Susceptibility Assessment above Underground Mining Exploitations – A Case Study in Bulqiza Mine

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Abstract: ***The sublevel open stoping mining method used in the chrome mine in Bulqizahas led to the creation of open spaces, which have been filled by the self-collapse of surrounding rocks located in the roof of the mineral body. For the Central and Southern area, the chrome ore deposit is at a relatively shallow depth of 0-100 m.The rocks of the roof have a variety of physical and mechanical properties (classified into bedrock and diluvional). The exploitable (recovered) thickness of the mineral body varies from 5 to 15 m. The horizontal and vertical extent of each ore body reaches up to 300 m and 100 m respectively and is affected by tectonics representing fluctuations from 15 to 30 m. On the ground surface of this undermined area are the presence of sinkholes and subsidence from mine roof failure. Studies have been conducted to determine the conditions leading to the development of the sinkholes and subsidence and to define the contours of the dangerous area, within which the possibility and intensity of risk vary. This paper presentsan evaluation of the susceptibilityusing a method of mapping the influencing parameters (diluvional surface, bedrock surface, ore body surface, etc.), weighting their impact based on the physical nature of the process and occurrences, superposition (Weighted Overlay) of these impacts and generation ofa quality evaluation susceptibility map. Mapping of the influencing parameters and the evaluation of the susceptibilityis performed using GIS technology.***

Keywords: Susceptibility, sinkhole, subsidence, mapping, GIS.

1. Introduction

The impact of underground mining exploitations on the ground surface has continuously drawn the attention of researchers, who have attempted to determine the nature of the impact and to estimate the extent of this influence, as well as to take appropriate measures to reduce or eliminate any harmful effects that mayendanger the lives of people and animals, damage the environment, or have an impacton the various facilities that occupy the surface of mining regions [1] - [5]. In this context, a number of methods have been developedto determine:

- Components of displacement (subsidence, horizontal displacement);
- Deformation parameters (slope, curvature, compression, traction, etc.);
- Conditions of stability of the surface over underground exploitation;
- The degree of danger for people and infrastructurein the mining region.

The development of technology for the acquisition, processing and visualization of data has also had an important impact on the modelling of the influences through the automation and standardization of the process[2],[6].

The methods used so far in Albania for determining the degree of danger to the surface from underground exploitations within the mining region have taken into consideration the adaptation of known models by measuring or calculating the determinant parameters [1],[3],[4].

The major types of influence of underground abandoned exploitations in Albania are categorized as subsidence troughs for nearly horizontal coal deposits [1],[3], sinkholes and chimney caving for coal deposits in steeply dipped beds (over 40°), sinkholes, block caving and sometimes progressive hanging wall caving for metallic chromium and copper deposits [1]. In all cases of underground exploitations where there was an impact on the ground surface, the depth of exploitations has been less than 100 m, classifying such exploitations as shallow.

2. Presentation of the Approach for Evaluating Susceptibility

This paper will consider the method of evaluation of susceptibility by weighting the influencing factors and their superposition (weighted overlay). The parameters taken into account for the implementation of this method are:

- The thickness of the exploitable ore body;
- Thickness of the bedrock over underground; exploitations (ultrabasic rocks, dunites, peridotites and piroxenites);
- Thickness of diluvional rocks;
- Physico-mechanical properties of rocks.

Regarding the dip ofthe ore bodies and the tectonics, it is judged that their weight will be taken into accountthroughthe size of underground cavities.

There are a variety of studies that have illustrated the relationship between these influential factors in a suitable model. Kuznjecov et al. [4] andRuff [7]have listed a number of methods that have given satisfactory results. Our intention was to use a method that provides fast acquisition of data, accuracy of obtained values, reliability in use, standardization in structuring of data, automation in performing the processing, visualization of results and verification of the accuracy of results.
Based on a review of several methods used to assess susceptibility [8], mainly in the analysis of landslide hazard

assessment, we focused on methods of indexing [7] used in the analysis of the landslide susceptibility on a regional scale in the Vorarlberg region of the Eastern Alps,accepting the hypothesis that the physical phenomenon of the process is the same and that theoverall conditions of the two mining regions are not substantially different.

The acquisition, processing, evaluation and visualization of data are performed using the computer program modules of ArcGIS,using the following steps:

a) Digitization of points for the construction of surfaces of:
- The relief;
- The contact between the diluvional rocks and the bedrocks;
- The contact between the bedrock and the roof of the ore body;
- The contact between the floor of the ore body and the surrounding rocks;

b) Construction of surfaces via IDW interpolation (Inverse Distance Weighted);
- Reclassification of surfaces via the geo-processor "Reclassify";
- Weighting of parameters based mainly on the physical nature of the process and the reproduction of previous cases;
- Superposition of weighted results using the geo-processor “Weighted Overlay”;
- Visualization of the susceptibility;
- Verification of the outcome based on previous cases.

3. The use of the method in the Central and Southern region of Bulqiza Chromite Mine

3.1 Presentation of the Mining Region

The chromite deposit of Bulqiza is located in northeastern Albania in a mountainous region with an altitude of 800 – 1,200m above sea level (Fig.1). Bulqiza's deposit is situated in ultrabasic rocks. The mining field is composed of three areas: Northern, Central and Southern (Fig.1).

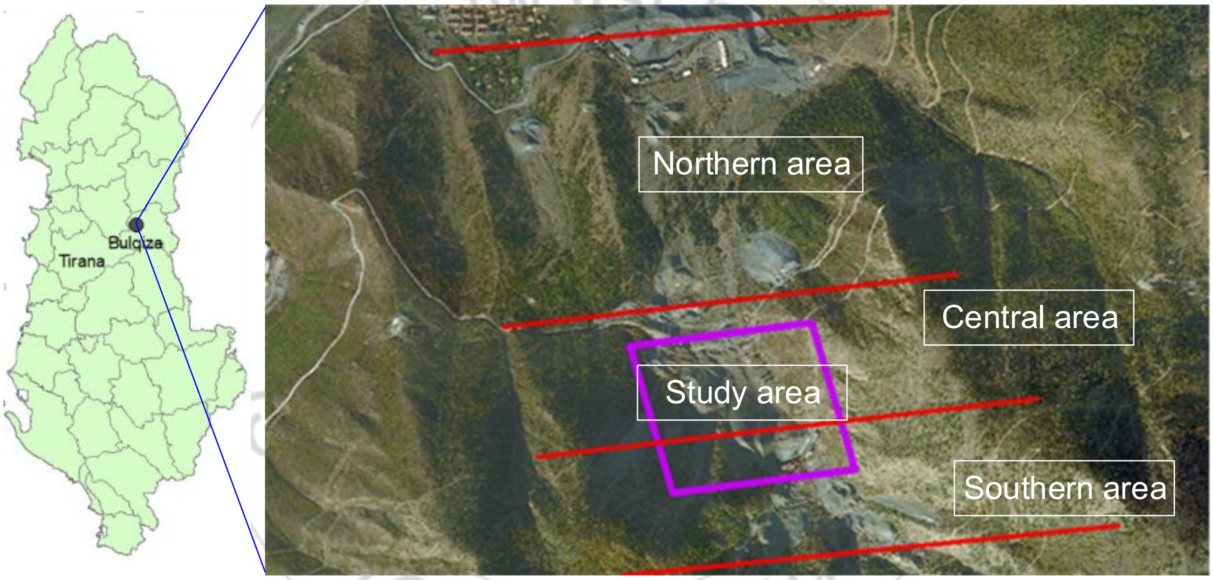


Figure 1: Bulqiza chromite mine and conventional administrative division of the mining region

From the geological point of view, the Bulqiza chromite ore bodies have undergone numerous episodes of deformation and are strongly folded and faulted. As a result of folding, the geological structure is characterized by a succession of anticlinal and synclinal structures, forming flanks with a dip between 18 and 85 degrees (Fig.2). The ore bodies represent the elements of the structure with a more stable dip, while the possible changes inside the bodies are called flanks. Their conventional designation refers to the position towards the central part of the geological structure. The geologists who have studied this chrome deposit haveidentified the following ore bodies (Fig.2):
- Central ore body (C)
- Eastern ore body (E)
- Western ore body (W)

In this configuration only the Central ore body is characterized by a stable dip and for this reason it is considered unique, while the Eastern and the Western ore bodies are split in flanks. Hence, for the Eastern ore body (E), the designations First Eastern (E_I) and Second Eastern (E_{II}) are used, each having five flanks. The Western ore body (W) is considered a “fragmented” ore body in five flanks, W_I, W_{II}, W_{III}, W_{IV} and W_V, respectively.

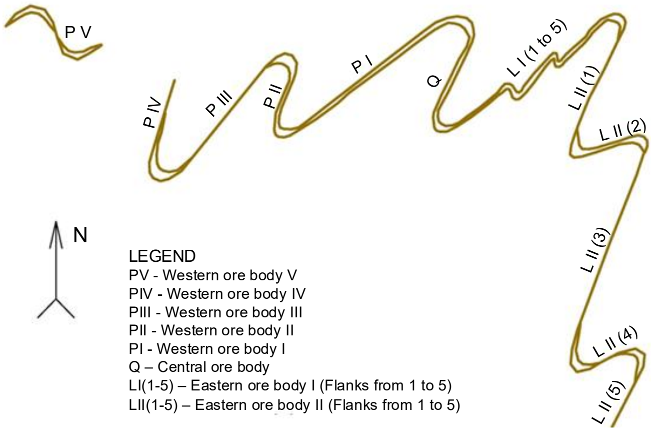


Figure 2: Schematic profile to identify ore bodies and flanks

The exploitation of the deposit began in 1948 and so far more than 13 milliontonnes have been extracted. The drillings show that the perspective of the mine at greater depth is hopeful. The exploitation system used isthe open stoping mining method (Sublevel Open Stoping). This system, which utilizes simple technology, is however characterized by high extraction rates and efficiency. Since the geological conditions of the chrome-bearing structure in this mine vary considerably, its technical and engineering staff have tested several variants of this system in order to reduce ore losses, increase safety at work and ensure higher extraction efficiency. The exploitation has almost ended in the Southern and Central areas and continues in the Northern area in what is called "the depth of Bulqiza".

As result of the sublevel open stoping mining exploitation method, the mined-out space created is left unfilled, being subject to uncontrolled roof collapse.The fill that occurs later due to the fragmented rock coming from the roof is very hazardous. The evolution throughtime of the process is still unstudied, while, in some cases, as a result of the roof collapse, the caving progression reaches the surface as a sinkhole or subsidence (Fig. 3, Fig. 4). Such a phenomenon presents a high risk to people's lives and to the various infrastructure developments in the region (such as a processing plant, workers' dormitories, administrative buildings, local transport routes, etc.).

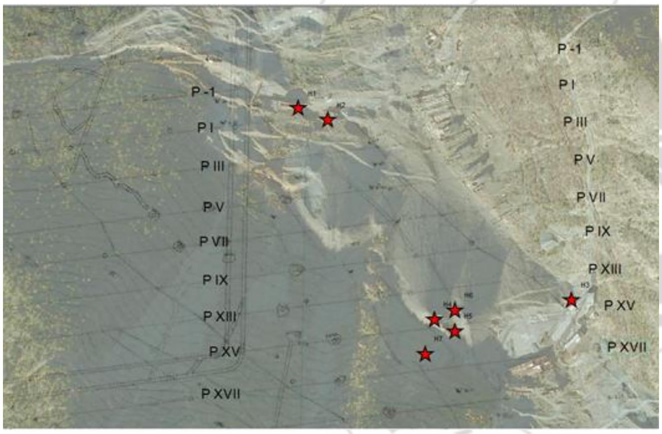


Figure 3: Position of sinkholes arising in Central area

As a result of this phenomenon, the Central and Southern areas have been declared dangerous and studies have been conducted in order to evaluate the potential locations of upcoming sinkholes. The adapted models method (empirical method) [4] has been used in this regard, considering the following parameters: thickness of the exploited ore body, horizontal projection of the open space created by the exploitation and the physico-mechanical properties of the rock mass [1], [9].

3.2 The Problem Statement

The assessment of susceptibility, i.e. the probability of risk to the ground surface of the studied area, is dictated by the sinkhole exit on the ground. In order to understand the process of sinkhole exit on the ground, the previously occurring sinkholes were first mapped out (Fig.4). Next, the conditions of their occurrence were analysed. This analysis showed that the main factors contributing to the appearance of the sinkholes are the parameters taken into account for the implementation of the method.

Figure 4: View of a sinkhole that emerged in the Southern area

3.3 The acquisition of data

For the acquisition of data, the graphic documentation that served as the basis for digitization was first provided.

The graphic documentation provided by the mine of Bulqiza consisted of:

- Drawings of mining openings at scale 1:1,000;
- Vertical projections and profiles every 50m at scale 1:1,000;
- Vertical projections of ore bodies and flanks at scale 1:1,000;
- Map of the mining area at scale 1:2,000;
- The orthophoto of the region with a 35cm pixel resolution.

The structuring and processing of data using the ArcGIS computer program was then carried out. Specificities on the creation of a database for the case study are related to:

- Creation of a "Personal Geodatabase" in the structure of ArcCatalog;
- Insertion of raster format documentation in the "Personal Geodatabase";
- Transformation of coordinates from the local system "Bulqiza" to the UTM system;
- Creation of the file "Feature Dataset";
- Digitalization of ore bodies in profile and the creation of "Feature Class" files for the ore bodies' contours (ArcMap);
- Digitalization of tectonics in profile and the creation of "Feature Class" files for the tectonics (ArcMap);
- Digitalization of mining openings in profile and the creation of "Feature Class" files for the mining openings (ArcMap).

The following were then created (Fig. 5):

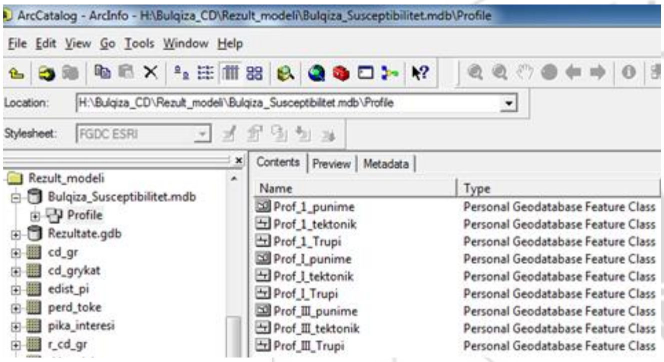
- Personal Geodatabase "Bulqiza_Susceptibilitet"
- Feature Dataset "Profile"
- Feature Class "Prof_X_Trupi"
- Feature Class "Prof_X_tektonika"
- Feature Class "Prof_X_punimet"

where the variable“X“takes the values of the number of profiles, -1, I, III, V, VII, IX, XI, XIII, XV and XVII respectively.

3.4 Processing of the Database

For processing of the database,the Personal Geodatabase “Bulqiza_Susceptibilitet” was used, creating within it the Feature Dataset “Pika_Siperfaqe” and the Feature Class files “Pika_Relievi”, Pika_Deluvione”, Pika_Rrënjësor”, “Pika_T1”, “Pika_T2”, “Pika_T3”, “Pika_T4”, “Pika_T5” and “Pika_T6”.

In these files all the characteristic points of the relief were memorized, as well asthe contact surface between diluvions and the bedrock, the contact of bedrock with the ore body and the contact of ore bodies with the rock floor. The visualization of these files was made in ArcMap. Figure 6 shows the points used for the construction of the contact surface between the diluvions and the bedrock.



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  edist_pi
  perd_toke
  pika_interesi
  r_cd_gr

Name	Type
Prof_1_punime	Personal Geodatabase Feature Class
Prof_1_tektonik	Personal Geodatabase Feature Class
Prof_1_Trupi	Personal Geodatabase Feature Class
Prof_I_punime	Personal Geodatabase Feature Class
Prof_I_tektonik	Personal Geodatabase Feature Class
Prof_I_Trupi	Personal Geodatabase Feature Class
Prof_III_punime	Personal Geodatabase Feature Class
Prof_III_tektonik	Personal Geodatabase Feature Class
Prof_III_Trupi	Personal Geodatabase Feature Class

Figure 5: Files created for storing the data

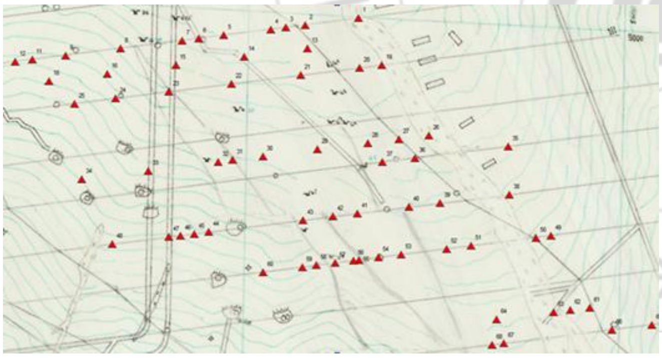

Figure 6: Points utilized to create the contact surface between the diluvions and the bedrock

Tectonics were used to control the borders of space, which were regionalized as separate if the tectonic width exceeded 15 m, which it did not in our case. For the “Feature Class” files, the folded structure of the chromite deposit was taken into consideration. Hence, during the digitalization, the points of the roof and the floor of the ore body were memorized separately for each body, consequently eliminating duplication in the visualization of surfaces and providing clarity in presentation.

After the creation of “Feature Class” files, the construction of the corresponding surfaces was conducted:

- The relief, was labelled “Sip_relievi”
- The contact diluvions-bedrock, was labelled “Sip_deluvione”
- For the contact of bedrock with the ore bodies roof, “Sip_rrënjësor”
- For the contact of ore bodies’ floor with the bedrock floor, “Sip_trupi X”

All surfaces were constructed through IDW interpolation (Inverse Distance Weighted). Figure 7 shows the contact surface obtained between diluvions and the bedrock.

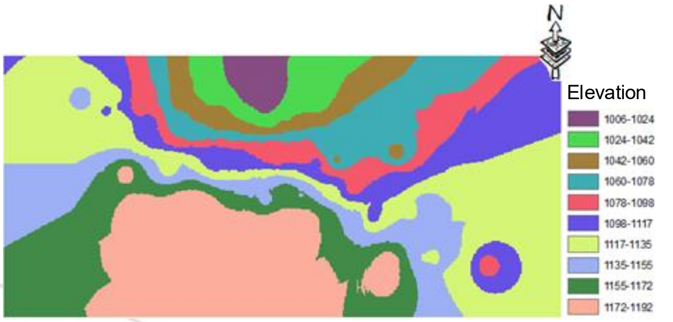

Figure 7: Surface obtained by IDW interpolation of characteristic points representing the contact between diluvions and the bedrock

3.5 Assessment of Susceptibility

The assessment is performed according to the following geo-processing:

- IDW interpolation to create surfaces of relief factors, diluvions, bedrocks and ore bodies using as input the elevation of points of the corresponding surface;
- Reclassification of product “surface”, enabling the weighted overlap assessment (weighted overlay);
- Weighted overlapping for the factors ofdiluvions, bedrock and ore bodies;
- Mapping of product “susceptibility”.

The modelling was performed by processing using parametric models (Fig.8).

The overlapping process was conducted giving weight of influence to the factors.

We based the process on geostatisticalconsiderations of each factor and recommendations given in the literature [7], [10],[1].

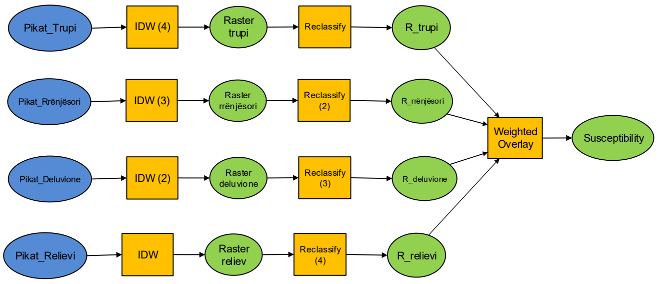

Figure 8: Parametric modelling for the assessment of susceptibility

The following weights were admitted:

- For the thickness: 42% (the influence of six flanks of the ore body was added). The flanks were mapped separately for the purpose of providing clarity on their surfaces.

- For diluvions: 33%
- For the bedrock: 25%
- For the relief the coefficient was taken to be 0%, because the Bulqiza structure in this area plunges almost parallel to the relief. The changes in depth are considered by the thickness of the diluvions.

To verify the results of this evaluation, the measurements from mapping the sinkholes that occurred in this area were used.

Figure 10 shows that, of seven sinkholes issued at Bulqiza, five of them fall into the very strong danger zone and two fall into the weak danger zone. After observing the concrete conditions of the occurrence of these two sinkholes, it is concluded that they are in an area where human activitieshave been very intense. These sinkholes first emerged in the 1970s, at the same time as the installation of a chrome enrichment plant in the area, close to which, therewas a motorway connecting the first zone with zone D (the rolling of the trucks loaded with chrome ore during this period was very intense).

The comparison of the model with these data shows its accuracy (rightness). Attention is also drawn to the immediate transfer of vulnerable buildings even if the risk level is not too high. The result of the evaluation is presented in Figure 9.

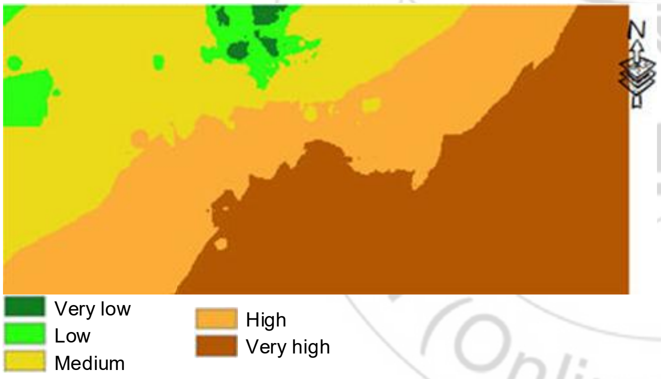

Figure 9: Susceptibility map (study area)

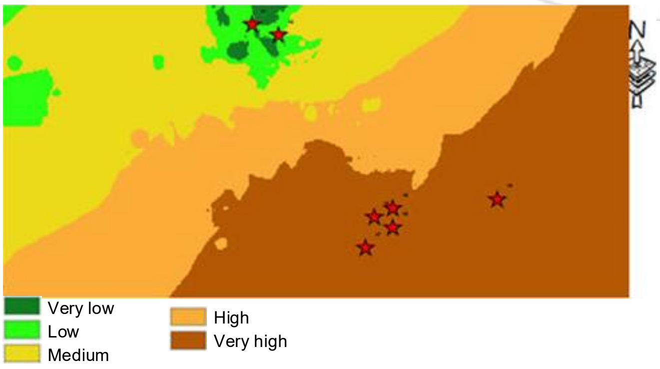

Figure 10: Susceptibility map and the sinkholes that are present in the area (study area)

4. Conclusions

The method of indexing based on the mapping of influencing parameters and the weighting of their impact on the assessment of susceptibility can also be used to determine the effect of abandoned mining exploitations on the ground surface.

The method used has advantages for the automation and standardization of the process of acquisition, management, processing, analysis and visualization of data.

The modelling of the influencing factors by this method refers to the real position of their occurrence (depth in relation to the ground surface).

The weighting of influencing factors is indexed relying not only on the reproduction of previously occurring cases, but also on the physical nature of the process. Therefore, diluvions receive greater weight than the bedrock because it is clear that if the progress of rock failure reaches the diluvions, then the probability of a sinkhole appearing is greater than the development of the same process within the bedrock.

Comparison of the modelled results with the previously occurring cases statistically confirms the fairness of the proposed method.

Since the phenomenon of the appearance of sinkholes over underground mining exploitations is typical for metal deposits located at arelatively shallow depth from the ground surface, the use of this method can also be extended to these kinds of deposits.

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