ASSESSMENT OF SOIL EROSION POTENTIAL BY THE USLE METHOD IN ROŞIA MONTANĂ MINING AREA AND ASSOCIATED NATECH EVENTS

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Abstract: The paper presents the application of the USLE methodology for the assessment of the soil erosion susceptibility in the Roşia Montană mining perimeter, a 2000 year-old exploitation area. The peculiarities of the mountain topography and the vulnerability induced by the mining activities have caused the occurrence of soil erosion in significant areas. The identification and assessment in quantitative terms of these areas is vital from the mining structures physical stability point of view and that of environmental safety in the investigated region. The soil loss assessment is also considered in terms of Natech events (natural hazards trigger technological accidents), which combine the natural and technological components of a disaster. The results of the study illustrate the fact that the highest values of soil erosion are located in the open pit and waste heaps area, inducing the risk of physical collapse of waste heaps, especially if triggered by extreme climatic phenomena, causing a possible Natech event. Revegetation and physical stabilization measures should be implemented immediately as part of a rehabilitation plan, for the provision of regional safety.

Key words: Soil erosion susceptibility, USLE, NATECH events, mining, Roşia Montană

1. INTRODUCTION

Since Roman times, Roşia Montană (Alburnus Maior) has been an El Dorado of the territory defined by the Carpathians, the Danube and the Black Sea. The history of the village is closely connected to the history of the basic productive sector, which imprinted the economic peculiarity. The historic gold outputs (630 tonnes) together with the newly reported 400 tonnes make the mineralized structures of Roşia Montană the largest gold deposit of Europe (Vlad, 2005).

The investigated area lies between 23°02′52″–23°08′33″ longitudes and 46°18′57″–46°17′24″ latitudes is 21.45 square kilometres and it. It includes the mining structures and objectives associated to the former gold mine: 2 tailing dams (Gura Roşiei and Valea Săliştei), 1 processing plant (Gura Roşiei), 2 open pits (Cetate and Cârnic) and 17 waste heaps. These mining structures represent highly disruptive visual elements in the natural landscape of the area, creating a mining-specific environment (Ştefănescu et al., 2010).

The development of the mining activities in the investigated area has had a significant negative environmental impact, affecting mostly the soil and underground waters. During the mining works, the topography was subjected to multiple changes, which induced its high fragility and the occurrence of exogenous processes such as: rock falls, landslides, ravine formations, etc.

The peculiarities of the mountain topography and the vulnerability given by the mining activities have caused the occurrence of soil erosion in significant areas. Soil erosion is a form of soil damage, directly influenced by the action of water and wind. The problem has far-reaching economic, political,

social and environmental implications due to both on-site and off-site damages (Dabral et al., 2008).

The observations and researches performed in the field have identified such phenomena. In order to support these remarks, it is necessary to identify the areas affected by erosion using validated scientific methods. Often, a quantitative assessment is needed to infer on the extent and magnitude of soil erosion problems so that sound management strategies can be developed on a regional basis (Fistikoglu & Harmancioglu, 2002).

At the same time, it is important to determine the annual amount of material loss in order to identify the measures for the assurance of ecological and economic sustainability of the investigated region. The environmental and population safety in the region needs to be approached from the perspective of possible technological hazards induced by extreme natural events.

The contemporary knowledge confirms that many hazards are hybrid, having natural and antropic components. Hybrid hazards or the so-called NATECH incidents (natural hazards trigger technological accidents) have a natural component (earthquakes, floods, massive landslides, volcanic eruptions) and a technological one (any types of damage on an industrial site: pipes ruptures, tank ruptures, explosions, etc.). Other authors speak of compounded hazards, as those that result from a combination of the natural and man-made hazard types, such as urban fires resulting from earthquakes, failures of dams resulting from flooding, or landslides resulting from wildfires and heavy rains (Pine, 2009).

The risks are higher as these disasters have a higher possibility to exceed the national borders and affect the neighbouring regions and countries (Şerban & Bălteanu, 2005). The frequency of Natech accidents is also an alarming fact, as approximately 2–4% of industrial accidents belong to this category (Cozzani et al., 2010).

2. DATA AND METHODS

2.1. The USLE methodology

Taking into consideration the factors influencing soil erosion, which are both dynamic and static, the estimation of the soil loss is best achieved by spatial analysis and modelling, using the GIS technology and the Universal Soil Loss Equation (USLE).

The scientific approach regarding soil erosion and determination of the soil erosion assessment methods was launched in USA during the '30s. Significant results were achieved during the '70s by the elaboration of a model based on the empirical equation called Universal Soil Loss Equation - USLE (Wischmeier & Smith, 1978).

The soil loss quantity may be estimated by the USLE method based on 6 factors: rainfall/runoff erosivity, soil erodibility coefficient, slope length and steepness factor (LS), slope, vegetation cover, and the impact of the agricultural erosion control practices.

Due to some issues regarding the assessment of the above factors, the USLE method was altered and revised by the MUSLE method (Modified Universal Soil Loss Equation), in which the R factor was replaced with one considering the flow of the river leaving the basin. As a result of these researches, the equation was revised once more, thus determining the RUSLE method (Revised Universal Soil Loss Equation). This last equation considers the rainfall/runoff erosivity factor, the LS factors and the time in assessing soil erodibility (Renard & Freimund, 1994).

The USLE method equation was adapted to the Romanian sites specific conditions in 1975 (Moţoc et al., 1975). The USLE method used to estimate the eroded soil quantity is based on the following equation:

$$E = K * LS * S * C * Cs \qquad (1)$$

Where:

E – quantity of soil loss (t/(ha/year)),

K – climatic aggressiveness coefficient,

LS – topographic index, calculated based on the slope length and steepness,

S – soil erodibility coefficient,

C – land use coefficient,

Cs – impact of agricultural erosion control practices.

Based on the above-mentioned methodology, the case study Roşia Montană was approached.

2.2. Application of USLE methodology - Roşia Montană case study

The identification of the areas susceptible to erosion according to the yearly soil loss quantity was based on both the knowledge of driving factors, the characteristics of the site and a detailed analysis regarding the most appropriate method for acquiring objective results.

When analyzing soil susceptibility in the investigation area, the GIS technology was used for the elaboration of the geospatial database used for the modelling of relevant maps. The geographic and mining peculiarities represented the starting point for the primary database preparation. In this direction, the

topographic map 1:25,000 was used and the level curves, the water courses, types of soil and vegetation, rural fabric and transport infrastructure were digitized. The 1:5,000 scale plans represented the basis for the vectorization of waste heaps, tailings dams, open pits, processing plant and other relevant objectives in the investigated area. Based on the ortophotoplan at 0.5 m resolution, the land use categories were vectorized. The geospatial database was performed in the Stereographic 1970 projection system.

By means of ArcGIS 9.2 and ArcInfo 8.2 software of the ESRI package, through spatial modelling, we performed a 10 m resolution grid for each factor, except the K, starting from the GIS database elaborated for the investigated area. The application of the USLE equation methodology in the investigated area is presented below:

- The climatic aggressiveness coefficient corresponding to factor K was introduced in the calculus equation in a numerical form; its value for the investigation area was found to be 0.120 (Stănescu et al., 1969).

- The starting point in determining the topographic factor was represented by the elaboration and spatial modelling of the Digital Elevation Model (DEM) for the investigated area. The DEM was achieved based on the level curves using the TopoGrid command in the ArcInfo 8.2 programme (Fig. 2).

Topography represents a critical factor in controlling water dispersion and soil movement. The detailed description of land surface is required in spatially distributed modelling of many hydrologic processes including soil erosion and sediment transport (Wu et al., 2005).

The slope length was determined by means of the Spatial Analyst extension using the Raster Calculator command in the ArcGIS 9.2 programme, using the equation proposed by Mitasova in 1996 (Bilaşco et al., 2009). Consequently, the equation used for the investigated area is:

$$Pow([FlowAcc\_10]*10/22.1, 0.4) * \qquad (2)$$
$$Pow(\sin[panta\_10]*0{,}01745)/0.09, 1.4)*1.4$$

Where:

[FlowAcc_10] – runoff accumulation

10 – grid resolution

22.1, 0.4, 0.01745, 0.09, 1.4 – experimental coefficients

[panta_10] – the slope

The grid in figure 3 represents the result of applying the above mentioned formula. By analyzing the slope map (Fig. 4), one may notice the high declivity in the open pit area, in the northern part of the investigated area and the left side of the Roşia Montană rivulet. In these areas, the slopes range between 30 and

41 degrees and it determines a high vulnerability regarding the gravitational geomorphologic processes. These influence soil erosion in the investigated area as they are directly correlated to the climatic characteristics of the area.

The soil erodibility factor (S) was acquired starting from the soil map and based on the soil type and texture. For Romania, the values of the S factor were calculated by the ICPA (Research Institute of Pedology and Agrochemistry) in 1986. The classification according to the soil structure and type was found in the ICPA's *Methodology for the Elaboration of Pedological Studies*.

In the investigated area, the specific soils are typical and andic Dystricambosols, Eutricambosols, Lithosols and Aluviosols. The soil map of the investigated area (Fig. 1) was performed based on the Romanian Soil Map, Scaled 1:200.000, Turda Sheet (Florea & Bălăceanu, 1988) and adapted to the new system of soil classification implemented in 2003 (SRTS–Romanian Soil Taxonomy System). According to the SRTS 2003 classification, all soils, except aluviosols are included in the category of the acid brown soils.
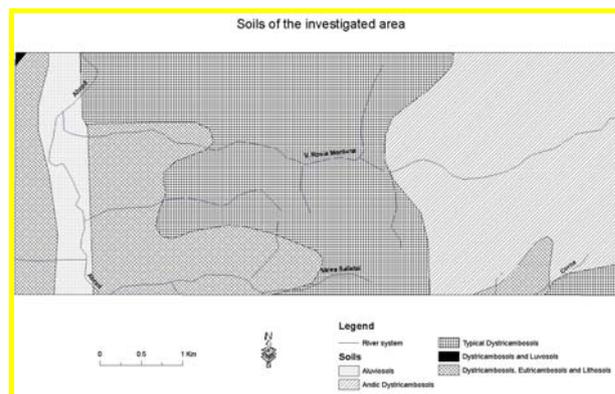

Figure 1. Soil map

Dystricambosols are found uniformly in the entire investigation area. These soils have evolved in cold and humid climate conditions and cover slopes of various inclination, as well as mountainous humid slopes, with very good drainage. The parental material is represented by all rocks categories (metamorphic, magmatic and sedimentary). These soil are formed under a coniferous vegetation (Florea & Munteanu, 2003).

Eutricambosols are well structured and have a good permeability. The parental material varies from sedimentary and metamorphic to volcanic rocks (the andic subtype). Lithosols cover dispersed areas in the investigation region, mainly rock slopes and rough terrains. They are not well structured, have a low fertility potential and low permeability due to the presence of the bedrock close to the surface.

Aluviosols develop in the river meadows, on fluvial parental material. Their distribution is rather discontinuous, as they do not cover large unitary surfaces. The predominant types of soil in the study area are Dystricambosols and Eutricambosols. Generally, soils are relatively acid, with a low to medium reaction buffering capacity and a low to medium vulnerability to acidifying impacts (Lăcătuşu et al., 2007).

Among the factors influencing soil erodibility, there are the humus content and soil fertility. The specialty literature mentions that low soil fertility has negative influences upon erosion, but this has not been quantified yet (Moţoc & Sevastel, 2002).

Soils in the investigated area have moderate contents of organic matter and medium contents of humus values. Exceptions are the two tailing ponds, the open pit areas and Gura Roşiei processing plant area, which present extremely low contents of humus.

Within the areas of Cetate and Cârnic open pits, erodosols and antrosols are found. These are highly eroded and influenced by the human activity (mining). These soils are characterized by an eroded profile (when occurring on slopes) or stripped profile (in case of soil stripping due to mining). They are less structured and have a low content of humus and nutritious elements, which cause their low fertility and productive properties.

Soil damage is also due to the presence of chemical pollutants. Studies on heavy metal concentrations in the Roşia Montană mining perimeter (Cetate open pit, waste dumps and tailing ponds) have shown that heavy metal content of soils is higher than the soil's general pedogeochemical background (Lăcătuşu et al., 2009).

The soils in the investigated area are classified into the following erodibility classes (Florea & Muntean, 2003):

- S = 0.8, soils specific to the acid brown category cover the largest surface in the investigated area, characteristic to the broad-leaved and mixed forests;

- S = 0.1, soils specific to the aluvisols category are characterized by the highest resistance to erosion.

The starting point in determining the C factor was represented by the processing of the geospatial database obtained by the digitization of the land use categories based on the ortophotoplan (Fig. 4). The values of the coefficient regarding the land use categories according to the land use types and cultures in the investigated area range between 0.005 and 0.25 (Moţoc et al., 1975). Based on these values, a classification of the land use categories was elaborated, and then the vector database was converted into a grid, defining the USLE equation. As a result of field researches and literature documentation, the Cs factor was not considered as there are no agricultural control erosion measures implemented in the investigated area.

Table 1. The value of the coefficient regarding the land use categories according to the types and culture

Land use	Factor C
Tailing dams	0.005
Rural fabric	
Mineral extraction areas	
Coniferous forests	0.1
Broad-leaved forests	
Mixed forests	
Secondary grasslands	0.15
Transition areas with shrubs	0.25
Complex cultures areas	

3. RESULTS AND DISCUSSIONS

3.1. Soil loss assessment

Analyzing the map of soil susceptibility to erosion in the investigated area (Fig. 6), one can notice that the largest amounts of soil loss are found in the mining exploitation area and on the high slope surfaces. The correspondence between the quantity of eroded soil and the susceptibility to erosion was established according to the ICPA (Institute of Pedological and Agrochemical Research) methodology, elaborated in 1986, as follows (ICPA, 1986):

- < 1 t/(ha/year) – insignificant erosion
- 1-8 t/(ha/year) – weak erosion
- 8- 16 t/(ha/year) – moderate erosion
- 16 - 30 t/(ha/year) – high erosion
- > 30 t/(ha/year) – extremely high erosion

One can notice that areas with extremely high erosion are located on the south-eastern slopes of the Cetate and Cârnic hills, respectively the area of the Valea Verde, Hop, Cârnicel, Napoleon and Piatra Corbului waste heaps.

The area is affected, beside erosion, by shallow and deep-seated landslides, which amplify the risk of stability failure and the vulnerability of the local communities (Corna village is located approximately 1 km downstream of the Valea Verde waste heap).

The western slope of the Cetate open pit falls in the "high erosion" susceptibility category. Within the entire area of the open pit and the surrounding area, the stabilizing vegetation cover is missing, and the washing of soil under the influence of wind and water amplifies the erosion process. High susceptibility to erosion of the

volcanites and of the volcanic-sedimentary rocks explains the land damage in the investigated area; the present morphodynamic processes are dominated by linear erosion (rills, ravines, gullies, torrents).

The rest of the investigated area presents higher susceptibility to erosion, mainly on the western slopes of the anticlinals, areas more subjected to the potential of rills, ravines and gullies occurrence. Significant areas with high values of erosion susceptibility are noticed in the area of the two tailing dams, which amplifies the associated risks and implicitly the vulnerability of the neighbouring local community.

The two tailing ponds Gura Roşiei and Valea Săliştei have a significant impact upon soils. The physical damage of soils occurs as one of the pollution forms induced to this environmental media. One could notice the physical effects of this damage by changes induced to local topography, through soil erosion and slopes instability.

The soil loss in the area of the two tailing ponds was favoured by the low humus content of soil, by intense stripping, vegetation removal and compaction by heavy machinery. All these are factors which negatively influence and greatly amplify the erosion process.
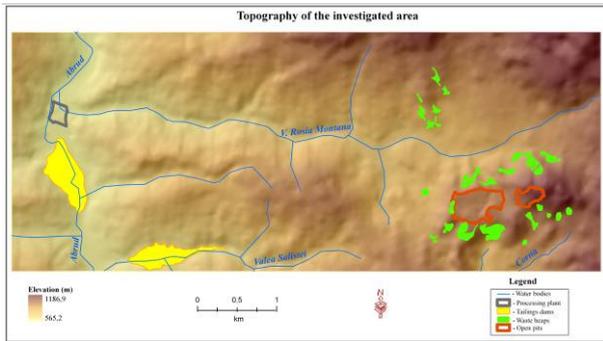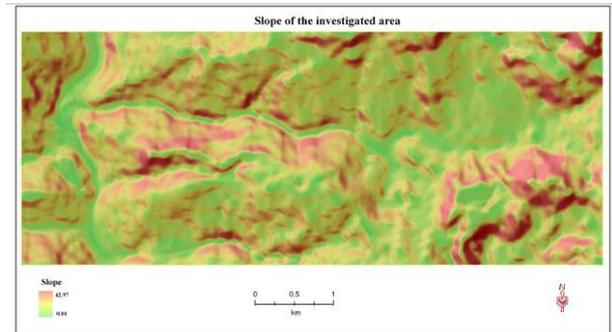

Figure 2. Digital Elevation Model map
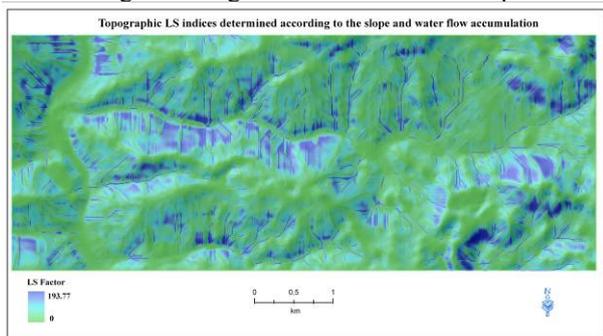

Figure 4. Slope map
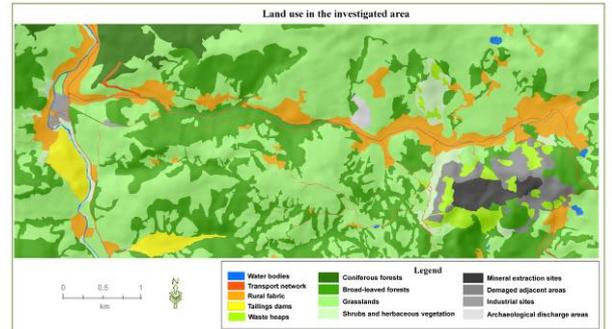

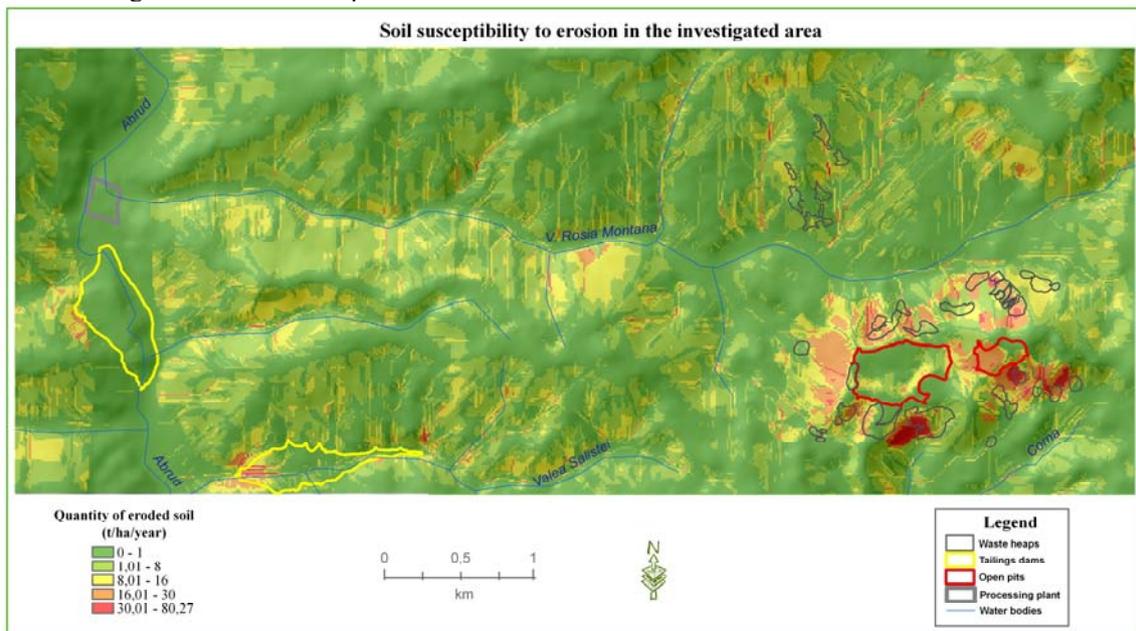Figure 3. LS factor map

Figure 5. Land use categories map

Figure 6. Map of soil erosion susceptibility in the investigated area

The most stable areas are located in the valley of Abrud river and of the Roşia Montană rivulet, where the low slope (below 6°), and the use of lands (predominance of built surfaces) have a protective role for the soil cover. Analyzing the distribution of the areas susceptible to erosion, the following results were obtained (see Table 2).

Table 2. Distribution of the erosion susceptible areas

Soil loss quantity t/(ha/year)	Susceptibility to erosion	Occupied surface (%)	Occupied surface (km²)
<1	Insignificant erosion	43.31	9.29
1.1 - 8	Weak erosion	50.13	10.75
8.1 - 16	Moderate erosion	3.21	0.69
16.1 - 30	High erosion	2.32	0.50
>30	Extremely high erosion	1.04	0.22

A percentage of 50% of the investigated area presents low values of soil-loss and thus a weak susceptibility to erosional processes. The largest part of the other half belongs to the insignificant erosion category and only 1.04% presents high erosion values. However, it is important to mention that this small percentage corresponds to the areas most affected by mining and to the mining structures having serious stability problems (Hop and Valea Verde waste heaps and the tailing dams). This amplifies the risks induced through these processes, by the occurrence of the NATECH incidents, with serious consequences to the communities located nearby.

Low potential of soil loss characterizes the oldest waste dumps from the Orlea area. These are the only waste dumps located North of the Roşia rivulet and they are 90% covered by *Calluna vulgaris* vegetation. Generally, this type of vegetation induces the moisturizing of the substratum and favours the intensification of the bacterial activity in the mine dump, as studies on similar waste dumps have indicated (Damian & Damian, 2006). On these waste dumps, the natural installation of vegetation was a slow process, which resulted in a greater stability.

3.2. Natural hazards trigger technological accidents (NATECHs)

It is well known that a degraded environment increases the likelihood and amplifies the impacts of natural hazards (Reyes, 2005).

The quality of environmental factors in the Roşia Montană mining district has been greatly affected by the past intensive and abusive mining exploitation.

Potential hazards existing on-site are represented by:
- the existence of the waste disposal structures (waste heaps and tailing dams),
- the instability of the waste heaps,
- the lack of stabilizing vegetation,
- the generation of acid mine drainage.

These hazards may be included in the following categories:

Hazards due to the intrinsic properties and characteristics:
- physical collapse, slope damage;
- subsidence, collapse of underground galleries.

Hazards due to exogenous factors and dislocation forces:
- erosion by the surface seepage with rich flows, forming torrents and rivulets;
- undermine by a water course (causing collapse);
- action of frost and accumulation of ice during the winter period;
- erosion by fine airborne particles.

These factors and forces are often modified or driven by biological factors, such as the presence or absence of the vegetation, and animal activity. Among the Natech-type hazards in the investigated area, there are:
- Failure of tailings dams caused by natural factors: earthquakes, floods, landslides, with catastrophic consequences for the local community;
- Poor system of mine water drainage in waste heaps and tailings dams, as well as the inadequate manner of land use and stabilization of mining waste structures may damage the environment and enhance the consequences in case of earthquake. The mining communities are subjected to technological risks, driven by natural hazard (earthquake);
- Foundation failure – exceed of the portent capacity of the natural land by the rapid overload, activation of landslides phenomena in the bottom layers, defective circuit of infiltration waters, alteration degree of the rocks, etc.;
- Exceeding the evacuation capacity of the waste heaps waters;
- Breakage of the waste heap material due to some efforts occurring in exceptional cases (earthquakes, pressures, etc.);
- Waste heaps sliding – natural disasters (earthquakes, heavy rainfalls followed by floods, etc.) can cause landslides, thus amplifying the destructive effects.

Major accidents in the case of storage sites where relevant inventories of industrial wastes are present may be triggered by seismic events, due to the damage of process equipment resulting in a loss of containment (Antonioni et al., 2007). The hazards associated to waste storage facilities are greatly amplified by the poor management of the tailings dams and waste heaps. The most frequent and common risks associated to the tailings dams are:

- failure of the dam structure and discharge of wastes;

- instability of waste heaps slopes;

- poor waters management and seepage of contaminated waters in the underground and surface waters;

- dust emissions on the shores of the tailings dams airborne and stored in water courses;

- soil erosion associated to wind and rainfall;

- dangerous chemical substances and heavy metal contamination.

Usually, in mining areas, oxidation and oxidation-hydrolysis reactions, bacterial leaching or even buffering reactions result in the increase of the solubility of heavy metals and their concentration in percolation waters is significant, leading to the pollution of groundwater and surface water, these waters being in immediate contact with the soils (Horaicu et al., 2010). Soil pollution with heavy metals is recognized today as being a significant problem, representing a major risk for human health and even for ecological systems (Damian et al., 2008).

The greatest danger induced by tailings dams is represented by the unexpected collapse, as it happened at the mines in Baia Mare and Borşa in 2000, due to overloading (Modoi et al., 2009). These are typical examples of Natech incidents, as natural phenomena (heavy rainfall and sudden snow melting) have caused dam failures. It is assumed that the risk arising from the waters that pass through the entire mass of the waste deposits (infiltration) is very high (Stumbea, 2010).

Natech accidents cause direct damages to the population present in nearby residential areas and indirect damages due to the delay of emergency rescue operations (Antonioni et al., 2009).

4. CONCLUSIONS

In conclusion, although the largest part of the investigated area is included in the weak and very weak erosion classes, one should notice a concentration of the areas very strongly affected by erosion in the area of the open pits and waste heaps.

As the vegetal cover represents the main factor controlling the erosion process, immediate measures are needed for the revegetation of the areas where the erosion presents high values, especially of the two waste heaps Hop and Valea Verde, located on the southern slope of the Cetate hill. For the control of erosion on slopes, these need to be subjected to earthworks, afforestation and revegetation. Earthworks and embankments are also necessary at the two tailing dams, especially at the Valea Săliştei tailing dam, for the control of the erosion and mass displacement processes and assurance of their physical stability. Studies have shown significant improvement of soil quality after the restoration actions in other mining regions in Romania (Horaicu et al., 2010).

Due to the proximity of residential areas (Corna village is located 1 km downstream of the Valea Verde waste heap), the mining wastes storage facilities mentioned above represent sources of risk for the local population.

The results of this study and the approach of erosion susceptibility from the Natech concept point of view represent contributions for the improvement or elaboration of strategic documents with the following objectives:

- environmental risk management,

- emergency response,

- land management and sustainable use of land resources,

- soil erosion control methods and techniques,

- alternatives for sustainable development by the use of degraded lands,

- prevention measures of some Natech events due to soil loss combined with extreme hydrological phenomena.

The paper highlights the significance of considering the complex interactions of the natural and technological components of hazards in the investigated region. This type of approach is the most efficient in assessing on-site environmental and safety risks and in preventing major mining accidents from happening.

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