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APPLICATION OF ROUGH SET THEORY FOR CHOOSING OPTIMAL LOCATION FOR FLOTATION TAILINGS DUMP

ZASTOSOWANIE TEORII ZBIORÓW PRZYBLIŻONYCH DO WYBORU OPTYMALNEJ LOKALIZACJI SKŁADOWISKA ODPADÓW POFLOTACYJNYCH

Flotation tailings dumps represent a potential threat to the environment. To corroborate this, numerous environmental disasters have occurred worldwide in the past. Pollution caused by breaking of tailings dump dams and overflowing of hazardous materials is still present, after several decades, and continue to threaten the environment.

This paper presents a method for determining the most appropriate location for the flotation tailings dump using rough set theory. The review of the criteria that influence the choice of flotation tailings dump location is given. Based on these criteria, an analysis and evaluation of the proposed locations for the flotation tailings dump are done using rough set theory and the most suitable location that meets all the requirements is suggested.

Keywords: flotation tailings, environmental disasters, location, rough set theory, decision making, criteria

Składowiska odpadów poflotacyjnych stanowią potencjalne zagrożenie dla środowiska naturalnego. Dla potwierdzenia, wymieniać można różnorakie katastrofy dla środowiska, które miały miejsce w przeszłości. Skażenie spowodowane przerwaniem tam zabezpieczających składowiska utrzymuje się nadal, nawet po upływie kilku dekad a przelewanie się materiałów niebezpiecznych wciąż stanowi zagrożenie dla środowiska.

W pracy przedstawiono metodę wyboru najodpowiedniejszej lokalizacji składowiska odpadów poflotacyjnych w oparciu o teorię zbiorów przybliżonych. Zaprezentowano przegląd kryteriów w oparciu o które dokonuje się wyboru lokalizacji składowiska. W oparciu o powyższe kryteria, przeprowadzono analizę i ocenę proponowanych lokalizacji składowisk odpadów poflotacyjnych przy zastosowaniu teorii zbiorów przybliżonych i na tej podstawie dokonano wyboru odpowiedniej lokalizacji, spełniającej wszystkie powyższe kryteria.

Słowa kluczowe: odpady poflotacyjne, katastrofy środowiskowe, teoria zbiorów przybliżonych, procesy decyzyjne, kryteria

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1. Introduction

Flotation tailings of the metallic ore flotation processing plants represents a potential threat to the environment, both because it contains flotation reagents and heavy metals minerals that due to the effects of atmospheric precipitation may enter the aquatic environment, and the fact that this material is comminuted and can induce pollution of the air and the surrounding land by wind (Golomoev et al., 2011; Benvenuti et al., 1997; Komnitsas et al., 1998; Panias, 2006). In addition to these environmental hazards there are also risks of dam rupture and spilling polluting materials into the waterways. Such accidents have occurred many times in history. One of the biggest environmental disasters in Serbia was breaking of water collector below the old flotation tailings dump in Bor, when a large quantity of effluent was released in the Borska reka river and then in Veliki Timok and Danube rivers (Marjanovic et al., 2003). As a result, Borska reka is polluted to the extent that today there are no living organisms, as well as land in its basin, which can no longer be used for agricultural production. Also, the ecological disasters of European proportions were the tailings dam breakage of gold mine in Baia Mare in Romania when 120 tons of material contaminated with cyanide and heavy metals were released in Tisza and Danube rivers (Wehland et al., 2002), and dam failure in Aznalcollar in Spain (Eriksson & Adamek, 2000; Alonso & Gens, 2006). This clearly indicates the potential dangers inherent in flotation tailings dumps, so that the proper selection of a location for storage this waste material is very important.

When choosing a location for the flotation tailings dump it is necessary to take into consideration many factors that influence the choice of optimal location, even without knowing the precise values. In order to select the optimum location all data should be grouped and analyzed simultaneously. For this reason we decided to investigate the possibility of implementing a relatively new theory, the Rough set theory, for choosing optimal location for flotation tailings dump.

The Rough set theory was presented in 1982 by the Polish mathematician Zdzislaw Pawlak (1982). The specificity of this theory lies in the fact that it deals with the imprecision, vagueness and uncertainty and can be applied in circumstances where there is insufficient previous knowledge or additional information on empirical data such as probability distributions in statistics, basic probability assignments in Dempster-Shafer theory, as well as membership or the value of possibility in fuzzy set theory (Pawlak & Skowron, 2007).

There are numerous examples of the use of this theory in many fields, such as engineering, medicine, economics, etc. (Pawlak, 2000; Rissino & Lambert-Torres, 2009).

Liu et al. (2009) applied Rough set theory in risk assessments of the disaster caused by the collapse of rocks. Lifang et al. (2008) have carried out the cement clinker strength prediction using rough sets. Zhang (2010) used rough set theory to identify and classify the genes responsible for cancer. Yan-bin et al. (2009) presented the possible applications of rough sets in geology. Araban et al. (2006) in their paper showed how rough set theory can simplify the selection of a location for a dam, which was one of the indicators that this theory can be applied in the selection of locations for the flotation tailings dump.

2. Experimental

2.1. Determination of criteria

The process of flotation tailings dump location selection is very delicate because of the large number of influencing factors to be taken into consideration, and also because of the potential environmental hazards of this waste material. Some factors are related to the criteria that should be met given the legislation that has governed this area, while the others are set by the designers taking into account the requirements set out in the terms of reference. There are various examples of criteria selection when choosing a location for the flotation tailings dump (Caldwell and Robertson1983; Robertson and Moss 1981; Robertson and Shaw 1999).

Given these examples and the designers experience the most important criteria for flotation tailings dump location selection are shown in Table 1.

TABLE 1

Criteria for the selection of flotation tailings dump location

Criteria	Description of criteria
1. Distance from production facility	It is necessary that the distance between flotation tailings dump and production facility is as small as possible so that the costs of construction of transportation systems and transport are kept as low as possible.
2. Capacity of flotation tailings dump	It is necessary to compare the available capacity of the location to the capacity of the flotation plant in order to do calculations of exploitation lifetime of location. It is believed that it is uneconomical to project flotation tailings dump for a period shorter than 15 years.
3. Topographical characteristics of the terrain	The size and also the type of flotation tailings dump, as well as type of transportation of tailings from production facility to the dump, depend on the configuration of the terrain. Construction of tailings dump is not recommended on terrains with slopes exceeding 15-20%.
4. Geological characteristics of the terrain	Flotation tailings dump should not be located on the ground with high water permeability or with some bearing minerals that could be exploited in the future. It is desirable that the terrain is composed of waterproofing and solid, stable rocks.
5. Geotechnical characteristics of the terrain	When choosing a location for the flotation tailings dump it should be taken to consideration if the terrain is prone to mudslides and landslides, as well as its seismic stability (Onargan et al., 2009).
6. Hydrological characteristics of the terrain	It is very important to study and analyze the flow of surface and groundwater and river basin area for each potential location for flotation tailings dump. It is not suitable to locate flotation tailings dump in the basin of a large river, or in a place that abounds with plenty of rainfall throughout the year.
7. Distance from traffic and technical infrastructure	When choosing a location for the tailings dump is necessary to take into account that it is not situated near to an important transportation and technical infrastructure such as: highway, runway, water, gas and oil pipelines, transmission lines, etc.
8. Impact on the environment	It is desirable to locate flotation tailings dump as far away as possible from the settlements, infrastructure, rivers, lakes, seas, out of the wind direction, and on waterproofing and arid terrain.
9. Economic viability	Economical factor is crucial in choosing a location for the flotation tailings dump. Since tailings dumps aren't producing any income, but represent only a cost it is necessary to take care that proposed location is the best solution in terms of investment, construction costs and maintenance costs.

From Table 1 it can be seen that there are nine criteria that influence the choice of location for the flotation tailing dumps. But not every criterion holds the same significance. The impact of some of the criteria on the choice of location is higher than the other criteria. For example, criteria such as economic viability and environmental impact are key criteria that decisively influence the selection of an optimum location. Besides them, distance from production facility, capacity of flotation tailings dump and topographical characteristics of the terrain have a major impact, while other criteria are important but they can be more or less affected and thus reduced their influence in the selection of locations for the flotation tailings dump.

2.2. Evaluation of locations based on rough set theory

In order to evaluate potential locations for the flotation tailings dump, each of the criteria in Table 1, which also represent the conditional attributes, are assigned with an appropriate value. For each value of the conditional attributes there is a corresponding value of decision level that may be positive or negative. Attribute values are expressed linguistically.

The values of conditional attributes and decision levels are presented in Table 2.

TABLE 2

Values of conditional attributes and decision levels

Conditional attributes	**Values of conditional attributes**	**Decision levels**
1. Distance from production facility	a) close to the facility	a) satisfactory
	b) far away from the facility	b) unsatisfactory
2. Capacity of flotation tailings dump	a) exploitation period > 15 years	a) satisfactory
	b) exploitation period < 15 years	b) unsatisfactory
3. Topographical characteristics of the terrain	a) slope < 15%	a) satisfactory
	b) slope > 15%	b) unsatisfactory
4. Geological characteristics of the terrain	a) waterproof terrain	a) satisfactory
	b) water permeable terrain	b) unsatisfactory
5. Geotechnical characteristics of the terrain	a) stable terrain	a) satisfactory
	b) unstable terrain	b) unsatisfactory
6. Hydrological characteristics of the terrain	a) favorable	a) satisfactory
	b) unfavorable	b) unsatisfactory
7. Distance from traffic and technical infrastructure	a) at a sufficient distance	a) satisfactory
	b) at a insufficient distance	b) unsatisfactory
8. Impact on the environment	a) no impact on the environment	a) satisfactory
	b) negative impact on the environment	b) unsatisfactory
9. Economic viability	a) profitable location	a) satisfactory
	b) unprofitable location	b) unsatisfactory

Based on these criteria, an analysis and evaluation of ten potential locations for flotation tailings dump is done. Locations are marked L_1 through L_{10}. Table 3 shows the results of the analysis and evaluation of the proposed locations.

TABLE 3

The results of the analysis and evaluation of suitability of locations for the flotation tailings dump

Location	**Conditional attributes**									**Decision levels**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
L_1	a	b	b	b	a	a	a	b	b	b
L_2	a	a	a	a	a	a	a	a	a	a
L_3	a	a	a	a	a	a	a	b	b	b
L_4	a	a	a	a	a	a	a	a	a	a
L_5	a	a	b	a	b	b	a	a	b	b
L_6	a	b	a	b	b	b	a	b	b	b
L_7	a	a	a	a	a	a	a	a	a	a
L_8	a	a	a	a	a	a	a	a	a	a
L_9	a	b	b	b	b	a	a	b	b	b
L_{10}	a	a	a	b	b	b	a	b	b	b

As it can be seen in Table 3, four locations (L_2, L_4, L_7 and L_8) meet all the requirements for tailings disposal. To determine which of these four locations is the most suitable for flotation tailing dump it is necessary to make their re-evaluation, but only on the basis of four criteria with the greatest impact, namely: economic viability, impact on the environment, capacity of flotation tailings dump and distance from production facility. However, as the conditional attributes values for these criteria were positive for all four locations, it is necessary to redefine their values, instead of two values add at least one or preferably more. In this way, it can make the difference needed in the evaluation of these four locations and make the best choice.

2.3. Additional evaluation of locations

In order to perform the additional evaluation of locations L_2, L_4, L_7 and L_8 first values of conditional attributes that will be used in the analysis must be redefined. New values of conditional attributes for additional evaluation of locations are shown in the Table 4.

TABLE 4

Redefined values of conditional attributes and decision levels

Conditional attributes	**Values of conditional attributes**	**Decision levels**
1	**2**	**3**
1. Distance from production facility	a) very close to the facility	a) very satisfactory
	b) close to the facility	b) satisfactory
	c) far away from the facility	c) unsatisfactory
	d) very far away from the facility	d) very unsatisfactory
2. Capacity of flotation tailings dump	a) exploitation period > 30 years	a) very satisfactory
	b) exploitation period 20-30 years	b) satisfactory
	c) exploitation period 15-20 years	c) unsatisfactory
	d) exploitation period < 15 years	d) very unsatisfactory

TABLE 4. Continued

1	2	3
8. Impact on the environment	a) no impact on the environment	a) very satisfactory
	b) little impact on the environment	b) satisfactory
	c) negative impact on the environment	c) unsatisfactory
	d) large impact on the environment	d) very unsatisfactory
9. Economic viability	a) very profitable location	a) very satisfactory
	b) profitable location	b) satisfactory
	c) unprofitable location	c) unsatisfactory
	d) very unprofitable location	d) very unsatisfactory

Based on the re-evaluation of conditional attributes and analysis of the locations with positive attribute value, the decision in the first evaluation was brought up. The results of this analysis are shown in Table 5.

TABLE 5

The results of additional analysis and evaluation of suitability of locations for the flotation tailings dump

Location	Conditional attributes				Decision levels
	1	2	8	9	
L_2	b	a	b	b	b
L_4	a	a	a	a	a
L_7	a	c	a	b	b
L_8	b	b	b	b	b

From Table 5 it can be seen that the additional evaluation of four locations which in the first round had positive values of conditional attributes values and decision levels after redefining conditions, showed that the most suitable location for depositing tailings is location L4. This location in the second round of evaluation had all the highest values of conditional attributes and thus the value of its decision level was the highest. In this way, the selection of the most suitable location, or a location that meets all the necessary criteria, is done.

3. Conclusion

Flotation tailings location selection is a complex and delicate process because of the potential environmental hazards of the tailings. Decision-making procedure has been further hampered by a number of factors that influence the selection of an optimum location. For these reasons it is necessary to find a way to simplify this process. This can be achieved by using methods that group all the significant parameters and analyze them simultaneously.

Rough set theory is one method by which practical problems from many fields can be analyzed and solved. This theory has now been applied in many areas, such as engineering (especially in the process control and system engineering), medicine, economics, social sciences, etc. However, examples of its application in mining are rare.

In this paper, on the example of choosing location for the flotation tailings dump it is shown that this theory can be successfully applied in mining engineering as well. Analyzing the proposed locations for tailings dump by applying rough set theory, we came to the conclusion that some of the locations meet the established criteria, but for a final decision on the most suitable location it was necessary to carry out additional evaluation on the basis of the most influential factors. Only after second round of evaluation it was decided what is the most appropriate location for the disposal of tailings.

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