Chapter 5
Natural Disasters in Industrial Areas

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Abstract Simulations of the environmental accidents related to the chemical hazard were performed in order to estimate the contamination triggered or caused by natural disasters occurrence in the area heavily loaded with passive hazardous waste deposits. The mining and metallurgy waste deposits, when being exposed to the extreme weather conditions and droughts are scattered on the wider areas, and washed down by the floods, creating erosion ditches along the river banks, and penetrating into the deeper layers of soil. For this purpose the waste materials characterizations were performed by using modern instrumental techniques, considering the heterogeneous nature of the waste. The screening tools are used to estimate the level of air contamination in different climatic conditions, and the simulation of the movement of water and variable solutes to predict the soil contamination along the depth column related to the river flows. The modeling can't replace the regular monitoring, but can help determine the regularity, frequency and location of the probes for measurements, and raise the red flag with the authorities. Finally, Application of intelligent Multi-Criteria Analysis has been performed for the purpose of ranking the degree of negative impact on the environment of tailing ponds. Analysis is performed for five tailing ponds of MMCC (Mining Metallurgy Chemical Combine) "Trepča", whereby two of the ponds are active and three inactive. In order to achieve the most objective results, the AHP and PROMETHEE methods were applied.

Keywords Tailing waste · Pollution · Extreme weather · Floods

5.1 Introduction

Mining presents a significant element of economic development in every state. It is also known that the biggest environmental pollutant is the mining sector. Mining is followed by a mass production of waste in the form of tailing on tailing ponds. They are often formed in areas which have other potential (agriculture, water supply, urban areas, water flows, etc.). In general, all material left after the extraction of minerals

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or after the process of exploitation is waste, which when dumped on the deposit spot creates the tailing pond (Ristovic et al. 2010).

Vast areas are covered with mining tailings. For example, amounts of waste from mining in EU countries are around 400 Mt, and tailing waste is approximately 29% of total waste produced as reported by the Commission of the European Communities (2003). In the Environment and Security Initiative Project: Mining in South East Europe (Peck 2004), it was concluded that almost the full range of warning signals for environmentally damaging incidents of large scale consequence are present in the region. These include large (historical) milling and metallurgy plants with significant slag deposits, mountainous terrain; abandoned sites with little or no closure or control; lack of ongoing physical and/or biochemical monitoring of operational and/or abandoned sites; lack of ongoing maintenance, both proactive and reactive.

According to the Environmental Protection Agency (Environmental Protection Agency 2005), in the "Report of the State of the Environment in Republic of Serbia," it is estimated that there are around 700 million tons of flotation and separation tailings, between 1.4 and 1.7 billion tons of tailing wastes from opening pits and around 170 million tons of ashes from thermal power plants on deposit spots and landfills in Serbia. Metallurgy in the Republic of Serbia contributes 10% to the total gross domestic product for production of basic metals and metal products.

In mines with metallic mineral ores, concentration of heavy metals in tailing has increased. This is why the problem of environmental protection is severe in systems like Mining Metallurgy Chemical Combine (MMCC) "Trepča". The oldest tailing waste deposit in Trepca is Gornje polje, and being located inside a processing plant and in a close vicinity to the residential are, a lot of attention is put on its environmental impact. Different reports were made on the projects initiated by international organization, about the proposed activities for solving the environmental problems, and in those reports the tailing waste deposit Gornje polje was described to be some 50 ha large surface area with 12,000,000 ton of waste materials (Milentijevic et al. 2016). The published studies on this tailing (Borgna et al. 2009; Nanonni et al. 2011) analyze the environmental impact of the Trepca's tailings, by analyzing the top soil in the surrounding location. The Gornje Polje tailing waste deposit is a resource to manage and a threat to control. By its location on the river bank, and constant risk from flooding and low level of slope stability, it presents an environmental disaster risk. On the other hand, by its heavy metal content, and occurrences of the rare metals, it can be treated as source of valuable components. In order to determine the level of environmental risk, in the changing climatic conditions, some proper materials characterization was conducted, and imported into simulation of the Natech situation where the extreme weather conditions were simulated.

The purpose of this paper is to rank the flotation tailings of MMCC "Trepča" in terms of negative environmental impact. For these purposes, selection of relevant parameters was undertaken and calculations were made through the application of multi-criteria analysis (MCA). This method has recently been used in a variety of studies by numerous researchers deliberating different problems. In the field of mining, such researchers include Bogdanović et al. (2012) and Ataei et al. (2008) and in the area of environmental protection, Kiker et al. (2005) among others.

In this paper, analysis includes five non-remediated flotation tailings. On all five tailings, MMCC "Trepča" disposed their waste. Two flotation tailings are active (waste is still being disposed there) and three are passive, meaning there is no longer any dumping of waste.

5.2 Methods and Materials

5.2.1 Study Area

The study area is situated on the large highland Kosovo, to the north of the Autonomous Region Kosovo and Metohija (Fig. 5.1). Administratively, it belongs to the municipalities of Zvečan and Kosovska Mitrovica. The study area has the typical continental climate with long and hot summers and cold winters (Milentijevic et al. 2016).

In the last century, Mining Metallurgy Chemical Combine "Trepča" has produced around 120,000 ton of raw lead, 100,000 ton refined lead, 100 ton of silver, 80,000 ton electrolyte zinc, 140,000 ton artificial fertilizer, 50,000 ton super phosphate, and 30,000 ton lead acid batteries, while daily production in mines was up to 10,000 ton of mined ores (Milentijevic et al. 2013).

By mining in Kopaonik's metallogenic zone and flotation processing of metallic minerals, MMCC "Trepča" established tailing ponds: Žarkov Potok, Gornje Polje, Žitkovac, Tvrđanski Do and Bostanište. All five tailings are in an administrative unit of the Kosovska Mitrovica area and in the municipalities of Zvečan and Mitrovica. The tailings are polymetallic and their mineral compositions are mostly heavy metals,

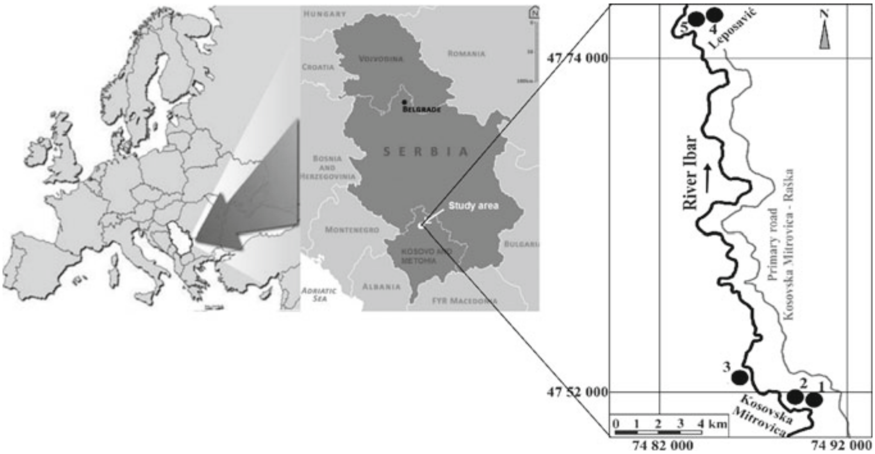


Fig. 5.1 Schematic review of the study area. ●—Tailing ponds: 1—Žarkov Potok; 2—Gornje Polje; 3—Žitkovac; 4—Bostanište; 5—Tvrđanski Do

as they were extracted from ore. In the process of creation and expansion of these five tailing ponds, material was transported hydraulically and deposed physically by hydrocyclone.

The landscape where the tailings are situated is the Ibar River's alluvial plain (Nikic 2003). Since the tailing deposits have not been rehabilitated, the material from the deposits have scattered over the years in the environment through the aeolian process, gravity and water flows. Tailing material from the analyzed deposits shows permanent toxic pollution of water and agricultural land. All atmospheric water and waters from tailing ponds are released into the Ibar River through drainage systems in the tailings. The water bodies from the area as well as those from remote areas are highly endangered by the leaching contamination from the tailings. On the northern part of the landfill, tailings from the lead smelter have been disposed for a long time, so the landfill has taken on the form of a cone. Deep cuts have been created as a result of erosion on both sides of the dam, through which comes discharge of atmospheric waters from the landfill directly into the Ibar. Deposed flotation tailing is in general oxidized and solid (Milentijevic et al. 2016).

5.2.2 Chemical Analysis

The chemical composition of the tailing waste is determined by using x-Ray fluorescence (ARL86480). For the chemical analysis of the samples also the following techniques are used: Ca and Mg concentrations are analyzed by using Volumetry-EDTA, Si is analyzed by Gravimetry, HCL digestion, Al, Na, K, Pb, Zn, Cd, Cu, Sb by AAS, equipment AAnalysist 300, Perkin-Elmer. Volumetry method by oxi-reduction is used for Fe analysis. The river Ibar water analysis is done by application of AAS (Atomic Absorption Spectrometry) instrument. The samples were taken from two sites: Dudin Krs and Rudare, i.e. before and after the tailing waste deposit Gornje polje, Fig. 5.1. In all the samples heavy metals concentrations are determined.

5.2.3 Microscopy and Mineralogy

SEM investigation was carried out on Scanning Electron Microscopy instrument from JEOL (JSM6460), with Energy Dispersive Spectrometer, EDS by Oxford Instruments. XRD (X-Ray Diffractometry) analysis was used for mineralogical investigation. Samples were investigated using diffractometer Philips PW 1710 under following conditions: radiation from copper anticathode with $\mathrm{CuK}\alpha = 1.54178$ Å and graphite monochromator, working voltage $U = 40$ kV, current strength $I = 30$ mA. Samples were investigated in the range of 5–70° 2θ (with step of 0.02° and time 0.5 s).

5.2.4 Dusting Experiment

A fan type ABVE-3,5 apparatus was employed for measuring dust loading (mg/m^2) in the laboratory, using a flow of 3600 m^3/h and a vacuum of 200 Pa for airflow simulation, with a gravimetric sampler of the respiratory dust. The sample was set in a shallow metal plate, along with the measuring scale for the residual solid particles on the filter paper and a digital anemometer (DA-4000). The measurements were performed with the material set in the airflow direction from the fan and before the apparatus for polluted air vacuuming. The wind velocity was changed by the distance between the fan and the metal plate for each sample. The measurements were performed in wind velocities of 5, 7 and 10 m/s. The humidity in the laboratory was within the interval of 37–53% and the dust concentration was 0%.

5.2.5 Modeling and Simulation

Simulation was performed by using Gaussian Plume Air Dispersion Model AERMOD. AERMOD was using the calculations for the complex terrain data, taken from the In this case the plume is modeled and impacting and following the terrain. AERMET first use the terrain characteristics as albedo, surface roughness and Bowen ratio, and meteorology data (wind speed, wind direction, temperature, and cloud cover. AERMET calculates the PBL parameters: friction velocity (u*), Monin-Obukhov length (L), convective velocity scale (w*), temperature scale (*), mixing height (z i), and surface heat flux (H). These parameters are used to calculate vertical profiles of wind speed (u), lateral and vertical turbulent fluctuations (v, w), temperature gradient (d/dz), potential temperature ( ), and the horizontal Lagrangian time scale (TLy).

5.2.6 Multi Criteria Analysis

The waste tailings from processing of flotation of metallic mineral ores are by-products of MMCC "Trepča" mining activities. The method for ranking the effect of tailings on the surrounding ecosystem had to fulfil the following criteria: it should be in compliance with the concept of sustainable development; it should be in compliance with different cultural, social and organizational frameworks; it should be applicable to large and small companies and for large and small-scale environmental pollutants. It was thus decided that the ranking of five current tailing ponds should be done by multi-criteria analysis.

Field work and analysis of flotation tailings and surroundings was undertaken as part of the preparation. Data collection and analysis of documentation and published papers addressing the problem were done. The mapping of five tailings with waste from the flotation process is done through terrain research for: Žarkov Potok, Gornje Polje, Žitkovac, Tvrđanski Do and Bostanište. All five tailings are in an environment with agricultural, urban, recreational, cultural and other potential. All are in close proximity to water streams or on the banks of the Ibar. It should be noted that, besides problematic ownership, lack of data about the current conditions of the landfill, characteristics of the deposed material and environmental impact assessment analyses is also a concern

Important environmental aspects (air, water, soil), character of deposed material (chemical, quantities and other), elements with special value in their environments (natural rarities, archaeological and religious sites, etc.), technical and sociological aspects as well as many others are included in the assessment of the tailing ponds' impact on the surrounding ecosystem.

The analysis started with criteria selection for the purpose of the ranking of the tailings for their ability to endanger the environment in the case of extreme weather and flooding (Milentijevic et al. 2016). The criteria selection for assessment is an important and very complex step, determining the final results of the MCA. The set criteria estimation result essentially depends on their weight factors. For coupling the weight factor to the selected criterion, it the mixed approach was applied, using subjective and objective methods in order to achieve final integrated weight factors. The analyzed criteria for all five flotation tailings are shown in Table 5.1.

In order to ascertain the impact ranking of tailing on the local environment, AHP (Analytic Hierarchy Process) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) are used. The consideration and description of these two methods from a mathematical aspect is presented briefly considering that these methods are explained in detail in numerous papers.

In the analysis conducted in this study for the PROMETHEE method, the commercial software Visual PROMETHEE 1.4 Academic Edition was used. The PROMETHEE method does not provide us the opportunity to analyze decision making on simpler parts compared to AHP. In cases of a bigger number of criteria, this method makes it harder to come to a conclusion for the analyzed problem.

Table 5.1 Presentation of criteria of analyzed flotation ponds

Criteria	Analyzed criteria
C1	Proximity of water source
C2	Proximity of the settlement
C3	Proximity of agricultural area
C4	Proximity of permanent water flow
C5	Quantity of material deposed
C6	Existence of the flooding water sources
C7	Activity of the tailings
C8	Geological environment
C9	General slope of the terrain
C10	Tailing maintenance

For a more complete graphic presentation of the results obtained by the PROMETHEE method, the GAIA plan (Geometrical Analysis for Interactive Assistance) was used from the software Visual PROMETHEE 1.4 Academic Edition. The basic purpose of this application is better visual presentation of the multi-criteria analysis. In the frame of the GAIA plan, some information can be lost after the projection. Based on the main components, the presentation is defined by two vectors, responding to the basic flow of one criterion. Although GAIA includes some percentage of total information, it does not provide strong graphic support.

5.3 Results and Discussion

The material characterization has shown that the waste is small grained, toxic mineral mixture. All five tailings were widely investigated by the authors. Zitkovac was widely investigated by its environmental impact (Frese et al. 2004), Zarkov potok was investigated for its drainage waters (Barac et al. 2016) and Bostaniste and Tvrdjanski Do were investigated for the estimation of the pollution range in the different climatic conditions (Djokic et al. 2012a). Gornje Polje tailing is on the river bank, with the large deposit of lead metallurgy slag in the form of cone on the top of it, with the piles of secondary lead production slag and waste (Djokic et al. 2012b). As a perfect example of the complex nature of this waste, in this chapter there will be only presented the results of the chemical, granulometric, mineralogical and morphological testing of the tailing waste material from the location Gornje Polje.

5.3.1 Chemical Composition and Granulometric Composition

Chemical composition of the tailing waste is presented in Tables 5.2 and 5.3 representing large difference in chemical compositions in the same tailing.

5.3.2 Scanning Electron Microscopy

SEM scans of the tailing waste deposit samples (Fig. 5.2) are presented and there are clearly visible the non-homogenous nature of this deposit. This heterogeneous structure of the one tailing waste deposit, which also represents the situation in all five observed tailing waste deposits is presented below.

From the samples taken from the different stages of mineral processing in Trepca, it can be concluded that there are different metals concentrations in the waste according to the technologies applied. As shown in Fig. 5.2a the sample taken from the site where the waste is deposited in the first half of the last century contains larger amount of lead, even 6.51% as the mineral processing technology was unefficient. The bright

Table 5.2 Chemical composition of waste deposit Gornje polje sample Dudin Krs

Element	O	Al	Si	S	Ca	Fe	Zn	As	Ag	Cd	Sb	Hg	Pb	Total
mass%	47.31	0.69	2.27	11.62	4.34	25.73	0.21	0.97	0.00	0.00	0.36	0.00	6.51	100.00

Table 5.3 Chemical composition of waste deposit Gornje polje sample Rudare

Element	O	Al	Si	S	Ca	Fe	Zn	As	Ag	Cd	Sb	Hg	Pb	Total
mass%	47.78	0.29	1.00	15.79	2.51	31.24	0.00	0.00	0.00	0.00	0.42	0.00	0.97	100.00

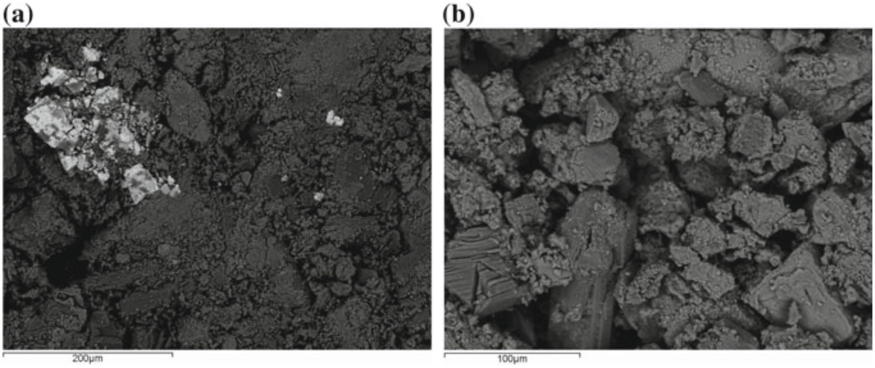
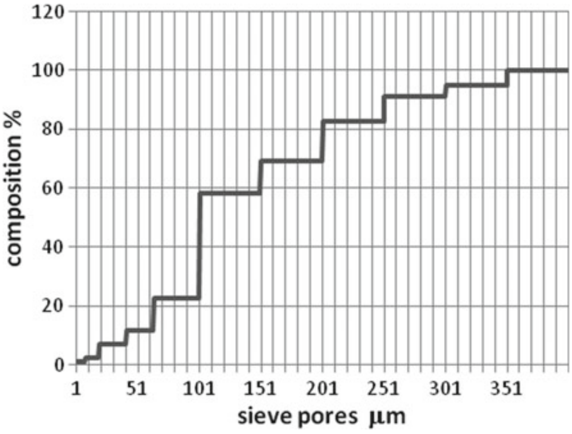


Fig. 5.2 SEM-EDS images of tailing waste deposit Gornje Polje in two locations: **a** Dudin krs and **b** Rudare

pattern on the SEM image represents lead particles. The second sample is taken from the site where the waste is deposited from 1950–1983. and the metals recovery was increased due to the modern technology applied, so the lead concentration didn't exceed 1%, as shown in Fig. 5.2b.

As the mineral processing is the process of metal's concentration, the ore is crushed, than milled to the average grain size of 0.1 mm in diameter, so the mineral grains are opened to be exposed to the flotation agents. After the years of storage on the open air, some of the particles are aggregated, and others are even smaller, being exposed to the wind and rain, Fig. 5.3. The most of the particles are larger than 10 μm in diameter, so the MAC for Total Solid Particles will be applied (Djokic et al. 2012b).

Fig. 5.3 Granulometric composition of the tailing waste deposit



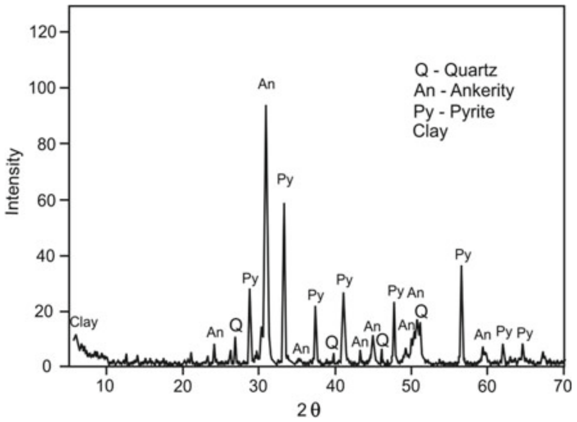


Fig. 5.4 X-ray diffractometry of the tailing waste deposit

5.3.3 X-ray Powder Diffraction

The composite sample of tailing waste is composed by several crystallized phases, as shown in Fig. 5.4. There are minerals of quartz, ankerite, pyrite, and there is some presence of clay minerals. As the concentrations of other metals compounds are small, they could not be detected by XRD analysis.

As the X-ray diffractomery analysis showed the presence of Ca, Mg, Mn, Fe in a form of carbonates as, there are several peaks of Ankerite plotted, it can be concluded that Ca, Mg, Mn, and some amount of Fe, listed in Tables 5.2 and 5.3 are actually carbonates, as the Carbon can not be detected by SEM-EDS. Also, the presence of quartz and clay minerals explains the amounts of Al_2O_3 and SiO_2 in the tailing waste deposit.

5.3.4 Water Quality

River Ibar quality was tested for heavy metals content in two different locations-before and after the tailing waste deposit Gornje Polje. In order to assess the quality according the EU Water Framework Directive, the Calcium content was determined.

For the concentrations of heavy metals EQS values depend on the hardness of water, which is expressed through the concentration of calcium and is divided into five categories according to the Annex III of the same Directive: (Class 1: <40 mg $CaCO_3$/l, class: 40 to <50 mg CaCO3/l, Class 3: 50 to <100 mg $CaCO_3$/l, Class 4: 100 to <200 mg $CaCO_3$/l and Class 5: $\geq$200 mg $CaCO_3$/l).

According to this division, based on data analysis, presented in a graphic in Fig. 5.5, the water of the river Ibar in the municipality of Zvecan, except in exceptional cases, one of the leading class III, and applied the standards of quality of surface water class III. Class III surface water can be used for irrigation, recreation,

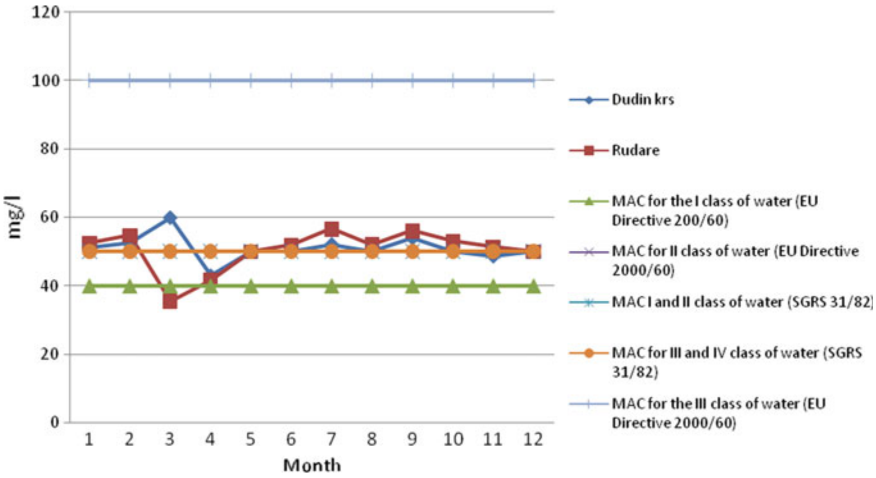


Fig. 5.5 Calcium concentrations in the river Ibar samples

industrial use, in energy production, mineral extraction and as a transport medium. Figure 5.6 shows the values obtained for lead concentration. Having considered the results from the river Ibar testing (Milentijevic 2013) it can be concluded that the values of the analyzed heavy metals in most cases exceed the values prescribed by the EU Directive 2000/60, on the basis of the UNECE, 1996 Guidelines on Water-Quality Monitoring and Assessment of Transboundary Rivers, while the values for Pb are constantly above the MAC, throughout year. The lead concentration peak was measured after the river passes the tailing waste deposit location (red line), and it is significantly higher than the value measured on the location before the tailing (blue).

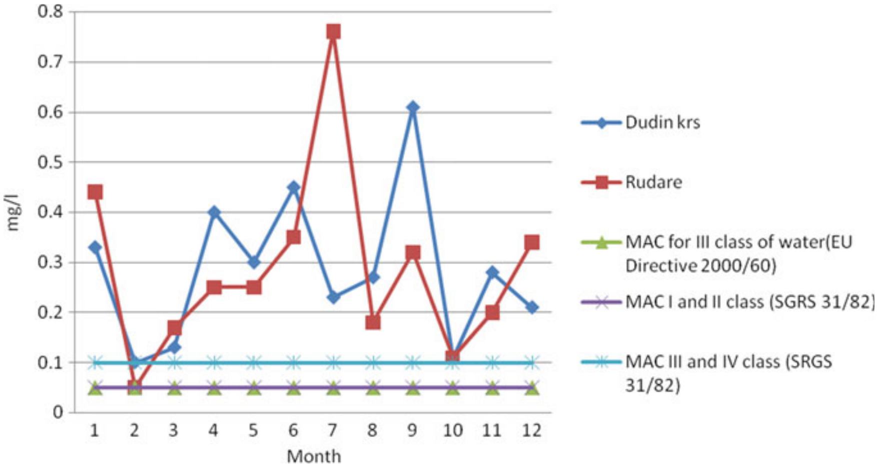


Fig. 5.6 Lead concentrations in the river Ibar samples (Color figure online)

That corresponds with the data obtained for the alluvium lead concentrations along the Ibar river before and after the floods 2014 (Barac et al. 2016)

Environmental Quality Standards (EQS) are given in Annex II of EU Directive 2000/60 are expressed as the total concentration in the whole sample of water. For the concentration of heavy metals EQS refers to the concentration of dissolved substances, i.e. the liquid phase of water samples obtained filtration.

The obtained values of heavy metals in the water of the river Ibar are quite negative, because almost all of the analyzed heavy metals: Cu, Fe, Pb and Zn exceed the EQS.

The situation on the terrain requires the statement that the flotation tailing waste deposit is the primary source of water pollution of the river Ibar in the municipality of Zvecan. First, the uncontrolled disposal of waste or incidental situations, both physically and chemically, directly affects the life and development of flora and fauna directly in the river and river bed, and on the river bank. There are also possible damages that may arise from large inundated by a wave of Ibar, and unprofessional work on flotation tailing waste deposition. Hazards that may be caused by the breakdown was complete destruction of flora and fauna in the bed of the river Ibar, endangering buildings and towns downstream from the barren land and permanent contamination of wells and heavy metals in the flooded area. As a measure of protection of the water of the river Ibar is proposed to technical and biological rehabilitation and remedy of the flotation tailing waste deposit.

For the purpose of the heavy metals particles plume simulation there was a need for the different meteorological data processing methods (Swhli et al. 2018). As the measurements were performed at a relatively small distance and under the actual climate conditions for the defined period, it was necessary to define the approximate dusting under different climatic conditions. By analyzing the data for wind speeds, directions and frequencies, it can be concluded that the winds have changed their frequencies over the last 20 years (Djokic et al. 2012b). In 1999, the weather was mostly stable, and just 7.0% of the winds had a speed of more than 3.6 m/s. Southern winds were the strongest and northeastern winds were the most frequent, i.e., 20% of the winds came from this direction. Just 1% of the winds were stronger than 8.8 m/s. In 2010, 21.1% was in the wind class 3.6–5.7 m/s, and 2.8% of the winds had a wind speed of more than 5.7 m/s. Southern winds were the most frequent, but southwestern winds also increased in frequency and speed. This is usually the case in the summer, when strong hot winds blow from the Mediterranean area, with hot and dry weather. For the purpose of simulation in assumed larger wind classes and frequencies the wind data from the Fig. 5.7 are used.

In extreme weather conditions, the wind speed larger than 10 m/s is expected, and there are no data on pollution in these climatic conditions. The potentially unstable weather was taken into consideration for modelling and simulation. The distance of 5000 m from the source of pollution was set for discrete distance calculations.

Simulation was performed by using Gaussian Plume Air Dispersion Model AERMOD. AERMOD was using the calculations for the complex terrain data, taken from the In this case the plume is modeled and impacting and following the terrain.

AERMET first use the terrain characteristics as albedo, surface roughness and Bowen ratio, and meteorology data (wind speed, wind direction, temperature, and

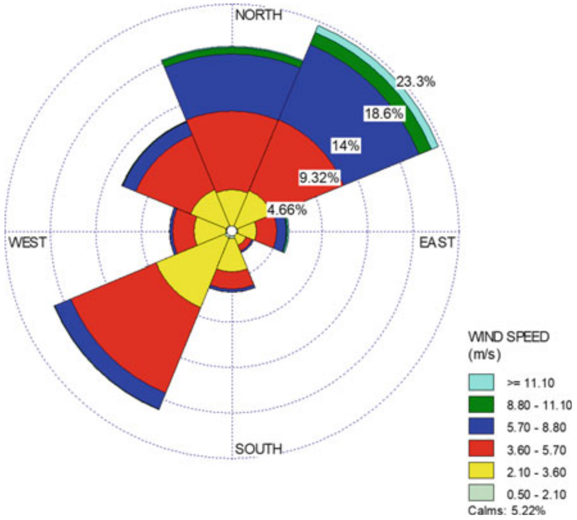


Fig. 5.7 Wind rose used for simulation

clouds). AERMET calculates the PBL parameters: friction velocity (u*), Monin-Obukhov length (L), convective velocity scale (w*), temperature scale (*), mixing height (z i), and surface heat flux (H). These parameters are used to calculate vertical profiles of wind speed (u), lateral and vertical turbulent fluctuations (v, w), temperature gradient (d/dz), potential temperature ( ), and the horizontal Lagrangian time scale (TLy).

After the calculation the air dispersion model is presented in Fig. 5.8. Red line shows the impact zone, and the pollution data are more than 20 times higher than allowed concentrations.

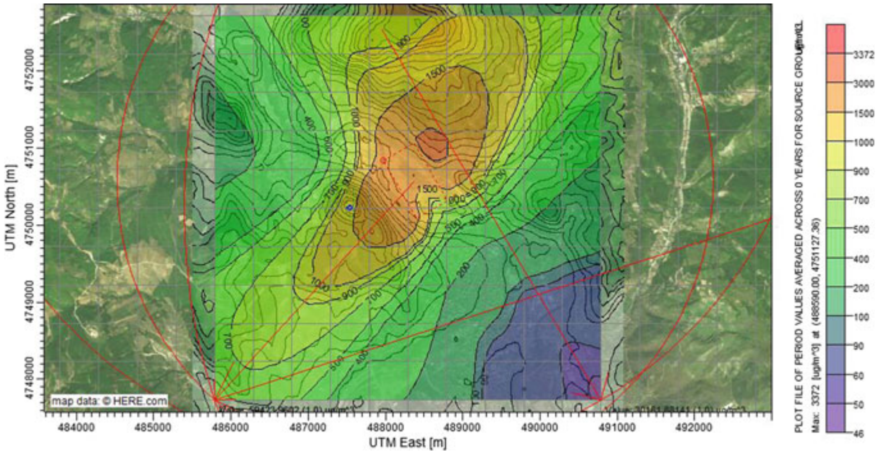


Fig. 5.8 Calculated PM10 concentrations in wind speed 11.1 m/s (Color figure online)

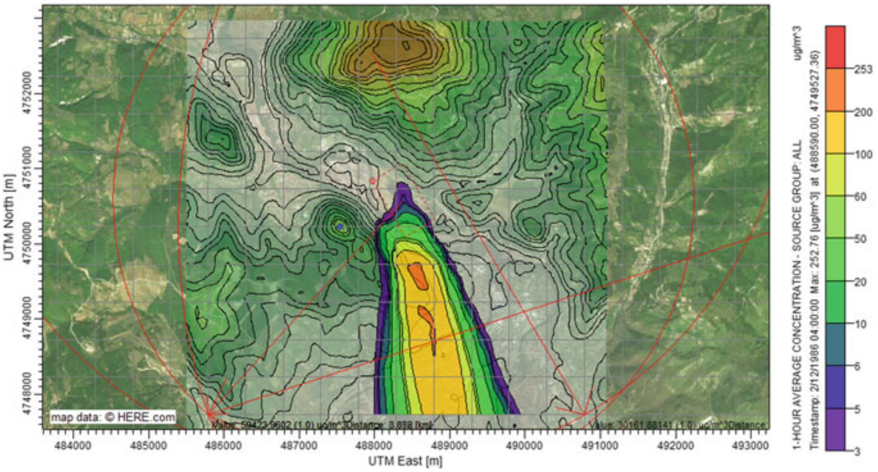


Fig. 5.9 Simulation with daily average data

In order to observe separate situations and the difference in dispersion in stable and extreme weather, the simulation with daily average data was presented in Fig. 5.9.

Comparing the impact of certain criteria to the environment was based on relevant data obtained in the field. The characteristics of the analyzed flotation tailing waste deposits are shown in Table 5.4. In Table 5.4, analyzed criteria which were used as input data for matrix formatting and quantification for coupled comparison of criteria according to the Saaty scale are presented (Table 5.5). Those data are than included into the calculations by AHP and PROMETHEE methods, by common steps in calculation process.

Based on results of the calculation done by AHP and PROMETHEE methods, final alternative rank was given-tailing ponds according to their negative impact to the environment.

Matrix with double comparison is formed by AHP method based on previously set criteria (Table 5.5). Weight coefficients for each criterion are calculated by mutual comparison and based on Saaty's scale (Table 5.1). Criteria are being added values by direct and inverted procedure in span from 1 to 9.

By valuing each criterion, coefficient weight of criteria was gained and are shown in Table 5.6. For the purpose of control of gained results, calculations of the *CR* are done. Results obtained confirmed that decision is consistent because its value is less than 0.1, or its value is 0.082062 (Table 5.6).

For individual criteria, weight coefficient values, consistency index (*CI*) and consistency rate (*CR)* for all five tailings were obtained by the APH method (Table 5.7). For criterion C1, the distance of water supply sources, the tailing A3 Žitkovac 0.4740 has the greatest value of weight coefficient, and A4 Tvrđanski Do 0.0715 has the minimum value. For criterion C2, vicinity of settlement, A5 Tvrđanski Do 0.4041 has the greatest value of weight coefficient, and A1 Žarkov Potok 0.05546 has the

Table 5.4 The characteristics of the analyzed flotation tailing waste

Tailing Ponds Criteria	Žarkov Potok-A1	Gornje Polje-A2	Žitkovac-A3	Tvrđanski Do-A4	Bostanište-A5
Vicinity of the water source—C1	No	50 m—wells	50 m—wells	12 km—wells	12 km—wells
Vicinity of the settlement—C2	About 500 m	About 200 m	About 100 m	About 50 m	About 50 m
Vicinity of agricultural area—C3	About 500 m	About 200 m	About 50 m	About 50 m	About 50 m
Vicinity of permanent water flow—C4	About 100 m, Ibar	About 50 m. Ibar	About 50 m, Ibar	About 50 m, Ibar	About 70 m, Ibar
Quantity of deposited material—C5	9,961,113 t	26,344,212 t	7,594,932 t	1,442,812 t	5,641,612 t
Occurrence of the flooding water sources—C6	No	Yes	No	No	No
Activity of the tailings—C7	Active	Not active	Not active	Not active	Active
Geological environment—C8	Alluvial	Alluvial	Alluvial	Alluvial	Alluvial
	4 m	4 m	4 m	4 m	4 m
General slope of the terrain—C9 (%)	8	0	0	7	8
Tailing maintenance—C10	No maintenance	No maintenance	No maintenance	No maintenance	No maintenance

minimum value. For criterion C3—the vicinity of agricultural environments—tailing A4 Tvrđanski Do 0.30954 has the greatest value of weight coefficient, and A1 Žarkov Potok 0.0373 has the minimum value. For criterion C4—the vicinity of waterstream—the tailing A4 Tvrđanski Do 0.3107 has the greatest value of weight coefficient and A1 Žarkov Potok 0.0837 has the minimum value. For criterion C5—the amount of deposited material—A2 Gornje Polje 0.4851 has the greatest value of weight coefficient, and A4 Tvrđanski Do 0.0420 has the minimum value. For criterion C6—the existence of torrential watercourses, the greatest value of weight coefficient has the tailing A2 Gornje Polje 0.4285, while the remaining tailings have the same value, 0.1428. For criterion C7, tailing activity, A1 Žarkov Potok and A5 Bostanište 0.3636 both have the greatest value of weight coefficient and the value of the remaining three tailings is 0.0909. For criterion C8, geology, all tailings have identical weight coefficient which is 0.2. For criterion C9, general slope of a region, A4 Tvrđanski Do and A5 Bostanište 0.2889 have the greatest value of weight coefficient, and the A2 Gornje Polje 0.0723 has the minimum value. For criterion C10—maintenance of tailings—all five tailings have identical value which is 0.2.

Table 5.5 Double comparison matrix of the criteria according to the Saaty scale

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	1	2	2	5	4	7	5	6	8
C2	1	1	2	2	4	4	5	6	7	8
C3	1/2	1/2	1	2	5	5	5	6	7	8
C4	1/2	1/2	1/2	1	2	2	5	4	6	7
C5	1/5	1/4	1/5	1/2	1	1	5	4	7	6
C6	1/4	1/4	1/5	1/2	1	1	5	4	5	6
C7	1/7	1/5	1/5	1/5	1/5	1/5	1	3	3	4
C8	1/5	1/6	1/6	1/4	1/4	1/4	1/3	1	3	5
C9	1/6	1/7	1/7	1/6	1/7	1/5	1/3	1/3	1	2
C10	1/8	1/8	1/8	1/7	1/6	1/4	1/4	1/5	1/2	1

Table 5.6 Weight coefficient criteria and their level of consistency

Criteria	Coefficient	*CR*
C1	0.214389322	0.082062
C2	0.2083418	
C3	0.179621064	
C4	0.117821399	
C5	0.083593285	
C6	0.080421814	
C7	0.041623037	
C8	0.036710749	
C9	0.02131439	
C10	0.016163141	

According to the conducted estimation with the application of the AHP method, the criterion C1, distance from the source of water supply, 0.2143, has the greatest value of weight coefficient and the criterion C10—maintenance of tailings, 0.0162—has the minimum value.

Alternatives have been evaluated and a quantified matrix of decision making has been formed (Table 5.8) by application of the PROMETHEE method for evaluation of environmental influence of tailing ponds. In this process, certain criteria have a quantitative structure, while others are qualitative. Consequently, certain criteria (C1, C2, C3, C4, C5, C8, C9) are stated quantitatively, while others are stated qualitatively. The application of qualitative and quantitative scales provides confidence that all criteria are well arranged in the best manner possible.

After quantified matrix of decision making was provided, analyzed alternatives (tailing ponds) were evaluated using Visual PROMETHEE software. This resulted with a rank order of alternatives. Multi-criteria ranking method PROMETHEE introduces qualities of positive, negative and net flow. The results obtained from positive, negative and net flow are presented in Table 5.9.

Numerous activities of the local population are taking place in relatively close proximity to these tailing ponds, despite the very precarious situation. Often, the local population has created facilities and taken part in activities, which are not safe so close to tailing ponds. For example, at about 50 m from some landfills there are wells used for irrigation and water supply, while some fields and streams are also only 50 m away from some landfills. Generally, all of the five treated tailings were formed in places that can have harmful effects on the surrounding ecosystem. The situation described here was meant to conduct an analysis and ranking of the tailings by the degree of potential danger to the living environment.

The ranking of the analyzed alternatives is given in Figs. 5.10, 5.11 and 5.12. using the PROMETHEE method.

In Fig. 5.10, the final ranking of analyzed tailing ponds is given. This figure is based on net flow Phi. The upper half of the given scale (colored in green) represents positive Phi value, and the lower half (red) represents negative Phi value. Alternative

Table 5.7 Display of maximum values of comparison matrix (λmax), consistency index (*CI*), random index (*RI*) and consistency rate (*CR*) for analyzed tailing ponds

C P	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
λ_{max}	5.08	5.46	5.12	5.46	5.34	5	5	5	5.04	5
CI	0.02	0.11	0.03	0.11	0.08	0	0	0	0.01	0
RI	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
CR	0.01	0.10	0.02	0.10	0.07	0	0	0	0.01	0

C criteria, *P* parameter

Table 5.8 Quantified matrix of decision making (evaluation matrix)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Unit	m	m	m	m	T	Yes/no	Yes/no	M	%	Yes/No
Max/min	Min	Min	Min	Min	Max	Max	Max	Min	Max	Min
Weights	0.214	0.208	0.180	0.118	0.084	0.080	0.042	0.037	0.021	0.016
Preference function	Linear	Linear	Linear	Linear	V shape	Level	Level	Linear	Linear	Level
A1	0	500	500	100	9,961,113	No	Yes	4	12	No
A2	50	200	200	50	2,634,421	Yes	No	4	0	No
A3	50	100	50	50	7,594,932	No	No	4	0	No
A4	1200	50	50	50	1,442,812	No	No	4	10	No
A5	1200	50	50	70	5,641,612	No	Yes	4	10	No

Table 5.9 PROMETHEE flows

Alternatives	Ph+	Ph−	Ph
A1	0.4019	0.2155	0.1864
A2	0.3157	0.2496	0.0661
A3	0.3071	0.3172	−0.0100
A4	0.3467	0.3606	−0.0140
A5	0.2983	0.5268	−0.2284

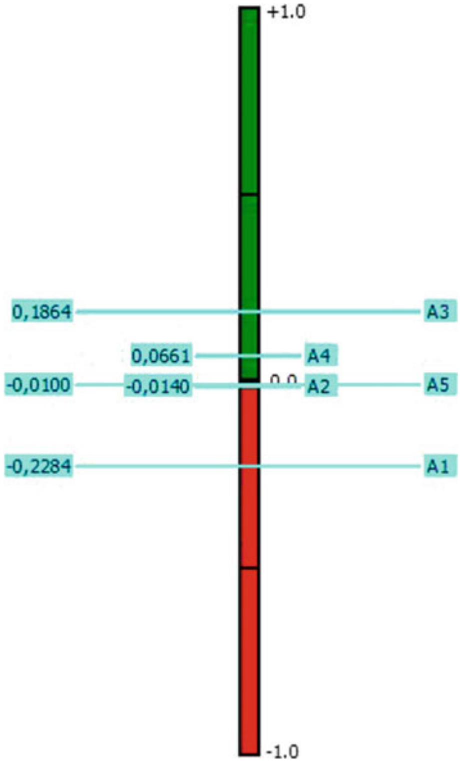


Fig. 5.10 Final ranking. Tailings—A1-Žarkov Potok; A2-Gornje Polje; A3-Žitkovac; A4-Tvrđanski Do; A5-Bostanište (Color figure online)

A3 (Žitkovac) is at the top of the analyzed alternatives, preceding A4 (Tvrđanski Do), while A2 (Gornje Polje) and A5 (Bostanište) are about the same negative Phi values. At the bottom of the list is the alternative A1 (Žarkov Potok). Values of the Phi flow for these alternatives are given in Fig. 5.10.

Figure 5.11. shows a diamond PROMETHEE solution. This solution shows partial PROMETHEE I and final ranking PROMETHEE II in a two-dimensional model. The PROMETHEE diamond solution is presented with the dot on (Phi+, Phi−) flat. The flat is at an angle of 45° so that the vertical dimension (red-green axis) corresponds to Phi net flow. A cone is drawn for every alternative. Cones A2 and A5 overlap, which indicates that these two alternatives are closely congruent, while the alternative A2

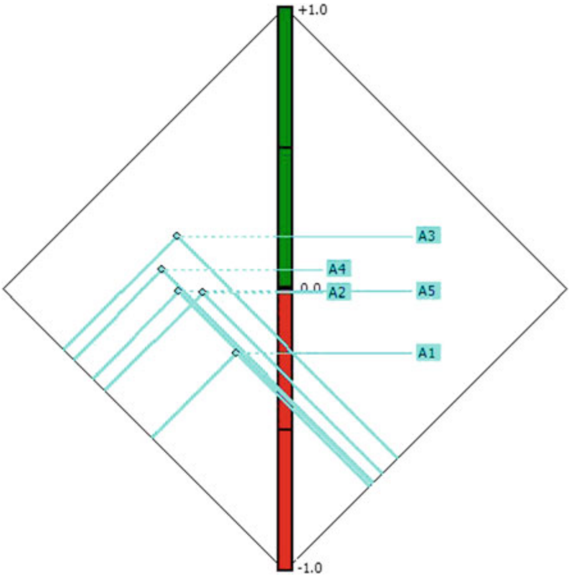


Fig. 5.11 PROMETHEE diamond solutions. Tailings—A1-Žarkov Potok; A2-Gornje Polje; A3-Žitkovac; A4-Tvrđanski Do; A5-Bostanište (Color figure online)

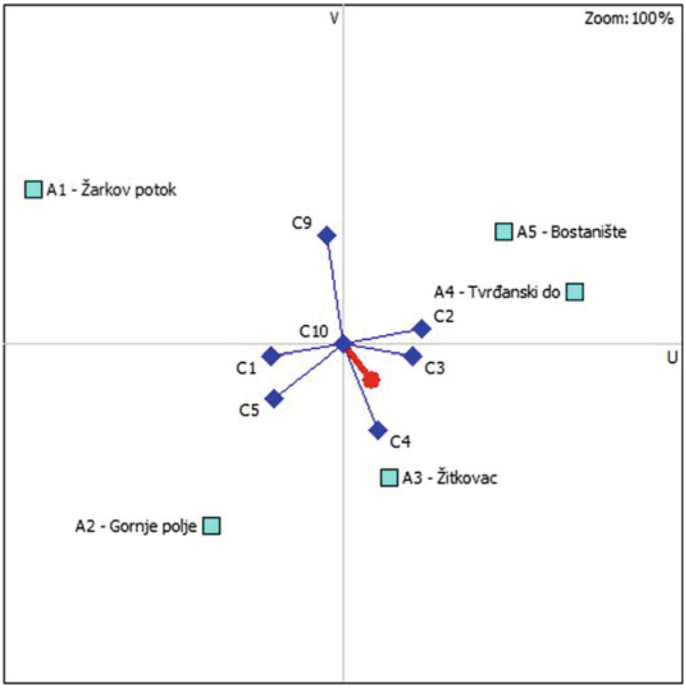


Fig. 5.12 GAIA plan for tailing ponds (Color figure online)

Table 5.10 The rank of solutions according to the AHP and PROMETHEE methods

Rank	AHP	PROMETHEE
A3—Žitkovac	1	1
A4—Tvrđanski Do	2	2
A5—Bostanište	3	3
A2—Gornje Polje	4	4
A1—Žarkov Potok	5	5

has the advantage in partial ranking PROMETHEE I. The highest priority alternative is A3 (Žitkovac), and the lowest is alternative A1 (Žarkov Potok).

In Fig. 5.12, the GAIA plan is shown (Geometrical Analysis for Interactive Assistance), which is a descriptive addition to the PROMETHEE ranking. Every alternative is presented with a dot found on the GAIA plan. The position of these alternatives is connected with the marks of a set of criteria. Each criterion is presented with the axis from the center of the GAIA plan. The orientation of these axes shows how these criteria are interrelated. Alternative A4 and A5 are similar because they are closer to each other, whereas the other alternatives are completely dissimilar. Criteria with similar preferences are C5, C1 and C2 and C3, conflicting criteria are C9 and C4. The determination axis (red axis) suggests the alternative A3 tailing Žitkovac has the least favourable impact on the surrounding ecosystem.

With implementation of estimation by using the AHP and PROMETHEE methods, with the aim of ranking the impact on the environment, the ranks are obtained according to their negative impact (Table 5.10). The comparative analysis of the negative impact on the surrounding ecosystem shows that the least favorable tailing pond is A3 Žitkovac, and that the least negative impact has the alternative A1 Žarkov Potok. Three remaining tailings have the following order of unfavorable impact on the environment: A4 Tvrđanski Do, A5 Bostanište and A2 Gornje Polje

It should be noted that other methods of multi-criteria analysis (VIKOR, TOPSIS, ELECTRE) also should be used to verify the results and the final decision.

5.4 Conclusion

This chapter analyzed and ranked the hazard on the surrounding ecosystem of five flotation tailings which are in the MMCC “Trepča,” located to the north of Kosovo and Metohija. The analysis was conducted for the following tailings: Žarkov Potok, Gornje Polje, Žitkovac, Tvrđanski Do and Bostanište, considering the chemical composition of the deposited tailings, as well as their locations on the river banks. These tailings are a major source of pollution in these areas of natural beauty and historical significance. The pollution simulation in extreme weather conditions, including floods, showed that all five large industrial waste deposits would cause devastation of the environment in the case of natural disasters.

The result obtained using multi-criteria analysis ranking the impact on the environment of five analyzed tailing ponds with the application of the AHP and PROMETHEE methods showed a certain reality, which is in accordance with the situation on the terrain. According to this analysis, the most problematic tailing pond is Žitkovac, and then Tvrđanski Do, Bostanište, Gornje Polje and finally Žarkov Potok. Application of the results can be used in the decision-making process for prioritizing the rehabilitation of the tailings in the course of response planning and preparedness in the natural disaster risk management.

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