Carpathian Journal of Earth and Environmental Sciences, August 2015, Vol. 10, No 3, p. 223 - 234

METHODOLOGY FOR ASSESSING THE ENVIRONMENTAL RISK DUE TO MINING WASTE DUMPS SLIDING - CASE STUDY OF JIU VALLEY

Maria LAZĂR, Izabela-Maria NYARI & Florin G. FAUR

University of Petrosani, Faculty of Mining, Department of Management, Environmental Engineering and Geology, 332006, University Str., no. 20, Petroasni, Romania, E-mail: marialazar@upet.ro, faurfloring@yahoo.com

Abstract: Starting from the necessity to ensure the physical stability of waste dumps and the protection of the natural and anthropogenic components of the environment situated in their vicinity, the paper presents a general and uniform methodology for assessing the environmental risk associated to waste dumps slides. For this purpose a case study on active waste dumps from Jiu Valley was chosen. Given the fact that the risk is defined as the product between vulnerability (in this case, the vulnerability of natural and anthropogenic components of the environment situated in the influence area of waste dumps) and the probability of an undesirable phenomenon (in this case, waste dumps sliding), the problem of determining the two key factors needed to solve the proposed theme was in question. To assess the vulnerability of natural and anthropogenic components of the environment it was started from waste dumps classification according to current legislation. This classification was completed and turned in to an assessment matrix that depends on the technical condition of the waste dumps. The probability of sliding was determined using classical and probabilistic methods of slope stability evaluation and the risk scale was defined for five risk categories, from minimal to extreme, with explanation for each interval. The advantage of the proposed methodology is that it provides data on the probability of sliding and not just a value at some given time of the stability reserve, relying on the values of physical and mechanical properties of the deposited material in various stages of construction of the waste dump. It can be considered that the proposed methodology can be successfully generalized and used for waste deposits that are under construction and/or in closure stages. By determining the environmental risk it is possible to establish the necessary measures to prevent the occurrence of landslides, which could have serious consequences on the natural and anthropogenic components of the environment present in adjacent areas.

Keywords: waste dumps, stability, sliding, vulnerability, risk, components of the environment

1. THE PROBLEMATIC

Mining industry is one of the main sources of environmental pollution. Prospecting and exploration, as well as the exploitation and preparation of ore have a major negative impact on the environment, which leads to an ecological imbalance affecting the life of living organisms (Lazăr et al., 2008).

The presence of waste dumps on the surface of natural terrains is a major problem in the context of environmental protection. The negative visual impact, occupation of land, destruction and removal of vegetation and fauna, environmental pollution and instability phenomena that can occur may often lead to material and human losses.

Waste dumps stability problem is particularly important because sliding phenomena can endanger the natural and anthropogenic components of the environment situated in the influence area. Also, waste dumps sliding involve works and additional costs to restore the geometry and/or may result in damage to equipments or even can endanger the personnel working with these equipments. In the particular case of mining areas where the number of waste dumps is high and they are located either in areas with high naturalistic value or close to infrastructures, industrial buildings, households etc., is important to know the technical condition of the dumps and the risks faced by the adjacent areas in case of a landslide.

Landslides are geodynamic phenomena which modify the landscape and restore the natural balance of the slopes. They appear as material movements when resistance forces are defeated by the shear efforts, being often announced by a series of changes of the shape and position in space of the slope (Lazăr, 2010).

The natural and anthropogenic components of the environment situated near active waste dumps are numerous, so that in case of slope stability loss the environmental risk can be major. However, the severity of the risk depends on the nature of the impact on the receiver and the probability of that impact to occur.

The Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 regarding the management of waste from extractive industries and amending Directive 2004/35/EC requires *long-term geotechnical stability of any dams or waste dumps rising above the pre-existing ground level* as well as *the physical stability to prevent pollution or contamination of soil, air, surface water or groundwater on short and long term, and to minimize, as much as possible, damages on landscape* (Directive 2006/21/EC).

Taking into account these aspects, the aim of this paper is to establish a risk assessment methodology to which the environment is subjected (both natural and anthropogenic components) in circumstances of waste dumps sliding.

Starting from the assessment of the technical conditions of active dumps from Jiu Valley, a matrix defining the vulnerability of natural and anthropogenic components of the environment in the adjacent areas in the event of sliding phenomena was developed. This matrix was modeled based on the classification of waste dumps according to the sliding hazard degree. Using several sets of values resulted from statistical processing of the physical and mechanical characteristics of the deposited material, stability studies were performed in order to determine the probability of waste dumps sliding. In the end an environmental risk scale was determined. This risk scale depends on the slopes sliding probability and the value of the natural and anthropogenic components of the environment that may be affected by sliding.

Based on the results, measures to stabilize recover and rehabilitate the waste dumps can be taken in order to ensure the physical stability both during construction and after completion of depositing works for their immediate reintegration in natural cycles.

2. OVERVIEW OF CURRENT SITUATION OF WASTE DUMPS FROM JIU VALLEY

Waste dumps produce by the mining exploitation from Jiu Valley are engineering constructions and they represent accumulations of sterile rocks from opening and preparation works. Usually, the sterile material found in the waste dumps from Jiu Valley consists of rocks that host the coal strata, being a mixture of clays, marls, microsandstones, clayey sandstones, carbonaceous shale and coal fragments (Lazăr, 2013). Additionally, there are waste dumps containing material resulting from coal preparation, where, besides sterile rocks, there are found coal fragments and various substances from coal washing and processing. Their location was chosen so that the whole process of transport and deposition to be technically and economically efficient.

In Jiu Valley mining basin there are now a total number of 49 waste dumps, 9 of them being still active (Fig. 1); the others are in different ecological rehabilitation stages or were abandoned.

Waste dumps from Jiu Valley stores a total amount of about 37 million m^3 of sterile rocks and occupies an area of over 250 ha (Lazăr, 2013). The 9 active waste dumps occupies an area of 50.75 ha and they store an amount of 6.46 million m^3 (Table 1).

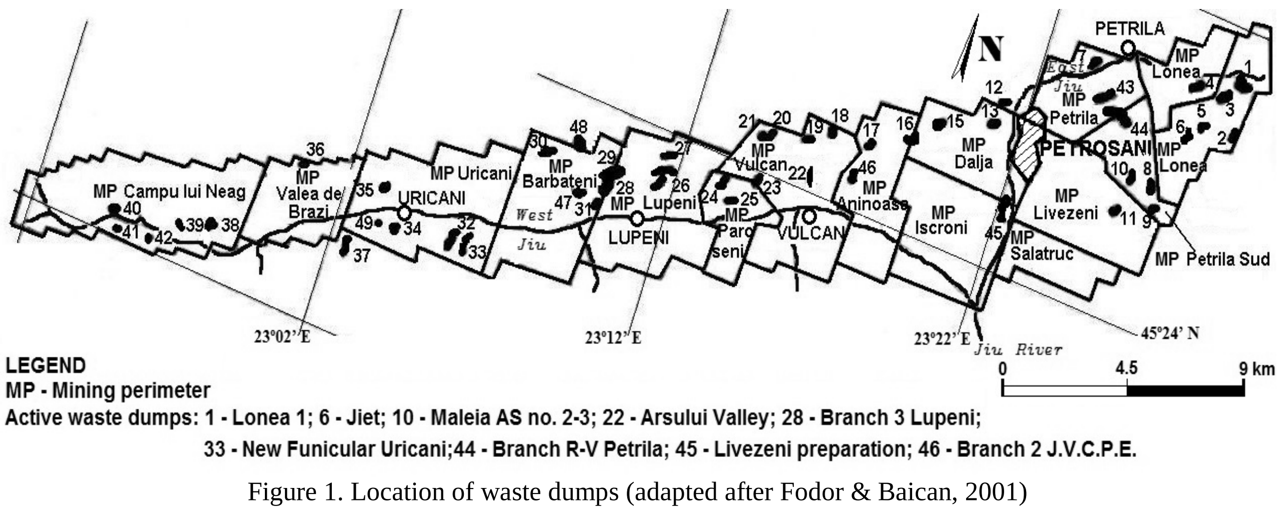

Figure 1. Location of waste dumps (adapted after Fodor & Baican, 2001)

Table 1. Active waste dumps from Jiu Valley (Source: Hunedoara Energetic Complex, Mining Division)

Waste dump	Mining Unit	Dump surface [m^2]	Designed capacity [m^3]	Used capacity [m^3]
Lonea 1	ME Lonea	23,000	4,000,000	426,119
Jieţ	ME Lonea	10,400	90,500	65,122
Branch R-V Petrila	ME Petrila	195,900	3,755,454	336,231
Maleia AS no. 2-3	ME Livezeni	23,000	380,000	318,758
Livezeni preparation	ME Livezeni	36,000	144,000	468,115
Arsului Valley	ME Vulcan	17,500	1,200,000	367,918
Branch 2 J.V.C.P.E.	J.V.C.P.E.	112,000	2,000,000	2,573,889
Branch 3 Lupeni	ME Lupeni	62,700	2,000,000	1,360,108
New Funicular	ME Uricani	27,000	700,000	547,329

AS – auxiliary shaft; J.V.C.P.E. – Jiu Valley coal preparation exploitation; ME – mining exploitation

3. INVESTIGATIONS AND RESEARCH METHODS

3.1. Field observations and mapping

In order to evaluate the technical conditions and behavior of the waste dumps visual observations and geotechnical mappings were made.

The waste dumps still active from Jiu Valley are located in valleys or on slopes, and in the adjacent areas there are natural and anthropogenic components of the environment that may be affected by their sliding.

Following field research, conducted from March to May 2014, there were identified the natural and anthropogenic components of the environment located in areas adjacent to the waste dumps (Table 2).

Table 2. Components of the environment in the waste dumps influence area and technical conditions of the dumps

Waste dump	Natural and anthropogenic components/technical conditions
Lonea 1	Households and School no. 3 at approx. 200 m, scattered (restricted) movement of people, East Jiu River, land with poor vegetation/affected by landslides, discharge of material and erosion.
Jieţ	Households, communication routes with limited traffic and scattered (restricted) movement of people, lake located S-W of the dump, river Jieţ, deciduous forests, farmland/relatively stable, some erosion.
Branch R-V Petrila	Households and DN7A road at approx. 500 m, communication routes with limited traffic and scattered (restricted) movement of people, the lake from the northern side belonging to Pro Fishermen Association, Ştiurţ Lake from the southern side, land with poor vegetation (grazing), brushes, especially birch, willow and acacia/superficial landslides and erosion.
Maleia AS no. 2-3	Households, DN7A road, woodworking hall belonging to SC ALPINE SRL, communication routes with intense traffic and intense movement of people, Maleia creek, deciduous forests/superficial landslides and erosion.
Livezeni preparation	Households, communication routes with limited traffic and scattered (restricted) movement of people, East Jiu River, land with poor vegetation (deciduous)/relatively stable, some erosion.
Arsului Valley	Coastal tunnel, individual households, communication routes with limited traffic and scattered movement of people, Arsului Valley creek, the lake formed due to sinking land, land with thick vegetation, deciduous forests/relatively stable, some erosion.
Branch 2 J.V.C.P.E.	Scattered movement of people, mine premises at approx. 1 km from the waste dump, Vulcan residential area at approx. 1.5 km, several individual households, West Jiu River, Priboi creek, two water reservoirs, land with thick vegetation, deciduous forests/affected by landslides and erosion.
Branch 3 Lupeni	Scattered movement of people, Lupeni residential area and mine premises at approx. 1.5 km, West Jiu River, Ferejele and Boncii creeks, water reservoirs (lakes and ponds), land with thick vegetation, mixed forests of predominantly deciduous species and less coniferous species/affected by landslides, discharge of material and erosion.
New Funicular Uricani	Scattered movement of people, West Jiu River at approx. 100 m, water reservoir (lake), springs, land with thick vegetation, mixed forests (deciduous and coniferous species)/ affected by material compaction, erosion and discharge of material.

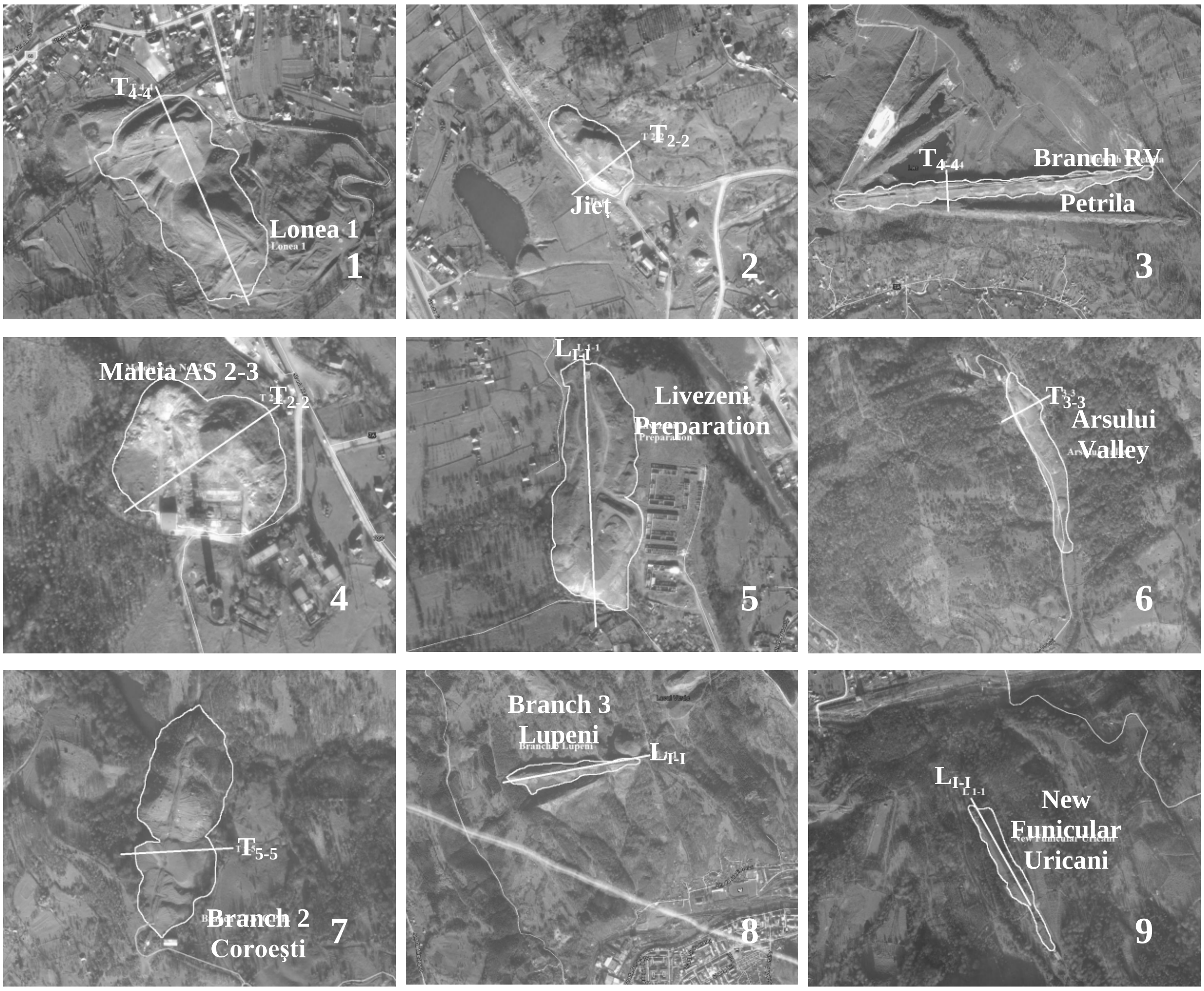

Figure 2. The active waste dumps and the natural and anthropogenic components of the environment located in their influence area (1 - Lonea 1; 2 – Jieţ; 3 – Branch R-V Petrila; 4 - Maleia AS no 2-3; 5 – Livezeni preparation; 6 - Arsului Valley; 7 - Branch 2 Coroeşti; 8 - Branch 3 Lupeni; 9 - New Funicular Uricani).

Also there were observed the geometry and technical conditions of the waste dumps, their behavior under the influence of external factors and the presence of signs indicating a decrease of the resistance of the deposited rocks (erosion, water reservoirs, etc.) (Fig. 2).

It can be observed that the components of the natural environment and those built up near active waste dumps are numerous and important. (natural ecosystems, industrial infrastructures and buildings, administrative buildings, households etc.). This underlines the need to ensure the stability of the waste dumps in order to eliminate the possibility of sliding phenomena to occur that may lead to their damage or destruction.

3.2. Stability analysis methods

3.2.1. Classical methods

For the stability analyses of the waste dumps slopes, a specialized software in geotechnics (GeoTecB) was used. This software analyzes the stability of natural and artificial slopes, with complex geometry, composed of homogeneous or heterogeneous rocks, taking into account the hydrostatic level, both under normal static conditions and under the influence of seismic shocks.

The first stage in using the software GeoTecB consists in the introduction of the geometric elements (the height and the inclination of the slope) and geotechnical characteristics of the rocks (volumetric weight, porosity, cohesion and internal friction angle) followed by defining the sliding surfaces. The software automatically calculates the stability coefficients, using for this purpose the methods of Fellenius (1936), Janbu (1954) and Bishop (1955). Finally, the critical sliding surface is determined, which corresponds to the minimum value of the stability coefficient.

For this study only the method of Fellenius was used, because this method (as confirmed by the authors experience and previous studies) leads to the lowest values of the stability coefficient (when analyzing the same slope, in the same conditions, through the three methods used by the software).

The method assumes that the sliding surface follows a cylindrical-circular (curved) pattern. The stability of the slope is analyzed in the hypotheses of equilibrium limit between active and passive forces acting on the sliding prism. In order to calculate the value of the stability coefficient the sliding prism is divided into several vertical strips (Lazăr et al., 2012).

The forces acting on each strip (in the absence of seismic shocks) are highlighted in figure 3.

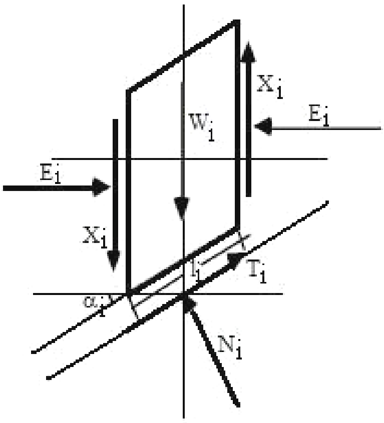

Figure 3. Forces acting on a strip (W_i - strip's weight; N_i - normal component of the force of gravity; T_i - tangential component of the force of gravity; E_i - horizontal forces transmitted to neighboring strips; X_i - vertical forces between neighboring strips; α_i - inclination of the strip to the horizontal; l_i - length of the strip)

The numerical solution of the stability coefficient was obtained assuming that the horizontal and vertical forces that occur along the strips (E_i, X_i) are equal to zero. Starting from the equilibrium condition, the stability coefficient Fs of a slope is calculated by the formula (Fellenius, 1936):

$$Fs = \frac{tg\varphi \sum_{1}^{n} W_i \cdot \cos\alpha_i + \sum_{1}^{n} c \cdot l_i}{\sum_{1}^{n} \pm W_i \cdot \sin\alpha_i} \quad (1)$$

where:

c – rock's cohesion along the strip;

φ – angle of internal friction along the strip;

n – number of considered strips.

The method verifies the stability of natural and artificial slopes under equilibrium conditions of forces or moments, by modeling the analyzed slope, defining loading conditions and adopting a failure criterion. Consequently, these analyzes depend essentially on the type of model adopted and the geotechnical characteristics attributed to different rocks (Abramson et al., 2002; Lazăr et al., 2012).

3.2.2. Probabilistic methods for assessing stability

Given that classical stability analysis provides inaccurate values due to errors, a probabilistic method was used that allows examination of errors so that the obtained values are more real.

A slope is considered to be in equilibrium, when the ratio between active forces (R) and passive forces (S) equals 1:

$$\frac{R}{S} = 1 \quad (2)$$

The ratio R/S is called stability coefficient or factor (Fs). To take into account possible errors introduced in the calculations, to obtain a higher degree of confidence and in order to respect the legal requirements, usually a reference stability factor is considered (greater than one, usually at least equal to 1.3) (MLSP, 1997).

Probabilistic analysis replaces the notion of stability coefficient to that of stability limit (LS), defined by the formula:

$$LS = \frac{R}{S} - 1 = Fs - 1 \quad (3)$$

The failure probability (p_r) is defined as the probability that the value of LS to be lower than 0 (equilibrium condition). The confidence index (I) is related to the probability of failure through the formula:

$$I = 1 - p_r \quad (4)$$

At equilibrium, the stability limit LS is equal to zero (S = R); values greater than zero indicate stable slopes and values less than zero unstable slopes.

Rosenblueth method applied to verify the stability of a slope in soft rocks, allows to obtain the most probable value of the stability limit LS (the average value LS_m) and an indication of its dispersion (standard deviation S_{LS}) (Rosenblueth, 1975). Using this method it can be obtained the reliability index of the slope and failure probability in the assumed probability distribution. Because it also meets the requirements of precision for the general slope stability evaluation it can be regarded as a very practical method (Luo, 2003).

In this case there are used as a causal variables the parameters volumetric weight (γ_v), porosity (n), cohesion (c) and internal friction angle (φ), assuming that they have a symmetric Gaussian distribution. The steps for applying the method in this case study are:

- determination of corresponding stability limits using formula (3):
  - $LS_1=Fs_{min}-1$;
  - $LS_2=Fs_{med-\sigma}-1$;
  - $LS_3=Fs_{med+\sigma}-1$;
  - $LS_4=Fs_{max}-1$;
- determination of average values of stability limits through formula:

$$LS_m = \frac{LS_1 + LS_2 + LS_3 + LS_4}{4} \quad (5)$$

and the standard deviation through formula:

$$S_{LS} = 0,5 \cdot \sqrt{\left(LS_1^2 + LS_2^2 + LS_3^2 + LS_4^2\right)} \quad (6)$$

Rosenblueth method allows to obtain accurate assessments of the average value LS_m and standard deviation S_{LS} of the stability limit (Rosenblueth, 1975; Rosenblueth, 1981).

These two values allow obtaining directly the value of LS associated with a certain probability of sliding (characteristic value of LS) using the formula:

$$LS_k = LS_m \cdot \left(1 + \chi \cdot K_{LS}\right) \quad (7)$$

where:

LS_k = characteristic value of the stability limit;

LS_m = average value of the stability limit;

K_{LS} = variation coefficient of LS, defined as the ratio between the standard deviation of the average S_{LS} and the average value of LS;

$$K_{LS} = \frac{S_{LS}}{LS_m} \quad (8)$$

χ = parameter depending on the probability distribution law (Rosenblueth, 1975; Rosenblueth, 1981).

Parameter χ associated to a value of LS = 0 is given by formula:

$$\chi = -\frac{1}{K_{LS}} \quad (9)$$

The sliding probability is obtained from the graph presented in figure 4 by calculating the value of the parameter χ (Bond & Harris, 2008; Bond et al., 2013).

In principle, the determined value of the sliding probability must be related to the importance of the studied case and the degree of knowledge of the terrain's characteristics (Priest & Brown, 1983).

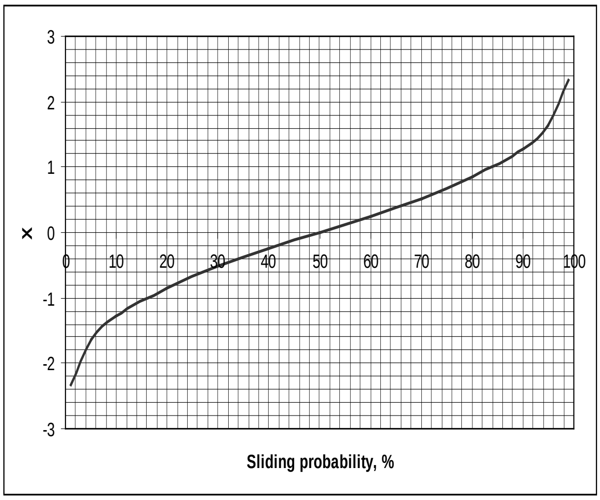

Figure 4. Graphical representation of the sliding probability depending on the parameter χ

4. RESULTS AND DISCUSSIONS

4.1. Developing the environmental vulnerability matrix for waste dumps slides

The vulnerability level is determined mostly by the physical exposure of natural or anthropogenic components of the environment, due to their location in areas where there is likelihood of various destructive phenomena to occur (Grozavu et al., 2013), including landslides or waste dumps slides.

In the literature there is a classification of waste dumps depending on the type of buildings and infrastructures situated in the influence area and their stability degree, (MLSP, 1997).

By adding to this classification the type of ecosystems present in the influence area, a matrix was developed. This matrix establishes the level of vulnerability of the natural and anthropogenic components of the environment in relation with the stability degree of the waste dumps (Table 3). The matrix of table 3 shows five types of vulnerability:

- V = 1 – very low vulnerability (stable waste dumps, natural components of low value, absence of anthropogenic components);
- V = 2 – low vulnerability (stable waste dumps or affected by controlled movements, natural or anthropogenic components of relatively low importance and/or value);
- V = 3 – medium vulnerability (stable waste dumps or affected by controlled movements – natural and/or anthropogenic components of high or very high value; waste dumps with active or uncontrolled movements - natural or anthropogenic components of relatively low importance and/or value);

Table 3. Matrix for determination of the environmental vulnerability based on the technical conditions of the dumps (adapted after the classification of waste dumps from MLSP, 1997)

Technical conditions of the waste dumps / Natural and anthropogenic components of the environment located in the influence area	Waste dumps with dangerous movements, active sliding, involving important volumes of material	Waste dumps with active superficial sliding that can go in to dangerous movements	Stable waste dumps, no active movements, can go in to sliding due to triggering factors	Stabilized waste dumps, for which sliding phenomena are not likely
Anthropogenic components Households and social constructions *Natural components* Forested areas, waterways and/or backwaters, land with high value	V = 5	V = 4	V = 4	V = 3
Anthropogenic components Industrial constructions and installations, communication routes with heavy traffic, waterways *Natural components* Arable areas, forested areas, waterways, productive land	V = 4	V = 4	V = 3	V = 3
Anthropogenic components Communication routes with limited traffic or scattered movement of people *Natural components* Wooded grasslands with varying degrees of consistency, limited water resources, land with low value	V = 3	V = 3	V = 3	V = 2
Anthropogenic components Areas without constructions or communication routes, sporadic people access *Natural components* Unproductive vacant lots, grasslands with shrubs	V = 3	V = 3	V = 2	V = 1

- V = 4 – high vulnerability (waste dumps with active or uncontrolled movements - natural and/or anthropogenic components of high or very high value; waste dumps affected by controlled movements - natural and/or anthropogenic components of very high value);
- V = 5 – very high vulnerability (waste dumps with active movements - natural and/or anthropogenic components of very high value).

Based on the objectives identified in the adjacent areas of the waste dumps (Table 2) and the categories of vulnerability based on the matrix presented in table 4, it was established the natural and anthropogenic environmental vulnerability for each waste dump in the study area (Table 4).

Considering that the anthropogenic and natural components that characterize the adjacent areas of waste dumps differ from one to another, the vulnerability class of highest values was considered.

As a result, given the natural and anthropogenic components existing in the area of influence of the waste dumps, in most cases they fall within the medium (Lonea 1, Jieţ, Maleia AS no 2-3, Arsului Valley) and high vulnerability classes (Branch R-V Petrila, Branch 2 Coroeşti, Branch 3 Lupeni, New Funicular Uricani).

4.2. Stability analysis

4.2.1. Determination of the stability factor using classical methods

The geometry of slopes was taken from previous studies based on the latest available (surveying) topographic documentation (Lazăr, 2013).

For the stability analyses there were

considered cross or longitudinal sections (one for each waste dump), in the less advantageous areas, respectively where the geometry is most unfavorable, or there is convergence between the direction of extension of the dump and the direction of slope inclination (Fig. 2). These sections have been established taking into account, generally, the heights and/or slope angles with the highest values.

Table 4. Establishing the vulnerability in case of sliding

Waste dump	**Anthropo-genic environment**	**Natural environment**	**V**
Lonea 1	3	3	3
Jieţ	2	3	3
Branch R-V Petrila	3	4	4
Maleia AS no. 2-3	3	3	3
Livezeni preparation	2	2	2
Arsului Valley	2	3	3
Branch 2 J.V.C.P.E.	3	4	4
Branch 3 Lupeni	3	4	4
New Funicular	3	4	4

The sterile material deposited in the waste dumps from Jiu Valley coal basin is generally a heterogeneous mixture of hard rocks embedded in a mass of soft rocks. Because the petrographic analyses revealed that the same types of rocks are present in the waste dumps, it was considered that the deposited material is similar.

Under these conditions the differences between the waste dumps that endangers the stability is represented by the location of the waste dump, the shape of base land, the geometry of the waste dumps, the presence of water, etc..

Between 1993 and 2010 the team from the Mining Engineering Research Center of Faculty of Mining Petrosani conducted 11 stability studies over the waste dumps from Jiu Valley (Lazăr, 2013). The samples collected from the waste dumps (216 samples) were analyzed in the Earth Mechanics Laboratory in order to determine their physical and geotechnical characteristics. These data were completed with recent data determined by the authors in 2014 on 27 samples (three for each waste dump).

The values of the geotechnical parameters used in stability analysis presented in this paper resulted from statistical processing of all raw data from previous studies and from 2014.

Thus, it was obtained a relevant database, which contains values of geotechnical properties of the sterile material that characterizes the waste dumps on their entire height (Table 5).

Table 5. Results of statistical processing (n = 243)

Specification	**γ_v [kN/m^3]**	**n [%]**	**c [kN/m^2]**	**φ [°]**
Minimum	13.60	23.90	4.00	6.00
Maximum	21.00	53.00	90.00	33.00
Average	17.68	35.08	27.81	19.75
σ	0.16	5.36	0.15	6.69
Average-σ	17.52	29.72	27.66	13.06
Average+σ	17.84	40.44	27.96	26.44

Stability calculations were performed for normal conditions of natural moisture, without taking into account the pore water pressure, considering that the base land morphology, the waste dump's geometry, the nature and granulometry of the deposited material facilitates drainage of groundwater.

As a result of running the input data for each of the cross or longitudinal sections considered, there were obtained the values of the stability coefficients for slides through waste dump body, for circular sliding surfaces as determined by Fellenius method.

For the first 2 sets of values in most of the cases the stability factor is below 1, meaning that the natural equilibrium is lost and the examined slope will slide. The stability coefficient is higher than 1 for the other two sets of values, exceeding in almost all cases the value of the safety factor (Fs = 1.3), as presented in table 6.

4.2.2. Determining the sliding probability - Rosenblueth method

The results obtained by deterministic methods offer a value at a given moment for the stability coefficient, depending on the set of values used for the geotechnical characteristics of the deposited material.

The Rosenblueth method was used in order to determine the probability of slope failure for different geometry and stress conditions.

Thus the values of χ were determined using formula (9) and by following the steps presented in paragraph 3.2.2 the results shown in table 7 were obtained.

Figure 5 presents a graph showing the correlation between the sliding probability and stability coefficient.

Table 6. Results obtained for cylindrical-circular (curved) sliding surfaces

Waste dump	Cross (T) and longitudinal (L) sections	H, [m]	α, [°]	Stability coefficient - Fellenius			
				Min	Average - σ	Average + σ	Max
Lonea 1	T_{4-4}	21.00	15.89	0.43	1.13	2.56	4.15
Jieţ	T_{2-2} western slope	11.22	36.41	0.42	1.06	2.65	4.51
Branch R-V Petrila	T_{4-4} northern slope	25.08	33.1	0.32	0.76	1.82	2.65
Maleia AS no. 2-3	T_{2-2} western slope	8.40	29.78	0.42	0.98	2.22	3.26
Livezeni preparation	L_{I-I} southern slope	20.10	26.58	0.38	0.93	2.21	3.29
Arsului Valley	T_{3-3} western slope	6.80	37.00	0.61	1.52	3.67	4.61
Branch 2 J.V.C.P.E.	T_{5-5} western slope	39.32	33.55	0.27	0.64	1.27	1.77
Branch 3 Lupeni	L_{I-I}	53.62	36.35	0.22	0.52	1.21	1.86
New Funicular	L_{I-I}	54.15	47.73	0.22	0.52	1.22	1.74

Table 7. Determining the probability of slopes sliding

Waste dump	LS_1	LS_2	LS_3	LS_4	LS_m	S_{LS}	K_{LS}	χ	Pr, %
Lonea 1	-0.57	0.13	1.57	3.15	1.068	1.782	1.669	-0.599	28
Jieţ	-0.58	0.06	1.65	3.51	1.160	1.961	1.691	-0.592	28
Branch R-V Petrila	-0.68	-0.24	0.82	1.65	0.388	0.989	2.553	-0.392	35
Maleia AS no. 2-3	-0.58	-0.02	1.22	2.26	0.72	1.535	2.132	-0.469	31
Livezeni preparation	-0.62	-0.07	1.21	2.29	0.703	1.332	1.896	-0.527	30
Arsului Valley	-0.39	0.52	2.67	3.61	1.603	2.268	1.416	-0.706	24
Branch 2 J.V.C.P.E.	-0.73	-0.36	0.27	0.77	-0.013	0.576	-46.101	0.022	50
Branch 3 Lupeni	-0.78	-0.48	0.21	0.86	-0.048	0.637	-13.408	0.075	51
New Funicular Uricani	-0.78	-0.48	0.22	0.74	-0.075	0.599	-7.986	0.125	53

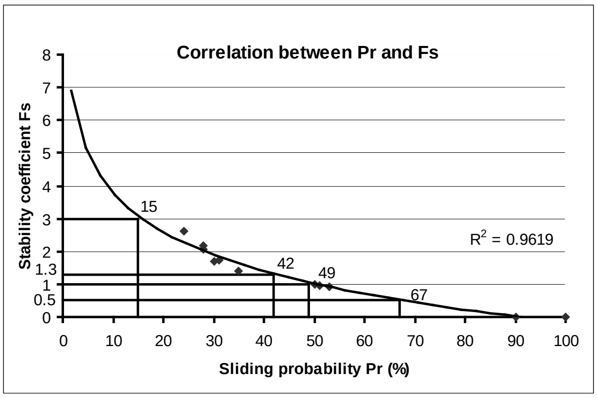

Figure 5. Correlation between the sliding probability (Pr) and the stability coefficient (Fs)

Based on this graph, taking into account the recommendations on adopting different values for the stability coefficient (Rotunjanu, 2005) and those presented in previous studies concerning the delimitation of sliding probability intervals (Gibson, 2011; US ACE, 1997; Kirsten, 1983), the following scale has been developed:

- P = 1 (P_r = 0÷15% for Fs > 3) → very low sliding probability;
- P = 2 (P_r = 16÷42% for Fs = 1.3÷3) → low sliding probability (Lonea 1, Jieţ, Branch R-V Petrila, Maleia AS no 2-3, Livezeni preparation, Arsului Valley);
- P = 3 (P_r = 43÷49% for Fs = 1÷1.3) → medium sliding probability;
- P = 4 (P_r = 50÷67% for Fs = 0.5÷1) → high sliding probability (Branch 2 - Coroeşti, Branch 3 - Lupeni, New Funicular Uricani);
- P = 5 (P_r = 68÷100% for Fs < 0.5) → very high sliding probability.

It must be underlined that according to previous studies (Gibson, 2011; US ACE, 1997; Kirsten, 1983) the sliding probability intervals can be variable depending on the specifics of each case study.

5. ASSESSING THE RISK OF SLIDING FOR ACTIVE WASTE DUMPS FROM JIU VALLEY

On the active waste dumps from Jiu Valley there were, over time, more or less severe phenomena like: erosion, fissures and cracks, slides. Next the assessment of the environmental risk associated to waste dumps slides using the probabilistic and classical methods previously presented is in question.

The risk may be defined as the product between the probability of occurrence of a potential hazard (in this case sliding of waste dumps) and the vulnerability of the natural and anthropogenic environment that may be affected (Smith, 1996). According to the simplified equation of risk, in case of slopes sliding, the next formula may be applied:

$$R = P \cdot V \quad (10)$$

where:

R – the environmental risk due to sliding;

P – sliding probability;

V – vulnerability of natural and anthropogenic environment in the event of a slide;

Using the formula (10) it was determined the environmental risk in the event of sliding for the active waste dump from Jiu Valley (Table 8).

Based on previous studies and literature in the field (Dumitran & Onutu, 2010; Fell et al., 2005), the following scale of environmental risk associated to waste dumps sliding was established:

- R=1 → minimum risk – insignificant damage to the natural and anthropogenic environment, reversible effects on very short term;
- R = 2÷7 → low risk – minor damage to the natural and anthropogenic environment, reversible consequences on relatively short term;
- R = 8÷13 → medium risk – partial destruction of habitats and associated biota, endangerment of anthropogenic environment, consequences on medium term;
- R = 14÷19 → high risk – destruction of habitats and associated biota on significant surfaces, real threat to anthropogenic environment, reversible consequences eventually on long term;
- R = 19÷25 → extreme risk – total destruction of the natural and anthropogenic environment, irreversible consequences.

According to this scale of sliding risk, the results from table 8 indicate that:

- three of the nine active dumps fall into the high risk category (branch 2 - Coroeşti, branch 3 - Lupeni, New Funicular);
- one of the nine active dumps fall into the medium risk category (branch V - Petrila);
- the other five fall into the low risk category (Lonea 1, Jieţ, Maleia AS no. 2-3, Livezeni preparation and Arsului Valley).

Given that all these waste dumps are under construction, they must be constantly monitored in terms of stability, as the geometry changes (increasing height and/or angle of slope).

6. CONCLUSIONS

The main aim of the paper was to develop a methodology to assess the environmental risk associated to active waste dumps slides and, in this purpose, the authors helped themselves by a case study performed in Jiu Valley.

Following field observations and research, the active waste dumps from Jiu Valley were grouped into vulnerability classes. This vulnerability classes were established by the authors by adapting the existing classification of waste dumps.

By taking into account the technical conditions of the waste dumps and the value of the natural and anthropogenic components of the environment present in the influence area, the 9 waste dumps were grouped in three classes: low vulnerability dumps (Livezeni preparation); medium vulnerability dumps (Lonea 1, Jieţ, Maleia AS no 2-3, Arsului Valley) and high vulnerability dumps (Branch R-V Petrila, Branch 2 Coroeşti, Branch 3 Lupeni, New Funicular Uricani).

Table 8. Establishing the environmental risk of slopes sliding

Waste dump	Environment vulnerability V	Slope failure probability P	Environmental risk R
Lonea 1	3	2	6
Jieţ	3	2	6
Branch R-V Petrila	4	2	8
Maleia AS no. 2-3	3	2	6
Livezeni preparation	2	2	4
Valea Arsului	3	2	6
Branch 2 J.V.C.P.E.	4	4	16
Branch 3 Lupeni	4	4	16
New Funicular Uricani	4	4	16

After conducting stability analyses (taking into account the values of the geotechnical characteristics resulted from statistical processing) and applying probabilistic methods for assessing the stability it was obtained a graph that shows the dependency between the stability coefficient and the sliding probability.

From this graph probability intervals were established and the 9 studied waste dumps were grouped as follows: dumps with low sliding probability (Lonea 1, Jieţ, Branch R-V Petrila, Maleia AS no 2-3, Livezeni prep., Arsului Valley) and dumps with high sliding probability (Branch 2 - Coroeşti, Branch 3 - Lupeni, New Funicular).

Finally, taking into account that the environmental risk is given by the product between the vulnerability of the natural and anthropogenic components of the environment and the sliding probability, the environmental risk for each of the 9 waste dumps was determined.

Depending on the environmental risk, the waste dumps were grouped in the following classes: 3 in the high risk class R = 14÷19 (Branch 2 - Coroeşti, Branch 3 - Lupeni, New Funicular); 1 in the medium risk class R = 8÷13 (Branch V - Petrila) and the other 5 in the low risk class (Lonea 1, Jieţ, Maleia AS no. 2-3, Livezeni preparation and Arsului Valley).

Although the level of risk characterizing the waste dumps is not an extreme one, the study shows that there is a probability of landslides to occur that may endanger the natural and anthropogenic components of the environment in adjacent areas.

Acknowledgments

The authors are grateful to Hunedoara Energetic Complex, Mining Division for providing the data regarding the active waste dumps from Jiu Valley (dumps surface, designed capacity and used capacity).

REFERENCES

Abramson L.W., Lee T.S., Sharma S. & Boyce G.M, 2002. *Slope stability and stabilization method,* John Wiley & Sons, Inc. New York, USA.

Bishop A.W., 1955, *The use of the slip circle in the stability analysis of slopes,* Geotechnique, Vol. 5, p. 7-17.

Bond, A. & Harris, A., 2008. *Decoding Eurocode 7*. Taylor and Francis, London, 598 p.

Bond, A., Schuppener, B., Scarpelli, G. & Orr, T., 2013. *Eurocode 7. Geotechnical Design Worked – Examples*. Report EUR 26227.

Dumitran, C. & Onutu, I., 2010. *Environmental risk analysis for crude oil soil pollution*. Carpathian Journal of Earth and Environmental Sciences, Vol. 5, No. 1, p. 83 - 92.

Fell, R., Ho, K.K.S., Lacasse, S. & Leroi, E., 2005. *A framework for landslide risk assessment and management*. In Landslide Risk Management – Hungr, Fell, Couture & Eberhardt (eds), Taylor and Francis Group, London, p. 3 – 26.

Fellenius, W., 1936. *Calculation of the stability of earth dam,* Proceedings of the Second Congress of Large Dams, Vol. 4, p. 445-463.

Fodor, M. & Baican, G., 2001. Impact of the mining industry on the environment. 392 p. Infomin Publishing House, Deva, (in Romanian).

Gibson, W., 2011. *Probabilistic methods for slope analysis and design,* Australian Geomechanics Vol 46, No 3 September.

Grozavu, A., Pleşcan, S. & Mărgărint, M. C., 2013. *Indicators for the assessment of exposure to geomorphologic and hydrologic processes*. Environmental Engineering and Management Journal, Vol. 12, No. 11, p. 2203-2210.

Janbu, N., 1954. *Stability analysis of slopes with dimensionless parameters,* Harvard Soil Mechanics, Series 46.

Kirsten, H., 1983. *Significance of the probability of failure in slope engineering,* The Civil Engineer in South Africa 25, p. 17-23.

Lazăr, M., Rotunjanu, I. & Fodor, D., 2008. *Geotechnical issues regarding the external waste rock dumps of Rosiuta Open Pit*. Proceedings of the 9th International Symposium Continuous Surface Mining, p. 139 – 144.

Lazăr, M., 2010. *Rehabilitation of degraded terrains*. 393 p. Universitas Publishing House, Petroşani, (in Romanian).

Lazăr, M., Faur, F., Dunca, E. & Ciolea, D., 2012. *Landslides occurred in Bujorascu Valley dump and stability improvement solutions.* Environmental Engineering and Management Journal, Vol. 11, No. 7, p. 1361-1366.

Lazăr, M., 2013. *Stability estimation for waste dumps from Jiu Valley using Fuzzy theory.* Proceeding of the 6th International Conference on Manufacturing Science And Education- MSE – Sibiu - Romania, Lucian Blaga University Publishing House, ISSN 1843-2522, p.. 359-362.

Luo, W., 2003. *Application of Rosenblueth moment estimation method into probability analysis of slope stability*. Chinese Journal of Rock Mechanics and Engineering, 22, p. 232－235.

Priest, S. D. & Brown, E. T., 1983. *Probabilistic stability analysis of variable rock slopes*. Transactions of the Institution of Mining and Metallurgy (Section A: Mining Industry), 92, p. A1–A12.

Rosenblueth E., 1975. - *Point estimates for probability moments [C]*. Proc. Nat. Acad. Sci. USA, 72: p. 3812-3814.

Rosenblueth E., 1981. *Two Point Estimates in Probabilities [J]*. Applied Mathematical Modeling, 5(5): p. 329-335.

Rotunjanu, I., 2005. *Stability of natural and artificial slopes.* 351 p, Infomin Publishing House, Deva, (in Romanian).

Smith, K. 1996. *Environmental hazards*, Routeledge Publishing House, London, p 389.

Ministry of Labor and Social Protection (MLSP), 1997, Technical prescriptions for *"Specific rules for labor protection for coal, oil shale and tar sands mines". Technical requirements for the design, development and conservation of waste dumps"*. 784 p. Elaborated and edited by INSEMEX Petroşani, (in Romanian).

US Army Corps of Engineers (US ACE), 1997. *Introduction to probability and reliability methods for use in geotechnical engineering*. No. 1110-2-547.

Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 regarding the management of waste from extractive industries and amending Directive 2004/35/EC.

Received at: 22. 01. 2015
Revised at: 17. 06. 2015
Accepted for publication at: 25. 07. 2015
Published online at: 28.07. 2015