supply dam, Peru	2001	16,000,000	-	-
23	Aitik mine, near Gällivare, Sweden (Boliden Ltd)	2000	15,000,000	1,800,000	12.0
24	Baia Mare, Romania	2000	800,000	100,000	12.5
25	Los Frailes, near Seville, Spain (Boliden Ltd.)	1998	15,000,000	6,800,000	45.3
26	Sgurigrad, Bulgaria	1996	1,520,000	220,000	14.5
27	Laisvall (Boliden), Sweden	1996	20,000,000	-	-
28	Omai Mine, Tailings dam No 1, 2, Guyana (Cambior)	1995	5,250,000	4,200,000	80.0
29	Middle Arm, Launceston, Tasmania	1995	25,000	5,000	20.0
30	Riltec, Mathinna, Tasmania	1995	120,000	40,000	33.3
31	Merriespruit, near Virginia, South Africa (Harmony) - No 4A Tailings Complex	1994	7,040,000	600,000	8.5
32	Minera Sera Grande: Crixas, Goias, Brazil	1994	2,250,000	-	-
33	Kojkovac, Montenegro	1992	3,500,000	-	-
34	Maritsa Istok 1, Bulgaria	1992	52,000,000	500,000	1.0
35	Tubu, Benguet, No.2 Tailings Pond, Luzon, Philippines - Padcal (Philex)	1992	102,000,000	32,243,000	31.6
36	Ajka Alumina Plant, Kolontár, Hungary	1991	4,500,000	43,200	1.0

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Relative amount of released material (%)
37	Stancil, Maryland, USA	1989	74,000	38,000	51.4
38	Silver King, Idaho, USA	1989	37,000	100	0.3
39	Little Bay Mine (Atlantic Coast Copper Co), Little Bay, Newfoundland and Labrador, Canada	1989	1,250,000	500,000	40.0
40	Unidentified, Hernando, County, Florida, USA #2	1988	3,300,000	4,600	0.1
41	Consolidated Coal No.1, Tennessee, USA,	1988	1,000,000	250,000	25.0
42	Bekovsky, Western Siberia	1987	52,000,000	-	-
43	Story's Creek, Tasmania	1986	30,000	100	0.3
44	Niujiaolong tailings pond, China	1985	1,100,000	730,000	66.4
45	Bonsal, North Carolina, USA	1985	38,000	11,000	28.9
46	Prestavel Mine - Stava, North Italy, 2, 3 (Prealpi Mineraria)	1985	400,000	180,000	45.0
47	Cerro Negro No. (4 of 5)	1985	2,000,000	500,000	25.0
48	Veta de Agua No. 1, Chile	1985	700,000	280,000	40.0
49	Niujiaolong, Hunan (Shizhuyuan Non-ferrous Metals Co.)	1985	1,100,000	731,000	66.5
50	Olinghouse, Nevada, USA	1985	120,000	25,000	20.8
51	Mirolubovka, Southern Ukraine	1984	80,000,000	-	-
52	Sipalay, Phillippines, No.3 Tailings Pond (Maricalum Mining Corp)	1982	22,000,000	15,000,000	68.2
53	Balka Chuficheva, Russia	1981	27,000,000	3,500,000	13.0
54	Tyrone, New Mexico (Phelps Dodge)	1980	2,500,000	2,000,000	80.0
55	Churchrock, New Mexico, United Nuclear	1979	370,000	370,000	100.0
56	Arcturus, Zimbabwe	1978	680,000	39,000	5.7
57	Mochikoshi No. 2, Japan (2 of 2)	1978	480,000	3,000	0.6

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Relative amount of released material (%)
58	Mochikoshi No. 1, Japan (1 of 2)	1978	480,000	80,000	16.7
59	Zlevoto No. 4, Yugoslavia	1976	1,000,000	300,000	30.0
60	Madjarevo, Bulgaria	1975	3,000,000	250,000	8.3
61	Mike Horse, Montana, USA (Asarco)	1975	750,000	150,000	20.0
62	Bafokeng, South Africa	1974	13,000,000	3,000,000	23.1
63	Deneen Mica Yancey County, North Carolina, USA	1974	300,000	38,000	12.7
64	Silver King, Idaho, USA	1974	37,000	13,600	36.8
65	(unidentified), Southwestern USA	1973	500,000	170,000	34.0
66	Brunita Mine, Caragena, Spain (SMM Penaroya)	1972	1,080,000	70,000	6.5
67	Buffalo Creek, West Virginia, USA (Pittson Coal Co.)	1972	500,000	500,000	100.0
68	Cities Service, Fort Meade, Florida, phosphate	1971	12,340,000	9,000,000	72.9
69	Mufulira, Zambia (Roan Consolidated Mines)	1970	1,000,000	68,000	6.8
70	Hokkaido, Japan	1968	300,000	90,000	30.0
71	Iwiny Tailings Dam, Poland	1967	16,000,000	4,600,000	28.8
72	Aberfan, Tip No 7, South Wales Colliery	1966	230,000	162,000	70.4
73	Mir mine, Sgurigrad, Bulgaria	1966	1,520,000	450,000	29.6
74	Gypsum Tailings Dam (Texas, USA)	1966	6,360,000	130,000	2.0
75	El Cobre Old Dam	1965	4,250,000	1,900,000	44.7
76	El Cobre New Dam	1965	350,000	350,000	100.0
77	Los Maquis No. 3	1965	43,000	21,000	48.8
78	Bellavista, Chile	1965	450,000	70,000	15.6

No	Mine	Year	Storage volume (m^3)	Release (m^3)	Relative amount of released material (%)
79	Los Maquis No. 1	1965	30,000	20,000	66.7
80	Cerro Negro No. (3 of 5)	1965	500,000	85,000	17.0
81	Castano Viejo Mine, San Juan, Argentina	1964	26,500	17,000	64.2
82	Louisville, USA	1963	910,000	667,000	73.3
83	Huogudu, Yunnan Tin Group Co., Yunnan	1962	5,420,000	3,300,000	60.9
84	Jupille, Belgium	1961	550,000	136,000	24.7
85	La Luciana, Reocín (Santander), Cantabria, Spain	1960	1,250,000	100,000	8.0

D Tailings dam failures with reported data on runout distance

No	Mine	Year	Reported runout in official sources (km)	Surface water transport distance included	Runout estimated by additional investigations (km)
1	Nossa Senhora do Livramento, Mato Grosso, Brazil (VM Mineração e Construção, Cuiabá)	2019	2.0		
2	Cobriza mine, San Pedro de Coris district, Churcampa province, Huancavelica region, Peru (Doe Run Perú S.R.L)	2019	375.0	Y	
3	Muri, Jharkhand, India (Hindalco Industries Limited)	2019	0.2		
4	Brumadinho, Mina Córrego do Feijão, Minas Gerais, Brazil (Vale)	2019	600.0	Y	7.0
5	Cieneguita mine, Urique municipality, Chihuahua, Mexico (Minera Rio Tinto and Pan American Goldfields)	2018	26.0	Y	12.0
6	Mishor Rotem, Israel (ICL Rotem)	2017	20.0	Y	0.5
7	Highland Valley Copper, British Columbia, Canada (Teck Resources)	2017	0.0		
8	Louyang Xiangjiang Wanji Aluminum, China	2016	2.0		
9	Fundao-Santarem (Germano), Minas Gerais, Brazil (Samarco = Vale & BHP)	2015	668.0	Y	1.0
10	Yellow Giant Mine, Banks Island, British Columbia, Canada	2015	1.0		
11	Imperial Metals, Mt Polley, British Columbia, Canada	2014	7.0		
12	Obed Mountain Coal Mine Alberta, Canada	2013	180.0	Y	20.0
13	Coalmont Energy Corporation, Basin Coal Mine	2013	30.0	Y	
14	Gullbridge Mine Newfoundland	2012	0.5		
15	Ajka Alumina Plant, Kolontár, Hungary (MAL Magyar Aluminum)	2010	80.0	Y	4.2
16	Huancavelica, Peru, Unidad Minera Caudalosa Chica	2010	110.0	Y	
17	Las Palmas, Pencahue, VII Region, Maule, Chile (COMINOR)	2010	0.5		

No	Mine	Year	Reported runout in official sources (km)	Surface water transport distance included	Runout estimated by additional investigations (km)
18	Veta del Agua Tranque No. 5, Nogales, V Region, Valparaíso, Chile	2010	0.1		
19	Kingston fossil plant, Harriman, Tennessee, USA (TVA)	2008	4.1		
20	Taoshi, Linfen City, Xiangfen county, Shanxi province, China (Tahsan Mining Co.)	2008	2.5		
21	Fonte Santa ,Freixia De Espado a Cinta, Potugal	2006	2.5		
22	Miliang, Zhen'an County, Shangluo, Shaanxi Province, China	2006	5.0	Y	
23	Tailings Dam, USA	2005	25.0	Y	
24	Captains Flat Dump No 3, Australia	2005	12.0		
25	Cerro Negro, near Santiago, Chile, (5 of 5)	2003	20.0	Y	4.6
26	Sasa Mine, Macedonia	2003	12.0		1.5
27	Sebastião das Águas Claras, Nova Lima district, Minas Gerais, Brazil	2001	8.0		
28	Inez, Martin County, Kentucky, USA (Massey Energy subsidiary Martin Co. Coal Corp)	2000	120.0	Y	
29	Aitik mine, near Gällivare, Sweden (Boliden Ltd)	2000	5.2		
30	Baia Mare, Romania	2000	2,000.0	Y	0.7
31	Surigao Del Norte Placer, Philippines (3 of 3) Manila Mining Corp	1999	12.0		0.7
32	Los Frailes, near Seville, Spain (Boliden Ltd.)	1998	41.0		1.2
33	Tranque Antiguo Planta La Cocinera, IV Region, Vallenar, Chile	1997	0.2		
34	El Porco, Bolivia (Comsur-62%, Rio Tinto-33%)	1996	300.0	Y	1.5
35	Sgurigrad, Bulgaria	1996	6.0		
36	Marcopper, Marinduque Island, Philippines (2 of 2) (Placer Dome and President Marcos)	1996	26.0	Y	8.5
37	Omai Mine, Tailings dam No 1, 2, Guyana (Cambior)	1995	80.0	Y	3.5

No	Mine	Year	Reported runout in official sources (km)	Surface water transport distance included	Runout estimated by additional investigations (km)
38	Merriespruit, near Virginia, South Africa (Harmony) - No 4A Tailings Complex	1994	4.0		
39	Tapo Canyon, Northbridge, California	1994	0.2		
40	Ray Complex, Pinal County, Arizona, AB-BA Impoundment	1993	18.0	Y	
41	Brewer Gold Mine Jefferson South Carolina	1990	80.0	Y	1.0
42	Matachewan Mines, Kirtland Lake, Ontario	1990	168.0	Y	3.5
43	Stancil, Maryland, USA	1989	0.1		
44	Montcoal No.7, Raleigh County, West Virginia, USA	1987	80.0	Y	2.0
45	Itabirito, Minas Gerais, Brazil (Itaminos Comercio de Minerios)	1986	12.0		
46	Niujiaolong tailings pond, China	1985	4.2		
47	Bonsal, North Carolina, USA	1985	0.8		
48	Prestavel Mine - Stava, North Italy, 2, 3 (Prealpi Mineraria)	1985	4.2		
49	Cerro Negro No. (4 of 5)	1985	8.0		
50	Veta de Agua No. 1, Chile	1985	5.0		
51	Niujiaolong, Hunan (Shizhuyuan Non-ferrous Metals Co.)	1985	4.2		
52	Olinghouse, Nevada, USA	1985	1.5		
53	Quintette, MaËmot, BC, Canada	1985	2.5		
54	Ages, Harlan County, Kentucky, USA	1981	163.0	Y	
55	Balka Chuficheva, Russia	1981	1.3		
56	Tyrone, New Mexico (Phelps Dodge)	1980	8.0		
57	Churchrock, New Mexico, United Nuclear	1979	110.0	Y	

No	Mine	Year	Reported runout in official sources (km)	Surface water transport distance included	Runout estimated by additional investigations (km)
58	Arcturus, Zimbabwe	1978	0.3		
59	Mochikoshi No. 2, Japan (2 of 2)	1978	0.2		
60	Mochikoshi No. 1, Japan (1 of 2)	1978	8.0		
61	Madjarevo, Bulgaria	1975	20.0	Y	
62	Mike Horse, Montana, USA (Asarco)	1975	24.0	Y	
63	Bafokeng, South Africa	1974	45.0	Y	
64	Deneen Mica Yancey County, North Carolina, USA	1974	0.0		
65	Galena Mine, Idaho, USA (ASARCO) (2 of 2)	1974	0.6		
66	(unidentified), Southwestern USA	1973	25.0	Y	
67	Buffalo Creek, West Virginia, USA (Pittson Coal Co.)	1972	64.4	Y	
68	Cities Service, Fort Meade, Florida, phosphate	1971	120.0	Y	
69	Maggie Pye, United Kingdom, clay	1970	0.0		
70	Bilbao, Spain	1969	0.0		
71	Hokkaido, Japan	1968	0.2		
72	Iwiny Tailings Dam, Poland	1967	15.0		
73	Aberfan, Tip No 7, South Wales Colliery	1966	0.6		
74	Mir mine, Sgurigrad, Bulgaria	1966	8.0		
75	Gypsum Tailings Dam (Texas, USA)	1966	0.3		
76	Derbyshire, United Kingdom	1966	0.1		
77	Tymawr, United Kindom #2	1965	0.7		
78	El Cobre Old Dam	1965	12.0		

No	Mine	Year	Reported runout in official sources (km)	Surface water transport distance included	Runout estimated by additional investigations (km)
79	El Cobre New Dam	1965	12.0		
80	La Patagua New Dam, Chile (La Patagua - private)	1965	5.0		
81	Los Maquis No. 3	1965	5.0		
82	Bellavista, Chile	1965	0.8		
83	Hierro Viejo, Chile	1965	1.0		
84	Cerro Negro No. (3 of 5)	1965	5.0		
85	Castano Viejo Mine, San Juan, Argentina	1964	2.2		
86	Louisville, USA	1963	0.1		
87	Huogudu, Yunnan Tin Group Co., Yunnan	1962	4.5		
88	Mines Development, Edgemont, South Dakota, USA	1962	40.0	Y	
89	Tymawr, United Kingdon #1	1961	0.7		
90	Jupille, Belgium	1961	0.6		
91	La Luciana, Reocín (Santander), Cantabria, Spain	1960	0.5		

E THI calculation example

For demonstrating the calculation of the THI (see Chapter 4), the Mortu TMF was chosen. This TMF is located in Romania, in Gorj county. All information that is needed for the calculation is presented in 7.

Table 18. General information about Motru TMF.

Information	Value
Latitude and longitude of the site (decimal degree)	22.968167 44.780417
Volume of the tailings in the TMF (million m^3)	1.5
Stored materials	Trace elements in fly ash
Management status	Active
Reference peak ground acceleration (m/s^2)	1.12
Location within the flood prone area with flood frequency of HQ-500	yes

<u>1st step: Tailings capacity</u>

$$THI_{Cap} = \text{Log}_{10}\,[1500000] = 6.2$$

<u>2nd step: Tailings toxicity</u>

As the TMF contains trace elements in fly ash, the stored materials have a low water hazard class (according to the WHC classification), therefore $THI_{Tox} = 1$.

<u>3rd step: Management conditions</u>

As the TMF is active, therefore $THI_{Man} = 3$.

<u>4th step: Natural conditions</u>

The TMF is located in the flood prone area of HQ-500 and the Reference PGA is higher than 0.1 m/s^2, therefore:

$$THI_{Nat} = THI_{Seism} + THI_{Flood} = 1 + 1 = 2$$

<u>5th step: Dam conditions</u>

For this TMF the Factor of Safety is not available, therefore $THI_{Dam} = 1$

<u>6th step: Total THI</u>

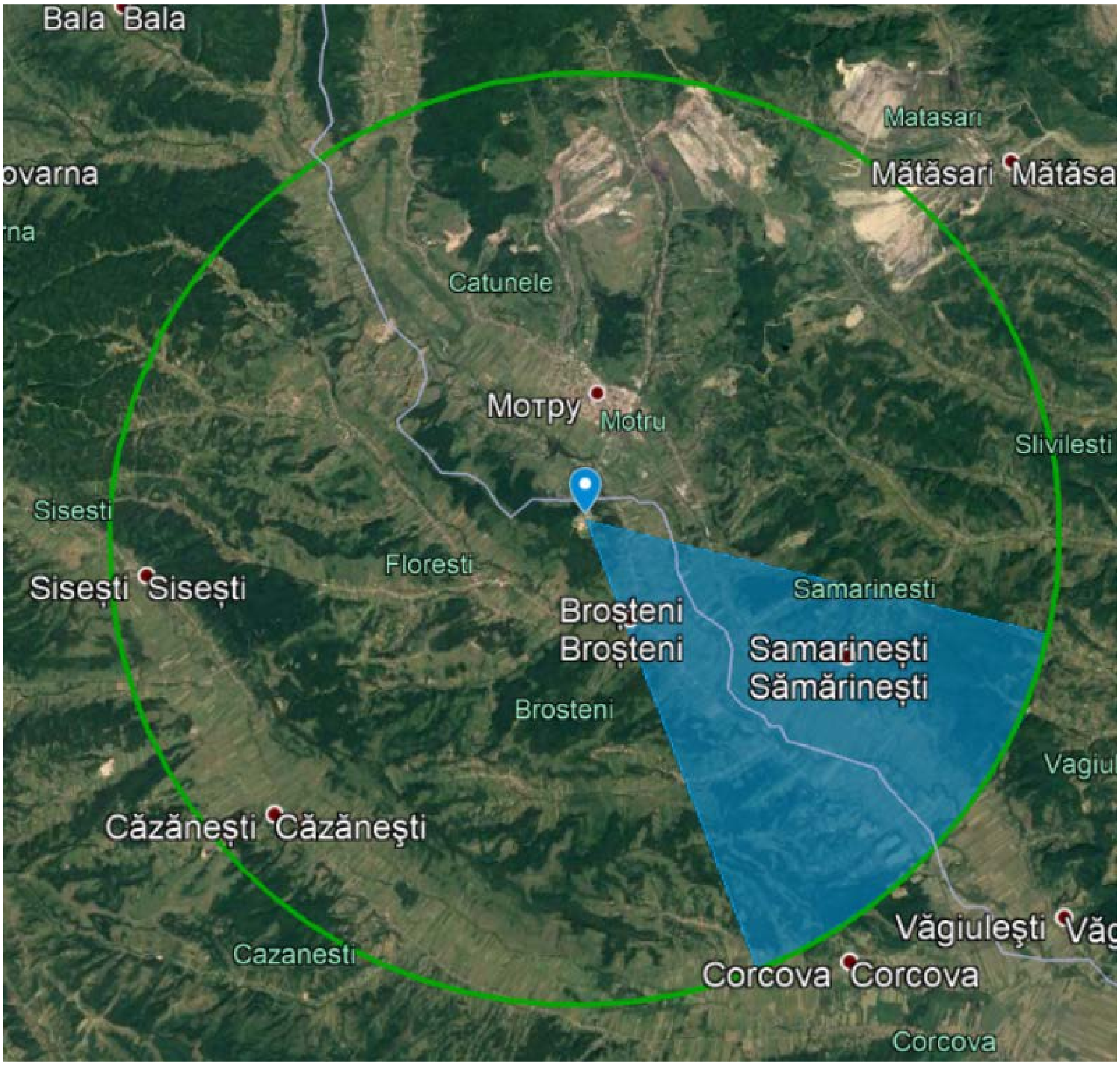
$$THI = THI_{Cap} + THI_{Tox} + THI_{Man} + THI_{Nat} + THI_{Dam} = 6.18 + 1 + 3 + 2 + 1 = 13.2$$

F TRI calculation example

The TRI calculation procedure (see Chapter 5) is demonstrated with the example of the same TMF in Motru. Both, the simplified (basic) and the detailed TRI calculation are demonstrated.

Using Google Earth map the 10 km risk zone and the area downstream of Motru TMF were identified (see Figure 16). The settlements and water bodies at risk were determined by intersecting the downstream area with the risk zone.

Figure 16. Definition of risk zone downstream of the Motru TMF.



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The green circle outlines the potential risk zone (with 10 km radius) and the blue zone shows the downstream territory that can be potentially affected within the risk zone in case of an accident.

1st step: Impact on population

Settlements in the potential risk zone (10 km downstream): Meris city with a population of 2145, villages Brosteni, Capatanesti, Lupsa de Jos and Luncsoara, their total population is 1491.

The total population in 10 km distance is 3636, therefore TEI_{Pop} = 4.

2nd step: Impact on environment

The nearest water body in the potential risk zone: Motru river, its mean flow rate is 15.2 m^3/s.

The river discharge of the nearest water body in 10 km distance is 15.2 m^3/s, therefore TEI_{Env} = 2.

3rd step: Total TEI

$$TEI = TEI_{Pop} + TEI_{Env} = 4 + 2 = 6$$

4th step: The TRI

$$TRI = THI + TEI = 13.2 + 6 = 19.2$$