Accidental Pollution Hazard in the Danube River Basin

ICPDR IKSD

International Commission for the Protection of the Danube River

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Accident Hazard Sites and Tailings Management Facilities

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AHS	Accident Hazard Sites
ARS	Accident Risk Sites
APC EG	Accident Prevention and Control Expert Group
BAT	Best Available Technique
DRB	Danube River Basin
EU	European Union
GIS	Geographic Information System
HQ-500	Flood events with 500-year return period
HS	Hazardous Substances
ICPDR	International Commission for the Protection of the Danube River
PAR	Population At Risk
PGA	Peak Ground Acceleration
TEI	Tailings Exposure Index
TEI_{Pop}	Tailings Exposure Index for population
TEI_{Env}	Tailings Exposure Index for environment
THI	Tailings Hazard Index
THI_{Cap}	Tailings Hazard Index for capacity
THI_{Tox}	Tailings Hazard Index for toxicity
THI_{Man}	Tailings Hazard Index for management conditions
THI_{Nat}	Tailings Hazard Index for natural conditions
THI_{Seism}	Tailings Hazard Index for seismic activity
THI_{Flood}	Tailings Hazard Index for flooding
THI_{Dam}	Tailings Hazard Index for dam conditions
TMF	Tailings Management Facilities
TRI	Tailings Risk Index
UNECE	United Nations Economic Commission for Europe
WFD	Water Framework Directive
WHC	Water Hazard Class
WHC_{3eq}	WHC3-equivalent
WHI	Water Hazard Index
WRI	Water Risk Index

1 Introduction

Hazardous substances (HS) pollution of surface waters has been among others identified as a significant water management issue of basin-wide importance in the Danube River Basin (DRB)[1]. HS pollution refers to contamination with priority substances, dangerous substances and other specific pollutants with toxic or damaging (carcinogenic, teratogenic, mutagenic or physically harming) effects on aquatic organisms and humans. HS can pose serious threat to the aquatic environment on both, short and long term. Depending on their concentration and the actual environmental conditions, they can cause acute (immediate) or chronic (latent) toxicity or severe damages. Some of the HS are persistent, slowly degradable and can accumulate in the food chain once present in the ecosystems. Although HS pollution is one of the major concerns regarding chemical and ecological status of waters in the DRB and the European Union (EU) Water Framework Directive[2] (WFD) and the EU Green Deal[3] set ambitious requirements towards sustainable management of chemical pollution, our knowledge on the volume and sources of pollutant emissions is insufficient and inaccurate that makes the determination and implementation of control measures rather difficult.

Accidental pollution events represent a specific and generally dangerous form of water contamination by hazardous substances. Industrial facilities, mining areas and contaminated sites that store, process or produce such substances in substantial amounts pose hazard (potential risk) to water by having a certain potential to cause serious pollution, even though they might not have any release in their regular operation. However, in case of emergency situations (natural hazard events like floods, earthquakes or landslides and operation failures) and without appropriate safety measures in place they can represent a real water pollution risk threatening population and ecosystems. Depending on the type and mixture of the HS, their released amount, the temporal variability of the pollution and the local circumstances, the accidental spills can adversely impact the receiving environmental media and the ecosystems, population, economic activities, goods and properties of the affected surrounding areas but even those of the regions far downstream if contaminants are further transported by streams.

The industrial sector in the DRB shows a wide range of activities. The character of the industry pallet has changed over the last three decades, particularly in the Eastern and Southern countries where the industrial sector has been privatised, restructured, adjusted to the market needs or closed due to economic constraints. According to the current industrial inventory of the European Industrial Emissions Portal[4] of the European Environment Agency, which disseminates information on the major industrial facilities in Europe, more than 2,000 large[5] facilities[6] are operated in the DRB[7]. Waste and wastewater management and metal processing have the highest importance among the industrial

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[1] ICPDR (2019): Interim Overview: Significant Water Management Issues in the Danube River Basin District. IC220, International Commission for the Protection of the Danube River, Vienna, https://www.icpdr.org/sites/default/files/nodes/documents/ic_220_interim_overview_swmi_final_19122019.pdf.

[2] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. 32000L0060, European Commission, Brussels, https://environment.ec.europa.eu/topics/water/water-framework-directive_en.

[3] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - The European Green Deal. COM/2019/640 final, European Commission, Brussels, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

[4] European Industrial Emissions Portal, European Environment Agency, https://industry.eea.europa.eu/.

[5] Above certain capacity, pollutant release and waste transfer thresholds.

[6] Without installations for intensive livestock production.

[7] Data are not reported to the European Industrial Emissions Portal by Bosnia and Herzegovina, Moldova, Montenegro and Ukraine.

activities by representing 29% and 22% of the installations, respectively. Energy sector, mineral and chemical industries have a similar proportion about 10% for each.

With regard to the mining sector, it 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 (TMF).

Ideally, industrial facilities and TMF should ensure the safe processing and storage of chemicals and fine-grained mineral processing waste. However, these facilities 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 these facilities, but also due to the significant amounts of stored volumes, they may pose a significant risk to the environment, population and socio-economic values.

The surface water bodies of the DRB were severely damaged by several major accident events in the last two decades. They dramatically demonstrated how catastrophic consequences the inappropriate operation of industrial facilities, the lack of adequate safety measures and the technological disasters triggered by natural hazards might have on the aquatic environment, population or socio-economic goods. These events also showed the importance of prompt and effective crisis management, putting into operation emergency measures and actions to minimize the adverse impacts on the environment.

Although preventing and controlling accidental pollution has a long story in the DRB, there is a substantial number of installations associated with high accident hazard in the basin where appropriate safety conditions should be ensured. One of the key activities in the field of accident prevention is the identification of industrial facilities and mining sites, which pose accident hazard to water bodies. The Accident Prevention and Control Expert Group (APC EG) of the International Commission for the Protection of the Danube River (ICPDR) regularly updates the accident hazard hot-spot inventory of the DRB and reassesses the accident hazard and risk of these hot-spots to identify the most dangerous sites and to prioritize industrial sectors according to accident hazard. The assessment is based on adopted hazard and risk assessment methods, which provide simple procedures for estimating accidental hazard and risk of industrial facilities and mining sites. Their main objectives are to raise awareness to the accidental pollution in the basin, identify hazard and risk hot-spots, and determine which priority industrial sectors need to be improved in different regions of the basin in order to minimize risk by implementing adequate safety measures and to give advice for financing institutes and decision makers where financial and/or technical supporting projects and capacity building activities should be targeted.

Recently, the former inventory[8] on operating industrial and energy production facilities that process, store, produce or release hazardous substances has been updated and the potential risk of causing accidental pollution has been assessed. Moreover, the first inventory on TMF has been developed for the DRB including hazard and risk assessments in the framework of the Danube TMF Project[9] (funded by the Advisory Assistance Programme of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, facilitated by the German Environment Agency). The project aimed at contributing to narrow the knowledge gaps and to raise awareness on TMF and their hazards in the DRB, ensuring to respect a common set of minimum standards and safety requirements in the DRB and strengthening the technical and management capacity at the concerned facilities and responsible

[8] ICPDR (2001): Inventory of Potential Accidental Risk Spots in the Danube River Basin. Technical report, International Commission for the Protection of the Danube River, Vienna.

[9] Capacity development to improve safety conditions of tailings management facilities (TMF) in the Danube River Basin – Phase I: North-Eastern Danube countries. Project funded by the German Federal Environment Ministry's Advisory Assistance Programme (AAP), 118221, https://www.umweltbundesamt.de/en/topics/sustainability-strategies-international/cooperation-eeca-centraleastern-european-states/project-database-advisory-assistance-programme/capacity-development-to-improve-safety-conditions.

authorities. Building on the strengths of the existing TMF-methodology[10] developed by the German Environment Agency but also improving and adapting it based on up-to-date technical knowledge, Danube countries were provided with a set of practical tools to improve safety conditions of TMF and to strengthen the capacity of operators and authority inspectors including hazard and risk assessment methods and a checklist methodology (TMF Checklist).

These investigations delivered valuable inputs to the elaboration of the Danube River Basin Management Plan Update 2021[11], one of the key strategic documents on transboundary water management in the DRB. This report provides an overview on the methods and results of the latest hazard and risk assessments accompanied with recommendations on sustainable management of accident hazard hot-spots.

[10] Vijgen, J. and Nikolaieva, I. (2016): Improving the safety of industrial tailings management facilities based on the example of Ukrainian facilities. 01/2016, German Environment Agency, Dessau-Roßlau, https://www.umweltbundesamt.de/publikationen/improving-the-safety-of-industrial-tailings.

[11] ICPDR (2021): The Danube River Basin Management Plan Update 2021. International Commission for the Protection of the Danube River, Vienna, https://www.icpdr.org/sites/default/files/nodes/documents/drbmp_2021_final_hires.pdf.

2 Hazard assessment for Accident Hazard Sites

The assessment of potential industrial hot-spots of accidental pollution events is based on a risk assessment method that has been adopted by the ICPDR and applied for a previous study in 2001. It provides a simple hazard estimation procedure for the so-called Accident Hazard Sites (AHS, formerly called Accident Risk Sites, ARS). AHS represent mainly existing industrial and energy production facilities that process, store, produce or release hazardous substances.

2.1 The Water Hazard Index method

The AHS inventory evaluates the potential risk (hazard) of the facilities based on the Water Hazard Index (WHI, formerly referred to as Water Risk Index, WRI) values. The WHI assesses the overall hazard of the industrial sites based on the hazard degree of the processed dangerous materials and their volume stored at the sites. The results provide support for the identification of the priority industrial sectors where accidental risk should be mitigated by implementing appropriate safety measures.

2.1.1 Water Hazard Class

The first step is the determination of the Water Hazard Class (WHC) for each substance stored, processed or produced at the facility. WHC values represent an integrated method of evaluating water hazards and they have been used e.g. in Germany for more than 30 years as a means of assessing "substance-specific water hazards", particularly in determining the potential for water pollution represented by dangerous installations. By now, about 7,000 chemical substances and mixtures of substances have been classified in these terms. For an 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).

WHC values take into account different properties of substances when classifying the hazardousness of a particular substance, its complex or mixture like toxicity (acute, chronic), toxicity to humans and mammals, aquatic toxicity, persistence, biological degradability, physiochemical eliminability, distribution properties in water and the soil, synergic factors and bioaccumulation in organism.

The WHC method classifies dangerous substances into four classes of danger to water:

- WHC0: no danger to water
- WHC1: low danger to water
- WHC2: dangerous to water
- WHC3: high danger to water

The WHC values can be obtained from the dangerous substances database established and maintained by the German Environment Agency[12]. If no WHC can be found for a particular substance, the classification is to be done based on expert judgement regarding the hazardous effects.

In the next step the amount of each HS is converted to the so called WHC3-equivalent (WHC_{3eq}) assuming one order of magnitude danger difference between the WHC classes. The WHC_{3eq} value is calculated with the following form:

$$WHC_{3eq} = M \cdot 10^{-(3-WHC)} \quad (1)$$

where WHC_{3eq} is the WHC3-equivalent of the substance [kg], M is the mass of the substance [kg], WHC is the Water Hazard Class of the substance [-].

[12] Rigoletto data base of "substances hazardous to water". German Environment Agency, https://webrigoletto.uba.de/Rigoletto/.

2.1.2 Calculation of the WHI

Finally, the WHI values of each facility is calculated based on the WHC_{3eq} values of the substances stored at the facility. The WHI corresponds to the base 10 logarithm of the summed WHC_{3eq} values of all HS stored at the facility:

$$WHI = \log_{10}\left(\sum_{i=1}^{n} WHC_{3eq,i}\right) \quad (2)$$

where *WHI* is the Water Hazard Index of the facility [-], $WHC_{3eq,i}$ is the WHC3-equivalent of substance i at the facility [kg], i is the index of the substances stored at the facility, n is the number of the HS stored at the facility.

Facilities with a WHI value higher than 5 are considered as highly hazardous installations in terms of accidental water pollution, therefore further detailed investigations on the safety conditions and measures are recommended.

2.2 Data collection and processing

As minimum requirement, all sites falling under the EU Seveso Directive[13] and the Convention on Transboundary Effects of Industrial Accidents of the United Nations Economic Commission for Europe (UNECE)[14] (for non-EU MS, if Seveso sites have not been defined yet) had to be reported. Optionally, additional relevant sites could have been reported if data were available for these sites. Data on active (operating) accident hazard sites located in the DRB District were collected.

Based on the agreements of the APC EG, the ICPDR Secretariat elaborated a specific template for the data collection and provision. Data collection and updates were carried out in the period of 2019-2021 and the data reflect to the current situation for this period. The template automatically calculates the hazard value from the input data according to the methods described above. The filled templates have been integrated into the ICPDR DanubeGIS database for further validation, processing, assessment, mapping, dissemination and publishing purposes. Based on these basin-wide datasets, the recent situation of the AHS in the DRB has been analysed and - reflecting to the main findings - recommendations for further assessments and risk mitigation actions have been formulated.

2.3 Assessment results

Data have been reported for 13 countries, only Montenegro has not provided updated information (see ANNEX). In total, more than 1,000 industrial facilities have been reported which store considerable amount of hazardous substances. Out of these, ca 470 facilities (47%) have been reported with a WHI value higher than 5.0 that is the threshold value considered for significant hazard (Figure 1). The number of installations is clearly decreasing as the WHI becomes higher defining particular high-risk facilities in the DRB (Figure 2, note that the WHI is on logarithmic scale, i.e. an increase of WHI by one unit means a rising danger by one order of magnitude in terms of mass). The number of installations with high ($7 \leq WHI < 8$), very high ($8 \leq WHI < 9$) and extremely high ($WHI \geq 9$) risk is 68, 24 and 2, respectively. In total, almost 12 million tons (expressed in WHC3-Equivalents) hazardous substances are stored in the basin which equals to a basin-wide WHI value of 10.1. More than 99% of the hazardous substances amount are stored in the high-risk facilities.

[13] Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC. 32012L0018, European Commission, Brussels, https://environment.ec.europa.eu/topics/industrial-emissions-and-safety/industrial-accidents_en.

[14] Convention of the United Nations Economic Commission for Europe on the Transboundary Effects of Industrial Accidents - as amended on 15 December 2015. ECE/CP.TEIA/33, United Nations, Geneva, https://unece.org/environment-policy/industrial-accidents.

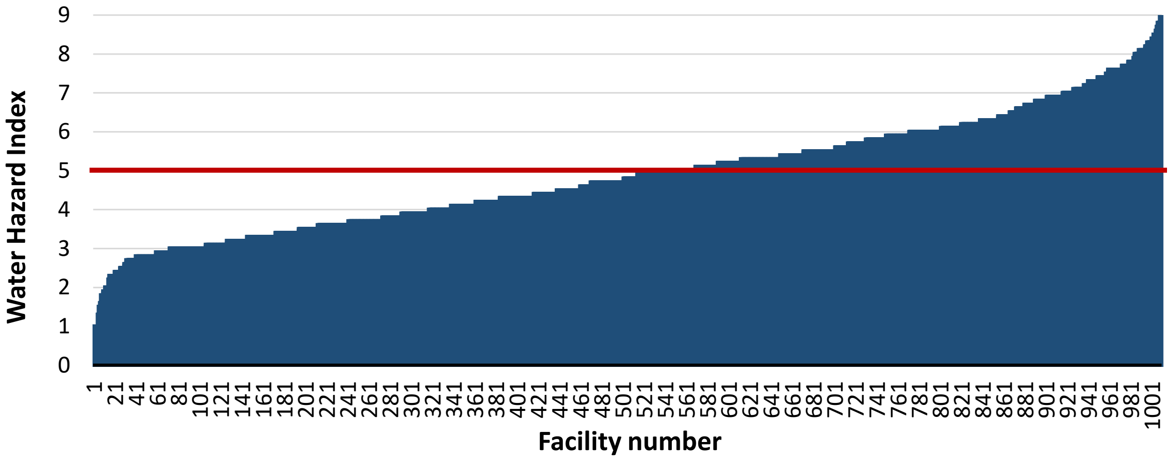

Figure 1: WHI values of the reported industrial facilities in the DRB.

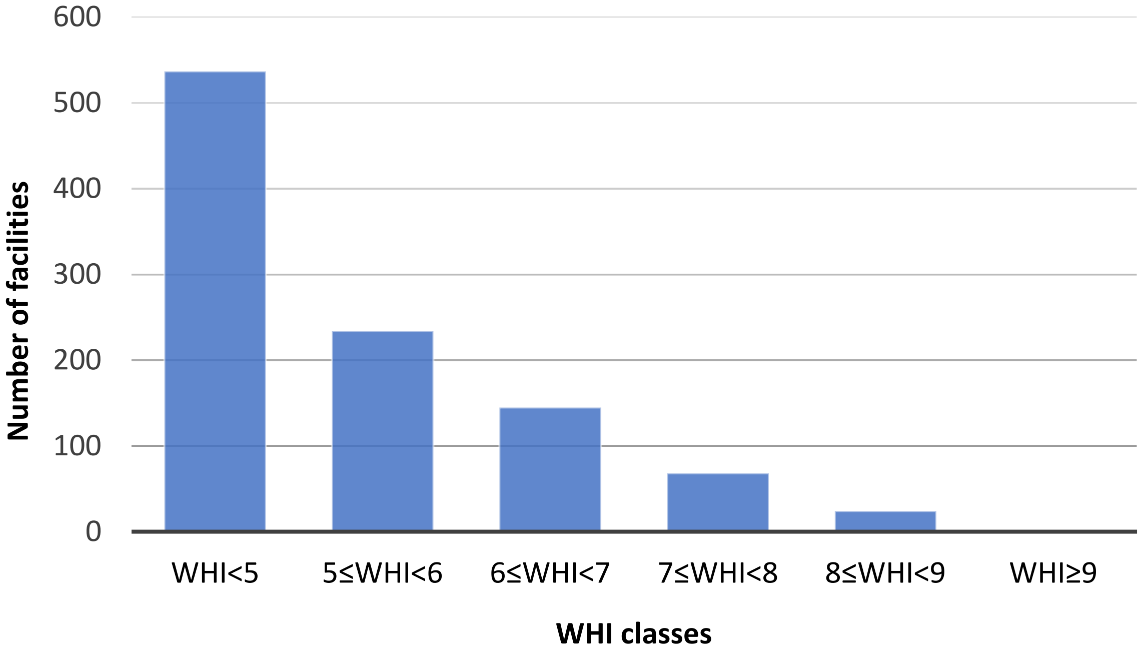

Figure 2: Distribution of the AHS according to WHI classes.

Country contributions are shown in Figure 3 and Figure 4 (only for sites with WHI higher than 5.0). Being the largest county in the DRB, Romania reported the highest number of dangerous installations, followed by Germany, Hungary and Slovakia, whilst just a few can be found in Bosnia & Herzegovina and Ukraine. Almost in each country as well as in the DRB the number of AHS progressively rises as the WHI becomes lower. Romania, Germany and Slovakia reported much more installations for the upper WHI classes than the others. The spatial location of the AHS posing potential risk of accidental pollution is shown in Map 1 in the ANNEX.

The total WHI value (indicating the quantity of hazardous substances) at country level is the highest in Romania, Germany, Serbia and Slovakia. These countries also show the highest specific quantity of hazardous materials (mass per facility) indicating higher danger levels at the facilities in their national territory. However, it must be emphasized that the potential risk values presented here do not correspond to the actual risk, since for the assessment of the real risk the safety measures applied at the facilities and the potential impact receptors in the vicinity of the facilities that may be exposed would need to be also taken into account.

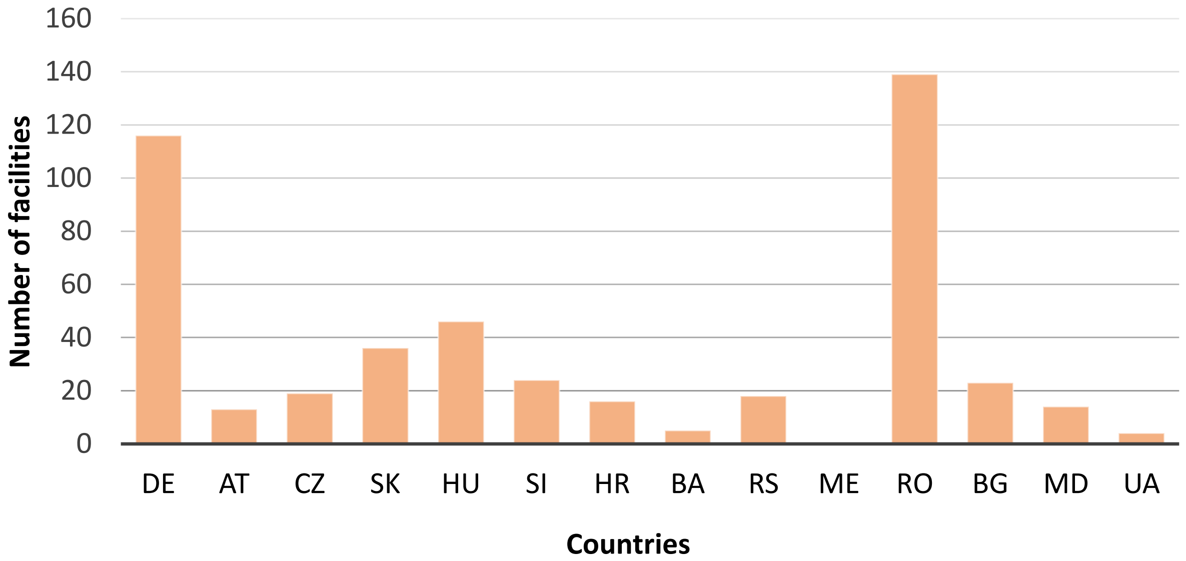

Figure 3: Number of dangerous facilities at national level (facilities with WHI≥5).

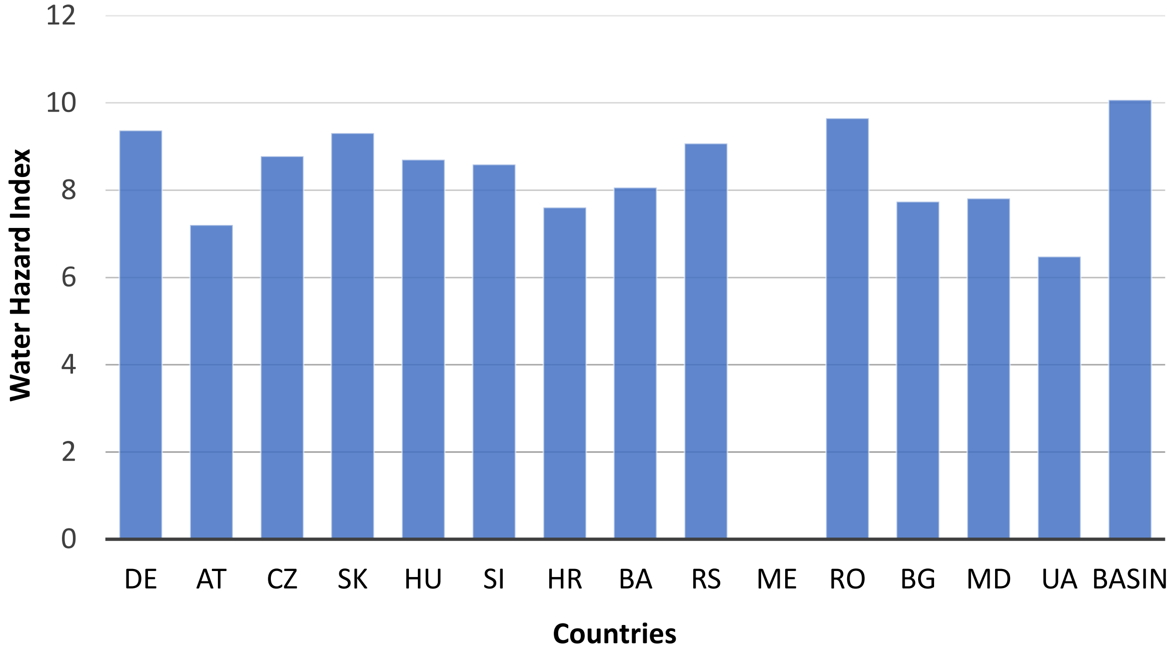

Figure 4: Total WHI values at country level (facilities with WHI≥5).

With regard to the main types of the industrial activities, the energy sector, the chemical industry, the storage facilities and the mineral industry have the highest number of facilities operating in the DRB (Figure 5 and ANNEX). Energy sector facilities that include a large number of oil industry facilities (refineries, terminals, distribution facilities, etc.), chemical industry and storage facilities (oil tanks, storage houses for chemicals) clearly dominate the distribution with 45%, 23% and 13% share, respectively. Energy sector also shows the largest amount of the stored hazardous substances hence the highest overall WHI (Figure 6). Storage facilities, mineral and chemical industry sectors also pose a high potential risk to the aquatic environment. Comparing the specific amounts of hazardous substances, the energy industry and storage sites have the largest quantities per facility indicating higher specific hazardousness for these sectors.

At the national level, energy sector is strongly dominant in Austria, Germany, Croatia, Hungary, Romania and Serbia. Storage facilities have the highest WHI values in Slovenia, the Czech Republic and Bulgaria, whilst chemical industry is the most dangerous sector in Bosnia and Herzegovina and Slovakia.

In total, 94 installations have been reported for the upper hazard classes (WHI above 7), which store the vast majority (95%) of the total amount of hazardous substances processed in the DRB. Oil and gas industry sites (refineries, tanks, storages, pipelines), power plants, storage sites, mining sites and several chemical factories can be found in the facility group associated with high potential danger. The top 10 sites are dominated by oil industry plants, and they store more than 7 million tons hazardous substances.

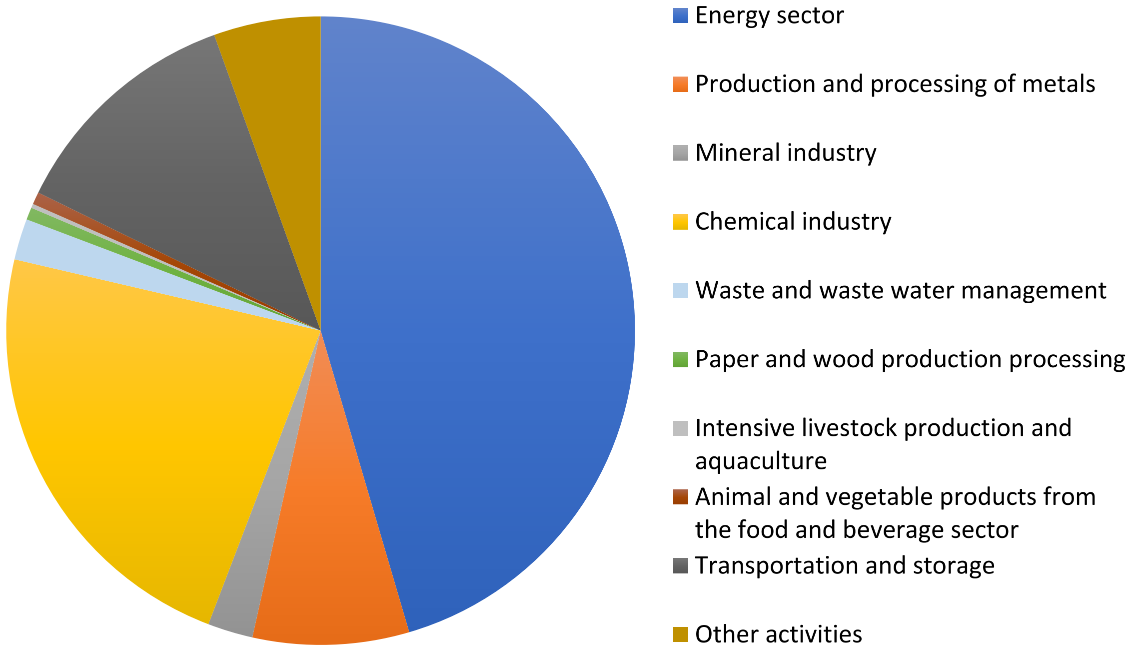

Figure 5: Distribution of AHS with high risk (WHI≥5) according to industrial sectors.

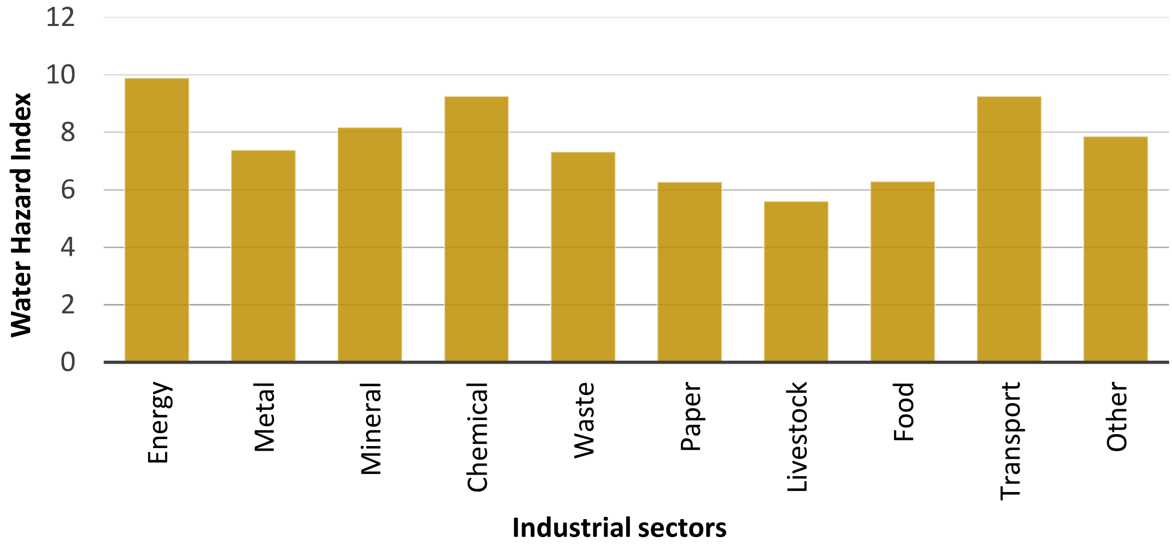

Figure 6: Total WHI values of the industrial sectors (facilities with WHI≥5).

2.4 Findings and recommendations

The most important findings and recommendations are the following:

- Mindful inspection and control of AHS with a high hazard is recommended, with specific attention to shortcomings in safety measures and technical and operational requirements.
- Identifying the relevant industrial facilities and collecting reliable information on these sites (stored materials and their amounts) is critical to undertake a sound hazard assessment and to draw realistic conclusions. Substantial data gaps or uncertainties in the hazard parameters can lead to inaccurate hazard estimations and questionable findings.
- The current assessment of AHS can only give a rough indication on the hazard of the facilities. It also depends on the safety measures that have been applied in each installation and the overall management conditions of the facilities.
- Moreover, natural hazards such as earthquakes and floods should be taken into account that can trigger events which might lead to major damages challenging the safety and operation of the installations.
- In order to estimate the current safety level of the facilities and to improve it, if necessary, specific checklists for various industrial sectors (e.g. oil terminals, pipelines, firefighting water management, tailings ponds) have been developed by the UNECE[15].
- The checklists should be used by the national authorities in order to investigate what safety measures are needed at the AHS associated with high hazard. Based on the results of the checklist methods, effective short-, mid- and long-term measures should be determined and implemented.
- Danube countries are encouraged to integrate these checklists into their national approaches by adjusting them to the specific conditions and needs of the DRB countries.
- Evaluation and revision of the relevant national legislation regarding its efficiency are recommended for the DRB countries to avoid any weaknesses or failures in their safety design and practice.
- Danube countries have to ensure that hazardous installations are equipped with up-to-date technologies and their operational conditions are compliant with the respective Best Available

[15] https://unece.org/guidelines-and-templates.

Technique (BAT) Reference Documents[16] specified under the EU Industrial Emission Directive[17].

- Moreover, all necessary safety and preventive measures and actions must be properly designed and implemented at the facilities to minimize accidental pollution risk, in line with the provisions of the EU Seveso Directive.
- Competent authorities have to establish a thorough control mechanism with regular inspections.
- Operating companies need to employ well-trained workforce with sufficient management and technical capacity at the installations.
- The APC EG should further provide Danube countries with a common platform for information exchange and know-how transfer in terms of measure implementation and risk mitigation in the identified key industrial fields. Examples for practical implementation should be demonstrated in the future.
- The AHS inventory should be kept as a living database allowing the Danube countries to provide additional or revised data as appropriate.
- The APC EG should discuss and decide whether there is a need for updating the hazard analysis due to better data availability, to reflect to significant industrial developments or changes in production or in order to support the elaboration of the river basin management plans. The applied methodology should also be revised and refined if needed.
- A common methodology and harmonized criteria over the DRB are needed for the site selection, including certain threshold values (e.g. site capacity, distance to rivers, material hazard).
- In some countries only a limited data reporting is possible due to confidentiality issues, this has to be taken into account for future reporting and mapping.
- Future revisions should consider involving natural hazards under changing climate and management/operational conditions into the hazard assessments.
- Moreover, a risk assessment method could be developed taking into account potential impact receptors in the vicinity of the installations (e.g. population, ecosystems).
- It should be explored what actions might be necessary to be taken in the future to ensure data reliability, consistency and comparability among the Danube countries (e.g. contracting a consultant for consistent data processing and evaluation, cooperation with the European Commission on data exchange).

[16] https://eippcb.jrc.ec.europa.eu/reference/.

[17] Directive 2010/75/EU of the European Parliament and the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). 02010L0075, European Commission, Brussels, https://environment.ec.europa.eu/topics/industrial-emissions-and-safety/industrial-emissions-directive_en.

3 Hazard and Risk Assessment for Tailings Management Facilities

The TMF-Methodology offers an index-based assessment of the hazard potential of a number of TMF, the so-called Tailings Hazard Index (THI) method. With this simple index method, a large number of TMF can be sorted and prioritised according the calculated hazard potential. The approach already proved its usefulness in directing limited country resources (financial and personnel) to TMF 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 TMF in countries or international regions (i.e. UNECE, river basins).

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

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.

3.1.1 Tailings capacity

The THI for 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:

$$THI_{Cap} = \text{Log}_{10}\,[V_t] \qquad (3)$$

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

3.1.2 Tailings toxicity

The THI for toxicity (THI_{Tox}) is evaluated based on the WHC of the materials in the tailings, similarly to the WHI approach (see Chapter 2). Table 1 shows the WHC classification and the respective toxicity index to be used.

Table 1: 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 TMF contain materials resulted from mining of radioactive substances. Therefore, it is suggested to apply $THI_{Tox} = 4$ in case radioactive substances are stored in TMF and their radioactivity exceeds the doubled value of the local background radioactivity.

3.1.3 Management conditions

The THI for management conditions (THI_{Man}) is the TMF status that should be identified from four options shown in Table 2. The parameter related to TMF management is assumed to be lower for the closed or rehabilitated facilities compared to the active TMF. As closed TMF 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 TMF may have at least the same hazard potential as active TMF 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. The value of THI_{Man} is determined according to Table 2.

Table 2: Evaluation of the management conditions.

Management status	THI_{Man}
Rehabilitated	0
Closed	1
Abandoned, orphaned	3
Active	3

3.1.4 Natural conditions

The THI for 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:

$$THI_{Nat} = THI_{Seism} + THI_{Flood} \quad (4)$$

where THI_{Seism} is the THI for seismic activity and THI_{Flood} is the THI 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 as recommended in the EUROCODE 8[18]. The parameter Reference PGA can be taken from freely available data sources, e.g. from the German Research Centre for Geosciences[19]. It allows harmonizing different scales of national classifications. The seismic hazard is defined as “Low” if the Reference PGA is below or equal to 10% of the standard Earth gravity (g), and “Moderate or High” if the Reference PGA is above 10% of g. Accordingly, the earthquake hazard (THI_{Seism}) is described based on the following assumption in Table 3.

[18] Solomos, G., Pinto Vieira, A. and Dimova, S. (2008): A Review of the Seismic Hazard Zonation in National Building Codes in the Context of Eurocode 8. EUR 23563 EN, JRC48352, OPOCE, https://publications.jrc.ec.europa.eu/repository/handle/JRC48352.

[19] The Global Seismic Hazard Map Online. Global Seismic Hazard Assessment Program (GSHAP), German Research Centre for Geosciences, http://gmo.gfz-potsdam.de/.

Table 3: Evaluation of the seismic hazard.

Reference PGA [1]	THI_{Seism}
≤ 0.1 g [2]	0
> 0.1 g	1

[1] as recommended in EUROCODE 8

[2] standard Earth gravity

The influence of floods (THI_{Flood}) is related to the flood prone areas with a statistical parameter that quantifies flood event frequency with a five-hundred-year return period (floods with a probability of 1 in 500 years, HQ-500). The flood-induced hazard at the TMF location area is determined according to Table 4. The flood prone areas according to the values of HQ-500 can be obtained from open sources, e.g. from the EU Joint Research Centre[20].

Table 4: Evaluation of the flood hazard.

TMF location	THI_{Flood}
Beyond the flood prone area of HQ-500	0
In the flood prone area of HQ-500	1

3.1.5 Dam safety

Dam stability is probably the most critical parameter within the hazard evaluation. The THI for 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. The term FoS is commonly used to express the safety margin of slopes on embankment dams. The influence of this parameter on the TMF hazard potential is assessed according to the literature[21] (Table 5).

Table 5: Evaluation of the dam safety.

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

3.1.6 Calculation of the 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:

$$THI = THI_{Cap} + THI_{Tox} + THI_{Man} + THI_{Nat} + THI_{Dam} \quad (5)$$

The THI is to be understood on logarithmic scale, meaning that an increase of the THI value with one indicates 10 times higher hazard.

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[20] Dottori, F., Alfieri, L., Bianchi, A., Skoien, J. and Salamon, P. (2021): River flood hazard maps for Europe and the Mediterranean Basin region. European Commission, Joint Research Centre, http://data.europa.eu/89h/1d128b6c-a4ee-4858-9e34-6210707f3c81.

[21] Cambridge, M. [ed.] (2018): The Hydraulic Transport and Storage of Extractive Waste. Guidelines to European Practice. Springer.

The THI provides a simple tool to roughly assess the accident hazard of a number of TMF 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 TMF 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.

3.2 The Tailings Risk Index method

The THI describes and quantifies the potential accidental hazard of TMF 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 Tailings Risk Index (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 TMF 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 TMF 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).

3.2.1 Potential risk zone delineation

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.

Assessment of past TMF accidents[22] shows that the usual runout length of the released tailings in the field (before reaching surface waters) is up to 10 km from the concerned TMF. Therefore, a zone with 10 km radius is considered as a potential risk zone for the TRI methodology.

[22] Kovacs, A., Lohunova, O., Winkelmann-Oei, G., Mádai, F. and Török, Z. (2020): Safety of the Tailings Management Facilities in the Danube River Basin. 185/2020, German Environment Agency, Dessau-Roßlau, https://www.umweltbundesamt.de/en/publikationen/safety-of-the-tailings-management-facilities-in-the.

The respective data collection and processing for population and water bodies within the risk zone 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.

3.2.2 Risk exposure

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.

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.

Impact on population

The TEI for population (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 6.

Table 6: Evaluation of the population exposure.

PAR in 10 km zone	TEI_{Pop}
< 100	2
100 – 1,000	3
1,000 – 10,000	4
10,000 – 100,000	5
≥ 100,000	6

Impact on the environment

The TEI for environment (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 7. 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 7: Evaluation of the environment exposure.

Stream flow rate, m^3/s or lake surface area, km^2	TEI_{Env}
< 100	2
100 - 1000	3
> 1,000	4

3.2.3 Calculation of the TEI

The total TEI is calculated by the following formula:

$$TEI = TEI_{Pop} + TEI_{Env} \tag{6}$$

3.2.4 Calculation of the TRI

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

$$TRI = THI + TEI \tag{7}$$

Similarly to the THI, the TEI and the TRI are also to be evaluated on the logarithmic scale.

3.3 Data collection and processing

As minimum requirement, all TMF (both miming and industrial) with a total used capacity larger than 1000 m^3 had to be reported. Data on TMF located in the DRB District were collected.

Based on the agreements of the APC EG, the ICPDR Secretariat elaborated a specific template for the data collection and provision. Data collection and updates were carried out in the period of 2019-2021 and the data reflect to the current situation for this period. Preliminary data were collected in the framework of the Danube TMF project that were revised and confirmed by the Danube countries afterwards (except SI and RS, for these countries data are still preliminary). The template automatically calculates the hazard and values from the input data according to the methods described above. The filled templates have been integrated into the ICPDR DanubeGIS database for further validation, processing, assessment, mapping, dissemination and publishing purposes. Based on these basin-wide datasets, the recent situation of the TMF in the DRB has been analysed and - reflecting to the main findings - recommendations for further assessments and risk mitigation actions have been formulated.

3.4 Assessment results

In total, 335 TMF were identified in the DRB[23] (Map 2 in ANNEX). These sites do not include mine waste heaps that store mining waste without dam retention and drainage facilities. The TMF are located in the territory of 9 Danube countries (see ANNEX). The highest shares to the total TMF number in the DRB (Figure 7, left) belong to Romania (45%, with 28% of the active TMF), Slovakia (18%) and Hungary (12%). The total volume of tailings materials in the 335 identified TMF (including 96 active TMF) is more almost 1600 million m^3. Most of the identified TMF (239 or 71%) are inactive, many of them were already rehabilitated or are currently under rehabilitation. The highest amount of tailings materials (Figure 7, right) was evaluated for Serbia (47%), Romania (29%) and Slovakia (8%).

[23] Preliminary database only, data have not been approved officially by RS and SI yet. No relevance for Germany, Austria. Croatia, Moldova and Ukraine.

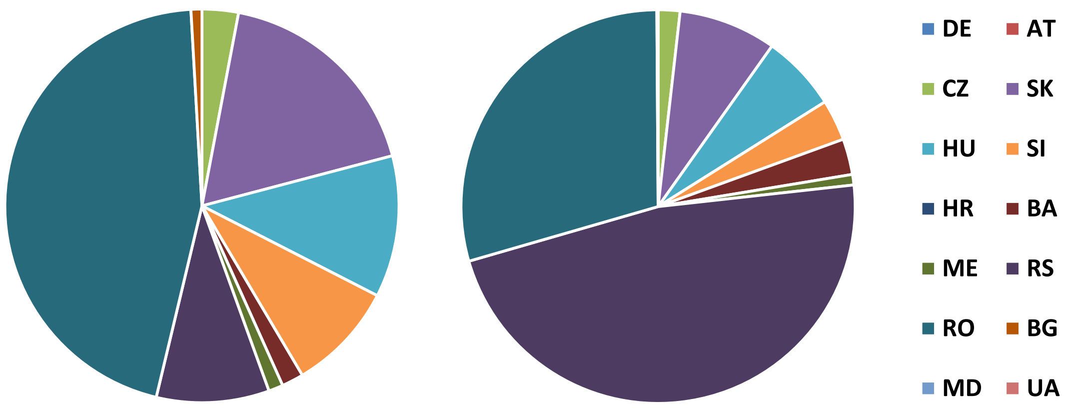

Figure 7: Distribution of the number of TMF (left) and the tailings volume (right) over the DRB countries.

Figure 8 demonstrates the distribution of the TMF in the DRB according to THI ranges. In total, 144 TMF have very low (THI≤8) or low (8<THI≤10) hazard. Additional 115 TMF have medium hazard (10<THI≤12), whereas high (12<THI≤14) and very high (THI>14) hazard was determined for 82 TMF. The country average values (Figure 9) are the highest in Serbia, Montenegro, Bosnia and Herzegovina and Slovakia. The difference of 5 between the highest (Serbia) and lowest (Hungary) average THI indicates 100,000 times higher hazard.

Statistical analysis of the results shows that the median THI value for the DRB (10.4) is exceeded in Bosnia and Herzegovina (11.3), Czech Republic (11.1), Montenegro (12.1), Serbia (14.7) and Slovakia (11.2). Majority of the TMF can be found in a relatively small upper range in Serbia and Montenegro. On the contrary, TMF are spread around a low value in Bulgaria and Hungary.

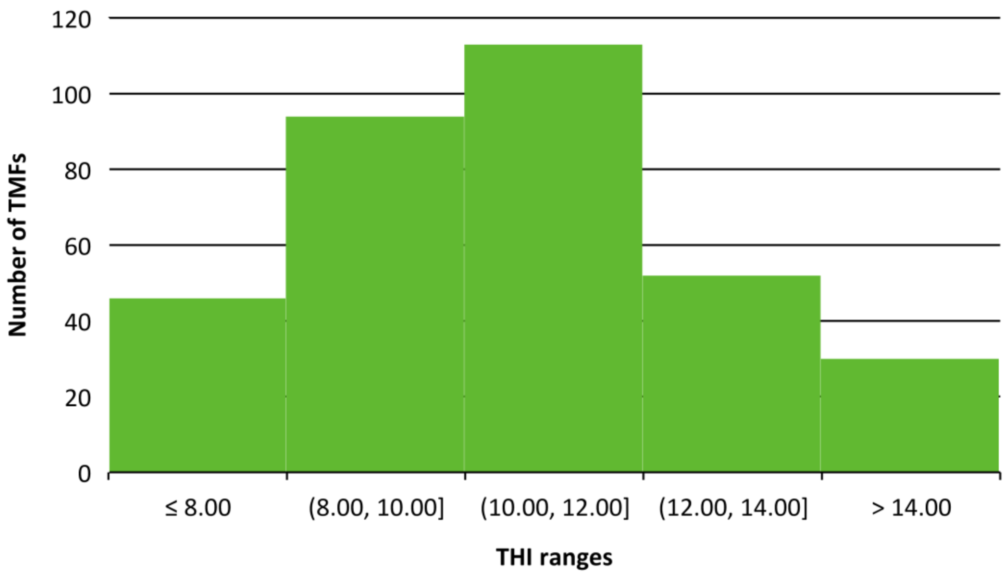

Figure 8: Distribution of the number of TMF in the DRB according to the THI.

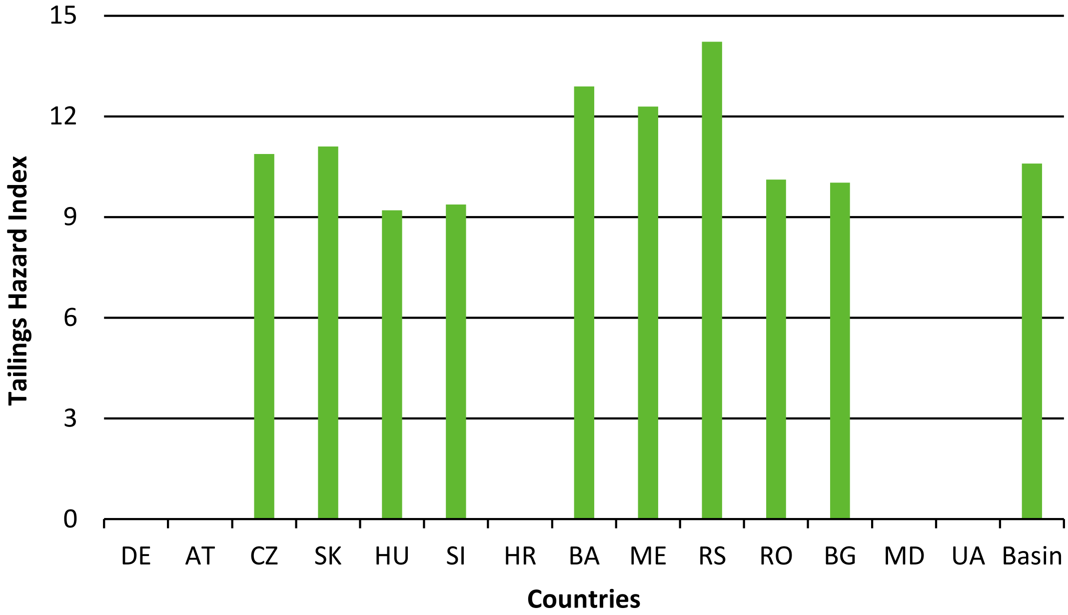

Figure 9: Average THI of the Danube countries.

Figure 10 demonstrates the breakdown of the average THI constituents for the DRB countries. The TMF capacity strongly dominates the hazard assessment, toxicity and management status related hazards have significant impact on the overall THI, whereas natural hazards and dam stability have minor influence. The hazard of dam failure was evaluated equally for all countries because no data were found or received on the Factor of Safety of the dams. The hazard of tailings toxicity is high for the TMF in Bulgaria, Serbia and Montenegro. The hazard caused by TMF capacity is substantial in Serbia, Bosnia and Herzegovina and Montenegro.

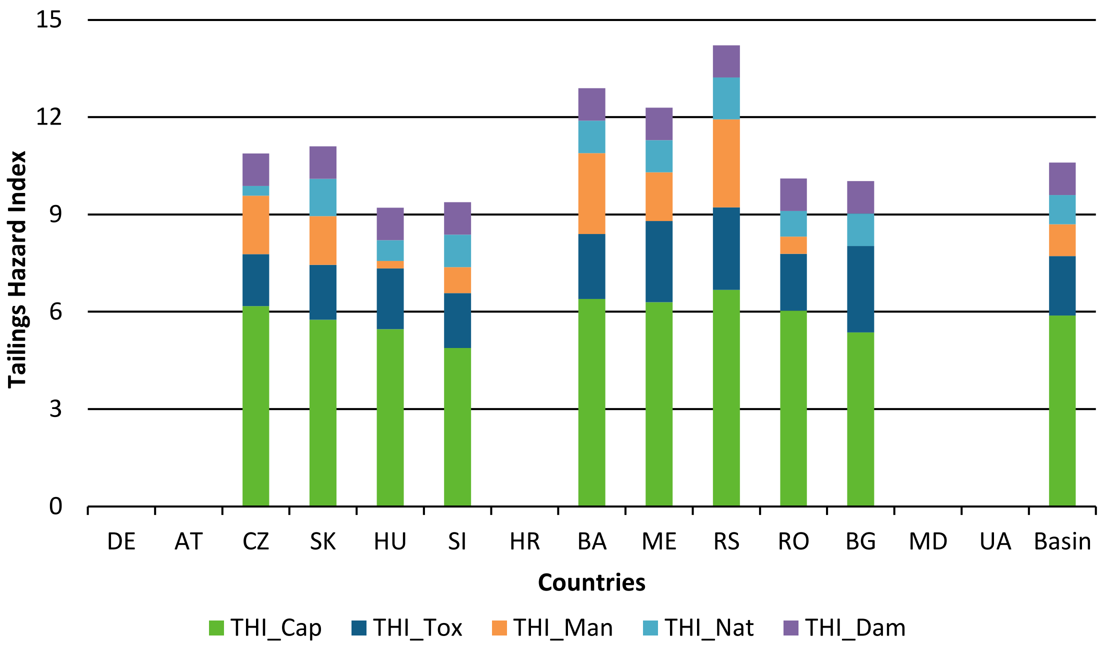

Figure 10: Average THI of the Danube countries.

Most of top 10% TMF with the highest THI values are located in Serbia. Out of the 34 TMF, 23 can be found in Serbia, 5 in Romania, 3 in Slovakia, 2 in the Czech Republic and 1 in Bosnia and Herzegovina. The vast majority of these TMF store slurry or sludge of non-ferrous and precious metal ore extraction with heavy metals as major contaminants. The TMF in Czech Republic are ranked as quite highly hazardous because they contain radionuclides.

The number of TMF and the amount of tailings materials in Bosnia and Herzegovina, Bulgaria, Czech Republic and Montenegro are relatively small. Nevertheless, there are also a few hazardous TMF in these countries. Hungary and Slovenia have a significant number of TMF, but of a lower hazard level due to lower toxicity of the waste, lower amount of tailings and closure and rehabilitation efforts. In contrast, the number, the amount of TMF or the calculated hazard index in Romania, Serbia and Slovakia are much higher, these countries are of high concern regarding TMF safety and they should be in focus of future activities on safety improvement and capacity building.

The TMF distribution according to TRI classes (Figure 11) is similar to that of based on the THI. Very low and low risk was calculated for 127 TMF, 131 TMF have medium risk and 83 facilities show high and very high risk. Similarly to the THI, the country average TRI value (the sum of THI and TEI) is the highest in Serbia and Montenegro, followed by Bosnia and Herzegovina, Czech Republic and Slovakia (Figure 12). The rest of the countries are below the DRB mean. The difference between the maximum (Serbia) and the minimum (Slovenia) is about 3.5, representing a risk 4,000 times higher.

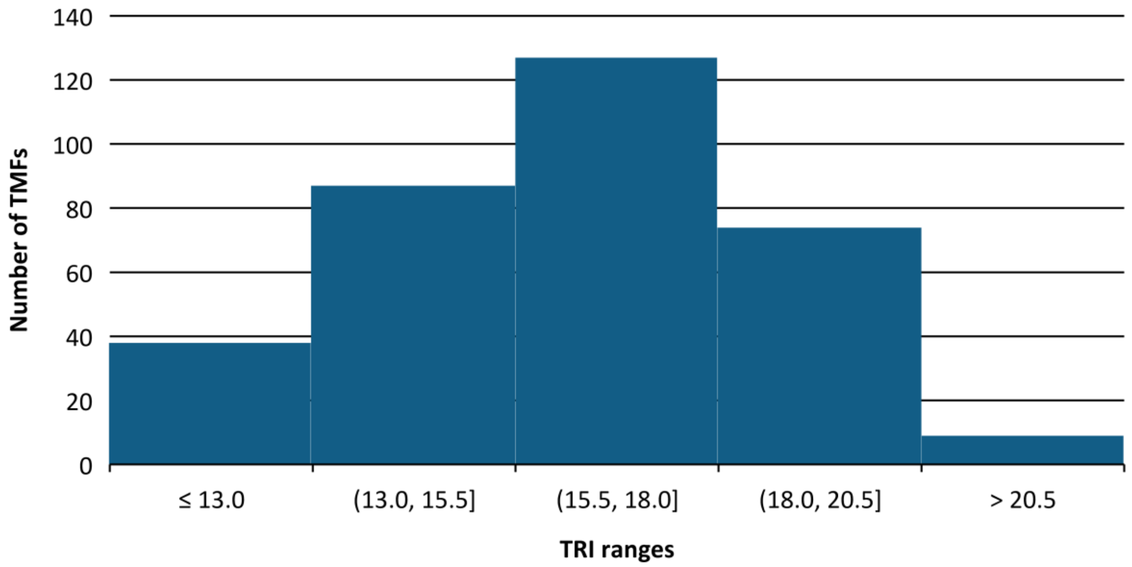

Figure 11: Distribution of the number of TMF in the DRB according to the TRI.

Figure 12: Average TRI of the Danube countries.

Assessment of the average TEI of the Danube countries is presented in Figure 13. Potential population exposure is the highest in Hungary and Montenegro. Nevertheless, the differences between countries are rather small, except in Serbia, where mainly small villages or scattered houses are located in the risk zones. The environmental exposure is the largest in Slovenia and Hungary, but their exposure index values are in a very similar range compared to the rest of countries.

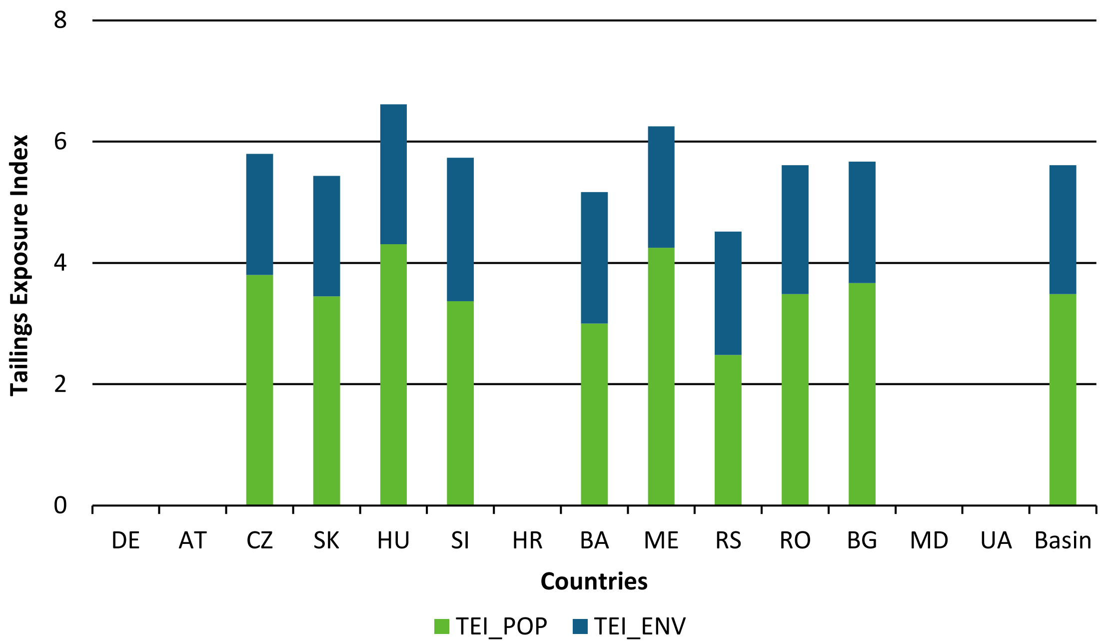

Figure 13: Breakdown of the average country's TEI in the DRB.

Ranking the TMF based on the TRI and the THI values shows that for many TMF the two indexes provide similar ranking results. This is because the TRI includes the THI and for these cases the TEI value has less impact on the overall TRI. However, for a high number of TMF the ranks based on the two indexes are significantly different, indicating the necessity of considering land-use planning aspects at the point when TMF are prioritized. For these TMF, the TEI has a major impact on the final TRI value. This is very apparent for the top 10% TRI list (34 TMF), where 16 TMF posing high risk to population and environment would have much lower priority if only hazard was taken into account, i.e. only the remaining 18 TMF are on both top 10% lists. Moreover, for only 10 TMF are the ranks similar (rank difference less than 10).

3.5 Findings and recommendations

Recommendations on sustainable management of tailings ponds are listed below.

1) At policy-making level (policies and strategies):

- It is recommended to establish and maintain an open dialogue and close cooperation between water management sector and competent authorities responsible for mining waste management and civil protection (e.g. ministry of interior, energy or environment) in order to ensure policy alignment and coherence, efficient information exchange and coordinated accident prevention and contingency management.
- It is crucial to develop an enabling policy framework for implementing up-to-date industrial technologies and safety measures in compliance with the EU Seveso Directive, the EU Extractive Waste Directive[24] and the respective BAT Reference Document[25] as defined in the EU Industrial Emission Directive and in line with the recommendations of the UNECE Safety guidelines and good practices for TMF[26], as well as for establishing an effective inspection and performance control system.
- Danube countries should take further joint actions to prevent transboundary accidental pollution of surface waters in relation to TMF disasters in line with WFD Article 11.

2) At policy implementation level (actions and measures):

- Countries are encouraged to optimize the limited institutional capacity and financial resources by targeting the most hazardous TMF where regular safety inspections are needed.
- Appropriate safety measures should be urgently taken in case of non-compliance with relevant technical standards and ensuring appropriate rehabilitation of closed and abandoned sites.
- It is recommended to link TMF hazard assessment to national or transboundary early warning systems in order to timely respond to potential accident events related to the identified hazard hot-spots.
- Development of specific contingency measures and disaster management plans are needed at the local level for the surrounding downstream area of TMF associated with high risk.
- It is necessary of involving land-use planning aspects and risk mapping into the design, siting and licensing of new and existing (in case of capacity enlargement) TMF in order to limit the number of potential receptors to be affected by and accident, in particular the vulnerable receptors.

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[24] Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC. 2006L0021, European Commission, Brussels, https://environment.ec.europa.eu/topics/waste-and-recycling/mining-waste_en.

[25] Garbarino, E., Orveillon, G., Saveyn, H., Barthe, P. and Eder, P. (2018): Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries in accordance with Directive 2006/21/EC. EUR 28963 EN, Publications Office of the European Union, https://publications.jrc.ec.europa.eu/repository/handle/JRC109657.

[26] UNECE (2014). Safety guidelines and good practices for tailings management facilities, ECE/CP.TEIA/26, United Nations, Geneva, https://unece.org/info/publications/pub/21637.

- Countries are advised to organize capacity building programs with regular training events at national or regional level for facility operators and authority inspectors to strengthen their knowledge and skills in the field of accident prevention and contingency management.
- Danube countries are encouraged to make use of the TMF Checklist as a consistent practical evaluation, self-assessment and training tool and adapt it to their national conditions where necessary to assess safety conditions of individual TMF and to identify potential measures to be implemented to improve safety.
- Application of the TMF Checklist and tool as education materials in the national mining curricula is highly recommended.
- It is recommended to openly communicate TMF risks, accident events, inspection results, capacity building events and disaster management exercises to the public.
- Safety issues should be discussed with local communities in the form of public hearings, dissemination materials and social media tools to raise awareness of TMF safety, accident prevention and emergency management.

3) At technical level (basin-wide joint activities):

- Danube countries are encouraged to develop and regularly update national inventories on TMF located in their territory, including basic parameters necessary to conduct hazard and risk assessments in line with the respective basin-wide activities (i.e. application of the THI and TRI methods or similar screening tools).
- Danube countries should further carry out and update consistent and comparable hazard and risk assessments at national or basin-wide level to prioritize the most hazardous TMF hot-spots and to identify receptors of high relevance (population, environmental resources, socio-economic goods) potentially exposed to accident impacts.
- Danube countries should make use of the existing international platforms (ICPDR, UNECE) for knowledge transfer and information exchange.
- Danube countries should organize demonstration training events and implement basin-wide or regional projects on capacity building.

4 ANNEX

Table A1: Number of AHS, summed stored volume of substances and total WHI of the Danube countries.

Country	All sites			Sites with WHI >5		
	Number of facilities	$WHC3_{eq}$ (kg)	WHI	Number of facilities	$WHC3_{eq}$ (kg)	WHI
DE*	139	2,350,971,458.2	9.3712	116	2,350,218,706.7	9.3711
AT	46	16,453,577.5	7.2163	13	15,979,341.8	7.2036
CZ	46	601,873,734.0	8.7795	19	601,309,932.1	8.7791
SK	39	2,049,505,525.5	9.3116	36	2,049,412,299.1	9.3116
HU	316	502,003,733.6	8.7007	46	498,958,095.3	8.6981
SI	49	389,769,201.2	8.5908	24	389,340,667.2	8.5903
HR	26	40,258,531.1	7.6049	16	39,956,198.2	7.6016
BA	18	115,405,091.6	8.0622	5	115,211,872.3	8.0615
ME	0	0.0	0.0000	0	0.0	0.0000
RS	23	1,172,820,772.0	9.0692	18	1,172,779,395.1	9.0692
BG	33	54,750,997.7	7.7384	23	54,683,826.9	7.7379
RO	234	4,438,144,124.4	9.6472	139	4,436,127,001.8	9.6470
MD	24	64,709,018.6	7.8110	14	64,521,156.2	7.8097
UA	17	3,061,676.6	6.4860	4	2,995,794.5	6.4765
Basin	**1,010**	**11,799,727,442.1**	**10.0719**	**473**	**11,791,494,287.2**	**10.0716**

$WHC3_{eq}$: Water Hazard Class 3-equivalent, WHI: Water Hazard Index

* Data are available only from Bavaria

Table A2: Number of AHS, summed stored volume of substances and total WHI of the industrial sectors (sites with WHI > 5).

Industrial sector	Sites with WHI >5		
	Number of facilities	$WHC3_{eq}$ (kg)	WHI
Energy sector	215	7,915,321,370.2	9.9
Production and processing of metals	38	24,277,359.4	7.4
Mineral industry	11	148,065,547.5	8.2
Chemical industry	108	1,813,031,621.8	9.3
Waste and wastewater management	10	21,148,458.0	7.3
Paper and wood production processing	3	1,892,872.0	6.3
Intensive livestock production and aquaculture	1	398,107.2	5.6
Animal and vegetable products from the food and beverage sector	3	1,959,638.9	6.3
Transportation and storage	58	1,793,571,367.0	9.3
Other activities	26	71,827,945.1	7.9
Basin	**473**	**11,791,494,287.2**	**10.1**

Table A3: Total number of TMF, summed tailings volume, weighted average tailings toxicity and average hazard and risk factors for the Danube countries.

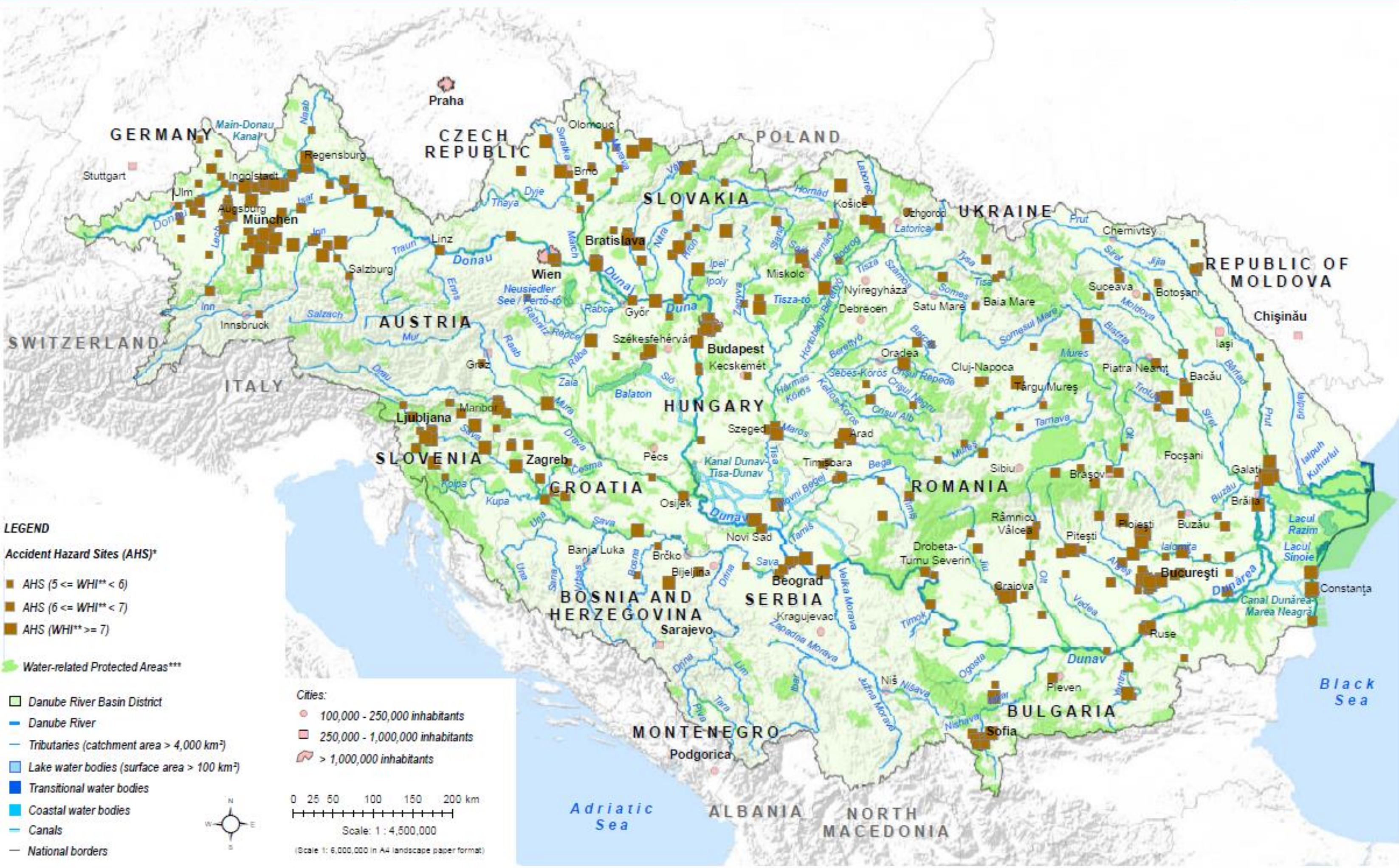
Country	Number of TMF	Number of active TMF	Tailings volume (million m^3)	Weighted Toxicity (WHC)	THI_{Cap}	THI_{Tox}	THI_{Man}	THI_{Seism}	THI_{Flood}	THI_{Nat}	THI_{Dam}	THI	TEI_{Pop}	TEI_{Env}	TEI	TRI
DE																
AT																
CZ	10	5	28.559	2.24	6.18	1.60	1.80	0.00	0.30	0.30	1.00	10.88	3.80	2.00	5.80	16.68
SK	60	26	128.006	1.40	5.75	1.70	1.50	0.43	0.72	1.15	1.00	11.10	3.45	1.98	5.43	16.53
HU	39	3	99.814	1.51	5.46	1.87	0.23	0.41	0.23	0.64	1.00	9.20	4.31	2.31	6.62	15.82
SI	30	8	53.836	1.56	4.88	1.70	0.80	0.87	0.13	1.00	1.00	9.38	3.37	2.37	5.73	15.11
HR																
BA	6	5	46.915	1.71	6.39	2.00	2.50	1.00	0.00	1.00	1.00	12.89	3.00	2.17	5.17	18.06
ME	4	2	13.780	1.59	6.30	2.50	1.50	1.00	0.00	1.00	1.00	12.30	4.25	2.00	6.25	18.55
RS	31	20	754.400	2.25	6.67	2.55	2.71	1.00	0.29	1.29	1.00	14.22	2.48	2.03	4.52	18.73
BG	3	0	1.643	2.88	5.36	2.67	0.00	1.00	0.00	1.00	1.00	10.03	3.67	2.00	5.67	15.69
RO	152	27	468.714	1.77	6.03	1.75	0.53	0.63	0.17	0.80	1.00	10.11	3.49	2.13	5.61	15.72
MD																
UA																
Basin	**335**	**96**	**1,595.667**	**1.95**	**5.88**	**1.84**	**0.98**	**0.62**	**0.28**	**0.90**	**1.00**	**10.60**	**3.48**	**2.13**	**5.61**	**16.21**

WHC: Water Hazard Class, THI_{Cap}: Capacity Index, THI_{Tox}: Toxicity Index, THI_{Man}: Management Index, THI_{Flood}: Flood Hazard Index, THI_{Seism}: Seismic Hazard Index, THI_{Nat}: Natural Hazard Index, THI_{Dam}: Dam Stability Index, THI: Tailings Hazard Index, TEI_{Pop}: Population Exposure Index, TEI_{Env}: Environmental Exposure Index, TEI: Tailings Exposure Index, TRI: Tailings Risk Index

Preliminary data for Slovenia and Serbia, official approval is pending.

No relevance for Germany, Austria, Croatia, Moldova and Ukraine.

Map 1: AHS and water-related protected areas.

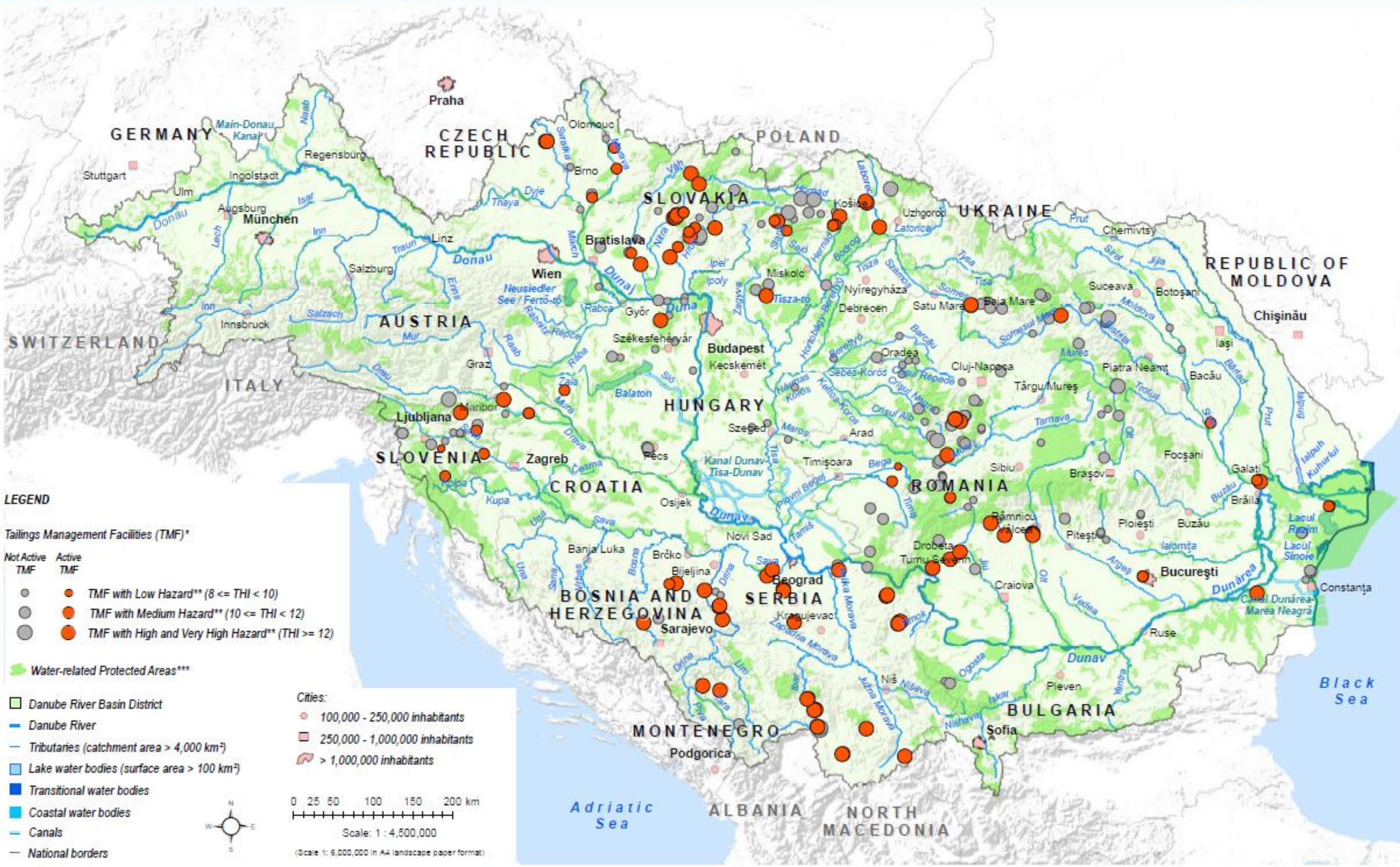


* Accident Hazard Sites are operating industrial and energy production facilities, with high potential risk of accidental pollution.
** Water Hazard Index (WHI) quantifies the accident hazard, considering the amount and hazardousness of the processed substances at the respective facility, without taking into account the safety measures implemented.
*** Protected Areas as defined by the EU Bird Directive, EU Habitat Directive, and other Protected Areas for water-dependent species and water related habitats.

This ICPDR product is based on national information provided by the Contracting Parties to the ICPDR (AT, BA, BG, CZ, DE, HR, HU, MD, ME, RO, RS, SI, SK, UA) and CH. EuroGlobalMap data from EuroGeographics was used for all national borders except for AL, BA, ME where the data from the ESRI World Countries was used; Shuttle Radar Topography Mission (SRTM) from USGS Seamless Data Distribution System was used as elevation data layer; data from the European Commission (Joint Research Center) was used for the outer border of the DRBD of AL, IT, ME and PL.

Vienna, November 2021

Map 2: TMF and water-related protected areas.



* Preliminary database only, data have not been approved officially by RS and SI yet.

** Tailings Hazard Index (THI) quantifies the hazard potential of each TMF, considering the TMF capacity and management conditions, stored tailings toxicity, natural conditions (seismic activity and flooding), and stability of a dam slope.

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This ICPDR product is based on national information provided by the Contracting Parties to the ICPDR (AT, BA, BG, CZ, DE, HR, HU, MD, ME, RO, RS, SI, SK, UA) and CH. EuroGlobalMap data from EuroGeographics was used for all national borders except for AL, BA, ME where the data from the ESRI World Countries was used; Shuttle Radar Topography Mission (SRTM) from USGS Seamless Data Distribution System was used as elevation data layer; data from the European Commission (Joint Research Center) was used for the outer border of the DRBD of AL, IT, ME and PL.

Vienna, November 2021