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Waste dumps rehabilitation measures based on physico-chemical analyses in Zăghid mining area (Sălaj County, Romania)

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Abstract. The present study deals with an abandoned coal mine from Zăghid area, North-Western Transylvanian Basin (Sălaj County). The mining activity was stopped in 2005, without any attempt of ecological rehabilitation of the mined area and especially of the waste dumps left behind. The proposed rehabilitation models are based on some physical-chemical analyses of soil and waste samples (e.g. pH, EC, Salinity, humidity, porosity, density, plasticity, organic substances, mineralogical composition, heavy metals). Erosion map has been drawn based on the determined mineralogical composition (according STAS 1913/5-85 – using Galton curve) of tailings and the soil type. The values obtained for moisture and plasticity have been used to determine the ideal general inclination angle of the landfill systems in the studied perimeter. Through chemical analysis, heavy metals like Ni and Cu have been identified, as the main pollution factors for surface and underground water. Therefore, the concentration of heavy metals in the waters from Zăghid area is high in the water bodies, which are formed on waste dumps, but also in the mine water. This analysis is useful in establishing the actual state of the waste dumps and their content and the negative effects, which exercise on the environment in order to select the rehabilitation model for the waste dumps from Zăghid mining area. The main measures consist in: waste dumps leveling, soil remediation, perennial plants culture and acid mine water decontamination.

Keywords: waste dumps, mining, environment, rehabilitation, brown coal.

Introduction. The coal mines from Sălaj are located on the northwestern side of the Transylvania (Romania). This sedimentary basin is a major structure of the eastern sector of the European Alpine chain (Huismans et al 1997; Ciulavu et al 2002). It is one of the most important hydrocarbon provinces of southeastern Europe, spread on more than 10 km of sediments (Perrodon 1980; Popescu 1995; Crânganu & Deming 1996).

The industrial exploitation of brown coal and lignite in Sălaj started around the beginning of 20th century, when important resources had been outlined in several sectors, followed by significant expansion for energy purposes (Petrescu et al 1986, 1987). Coal was mined in several areas such as: Zăghid, Cristolţel, Teştioara, Chieşd, Sărmăşag, Zăuan mines, and others (Varga 2008). All these mines closed, some of them being in reconstruction, some already reconstructed, with more or less success (Varga & Ciurte 2007).

This paper presents problems related to the environmental aspects concerning the coal exploitation on environment. From soil, waste and water analyses, we make some remarks on the pollution induced by the coal mining and based on this information's we proposed some rehabilitation methods of the affected area. In this article the coal mine from Zăghid area (Sălaj) is studied. Here it was exploited brown coal of Oligocene–Miocene age, bore in the Cuzăplac, Cubleşu, Sâncraiu or Dealu Cotului formations (Petrescu et al 1987; Földvary 1988; Filipescu 2001; Fărcaş & Codrea 2004; Ştefănescu et al 2006).

Material and Method. The main physico-chemical parameters of soil and tailings (pH, redox potential (ORP), electrical conductivity (EC), total dissolved solids (TDS) and salinity), were analyzed with a Multiparameter WTW 730 Series – InoLab. To determine the pH of soil and wastes the samples were processed according to SR ISO 10390. The pH electrode used in determination present internal temperature compensation. The samples were dried at 40 °C, passed through a sieve of 2 mm from which was measured a volume of 20 ml of soil / tailings, to which 100 mL distilled water was added and then these were stirred for 10 minutes and left to stand for 2 h.

To analyze the current state of soil quality and the impact of coal mining in the Zăghid area on soil, 9 waste samples were taken from the tailings deposits from the hole area of exploitation (see Figure 2) and 3 soil samples, from which two are taken outside the exploitation area (Figure 1). These two soil samples (J and K) are considered as control sample.

The soil and tailings samples were taken in plastic bags using a plastic spatula.

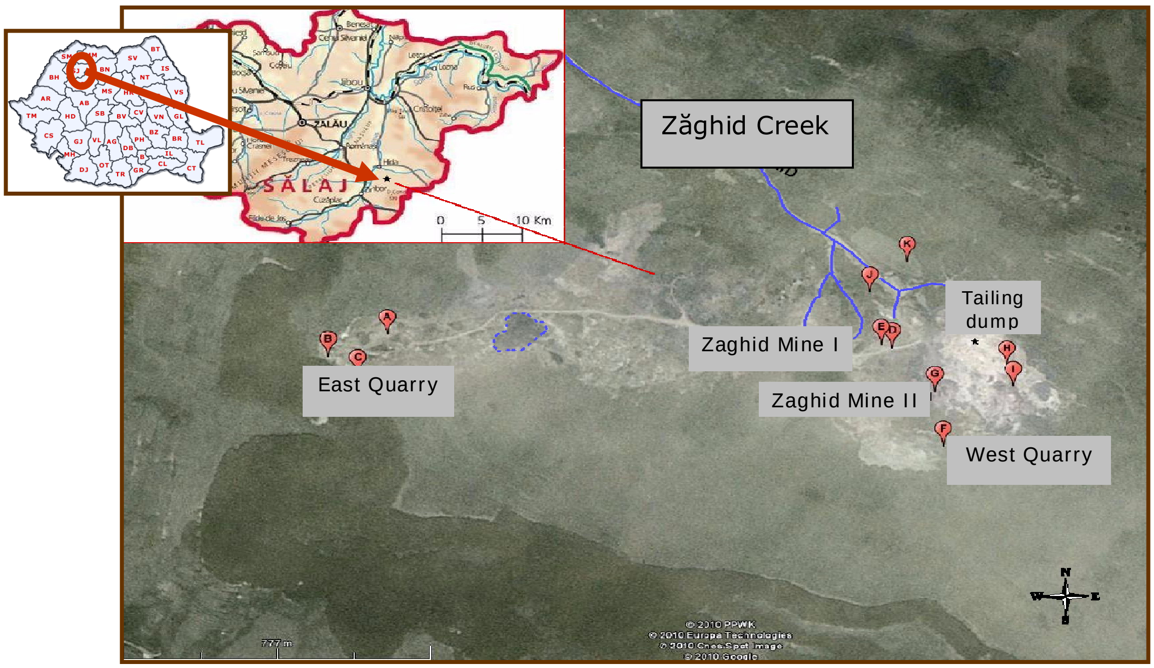


Figure 1. Localization of soil and waste sampling points

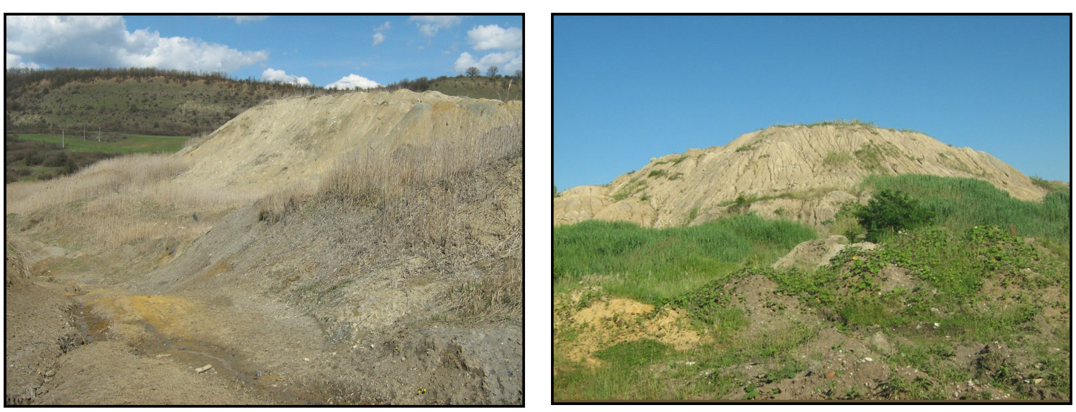


Figure 2. The main tailing dumps from Zăghid exploitation area.

Following the activity of brown coal mining in the Zăghid area, has resulted a significant quantity in the form of mineral waste tailings, which are mostly stored in dumps.

To know the characteristics and the particularities of those dumps, some physical-mechanical studies were performed. These physical-mechanical parameters are very important in determining the stability of the dumps.

In this scope were made the following analyses: texture, density, composition, grain size, porosity, plasticity and moisture. These parameters were determined at the Geo Search SRL lab, Cluj-Napoca.

Methods used in determining the granulometry:

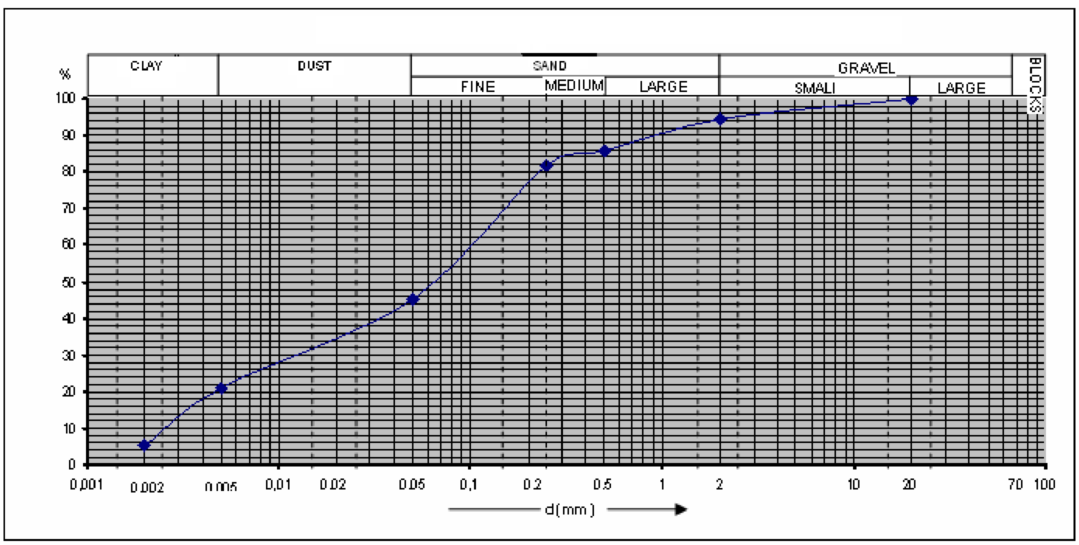
- by sifting through sieve method for soils with a grain of more than 0.063 mm,
- sedimentation method for soils with a grain of less than 0.063 mm.

The analyses of heavy metals from soil and waste samples were made at the Faculty of Environmental Sciences. To determine the content of heavy metals in soil and wastes by Atomic Absorption Spectrometry (AAS) method (using the apparatus ZeEnit) their extraction in aqueous solution was necessary. Mineralization of the samples was made according to SR ISO 11466 by extraction with aqua regia (3 parts HCl: 1 part HNO_3).

Results and Discussion

A. Determination of granulometric composition (STAS 1913/5-85). Particle size composition is the proportion of the solid particles of different sizes of soil involved in total soil composition.

Presentation of granulometry can be performed graphically by a semi-logarithmic curve, the curve of grain (Galton curve type) (Figure 3) or a histogram. Below is presented a Galton curve for the sample C.



	CLAY = 20.91 %
dusty-sandy clay	**DUST =** 24.39 %
	SAND = 49.19 %
	GRAVEL = 5.50 %

Figure 3. Granulometric composition determination based on Galton curve type (Sample C)

Expression results are based on data related to grain size and their percentage participation. The results for all the analyzed samples are shown in Table 1.

Table 1

Granulometric composition of the soil and waste samples from Zăghid area

No.	Sample	Layer description
1.	A	coal + sandy clay
2.	B	coal + sandy clay
3.	C	dusty-sandy clay plastic consistent /stout
4.	D	sandy clay plastic consistent
5.	E	sandy clay plastic consistent /stout
6.	F	sandy clay plastic stout
7.	G	sandy clay + coal
8.	H	sandy clay plastic consistent /stout
9.	I	sandy clay + coal
10.	J	sandy clay plastic consistent /stout
11.	K	sandy clay plastic consistent /stout

B. Determination of volumic weight, porosity, plasticity and moisture. The obtained results for these physico-mechanical parameters are presented in Table 2. The analyzed samples have an average porosity, having the ability to store a considerable amount of water. Soil with a total porosity of 48-60% has optimal conditions for plant growth and development.

Table 2

Physico-mechanical parameters

No.	Sample	Volumic weight of the skeleton γs kN/m^3	Porosity n %	Pore index e	Plasticity Index Ip %	Consistency Index Ic	Natural Moisture w %
1.	A	-	-	-	-	-	31.60
2.	C	27.10	50.00	1.01	21.97	0.78	22.34
3.	D	27.00	55.00	1.20	21.25	0.67	26.50
4.	E	27.00	51.00	1.02	31.39	0.75	28.95
5.	F	27.00	55.00	1.24	25.93	0.80	31.17
6.	G	-	-	-	-	-	27.39
7.	H	27.00	53.00	1.15	20.17	0.77	24.95
8.	I	-	-	-	-	-	47.50
9.	J	27.00	56.00	1.27	34.91	0.77	29.55

To determine the plasticity index, soil and tailings samples were processed according to STAS 3300/2-85.

The soils with Ic < 0.5 have a high plasticity, and those with Ic> 0.5 are considered low plasticity soils (Caius et al 1980). Therefore, the samples from the Zăghid mining area present a low to medium plasticity and in case of rainfall conditions; these have a good resistance to slip (Chatwin et al 1994).

For Zăghid mining area, moisture values range from 22.30 to 31.17% for clay and sandy clay from 31.60 to 47.50% for the samples with high content of coal.

To give a larger possible stability of waste dumps a few rules were imposed to construct the slope angle, depending on the humidity of the deposit (see Table 3).

Table 3

The angle of slope depending on the material moisture
(according to Fodor 1995-1996)

Tailings Type	Slope angle (Dry material) (º)	Slope angle (Wet material) (º)	Slope angle (Flowable) (º)
Sand	28-35	30-40	22-27
Sandy Clay	40-50	35-40	25-30
Heavy Clay	40-45	35	15-20
Soil	40	35	35
Hard rock, loose with different granulometric particles	32-45	36-48	30-40

The stability of the waste is subject to the construction of angles adapted to local conditions and lithological composition of the heap. Based on the performed analyses it is recommended that the angle of inclination of the pile gear systems for the mining perimeter Zăghid to be about 30 degrees.

In Zăghid mining area, in addition to the two external dumps, there are numerous deposits of small volume of tailings throughout the entire mining area, which need relocation and/or leveling.

C. Determination of pH from soil and tailings. In terms of pH, the analyzed samples, except the two control soil samples (J and K) are characterized as very acidic to acidic (Figure 4). In these conditions the acidity of soil has to be ameliorated, to decrease the possibility of acid mine drainage (AMD) occurrence and to reduce the possibility to introduce a significant content of heavy metals in the environment.

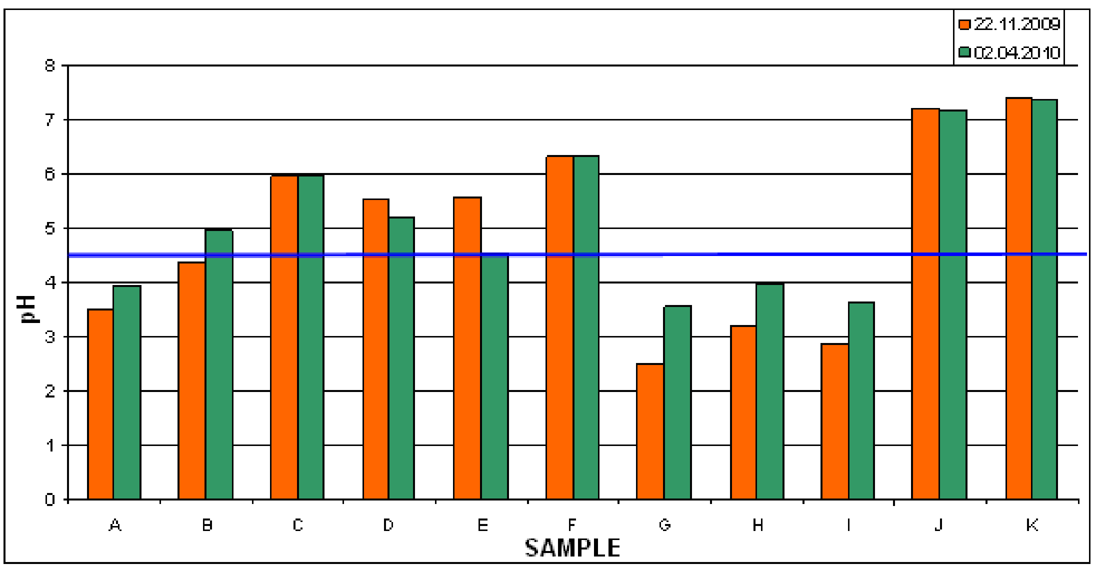


Figure 4. Soil and waste pH.

D. Determination of heavy metals in soil and wastes. To determine the concentration of heavy metals (Cu, Pb, Zn, Cd, Fe, Ni, Cr, Mn) from soil and tailings were analyzed 11 samples with an atomic absorption spectrometer. The sampling and analyses were performed in November 2009 and April 2010. The investigated soil quality in some sampling point's shows overcomes of normal concentrations at heavy metals. Ni and Cu present the highest concentrations in soil and tailings (Figs 5-6).

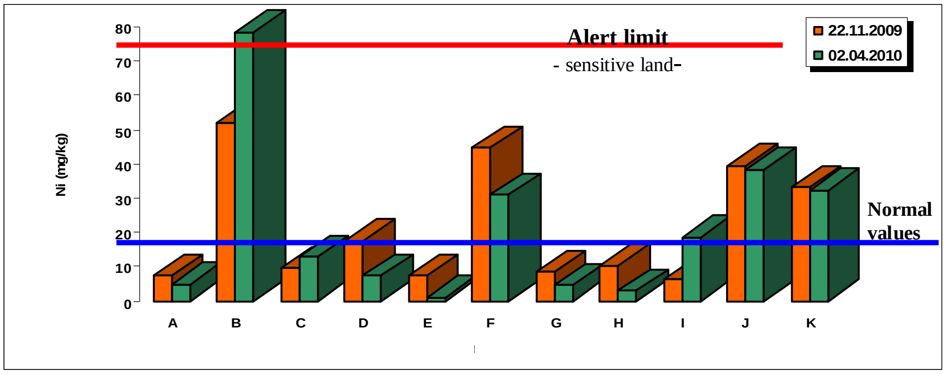


Figure 5. Ni content in soil and waste samples from Zăghid perimeter.

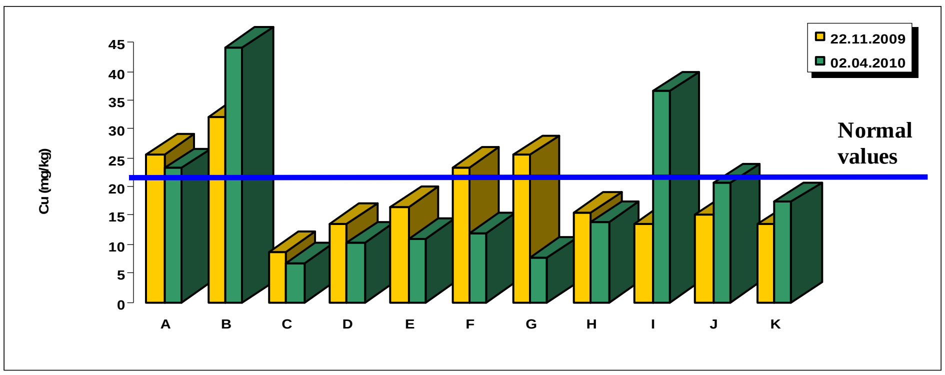


Figure 6. Cu content in soil and waste samples from Zăghid perimeter.

Control soil samples (J and K), collected from a distance of 100 m and 200 m from the mining area, have a very low content of heavy metals in comparison with waste samples from the tailing dumps. This suggests that there is no obvious soil contamination with heavy metals in the vicinity of mine.

Proposed solutions for the rehabilitation of Zăghid mining perimeter. Environmental restoration is important in a mining operation, because it improves the quality of the environment (air, water, soil, vegetation) which was negatively affected by mining.

Rehabilitation of former mining areas affected by the exploitation operations should be viewed as a part of mining activity which can be defined as the methodical modeling of the mined areas.

Models for the rehabilitation of the degraded mining areas are in the works of: Bradshaw & Chadwick (1980), Ma & Wu (1982), Hossner (1988), Hannan & Bell (1993), Hester & Harrison (1995), Ward et al (1996), Loch (2000ab), Williams (2006), Meng (2010) etc.

Under old mining methods, once the mine became uneconomic, it was abandoned with little or no attempt to rehabilitate the land.

a. The rehabilitation works at Zăghid East and West Quarry should pursue the following steps:

1. Spatial modeling, land leveling (S = 20 ha). Main phases: shaping, smoothing, stabilization of the land with walls, fitting leaking rainwater, cover with soil and revegetation (S = 14 ha) and in some places afforestation;
2. Fitting the left side of the Zăghid Valley which is affected by landslides (S = 15 ha);
3. Zăghid riverbed clogging and roll over a length of 500 m in the area of influence of quarry;

4. Sanitation of the area, main phases: removing the residues of any kind and transportation to approved landfills;

5. Monitoring the works for at least three years, main phases: observations, measurements and tracking dynamics.

b. The rehabilitation works at Zăghid I an II Mine should pursue the following steps:

1. Closing and stabilization of all ventilation holes;
2. Disposal of the constructions and installations;
3. Land management affected by the exploitation process, to restore the forest cycle (S = 6 ha);
4. To eliminate the radioactive elements and to neutralize any chemicals which present high concentrations and exceed the concentration admitted by law;
5. To redevelop the brook points of the water in Zăghid River (L = 1000 m);
6. Monitoring of the rehabilitation actions for 2-3 years after the mine was closed.

c. Rearrangement of the waste deposits. Rearrangement of the Zăghid mining tailings dump involves the following steps:

- dump planning;
- landfill surface leveling;
- topsoil deposit on the smoothed surfaces;
- improve the landfill land.

d. Reshaping the body of the waste rock dump is a fundamental requirement in achieving long-term geotechnical stability.

The mining activity in the Zăghid mining perimeter disturbed the geological structure, causing underground collapses, whose effect was transmitted to the surface through the processes of subsidence and landslides. This leads to the existence of a large gradient, which in turn generates associated geomorphologic processes: crumbling, ravines, superficial landslides etc.

In this purpose, a water erosion analysis for the surface mining area Zăghid have been performed.

To determine the degree of soil erosion and the amount of eroded material the validated USLE method (Universal Soil Loss Equation) have been used (Figs 7-8).

It is important to determine the annual amount of eroded material, to identify the measures necessary to ensure environmental and economic sustainability of the study area.

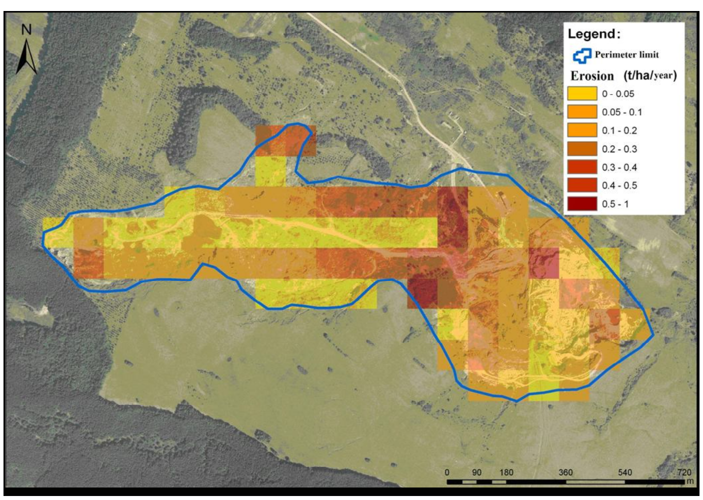


Figure 7. Soil erosion map in the studied area.

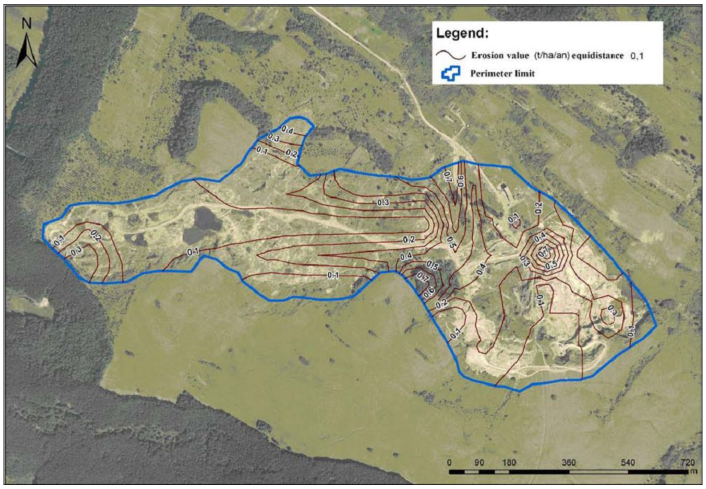


Figure 8. Erosion rate in the mining area Zăghid.

The model results show a maximum erosion rate of 0.792 t/ha/year, while the medium value for the studied area is 0.18 t/ha/year.

e. Revegetation in this area is recommended to be performed with perennial weeds specific to this area (Figure 9), which are unpretentious to soil conditions and are resistant to diseases.

The soil covers should be sown with grass in order to obtain immediate protection against erosion, which can be later reduced to minimum by planting trees or shrubs to a better stabilization (Loch 2000a).

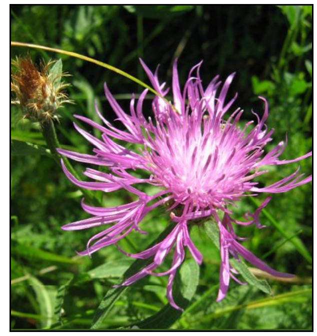
After the rehabilitation of tailing dumps is complete it is necessary to build a drainage system for the mining waters, to reduce the volume of surface water that may come into contact with acid drainage generating material or contaminated water. This method will lead to lower potential environmental impact of mining acid waters outside the perimeter.

Conclusions

- In terms of size, the samples (both the waste and soil) consist by clay that varies from sandy clay to dusty- sandy clay.
- The analyzed samples have an average porosity, with the ability to store a considerable amount of water. Soils with a total porosity of 48-60% present optimal conditions for plant growth and development.
- The analyzed soil and waste samples have a low to medium plasticity, consistency index values are between Ic = 0.67 to 0.80. These soils present resistances to slip under rainfall conditions.
- The stability of waste dumps is conditioned by the constructed angles, which have to be adapted to local conditions and to the lithological composition of the heap. Based on analysis performed it is generally recommended that the angle of inclination of the pile systems for the Zăghid mining perimeter to be approximately of 30 degrees.
- The maximum erosion rate in Zăghid area is 0.792 t/ha/year, while the medium value is 0.18 t/ha/year.
- The acidity of soil and especially of wastes is high (above the 4.5 value).
- The most abundant metals from soil and wastes are Ni and Cu.
- The plants recommended for revegetation in this area are the perennial plants specific to this area, such as: *Trifolium repens, Centaurea phrygia, Festuca rubra* etc.

a). *Trifolium pratense*

b). *Trifolium repens*



c). *Centaurea Phrygia*

d). *Festuca rubra*

e). *Setaria glauca*

f). *Dactylis glomerata*

g). *Achillea millefolium*

h). *Tussilago farfara*

i). *Lotus corniculatus*

Figure 9. The main plant species found in the vicinity of the Zăghid mine and recommended in the process of revegetation.

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