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Geomorphological Risk and Denudational Index (Land Erodability) in Karstic Terrain of Anina Mining Area (Banat Mountains, Romania)

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Abstract

Anina Mining Area was defined by Vasile Sencu in 1977 as the area that is surrounding Anina town and may be exploited by mining activities.
The aim of this paper is to present two parameters regarding geomorphometry in Anina Mining Area, naming here Geomorphological Risk and Denudational Index (Land Erodability Index). These two morphometric parameters are obtained using geomorphological parameters that we obtained in previous works, as slope, hypsometry, drainage density, depth drainage and morphodynamic potential. The methodology to derive Geomorphological risk and Denudational index (Land Erodability Index) is based on GIS techniques.
The results we obtained point out that the study area of this paper is a region where parameters such as geomorphological risk and denudational index have small incidence. This fact is due to the large homogeneous areas from the standpoint of geology and land cover, but also as an effect of large surfaces with a planar aspect as karstic plateaus.
From the analysis of these two parameters we must conclude that Anina Mining Area represents a space with small surfaces which are prone to risks associated with geomorphological process and also with small areas where denudation may have high rates due to the large areas where vegetation is present and also due to large plateaus where the primary processes are related to karstification, and these ones are very slow processes.

Keywords: *karst, morphometry, applied geomorphology, Anina*

Rezumat. Riscul geomorfologic și erodabilitatea terenului (indice de denudare) în carstul Câmpului Minier Anina (Munții Banatului, România)

Câmpul Minier Anina a fost definit de către Vasile Sencu (1977) ca arealul din jurul localității Anina, care poate fi valorificat prin activități miniere.
Scopul acestei lucrări este acela de a prezenta doi parametri referitori la geomorfometria în Câmpul Minier Anina, numind aici riscul geomorfologic și indexul de denudare (erodabilitatea terenului). Acești doi parametrii morfometrici sunt obținuți folosind parametrii geomorfologici pe care i-am obținut în lucrări anterioare, precum panta, hipsometria, densitatea fragmentării reliefului, adâncimea fragmentării reliefului și potențialul morfodinamic. Metodologia de obținere a riscului gemorfologic și a indicelui de denudare (indicele de eroziune a terenului) s-a bazat pe tehnici S.I.G.
Rezultatele obținute scot în evidență faptul că arealul care face subiectul acestui studiu de caz este o regiune unde parametrii precum riscul geomorfologic și indicele de denudare au o incidență redusă. Acest lucru se datorează suprafețelor întinse omogene din punct de vedere al geologiei și al utilizării terenului, dar și suprafețelor întinse cu aspect plan cum sunt platourile carstice.
Din analiza acestor doi parametri putem concluziona faptul că arealul Câmpului Minier Anina reprezintă o regiune cu suprafețe reduse predispuse riscurilor asociate proceselor geomorfologice și, de asemenea, acest areal are suprafețe mici unde indicele de denudare are valori ridicate ca urmare a faptului că există suprafețe foarte întinse acoperite cu vegetație și ca urmare a întinselor platouri carstice unde principalul proces, carstificarea, este un proces foarte lent.

Cuvinte-cheie: *carst, morfometrie, geomorfologie aplicată, Anina*

Introduction

Geomorphology is dealing with understanding the processes that are modelling ground surface, the forms that result and the history of its development (Ford & Williams, 2007). Karstic geomorphology is concerned with the study of landforms, both on the surface and underground, that are developing on carbonate rocks as an outcome of dissolution and other processes related to dissolution (De Waele et al., 2009). Geomorphic processes developed on karst terrain slopes are different than those developed on slopes of other geomorphic systems. Processes on karst terrain slopes are determined simply by mechanical and chemical weathering of bedrock, mass movement and the accumulation of weathered material at footslope (Stepisnik & Kosec, 2011).

Geomorphological risks, natural hazards and disasters are one of the main topics in research area of environmental science during the last decades. Demek et al. (2006) have developed a study regarding geomorphological hazards and risks in the Czech Republic; Alcántara-Ayala, I. (2002) dealt with geomorphic hazards, vulnerability in developing countries; De Waele et al., (2011) have written a review about geomorphology and natural hazards in karst regions.

Mountain areas present very high morhophodynamic energy. Nowadays some mountain regions tend to be overexploited, being supposed to “release” this energy as extreme processes, hazards or disasters (Heuberger & Ives, 1994).

Increasing our knowledge regarding karst geomorphology and hydrology helps us to live with karst, instead of living on karst, for a sustainable use of karst resources in the near future (De Waele et al., 2011).

In areas with high recreational attractions, we should pay attention to the risk that might occur in the interaction of geomorphic processes. The assessments of these risks are rather significant in regions with high relief dynamics (Blinova & Bredikhin, 2013).

In Romania, there are also studies regarding geomorphological risks, most of them about landslides: Bălteanu et al. (1996); Micu & Bălteanu (2009); Bălteanu et al. (2010); Grecu & Sandu (2012). But regarding geomorphic risks in karst areas, papers are missing, even if Romania has many interesting karst regions.

The aim of this paper is to present two parameters regarding geomorphometry in Anina Mining Area, naming here Geomorphological risk and Denudational index (Land Erodability Index). These two morphometric parameters were obtained using geomorphological parameters that we obtained in previous works, as slope, hypsometry, drainage density, depth drainage and morphodynamic potential. The methodology to derive Geomorphological Risk and Denudational Index (Land Erodability Index) is based on GIS techniques.

These parameters involve in their analysis some other elements related to geomorphometry. It is worth mentioning slope, land use, geology, and morphodinamic potential. Some of these parameters such as slope (Artugyan, 2013) and morphodynamic potential (Artugyan, *in press*) were obtained in previous works.

Morphometric and morphographic aspects are decisive for the importance of percolation water flow, especially in karst terrains. Planar surfaces in karst terrains are more prone to develop karstification processes. Among the terrain parameters, slope, drainage density, drainage depth, orientation and sinkholes (Ilie, 1970b) are the most important in karstification processes.

Limestones are subject to dissolution processes, independently of slope conditions. In forested areas, even if carbonate rocks are covered with soils (rendzinas), they are conditioned by slowly dissolution processes, because humic acids have easy access through water at the contact with the bedrock (Mihai, 2005).

The density and size of sinkholes indicate the degree of dissolution that geological substrate has undergone locally (Shofner et al., 2001).

Study area

Anina Mining Area is situated in the South-West of Romania, within the Banat Mountains, more precisely in the centre of a subunit of Banat Mountains, Anina Mountains (Fig. 1).

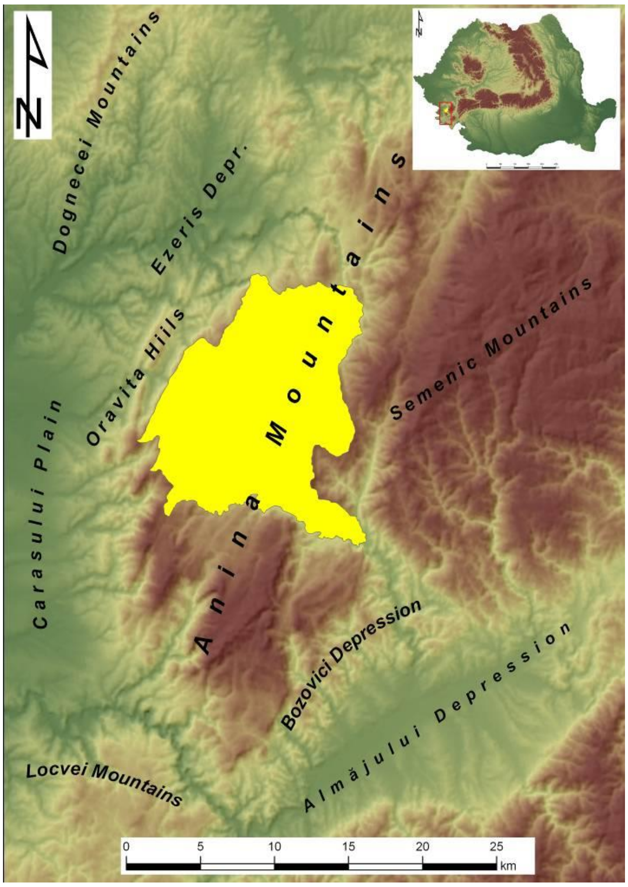

Fig. 1: Location of the study area in Romania and in Banat Mountains

Anina Mining Area was defined by Vasile Sencu in 1977 as the region that is surrounding Anina town and which may be exploited by mining activities. The paper of Sencu (1977) regarding Anina Mining Area is a work based on two previous papers regarding two important karstic regions situated in this area: the first was about the karst of Anina and Buhui creeks (Sencu, 1963) and the second was about the karst region of Steierdorf and Ponor creeks (Sencu, 1964). Based on his surveys, after many years of field work and geomorphological approaches, Sencu also published a tourist guide where he presented Anina Mountains from the tourist's point of view (Sencu, 1978).

Anina Mining Area is located in the central area of Reșița - Moldova Nouă Synclinorium, the largest and most compact surface covered by carbonate rocks in Romania (Orășeanu, Iurkiewicz, 2010).

Based on the geology, our study area is located in the structural Reșița - Moldova Nouă

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Synclinorium, in the geographical unit of Anina Mountains (Fig. 2a).

The large number of faults is favourable in the karstification processes. Faults orientation is passed on the main drainage direction. These tectonic features act as boundaries between the main karst systems in the region (Iurkiewicz et al., 1996a).

The relief shows an alternation of limestone ridges and plateaus, separated by deep valleys that succeed from West to East in the focusing of the geological structure, NNE-SSW. The main orientation is very well explained by the rose diagram that is showing the large number of faults that are imposing the general aspect of the morphology. Some faults orientated W-E acts as brakes in the relief continuity. The development of large areas with a high degree of fragmentation has as consequences peaks and disorganized valleys (Fig. 2b).

In the past, this region was very significant for the Romanian economy due to the coal reserves. Nowadays Anina karstic area is a very poor one, with many social and economic problems. This state of affairs is the consequence of the fact that in 2006 the mining activities were closed. Tourism appears to be one of the best options to revitalize this karstic region, but the development of tourism should be done based on sustainable principles.

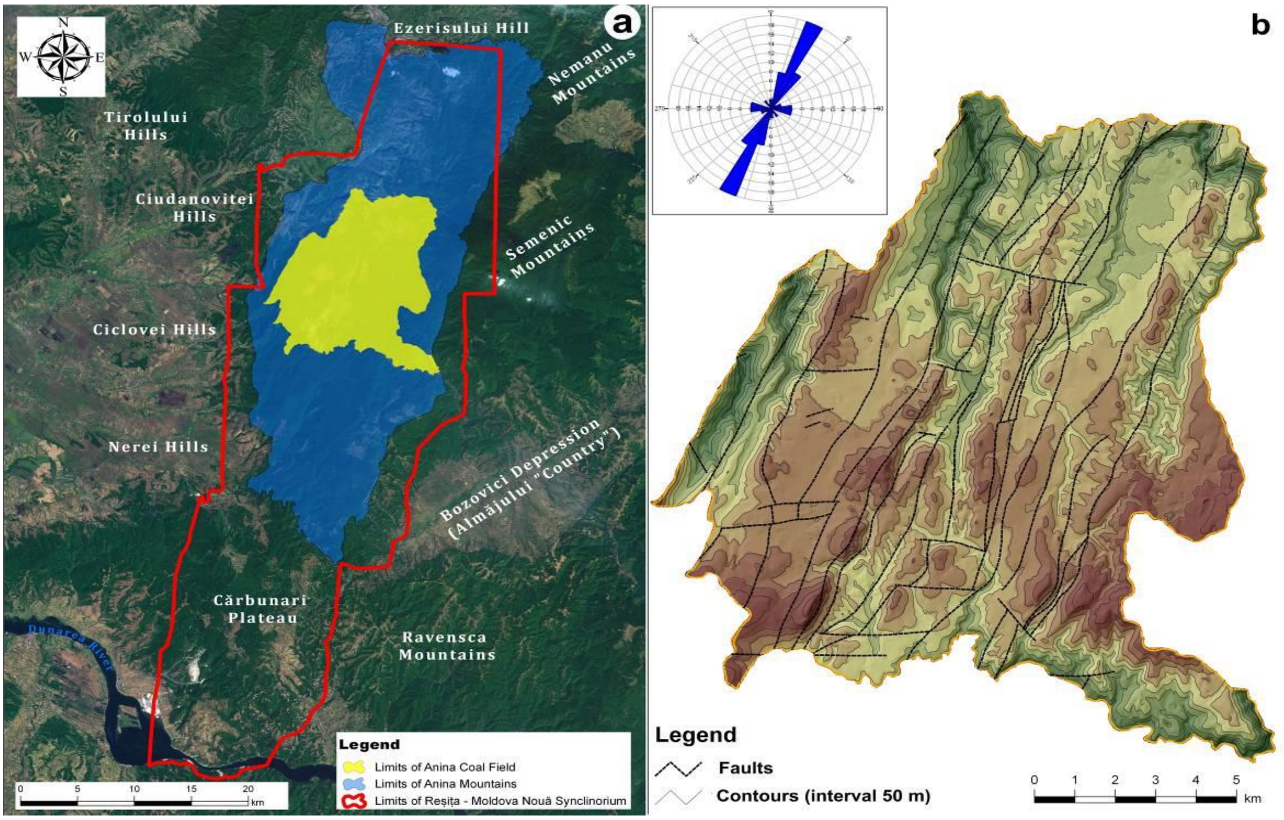

Fig. 2: Location of Anina Mining Area within structural area of Reşiţa - Moldova Nouă Synclinorium, in the centre of the geographical unit of Anina Mountains (a); the main aspect of morphology and the main orientation of relief in Anina Mining Area (b)

Research methodology

We have chosen to determine two morphometric parameters as a preliminary study in the Anina karstic area to identify using GIS methods those areas that presents high risks as consequence of different geomorphic processes.

Materials

To obtain these two parameters we used as materials topographical maps of scale at 1:25,000, a karstic map of the Anina Mining Area of scale at 1:50,000 (author Vasile Sencu, 1977), a geological map of scale at 1:50,000, L-34-104-D-121d Anina (National Geological Institute) and Corine Land Cover data from 2006 (http://www.eea.europa.eu).

Data

All the input data necessary to derive geomorphological risk and denudational index were generated from the materials mentioned above. A DEM was obtained by extracting contours from the topographical map's scale of 1:25000 and then we interpolate these isolines using Topo to Raster tool from ArcGIS 10. Using the DEM we generate hypsometry, slope, orientation and drainage depth. The next step was to involve in our analysis hydrographic network to obtain drainage density. These parameters were used to derive morphodynamic potential.

We also need litohology in our analysis. We referenced the geological map L-34-104-D-121d Anina, and then digitized the lithological units from this map. To be able to utilize in our work, we used the Conversion tool from ArcGIS 10 to transform the vector information into a raster one.

The data regarding land use and land cover was downloaded as vector data. To be usable with the other data, we performed again a conversion to raster format, to induce the entire data into a raster format. The next step in our processing methodology was to reclassify the raster data into the same number of classes, to be able to introduce in a map algebra operation in ArcGIS.

The last step was to overlap the sinkholes as points on geomorphological risk parameter and denudational index. These karstic depressions are the most specific surface karst features present in the Anina Mining Area. We intend to observe the distribution of these features regarding the two geomorphological parameters. The karstic depressions were extracted from the karstic map of Anina Mining Area scale at 1:50000 (author Vasile Sencu, 1977) as points. Using Extract Values to Points tool from ArcGIS 10 we counted the number of sinkholes that are situated in different classes of those two geomorphometric parameters.

Working steps

Geomorphological risk (Gr)

To obtain the geomorphological risk we should take up a workflow presented in brief in figure 3. This index is based on the next formula:

$$Gr = \sum (S, Mp, LU, L), \text{(Mihai, 2005)},$$

where:

Gr – Geomorphological risk;

S – Slope;

Mp – Morphological potential;

L – Lithology;

LU – Land use.

We reclassified the following parameters: slope, land use, potential morphodynamic and geology. These parameters were used in the formula given above (Mihai, 2005). Reclassification involved a type of sorting of different classes within a parameter on the basis of their contribution toward geomorphological risk parameter.

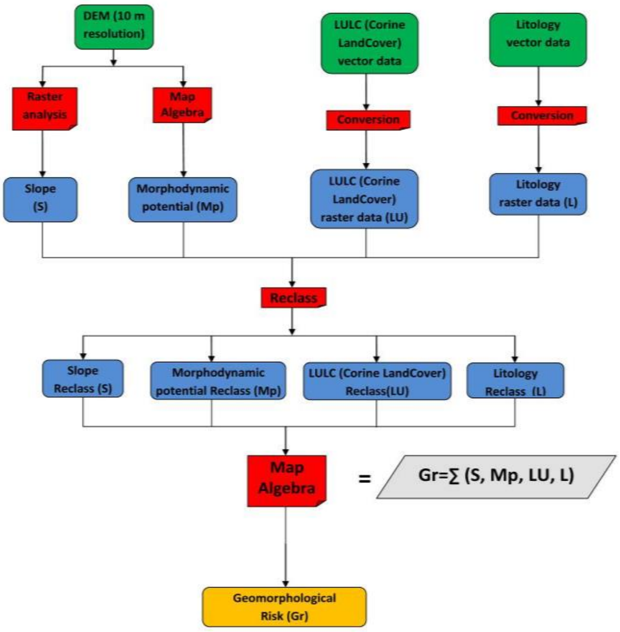

Fig. 3: Workflow to obtain the geomorphological risk (Gr)

The Gr map is the result of algebraic operations with the reclassified parameters obtained before (Artugyan, 2013). In the final map, a pixel value represents the Gr, as areas with small, medium or large risk. Parameters have been set so that the slope represents the value of thousands (for small slope there is low risk and the value is 1000, and for high slope thre is high risk, value 3000), land use for hundreds (with values range between 100 and 300), the potential morphodynamic represents order tens (range between 10 and 30) and rocks the units (between 1 and 3). The last step was to sum the before mentioned parameters, to obtain the geomorphological risk.

Denudational Index (Di)

Terrain erosion, defined as the moving process on slopes of soil elements, rocks, eluvials, deluvials, becomes a highly economic problem. Terrains degradation, independently of terrains use, is characterized by soil loss and is requiring activities for protection (Latulippe & Peiry, 1996).

The goal of GIS analysis regarding terrain denudation is to generate a cartographic representation, to locate and estimate those areas with high rates of vulnerability. The steps to derive the denudational index are presented in the next workflow (Fig. 4). We have reclassified geomorphological risk, slope, land use, potential morphodynamic and geology. The vulnerability to erosion index needs an additional element to be derived, the geomorphological risk, which was obtained earlier.

The reclassification of the parameters used in the calculation of denudational index is based on Table 1 (after Mihai, 2005), which was adapted to our study site.

Table 1: (modified after Mihai, 2005)

Morphodynamic Factor	High Denudation	Average Denudation	Low Denudation
Geology (Lithology)	Gravels, sands, marls, flysch	Conglomerates, sandstones	Limestone
Slope	20-90°	5-20°	Smaller than 5°
Land Use	Pastures and meadows, thickets, settlements, land erosion	Pastures and meadows, glades, thickets, orchards and meadows	Forests
Morphodynamic potential	Slips, disintegration, collapse, torrents	Wash in surface, torrents	Wash in surface, alluvial
Geomorphologycal risk	High	Average	Low

Using the next formula, we may obtain the denudational index (Mihai, 2005):

Di = ∑Div (S, L, LU, Mp, Gr), (Mihai, 2005), where:

Di - Denudational index
Div - Denudational index variables
S – Slope
L - Lithology
LU – Land Use
Mp - Morphodynamic potential
Gr – Geomorphological risk

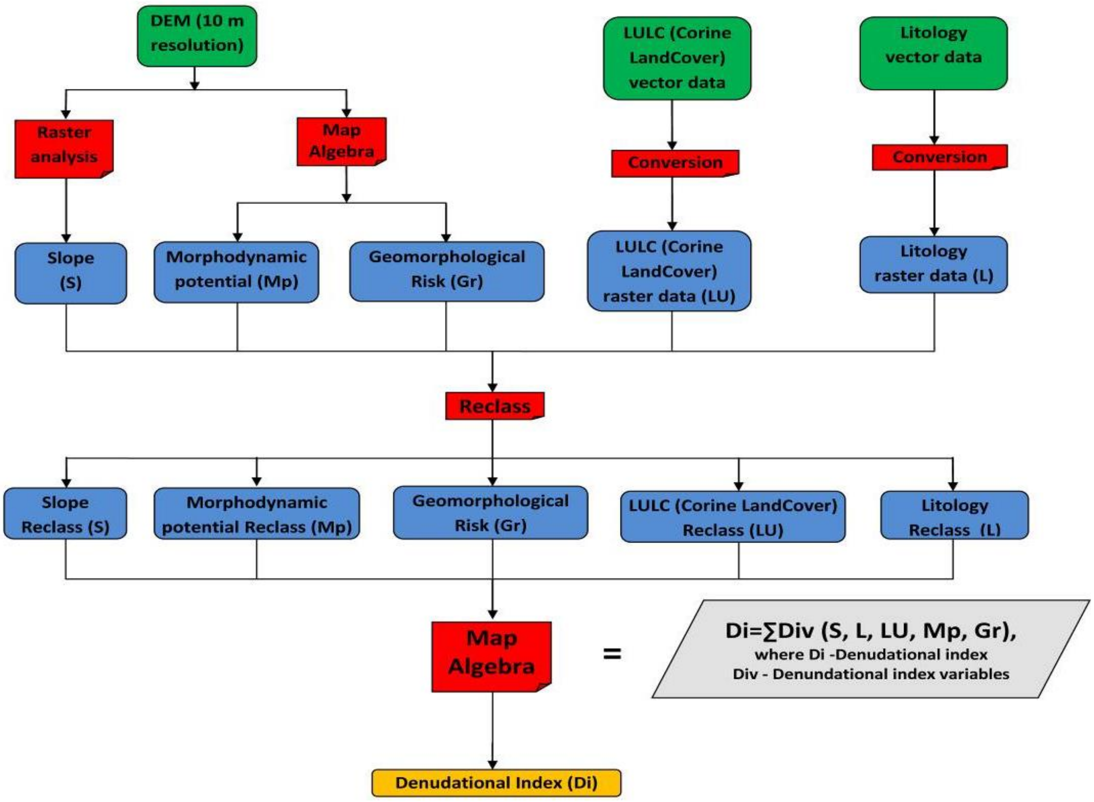

Fig. 4: Workflow to obtain the denudational index (Di)

Results

The results obtained are influenced by the parameters involved in the analysis. The most important factor is slope which is decisive in both parameters because steep slope favoursthe production of different processes that may be seen as a risk from the geomorphologic perspective, but also favourable for erosion, denudation.

Geomorphological Risk (Gr)

Due to the classification of the parameters included in the geomorphological risk, the final result is also reclassified into the following three categories:

a. Areas with high risk are representative for those areas where on the map are located deep valleys and gorges (Caraș, Celnicul Mic, Jitin, Gârliște, Buhui) (fig. 5b), based on slope parameter and a morphodynamic potential index. These areas cover a little more than 6% of the total region (Fig. 6). Some other areas with high risk are Crucii Hill, Tâlva Ştefan Hill, Tâlva Zânei Hill (Fig. 5b).

b. Medium-risk areas cover those surfaces which ensure the transition from the steepest slopes to the planar surfaces located in the karstic plateaus (Fig. 5b). The percentage of these values confirms the map because it covers more than 48% (Fig. 6). Such areas we may find in Marila area, in Moghila Hill, on Cârneală Plateau and on the Mociur Hill.

c. Areas with low risk are found in most planar areas, naming here the karst plateaus (Brădet, Colonovățul Mare, Colonovățul Mic, Ravniștea Mare, Mărghitaș) where the slope is very small, and also morphodynamic processes are given very small values. Due to large areas that are representing these plateaus, areas with low geomorphological risk values covers more than 45%.

Sinkholes are located especially in areas with low risk and only a few of them are situated in areas with medium risk (Fig. 5a). We counted a total of 975 sinkholes on the map and 781 of them (80.1 %) are overlapping areas with low Gr, 198 (20.3 %) sinkholes are situated in medium risk and 4 (0.5 %) in high risk areas. This data are valuable because they point out that in this karstic region geomorphological risks based on DEM analysis are prone to appear in regions with rich valleys and gorges, excluding karstic plateaus.

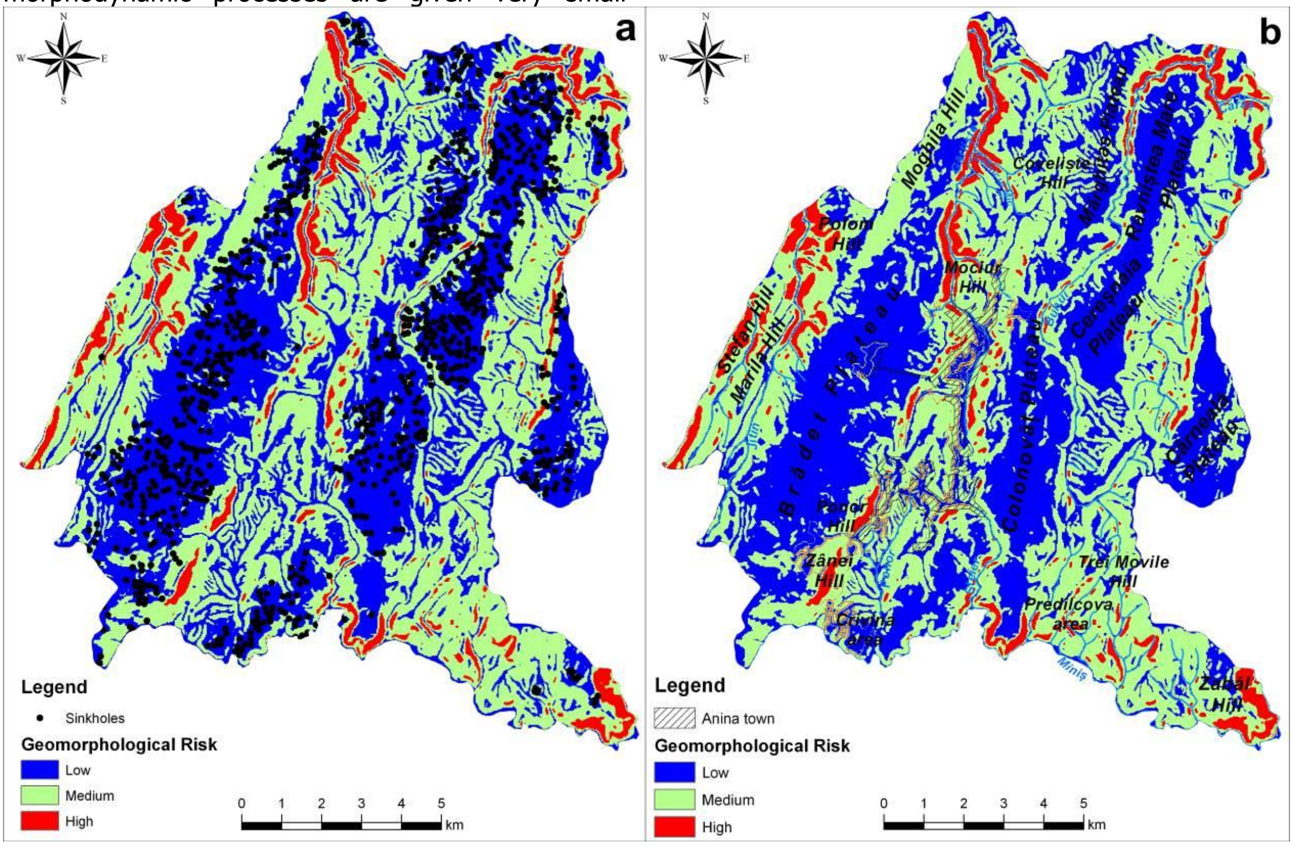

Fig. 5: Geomorphological Risk parameter and sinkholes in Anina Mining Area (a); Geomorphological Risk parameter and most representative sites in Anina Mining Area (b)

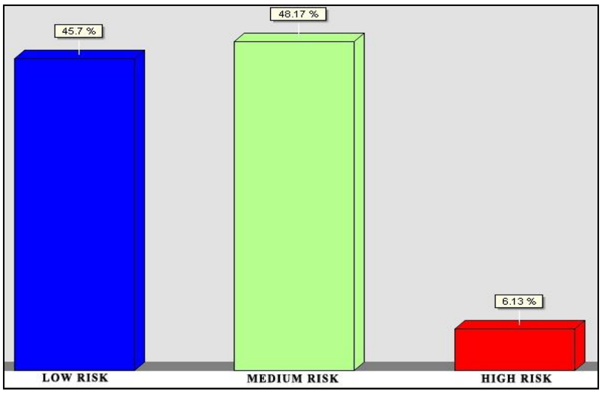

Fig. 6: Histogram of Geomorphological Risk parameter

Denudational Index (Di)

Slope terrain is the main factor that is imposing the land erodability or denudation. Besides, denudational index is highly influenced by morphodynamic potential and geomorphological risk parameters. Higher values for those parameters will also give a higher value for Di, because dynamic processes on terrain are sometimes given by erosional processes.

Founded on the workflow presented above (Fig. 4) and on the parameters involved in the analysis,

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the result of the denudational index was be also reclassified into three classes:

a. Areas with high denudation index.

These areas are located near or along the valleys and gorges (Caraș, Celnicul Mic, Jitin, Gârliște, Buhui). This is due to the slope parameter which in these regions has favourable values for erosion due to the inclination of the slope (Zabăl Hill, Tâlva Ponor Hill, Tâlva Zânei Hill or Tâlva Ştefan Hill) (Fig. 7b) and also due to the fact that most of these surfaces are covered with bare rock and the vegetation is often missing. The high denudation index covers nearly 9% of the studied area (Fig. 8).

b. Areas with average denudation index cover surfaces that are making the transition between planar plateaus and deep valleys (Fig. 7a). These regions are defined by parameters as slopes, geomorphologycal risk and morphodynamic potential with medium values, but also by bedrock which is more suitable to erosion. Such areas are located in Trei Movile Hill, Predilcova area, Iudina Mare area, Polom Hill, Tâlva Lupului Hill, Colonovățul Mic area, Straja Hill, Moghila Hill, Coveliște Hill (Fig. 7b). This class represents less than 45% of the Anina Mining Area (Fig. 8).

c. Areas with low denudation index are situated in the plain regions, the karstic plateaus (Brădet, Ravniștea Mare, Mărghitaș, Cârneală, Colonovăț) in Anina Mining Area (Fig. 7b), and the most compact are the plateaus which have low values of erosion index due to the small values of slopes, geomorphological risk and morphodynamic potential. Other areas with low index are located in Culmea Frumoasă area, Crivina area and Cereșnaia area. The class representing the lowest values of this parameter covers almost the same as the medium class, 45% (Fig. 8).

Overlapping the sinkholes with Di, we notice that most of them are situated on surfaces with low value of denudational index, naming here karstic plateaus (Fig. 7a). From 975 karstic depressions counted in this map, 781 of them (80.1 %) are situated in areas with low Di, 186 (19.1 %) in areas with medium Di and 8 (0.8 %) sinkholes in surfaces with high Di.

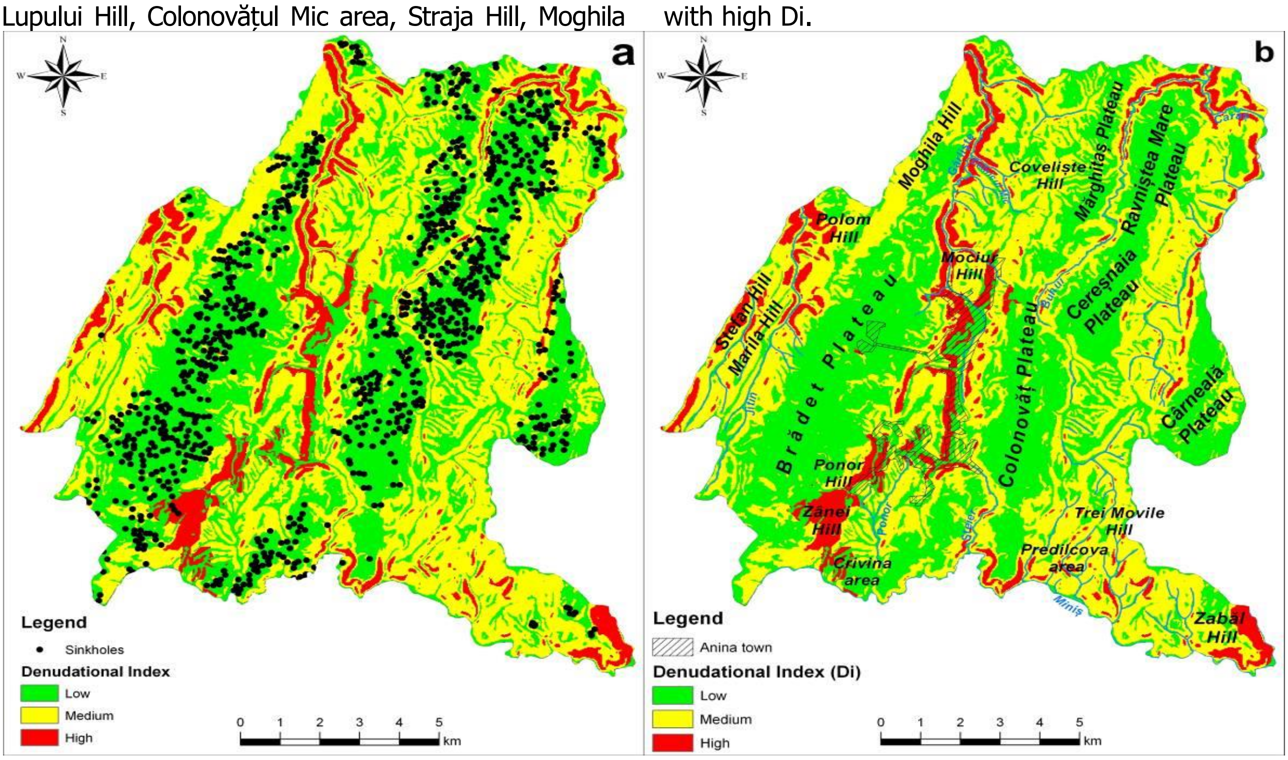

Fig. 7: Denudational Index parameter and sinkholes in Anina Mining Area (a); Denudational Index parameter and most representative sites in Anina Mining Area (b)

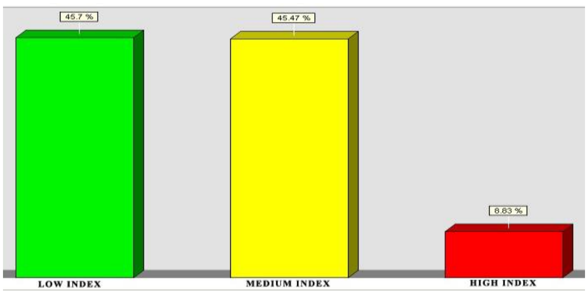

Fig. 8: Histogram of Denudational Index parameter

Discussions

Anina Mining Area is predominantly a forested area. Consequently, in the analysis of geomorphological risk and denudational index we consider more important to analyse morphometric parameters as slope and morphodynamic potential, because land use parameter in our case would not have had a major impact in the analysis due to its homogeneity.

Another factor which we prefer not to focus very much when we discuss the results is lithology. The reason is the same as in the situation of land use parameter, because the lithology of the Anina Mining Area is very homogeneous regarding the bedrock, almost the entire area comprising carbonate rocks (different types of limestone and marl). Because of this we chose to yield a higher importance to the slope factor and other parameters derived based on the slope, namely morphodynamic potential and geomorphological risk.

This approach could be considered as the first step in studying a karstic area from the geomorphological risk perspective, based on digital data and using GIS methods. The validation should be done using more accurate data, as aerial photos, high resolution DEMs and field validation.

For better results and a complete analysis, we would need the sinkholes as polygons, to be able to calculate the area represented by these karstic depressions in each class of those two parameters, Gr and Di. For more accurate results, a DEM with a better resolution would be very helpful. The limits regarding the methodology are speaking about the data that we analyze, only digital elevation model derived parameters. In consequence, some local landforms, which may be smaller than the DEM resolution, could not be included in our analysis. Another restriction of this methodology could be the inductive reasoning that is received after the reclassification step.

The results presented in this paper could be useful in different projects by local authorities. This area is proposed for a touristic development in the near future, with many investments in building accommodation spaces. Our results could be helpful to establish those areas that might be considered as high risk areas from the geomorphological perspective.

Both parameters present highest risk areas across gorges sectors or in the neighbourhood. Many tourist paths are "painted" on the gorges sectors, these landforms representing one of the most important touristic attractions in the region. It should be important for tourists administrations to mind our results and produce a more elaborate written report in these gorges sectors to prevent any possible incident related to tourist activities.

The interpretation of Gr and Di maps should be managed as a correlation between GIS analysis and field characteristics. Large forested areas, large areas with low geomorphological risk and denudational index (> 45% for both of these parameters) represents good conditions for a sustainable development at local or regional scale.

Conclusions

Anina Mining Area is an area with small surfaces which are prone to risks associated with geomorphological process and also with small areas where denudation may have high rates. This is due to the large forested areas and also due to large plateaus where the primary processes are related to karstification, and these ones are very slow processes.

Our GIS approach has captured mainly general aspects of geomorphological risks. There stands out in local differences given by thematic layers as lithology, land use or small landforms that are not highlighted in our Digital Elevation Model.

We intend to use in the analysis of geomorphological risk and denudational index more accurate data regarding surface landforms (karrens, dry valleys, sinkhole valleys etc.), to obtain local indices where karstic surface landforms are present.

The indices calculated for geomorphological risk and land erodability index could be used in territorial planning works, for example to identify those areas that require attention in arranging tourist routes.

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