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TECHNICAL COMMUNICATION

Criteria for Identifying the Major Risks Associated with Tailings Ponds in Romania

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Abstract Damage caused by accidents at hydraulic structures, due to natural hazards or human causes (e.g. terrorist sabotage) can be comparable to those caused by natural disasters. The paper identifies the major advantages of a common methodology for risk identification and quantification regarding the potential impact of accidents at tailings dams on the environment. Relevant Romanian and EU legislation and regulations enacted following the "Baia Mare" accident in 2000 are reviewed, along with a common risk evaluation methodology that can be applied by the mining sector to tailings dams.

Keywords Accidental pollution · Mining industry · NATECH event · Risk evaluation · Tailings dam · Vulnerability assessment

Introduction

Lessons learned from detailed analysis of past accidents at mine tailings dams (e.g. 30 January 2000, at the Aurul Mine Tailings Recovery Plant near Baia Mare in north-western Romania) are very important in improving safety measures for this type of hydraulic structure. Achieving safe operational conditions through proper dam risk management, is of great interest of the authorities and public in Romania, given the great number of the dams at risk, especially considering the potential effects of climatic changes, which can trigger technical accidents due to natural hazards (NATECH hazards) (Fig. 1).

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Background

Implementation of the Aquis communautaire (the entire body of EU laws) is necessary, especially in the acceding or candidate countries, for integration in the Communitarian structures, and has profound implications at all social-economical levels. A particular aspect of this relates to the safety aspects of existent industry processes. One of the most sensitive industrial activities is mining, especially in countries like Spain, Turkey, and Romania, where gold mines exist.

Appropriate risk assessment and management is required to assure safe exploitation and operation of mine waste tailings dams, which can contain environmentally dangerous substances. The implementation of the Seveso II Directive, recently amended, regarding the prevention of major accidents involving dangerous substances, induces supplementary uncertainties due to the lack of risk assessment and inventory data at the European level, for tailings dams that may contain potentially dangerous substances (Fig. 2).

The quantification of risk associated with tailings dams and industrial waste deposits requires the use of a unified system of categorisation, for better correlation of the characteristics of varied sites and their potential hazards. Managing such risks requires that the obligations of dam owners and operators be defined so that they can be operated safely and so that adequate measures can be taken to reduce the risks of an accident. The nature of required controls will vary, based on the degree of potential risk and

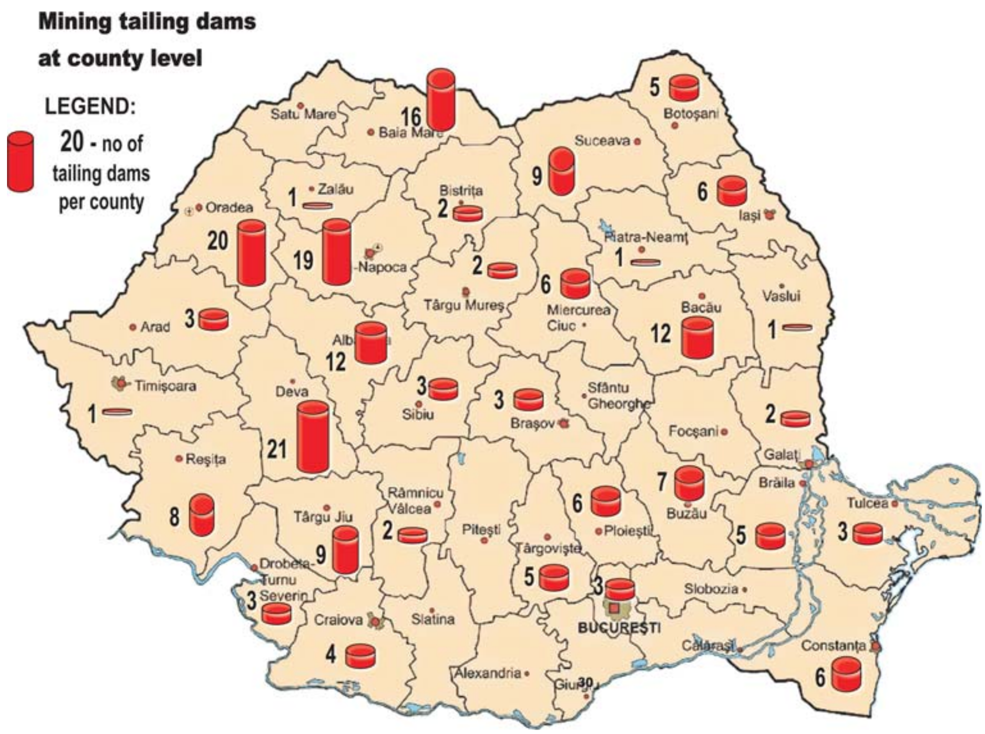


Fig. 1 Inventory of the tailing dams in Romania by counties

Fig. 2 Damage to hydraulic facilities, caused by NATECH type events (technological hazards generated by natural hazards), can be compared to damages caused by major natural disasters

their potential environmental impact. A useful tool for dam owners would be the use of a common methodology based on quantification of the risk components, using a standardised system of criteria, indices, and notes.

Risk is defined as the probability of an event multiplied by an evaluation of the adverse consequences if such an event occurred (vulnerability):

$$\text{Risk} = \text{Probability} \times \text{Vulnerability}$$

While the occurrence probability of the disaster in generally known, the potential consequences of a disaster can be difficult to quantify and involves a lot of unknown factors. Therefore, special attention has to be given to assessing vulnerability. Natural hazards that could affect tailings dams (such as floods, earthquake, landslides, and freeze-thaw) can be compared at the national level (Fig. 3). This approach can lead to a prioritisation of the needs and measures to be used by local or national authorities involved in technological risk management. GIS maps can also aid in visualising the potential adverse effects of technological accidents at a dangerous installation due to a natural hazards (NATECH type hazards). This type of disaster was not often studied in Romania until now. Even the use of multiple-hazard recognition is relatively new in Romania, representing a new direction of research, with significant practical implications.

Lessons Learned: Minimising the Risk of a NATECH Accident at Tailing Dams

Disseminating lessons learned by analysing past natural disasters to the public and interested parties should constitute an efficient informational method of reducing and preventing several types of hazards. To be effective, measures have to be taken by the local public administration to make such information available, using all the mass media means for communication. Also, based on lessons learned from such disasters, recommendations should be made to the local and regional administration authorities involved in

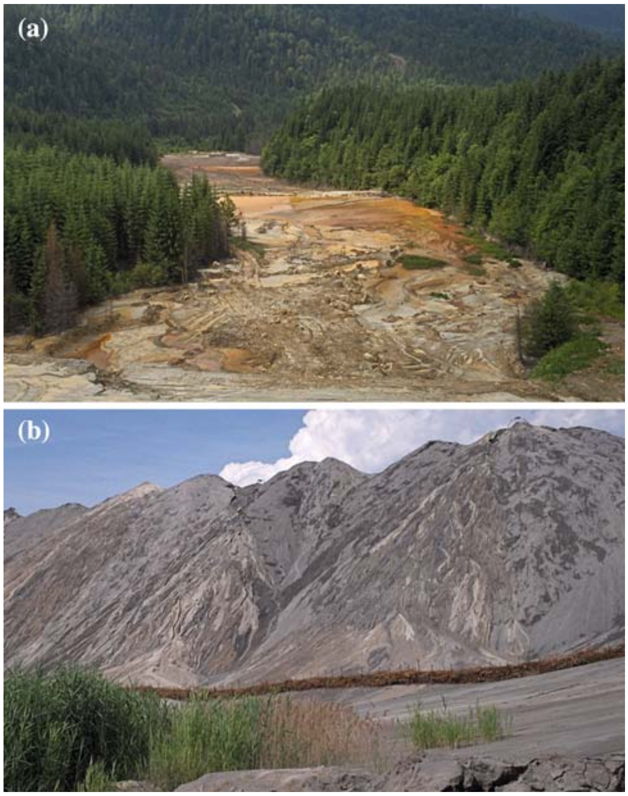


Fig. 3 **a**, **b** Runoff and wind deposition of fine-grained mine waste are a major concern for tailing dam owners and the public

natural disaster management in order to improve preventive measures and better cope with possible failures of technical structures, including tailing dams. Therefore, at the local level, a series of initiatives should be taken to:

- Reduce or prevent disasters caused by extreme meteorological phenomena, such as floods, and accidental pollution;
- Improve speed and accuracy of flood prediction;
- Improve speed and reliability of emergency response;
- Reduce potential risks and damages;
- Disseminate lessons learned and results via the Internet for easy access;
- Use server/desktop configuration to facilitate coordination between central and regional river basin operations;
- Develop a system to warn potentially affected people;
- Use simulations to assess emergency action plans;
- Develop what-if scenarios and emergency action plans for potential accidental releases from mining or industrial operations;
- Disseminate and communicate accurate, timely, locally relevant, and reliable assessments of risk.

To better assimilate in practice the lessons learned from previous significant NATECH disaster at tailing dams, the involved authorities should be able to:

- Provide information to the population concerning the level of risk near their inhabited areas, including measures that have been taken to minimise risk. Information must be disclosed at the local or regional level in order to allow the public to access information regarding the relative risk of natural or technical accidents (NATECH) in various areas, thereby allowing the local population to avoid living in areas that are more prone to hazards;
- Develop, at the request of stakeholders and companies, a detailed analysis of the potential consequences and damage distances for possible scenarios of NATECH accidents involving potentially dangerous installations and sites storing highly toxic compounds;
- Define a set of potential accidents and related consequences that could happen at the selected facilities, given various NATECH events. Information gathered on population and the environment should allow potential consequences to be defined for every environmental component;
- Develop a complete perceived risk report for the inhabited centres around industrial sites that are considered potentially vulnerable to NATECH accidents, extending the implementation and integrating the process with other EU and Candidate countries to provide an overall common view of the risk for NATECH;
- Be able to participate in the extension of this NATECH risk evaluation methodology to include more detailed analysis of other risks associated with the mining industry. Europe needs to support the local authorities in promoting sustainable development, factoring in current and prospective land use and disaster management;
- Inform the public, including tourist resorts, regarding the possible consequences associated with natural hazards specific to the region. This should result in a more precautionary behaviour of the local population and tourists, and limit the consequences in case of a natural disaster, including NATECH. This should involve the use of all available means, including warning panels, posters, and leaflets, in resort areas that are highly vulnerable to natural disasters, advising people to be aware of and avoid the dangerous areas, since natural and NATECH disasters frequently affect inhabited areas, and endanger the environment and infrastructure;
- Develop and maintain a good information system on the risks of natural and technological disasters and provide access to local authorities, environmental protection agencies, and water management systems. The EU's Natural and Environmental Disaster Information Exchange System (NEDIES) data base of

lessons learned should help improve disaster management activity in EU and candidate countries.

Avoiding NATECH-Type Accidents at Tailing Dams

Romania experiences a wide range of temperatures between warm and cold seasons, with a lower evaporation rate than other countries with similar extractive industries, such as Australia, Spain, and Turkey (Mediterranean Region), that are more arid and therefore do not have the same problems that Romanian operations have with the deposition of the sterile materials in settling ponds. In compliance with the Seveso II Directive, mining companies that intend to implement settling pond technologies will have to comply with the Romanian safety requirements, respecting the great differences in climate and hydrology. The Romanian regulations for the issuing of safe operation permits for dams and other hydrotechnical works should be updated, including assuring, through certification, that there is adequate expertise to assess and operate hydrotechnical works that can pose risks for the environment and human beings.

Proper monitoring systems must be in place to assess structural performance, allowing accurate risk analysis and assessment of the operating functions for the tailing disposal facilities for the mining, power generation, and chemical industry sector.

Appropriate functional regimes and operating parameters should be established for each tailings dam, accompanied by plans on how to alert the public to the possible danger. These plans should assess the worst case scenario and project the rupture wave travel time, as factored for the capacity of the dam and the extent of rupture, or other specific accident hypothesis, according to the type of dam. Dam operators should be properly trained, including running possible dam accidents scenarios, testing warning alarm systems for downstream localities and socio-economical units, and intervention capabilities that could minimise the extent and severity of pollution. The technical expertise of dam safety operation should be regularly reviewed.

Guidelines concerning the potential adverse effects of the pollutants on the environment and the intervention procedures for their mitigation have to be completed. Monitoring system should be modernised by adding automatic stations for the continuous surveillance of water quality parameters, mostly downstream of the potential pollution sources and upstream of the border of transboundary watercourses. In addition, new indicators for evaluating the quality of the environment relative to potentially dangerous substances should be implemented. For example, the health of stream biota, especially endangered species, can be used to gauge the extent of pollution, especially for transboundary cases.

The means of transporting the waste material and, where appropriate, the dam construction methodology, should be updated to increase the safety of the settling ponds. By way of example, since 2002, the ash at the SE Timisoara/CET South thermoelectric power plant is now transported and deposited as a relatively dense fluid allowing higher contour dams and increasing the height of the ash deposit. This system use low water quantities (or other liquids), so that in less than 24 h, the detritus reaches the consistency of concrete, allowing one to walk on the settling pond without any risk. In this way, the water and mud is completely eliminated from the settling pond structure, and there is no return of waste water or any other liquids back from the settling pond.

Following the Baia Mare NATECH accident, Romania is improving communication between the public administration and the authorities involved in the management of natural disasters on one side with the public and experts from different sectors of the society involved in land planning, to better allocate the resources necessary for hazard reduction and mitigation activity. The lessons learned from disasters that have recently occurred in Europe will lead to improved management of natural hazards within EU and candidates countries, and will reveal the existent inherent gaps in mitigation activity. We recommend that the involved public authorities:

- Implement a standardised computer-supported methodology to facilitate the national process of collecting and accessing information;
- Harmonize EU safety policies and current and possible future requirements regarding disaster reporting and consider the possible issuance of EU guidelines;
- Complete the existing databases with lessons learned from disasters and multi-hazard risk analysis;
- Further investigate how the effects of such disasters historically extend beyond the hazard areas, and how they have affected the population and environment, and even other countries;
- Based on the various lessons learned from previous disasters, establish a set of possible prevention and emergency measures that might be useful in reducing the overall risk of such hazards.

Measures Undertaken by the Romanian Authorities Following the Baia Mare NATECH Accident

Concerning the safe operation of Aurul or Novat pond-type disposal facilities, Romania’s Ministry of the Environment and Sustainable Development (MESD) promoted legislation to improve the legal framework for hydrotechnical works that can pose risks for the environment and human beings. This resulted in a Joint Order of the MESD and Ministry of Public Works and Territorial Planning approving: "methodology for categorisation of dams", "methodology for assessing the operational safety of reservoirs and dams," and "methodology for assessing the operational safety of dykes associated with industrial waste deposits" (NTLH 2002a).

A law was issued concerning dam safety, where the term dam refers to all kinds of retaining works, including those carried out for industrial waste disposal. This law imposed regulations that require that safe operation permits for dams and other hydrotechnical works be frequently updated (Government Emergency Ordinance 2001). In addition, a government program on safe dam operation has been established, requiring that settling ponds from the mining, power generation, and chemical industry sector by continuously checking and inventoried (Fig. 4). In addition, certification of expertise was required at all hydrotechnical works, including mine settling ponds, and specific procedures were established to evaluate potential risks (Fig. 5) (NTLH 2002b).

The monitoring system is being modernised by adding automatic stations for the continuous surveillance of water quality parameters. These are located mainly downstream of pollution sources and upstream of the border of the transboundary watercourses. At the same time, a complex program for monitoring water quality, including sediments and biota, was undertaken on the Somes River. Guidelines concerning the effects of pollutants on the environment and intervention procedures required for mitigation have been elaborated.

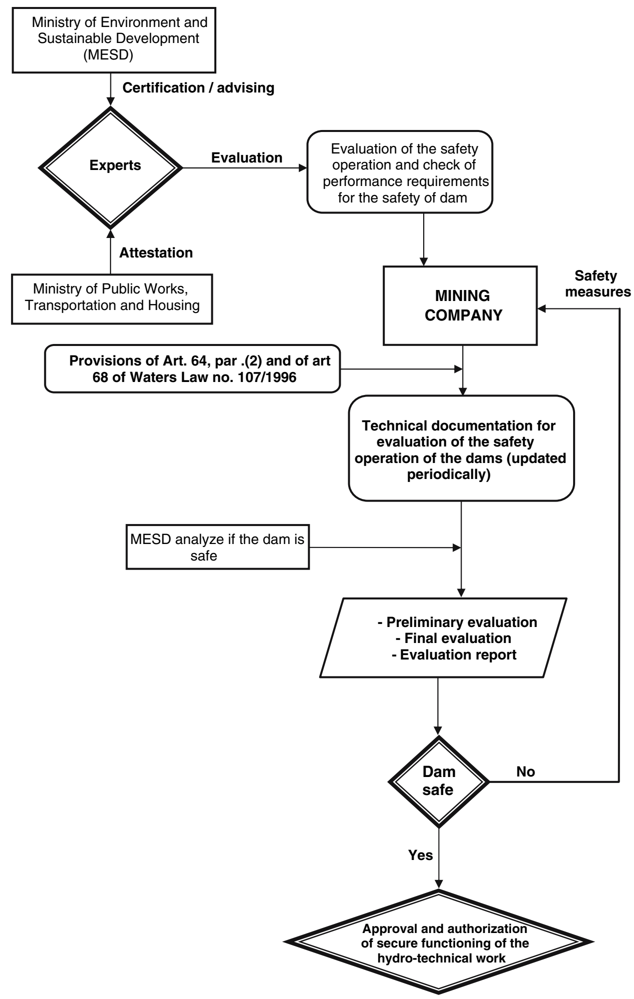


Fig. 4 Procedure for evaluating the operational safety of dams in Romania

Hazard Assessment Methodology for Tailing Dams

The methodology now being used to assess the hazards associated with industrial or mine waste tailings dams is based on quantifying the hazardous components and assigning a hazard value, using a system of criteria, indexes, and notes.

Indexes used in the evaluation of dams and deposits are:

The BA index is determined by the dam's or deposit's characteristics (dimensions, type, discharge, importance class), it's location (the nature of the ground and seismicity), and the condition of the lake or waste deposit;

The CB index is determined by the situation of the dam, the sophistication of the operational controls and monitoring system(s), the level of maintenance, the dam's behaviour over time, the conditions of the accumulation lake, and the level of site-specific knowledge; and

The CA index quantifies the consequences of damage to the dam/deposit, taking into consideration: the possibility of loss of lives, potential effects on the environment, potential social-economical effects, etc.

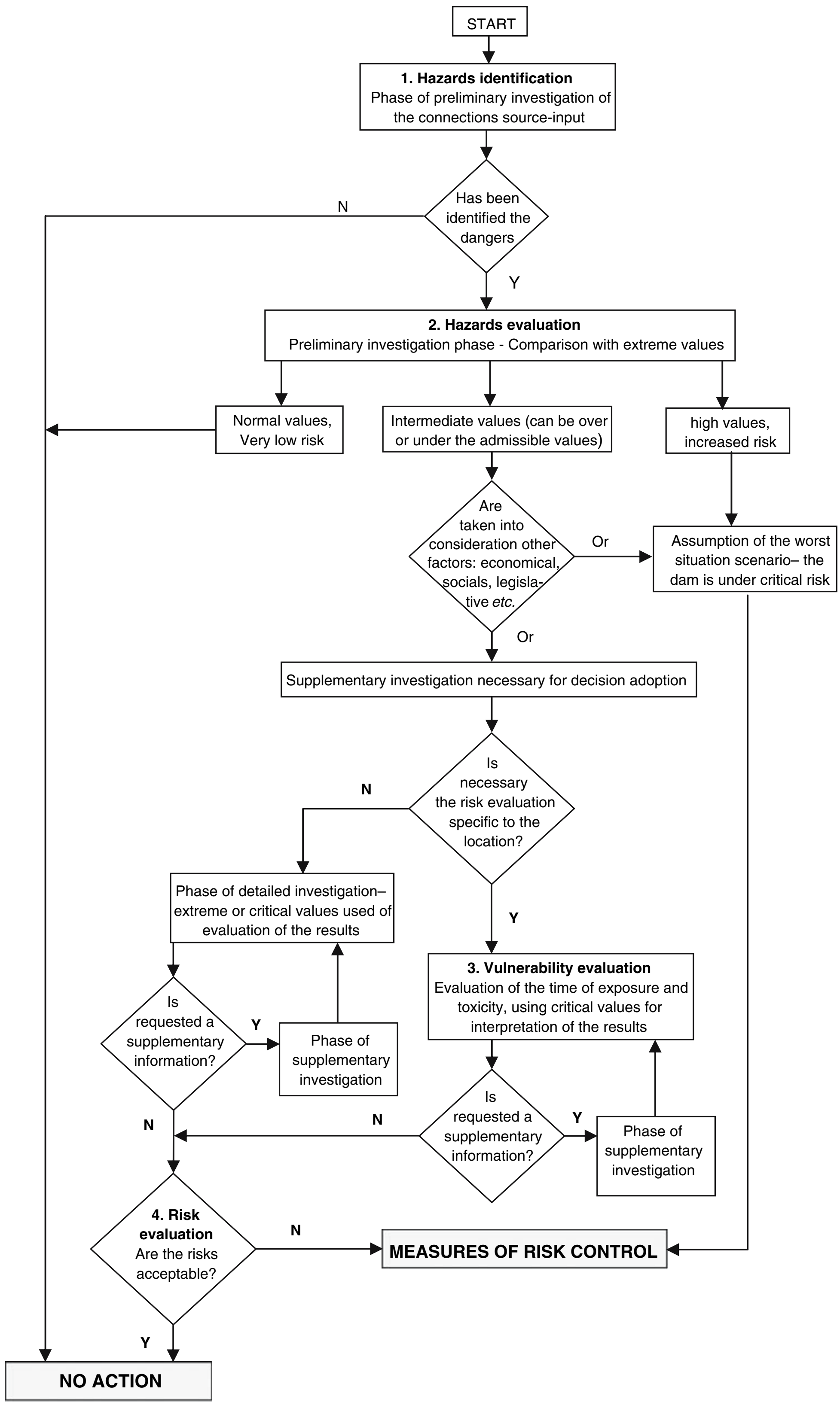
The hazard associated to a dam is appreciated by the RB index: $RB = CA/(\alpha \times BA + \beta \times CB)$

In which the weight coefficients α and β have the values:

$\alpha = 1$ for dams and deposits that have been established according to the current provisions;
$\alpha = 0.8$ for dams and deposits that have been established based on older regulations;
$\alpha = 0.4$ for situations in which there is a lack of adequate data regarding the project;
$\beta = 1$ for dams or deposits that have had no problems during or since construction;
$\beta = 0.7$ for dams or deposits that had incidents or accidents during or since construction, resolved through supplementary works.

Depending on the value of the RB index, the dams are assigned to one of four hazard categories (A, B, C, or D):

Fig. 5 Procedural steps for evaluating risks at a Romanian mine tailings dam containing potentially dangerous substances



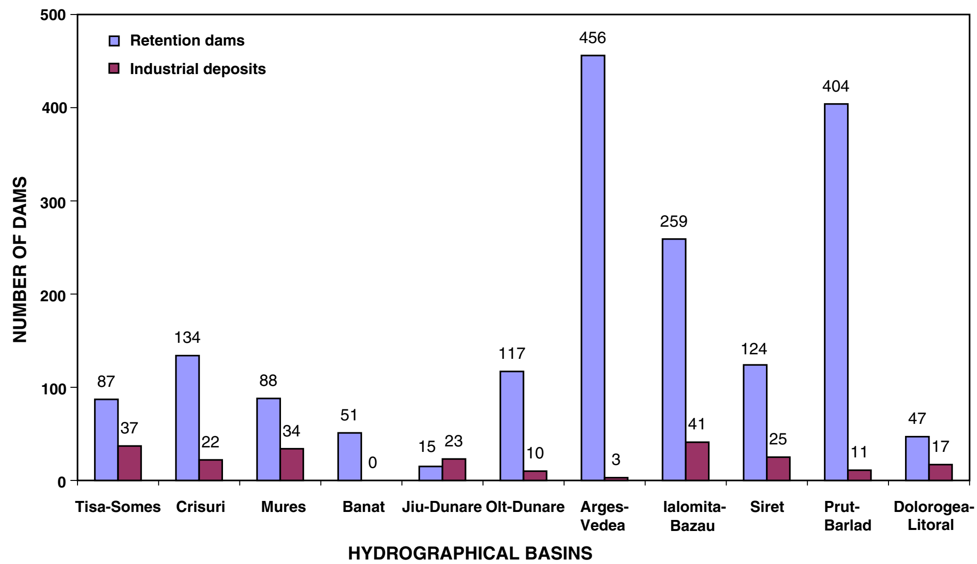


Fig. 6 Inventory of the tailing dams in Romania by hydrographical basins

RB > 0.8	a dam of exceptional importance (A)
0.8 ≥ RB > 0.15	a dam of special importance (B)
0.15 ≥ RB > 0.05	a dam of normal importance (C)
RB ≤ 0.05	a dam of low importance (D)

Vulnerability Assessment in Case of Tailing Dams

The new alert thresholds for water pollution recently issued in the framework of the Danubian Accident Emergency Warning System (AEWS) of the ICPDR (2005) are leading in Romania to an improved approach to environmental safety and improved water protection. If the nature and concentration of the discharged dangerous chemicals stored in a tailings dam is known (Fig. 6), alert thresholds can be assessed for water pollution incidents using the international Danubian AEWS based on emissions.

With the help of Table 1, the substances classified according to Water Risk Classes (WRC) and/or *R*-phrases can be linked to certain alert thresholds. The alert thresholds mentioned (loading resulting from an accident), as well as the ranking according to the Water Risk Indexes (WRI), quantify the vulnerability of the environment to pollution due to possible accidents at the tailing dams. For practical application, the streams in Romania, as part of the Danube Hydrographical Basin, can be divided into two separate groups (see Tables 2, 3), with discharge rates less than or greater than 1,000 m^3/s (e.g. the River Somes/Samos) in Romania.

The WRC classes are categorised as follows: WRC 3: severely hazardous to water quality; WRC 2: hazardous to water quality; and WRC 1: low hazard to water quality. The WRC values (in German: WGK values) are available at: http://www.umweltbundesamt.de/wgs/ (Katalog

Table 1 Expression of a hazardous substance in water risk classes (WRC)

Quantity (kg)	WRC value	WRC equivalent quantity
M	0	$M \times 10^{-3}$
M	1	$M \times 10^{-2}$
M	2	$M \times 10^{-1}$
M	3	M

Table 2 Alert thresholds for rivers with flow rates up to 1,000 m^3/s

Substance classifications		Alert thresholds	
WRC	*R*-phrases	Information [kg] or [L]	Warning [kg] or [L]
"0"	22	≥10,000	≥100,000
"1"	25, 52/53, 52, or 53	≥1,000	≥10,000
"2"	50, 51/53, 28, 45, 52, 53, 52/53, 22 or 25	≥100	≥1,000
"3"	50/53, 50, 51/53, 52/53, 52, 53, and 45 and/or 28	≥10	≥100
Water Risk Index (WRI)		≤1	≥2

Explanation of *R*-phrases: *R*22 Harmful if swallowed; *R*25 Toxic if swallowed; *R*28 Very toxic if swallowed; *R*45 may cause cancer; *R*50 Very toxic to aquatic organisms; *R*52 Harmful to aquatic organisms; *R*53 May cause long-term adverse effects in the aquatic environment; *R*50/53 Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment; *R*51/53 Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment; *R*52/53 Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment. Note: The full list of "*R*" values is indicated in Directive 67/548/EEC on classification, packaging, and labelling of dangerous substances

Table 3 Alert thresholds for rivers with flow rates exceeding 1,000 m^3/s

Substance classifications		Alert thresholds	
WRC	*R*-phrases	Information [kg] or [L]	Warning [kg] or [L]
"0"	22	≥100,000	≥1,000,000
"1"	25, 52/53, 52, 53	≥10,000	≥100,000
"2"	50, 51/53, 28, 45, 52/53, 52, 53 and 22 or 25	≥1,000	≥10,000
"3"	50/53, 50, 52, 53, 51/53, 52/53, and 45 or 28	≥100	≥1,000
Water Risk Index (WRI)		≤1	≥2

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The Water Risk Index (WRI) value is equal to the base 10 logarithmic value of the summarised equivalent values of the WRC: WRI = log (ΣWRC). The WRI value is a very important factor to be considered when estimating the overall risk of a tailing dam accident and can be assimilated when considering a site's vulnerability to accidental pollution.

Conclusions

The risk of tailing dams to surface waters can be defined as:

$$\begin{aligned} \text{Risk} &= \text{Probability} \times \text{Vulnerability} = \text{RB} \times \text{WRI} \\ &= [\text{CA}/(\alpha \times \text{BA} + \beta \times \text{CB})] \times \log(\Sigma\text{WRC}) \end{aligned}$$

This risk evaluation methodology is being applied at the national level for the tailing dams in Romania, and will: allow risk managers to better evaluate the relative threat posed by varied levels of various potential contaminants to the environment; improve projected evaluations of potential damage and the social-economical impact in case of an accident at a tailing dam; allow managers to develop safer operating procedures for tailings dams; identify potential hazard sources and accident scenarios related NATECH events for tailings dams (Mara et. al 2006a, b).

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