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USING DIGITAL ELEVATION MODEL (DEM) IN KARST TERRAIN ANALYSIS. STUDY CASE: ANINA MINING AREA (BANAT MOUNTAINS, ROMANIA)

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Abstract: Geomorphometry is essential in nowadays Earth sciences approaches. Earth-surface parameters will generate different values for the same position, based on the DEM resolution. The aim of this paper is to present a geomorphometric approach developed in Anina Mining Area, situated in the most compact karstic area in Romania. The study area is situated in the South-West of Romania, within the Banat Mountains, more precisely in the centre Anina Mountains. We derived the following parameters: slope gradient, drainage depth, drainage density, Topographic Position Index and Topographic Wetness Index. All parameters that were derived using DEM indicate that the study area is a highly karstificated one, with an evoluted karst, where slope, drainage density and drainage depth are morphometric parameters that are highly influenced by karstic evolution. After this approach we can sintetize that using DEM in geomorphometry analysis applied to a karst area, we observe that there is a strong dependency on morphometric parameters and diagnostic karst feature, sinkholes. Our DEM analysis confirms certain hypothesis regarding karst morphology: low-surfaces slopes are favourable for dissolution process; the disorganized drainage network is specifically for karstic areas; high density of karstic depressions on those karstic plateaus indicates a higher wetness value. By practical point of view, connected to the applied geomorphology, this approach could be useful for natural resource management, the study area being part of two national parks, where limestone and karst landforms are prevalent. It could be considered as the first step in the geomorphological description of the Anina Mining Area.

Keywords: karst, morphometry, DEM, Anina, Romania

1. INTRODUCTION

Digital elevation model (DEM) represents a numerical model for land-surface aspect as altitude, taking the shape of a regular grid of points (Burrough & McDonnell, 1998). By building digital models, humans can enrich their knowledge about Earth, but we must be aware that our world is infinitely complex and computational representations are limited (Longley et al., 2005).

Geomorphometry or ground-surface quantification is scale dependent, but we can develop analysis on different sources of DEMs: field measurements terrain model and elevations read from contour maps (Pike, 2000). Modelling and mapping of natural landscapes, at both regional and local scales using geomorphometry is essential in nowadays Earth sciences approaches. For geomorphometric analysis, the input is commonly a digital elevation model (DEM), a rectangular array of surface heights (Pike et al., 2008).

There are many underestimate of the land surface complexity and runs DEMs analyses blindly, generating results that are neglecting important aspects regarding land surface (Hengl & Evans, 2008). Earth-surface parameters will cause different values for the same position, depending on the DEM resolution that we build up our analysis. As a consequence, the scale has a quite an important impact on the results of geomorphometric analysis (Drăguț & Eisank, 2011).

Karst terrain is represented as a distinct relief as a result of rock masses dissolution which subsequently produces an effective underground flow (Waltham et al., 2005). Understanding karst topography means knowing the nature and the factors that are controlling dissolution processes in karst soluble rocks and drainage as a result of these processes (Ford & Williams, 2011).

Studies using DEMs in karstic areas were made in Yazoren Polje, Turkey (Tagil & Jenness, 2008), in Biokovo Mountains, Croatia, focusing more on doline morphometry (Telbisz *et al*., 2009), in Julian Alps, Italy (Telbisz et al., 2011), in Slovak karst and Aggtelek Karst (Telbisz, 2011); for the automatic delineation of karst depressions (Pardo-Igúzquiza et al., 2013) and OBIA applied on karst terrains (Zylshal & Haryono, 2013).

In Romania, geomorphometric studies in karst areas are almost missing. Papers using DEMs or GIS techniques: Torok et al., (2009) using DEM for the identification of the planation surfaces in Mehedinți Mountains; Torok & Ardelean (2012) with an OBIA approach in Mehedinți Mountains; Telbisz et al. (2014) with a geomorphometric analysis in Trascău Mountains.

The aim of this paper is to present a geomorphometric approach developed in Anina Mining Area, situated in the most compact karstic area in Romania.

2. STUDY AREA

The study area is situated, from a geographical perspective, in the South-West of Romania, within the Banat Mountains, more precisely in the centre of Anina Mountains (Fig. 1).

The region under this toponymy, Anina Mining Area, was introduced by Vasile Sencu (1977), when he published a detailed study regarding the geomorphology, hidrogeology and speleology of this karstic area, based on two previous papers regarding two important karstic regions in Anina Mining 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).

From a geological point of view, this area is situated in the most compact area of carbonate rocks in Romania, Reșița-Moldova Nouă Synclinorium (Orășeanu & Iurkiewicz, 2010). In the Reșița-Moldova Nouă Zone over fundamental crystalline domain overlap Paleozoico-Mesozoic formations (Bucur, 1997).

Oncescu (1965) explain this by the fact that the Paleozoic and Mesozoic sedimentary deposits were deposited either before main tectonic meso Cretaceous phase or in the phase that followed the meso Cretaceous phase searching and Reșița-Moldova Nouă zone is an area where sediment has an important development.

The Reșița - Moldova Nouă Zone is considered as the classic area where the sediment is developed, although sediments that covered a significant part of the field was largely removed by erosion, yet it has remained in the area since the Reșița - Moldova Nouă worked as a depression in which succession and erosion of sedimentary cover were complete (Mutihac & Ionesi, 1974). In the synclinorium area, only the Jurassic-Lower Cretaceous includes limestone deposits. The impact of physical-chemical processes may be seen mostly between 200 and 600 m altitude (Iurkiewicz et al., 1996).

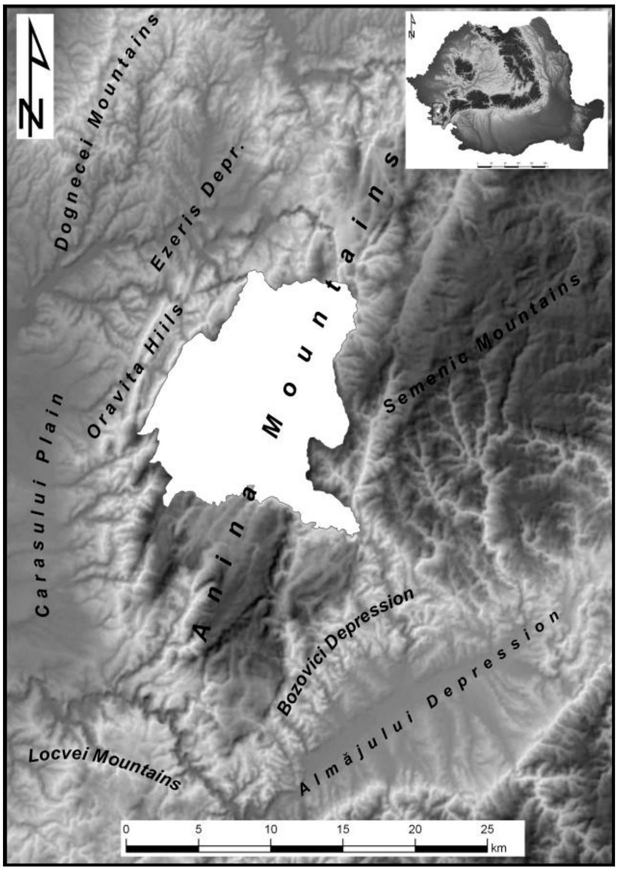

Figure 1. Location of Anina Mining Area.

3. METHODOLOGY AND DATA

Morphographical characteristics, morphometric and positional elements of relief are decisive in differentiating karst development (Onac, 2000). Greater frequency of horizontal surfaces or subhorizontal and depression forms, are favouring the possibility of percolation of rain water, and the karstification process is facilitated. The more common horizontal and sub-horizontal surfaces or negative forms of relief (lower surface), the more it emphasizes the possibility percolation of precipitation water and the result is a faster karstification process.

The following parameters of the relief that are influencing particularly the karstification are: slope gradient, drainage density, landforms energy (or drainage depth), morphographical aspect, karst forms depressions frequency per unit area (Ilie, 1970).

To have a better perspective, we involve in our analysis sinkholes. As forms of surface karst, sinkholes are the most diagnostic features of karstification. These characteristics are indicators of the degree of dissolution that has undergone geological substrate locally (Shofner et al., 2001). Previous geomorphometric studies regarding sinkholes (Orndorff et al., 2000) indicate that most of these depressions develop on low slope surfaces.

Based on the theoretical analysis of the parameters mentioned before, we derived these parameters for our study area using GIS techniques.

Morphometric analysis was obtained using a digital terrain model with a resolution of 10 m, using contour lines extracted from topographical map's scale at 1:25000 and then we interpolate these isolines using Topo to Raster tool from ArcGIS 10. In our interpolation process, we included also peaks, rivers, lakes, sinkholes. Sinkholes were extracted as points, using the karstic map of Anina Mining Area scale at 1:50000 (Sencu, 1977).

The tool Extract Values to Points from ArcGIS 10 permits us to count the sinkholes that are situated in different classes of each parameter. We derived the following parameters: slope gradient, drainage depth, drainage density, Topographic Position Index and Topographic Wetness Index. To obtain these parameters we use ArcGIS 10 software and the final maps were edited with Adobe Photoshop.

4. RESULTS

4.1. Slope gradient

Slope gradient determined water drainage to the topographic surface water. Between the values of the slope and the seepage water quantity are inversely proportional ratios (Ilie, 1970).

The slope gradient map (Fig. 2) evidence the alternation of karstic plateaus with low slope that are not exceeding 10°, with the valleys, most of them having the aspect of gorges, with slopes often exceeding even 40°. This map reveals also large areas without surface water through very small values of the slope. These areas, with very small slopes are extremely favourable for karstification processes due to the stagnation of percolation water and melted snow for a longer period than in very steep areas and this facilitates karstification process. The presence of numerous karst depressions in these areas confirms the importance of this parameter in the development of karst geomorphology.

Table 1. Sinkholes in slope gradient classes

Slope	Sinkholes (no.)	Sinkholes (%)
< 5	392	40.9
5 - 10	322	33.6
10 - 15	184	19.2
15 - 20	36	3.8
20 - 25	15	1.6
25 - 30	9	0.9
30 - 35	0	0
35 - 40	0	0
> 40	0	0
TOTAL	958	100

Slope gradient map and histogram, combined with table 1 regarding the distribution of karstic depressions in slope gradient classes indicate the importance of this land-surface parameter in karstic evolution.

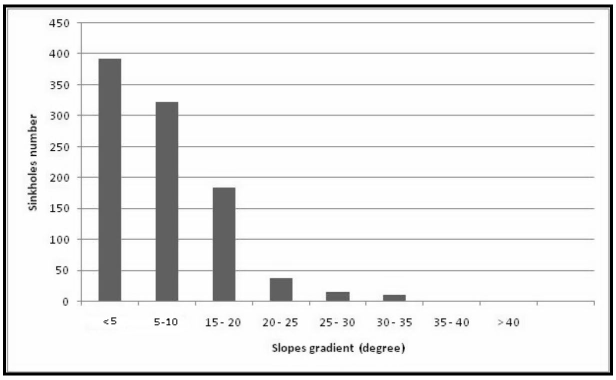

Figure 3. Number of sinkholes in slopes classes.

4.2. Drainage depth

The energy of the landscape can reveal, chronologically, the progressive increase of this parameter by gradual deepening valleys, as evidenced by the different relative altitudes of caves and springs (Ilie, 1970).

The drainage depth represents a parameter that refers to the difference in altitude between various points on the surface of the Earth and indicates the true extent of its evolution and current intensity morphodynamic processes.

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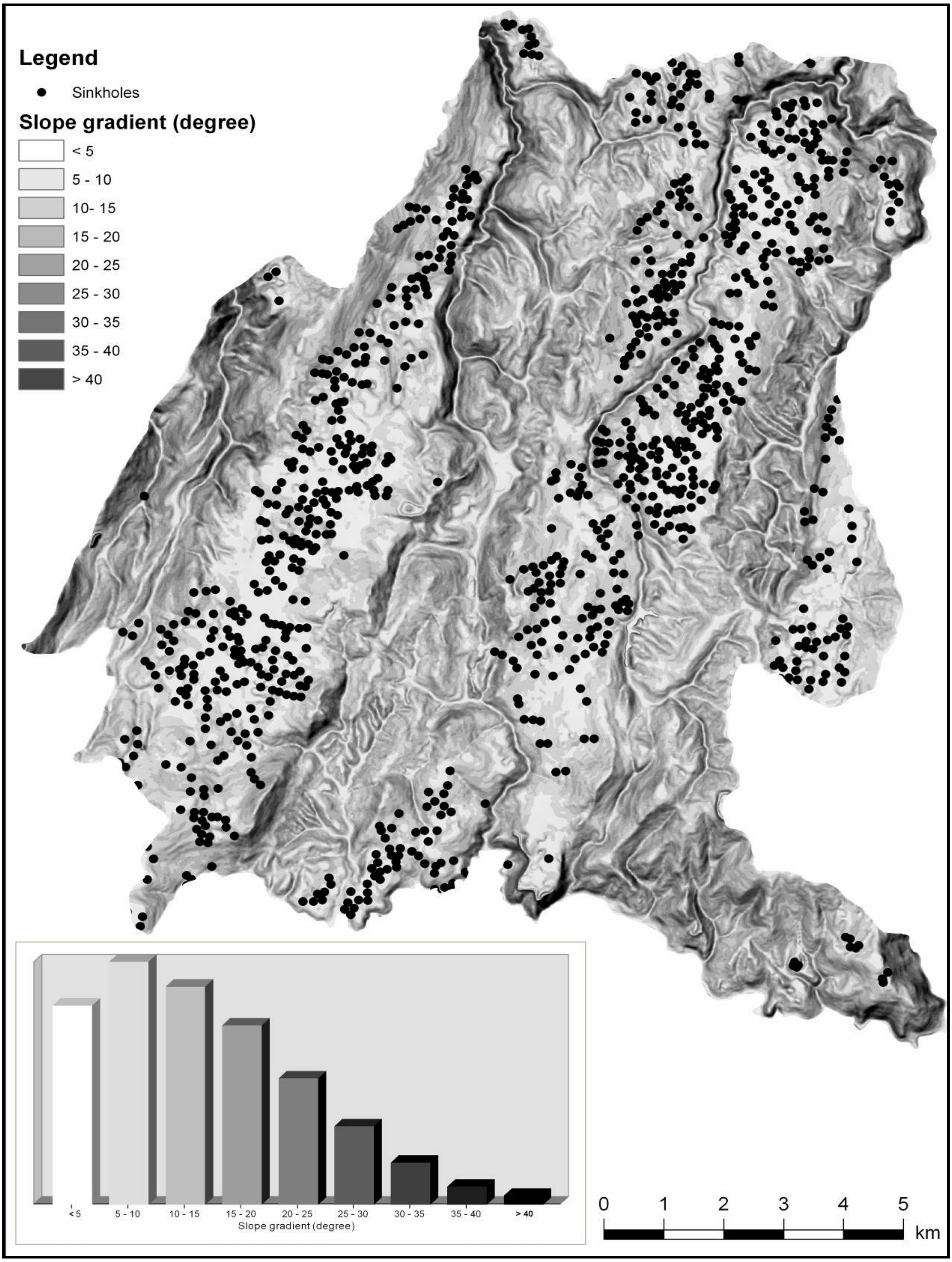

Figure 2. The slope gradient map and histogram

The drainage depth represents a parameter that refers to the difference in altitude between various points on the surface of the Earth and indicates the true extent of its evolution and current intensity morphodynamic processes.

We derived this parameter using the cartogram method, calculating the difference in altitude in squares with an area of 1 km^2. This approach generates a more generalized aspect of drainage depth. The map highlights again the plateau areas, with very low values due to lower slopes, and areas with valleys and gorges, where the depth of fragmentation has the highest values, due to the difference in level between the bed of the watercourse and summit slopes (Fig. 4).

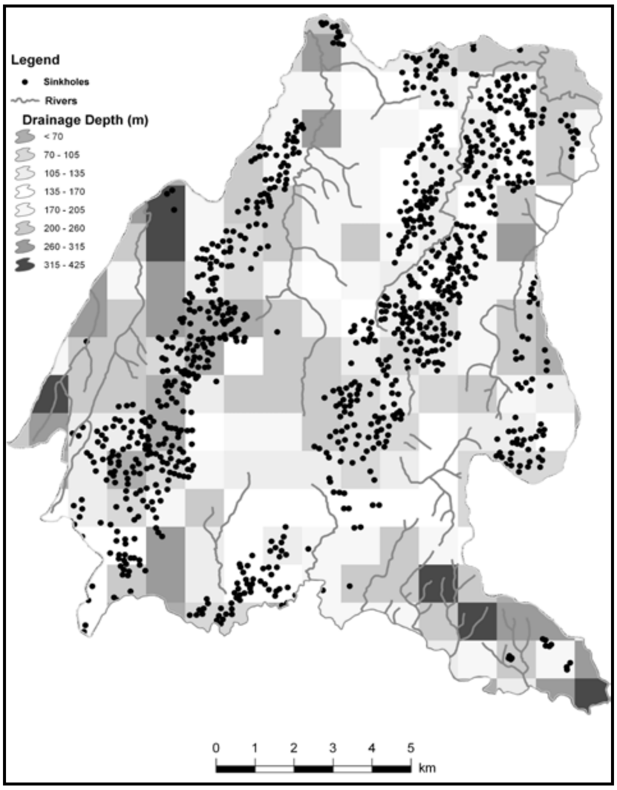

Figure 4. Drainage depth map and sinkholes.

The histogram indicates that the smallest values are representing less than 5%, and the classes considered as average values of this parameter, predominantly with depths between 105 and 240 m, are covering more than 76% (Fig. 5). The highest densities of karstic depressions (> 80%) are situated in the first 4 classes of drainage depth (Table 2).

Table 2. Sinkholes in drainage depth parameter classes

Drainage depth	Sinkholes (no.)	Sinkholes (%)
< 70	116	12.1
70 - 105	208	21.7
105 - 135	224	23.4
135 - 170	209	21.8
170 - 205	73	7.6
205 - 240	99	10.4
240 - 315	29	3.1
315 - 425	0	0
TOTAL	958	100

4.4. Drainage density

Temporary watercourses as ditches, basins and torrents, or permanent watercourses as rivers and creeks, provide both rock erosion and corrosion, and also infiltration in erosive or accumulative bedrock. Between the karstification processes intensity and drainage density, in equal rainfall conditions, ratios are proportional (Ilie, 1970).

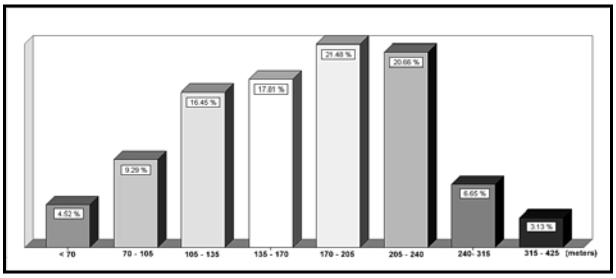

Figure 5. The drainage depth histogram.

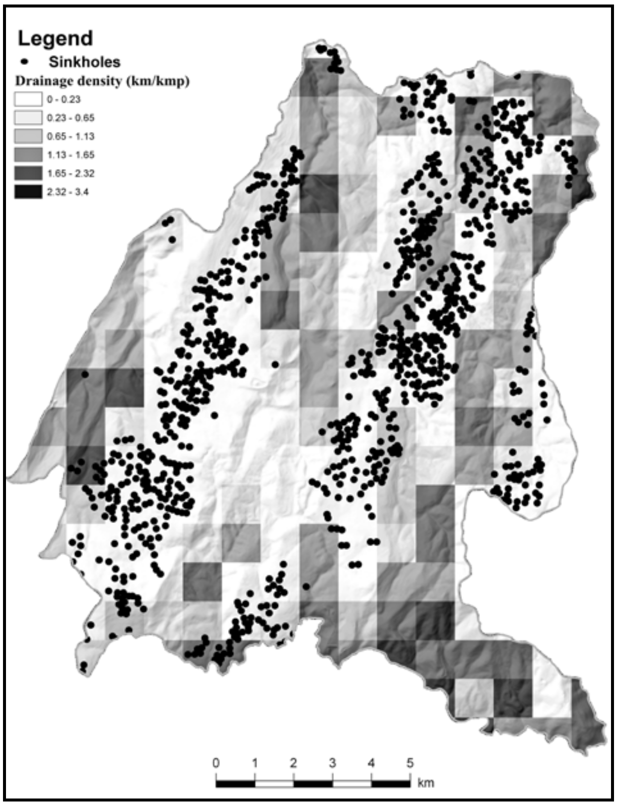

Figure 6. The drainage density map.

Any surface is subjected to erosion resulting plan mainly due to the permanent or temporary action hydrographic network. Through horizontal fragmentation relief understand the degree of "dissecting" horizontal surface of certain regions, and this parameter has a certain "density" representing the ratio of the total length of the river network in km and unit area km^2. Drainage density map (Fig. 6) evidence plateau areas, where karst processes have created and continue to create depression forms. The fact that these areas are without surface water and the slope is very low, indicate the suitability of these areas for the presence of forms resulting from karst processes. Also, the drainage density map points out that the river network layout and the relief are developed in tectonic direction, meaning NNE-SSW. The map below highlights the alternation of valleys and plateaus, and the disorganized river network.

From the drainage density histogram (Fig. 7) it can be ascertained that the areas with null value or very low values of this parameter is representing more than 55%. This indicates a weak presence of surface water. Other ranges of values, between 0.6 and 2.3 km/km^2 have approximately equal weights (12 %, 15 % and 13 %) and the largest range of values of this parameter is not exceeding 3.4 km/km^2 have a rate about 4%.

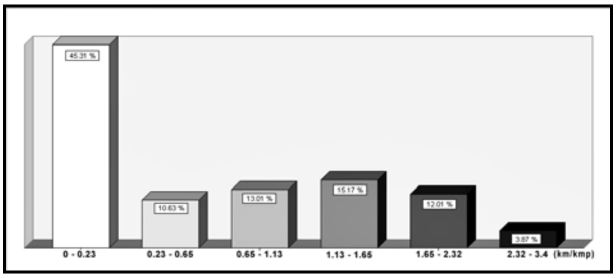

Figure 7. The drainage density histogram.

Table 3. Sinkholes in drainage density parameter classes

Drainage density	Sinkholes (no.)	Sinkholes (%)
0 - 0.23	692	72.3
0.23 - 0.65	62	6.5
0.65 - 1.13	73	7.6
1.13 - 1.65	92	9.5
1.65 - 2.32	30	3.2
2.32 - 3.4	9	0.9
TOTAL	958	100

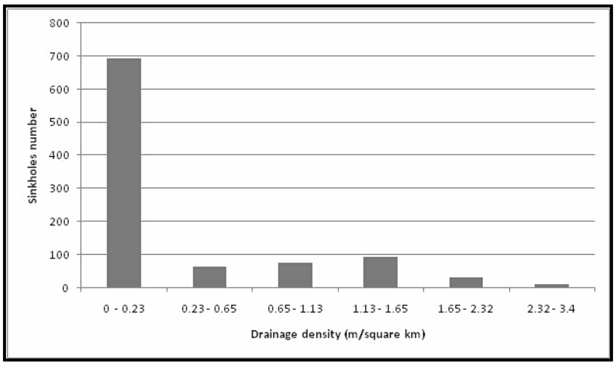

Figure 8. Drainage density classes and number of sinkholes.

Counting the sinkholes that are situated in different classes of drainage density parameters, we observe that more than 70% (692 sinkholes from 958) are situated in areas where surface drainage is missing or presents very low values, table 3. The other classes retain much less karstic depressions. Helped by drainage density parameter we observe a strong relation between surface drainage and sinkhole development (Fig. 8).

4.5. Topographic Wetness Index (TWI)

This parameter is calculated as the ratio between catchment area that is giving value to a pixel and the slope value of that pixel (Wilson & Gallant, 2000).

Topographic Wetness Index indicates those areas where the DEM analysis indicates higher humidity. For a karstic area this an important factor because in such regions disorganized surface drainage and highly percolation of the water in the underground represents a specific for an evoluted karstic region. We obtained values that indicate higher wetness in valleys, but also in the middle of the suspended karstic plateaus, where the sinkholes density is high (Fig. 9). This is due to the presence of these karstic depressions that are retaining humidity for a longer period. In table 4 we notice that 856 sinkholes of those 958 counted are situated in pixels with medium or higher wetness value.

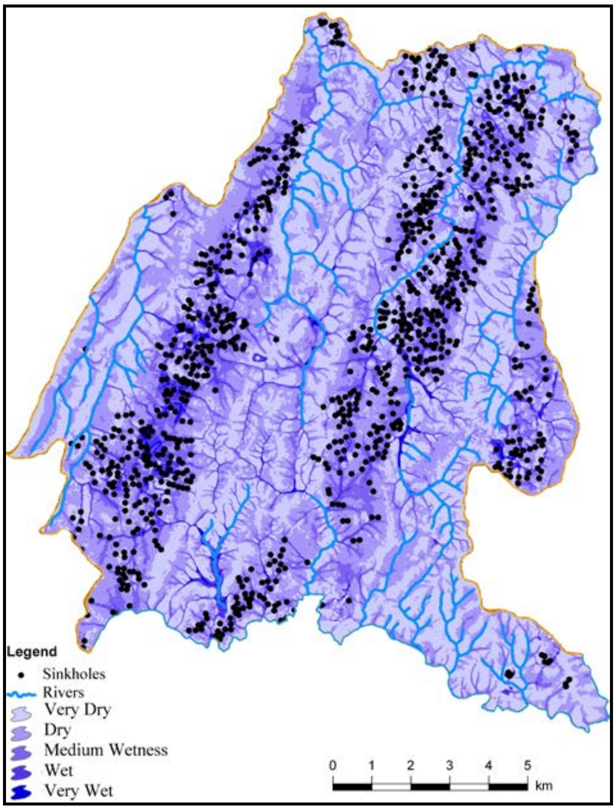

Figure 9. TWI and sinkholes in Anina Mining Area.

4.6. Topographic Position Index (TPI)

As its name says, this index classifies landscapes in slope position classes. TPI measures the relative topographic position of the central point as the difference between the elevation at this point and the mean elevation within a predetermined neighbourhood (De Reu et al., 2013).

Table 4. Sinkholes in TWI parameter classes

Wetness Index	Sinkholes (no.)	Sinkholes (%)
Very Dry	0	0
Dry	52	5.4
Medium Wetness	453	47.3
Wet	374	39
Very Wet	79	8.2
TOTAL	958	100

Based on our DEM we obtained certain groups of pixels that are indicating specific karst landforms as gorges, dry valleys, sinkhole valleys, suspended karst plateaus, areas with low slopes and also ridges, peaks or steep slope areas (Fig. 10).

These landforms are covering important surfaces: 43% karst plateaus, 14% dry valleys and sinkhole valleys and 29% areas with low-surfaces slopes (Fig. 11).

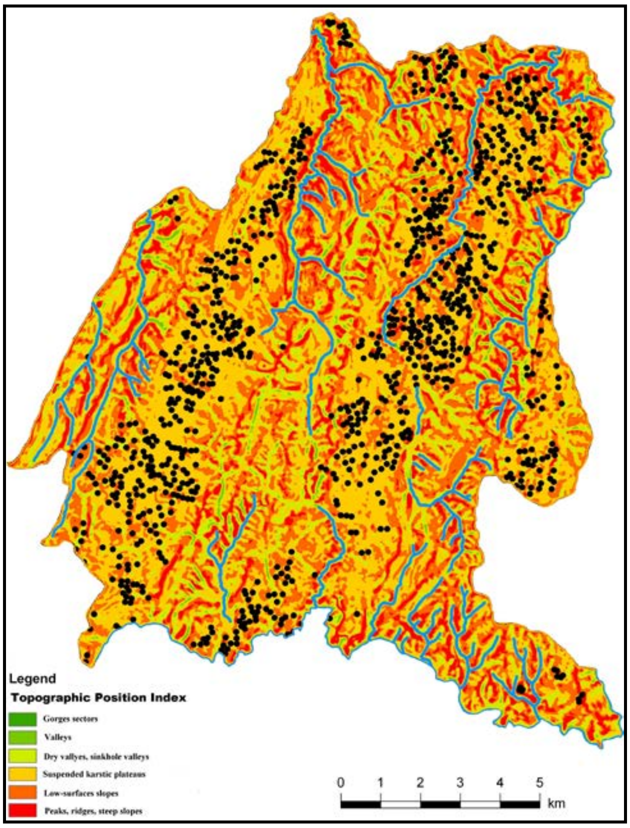

Figure 10. Topographic Position Index map.

Sinkholes density is very high on those suspended karstic plateaus, with almost 70%. This is representative of a high evoluted karst region, as Anina karstic area. Topographic Position Index shows that using DEM processing, we were able to delimit certain landscape features. We observe that more than 57% (87.2 km^2) is covered with specific karst features as dry valleys, sinkhole valleys and suspended karst plateaus. Also, less steep slopes that occupy present at the edges of karstic plateaus 29.3% (Table 5).

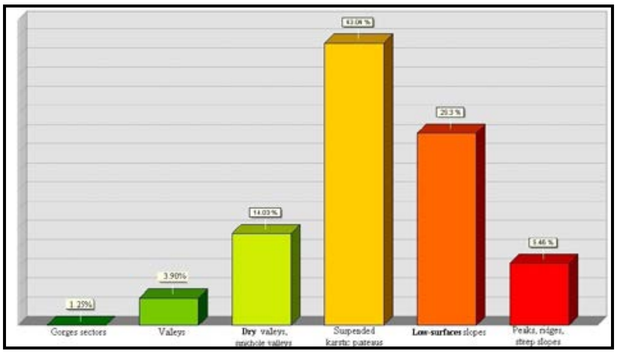

Figure 11. TPI histogram in the Anina Mining Area.

Table 5. Sinkholes in TPI parameter classes

Topographic Position Index	Surface (km^2)	Sinkholes (no.)	Sinkholes (%)
Gorges sectors	2.1	0	0
Valleys	6.55	16	1.7
Dry valleys, sinkhole valleys	22.8	215	22.5
Suspended karstic plateaus	74.4	666	69.5
Low-surfaces slopes	49.5	59	6.1
Peaks, ridges, steep slopes	15.1	2	0.2
TOTAL	170.45	958	100

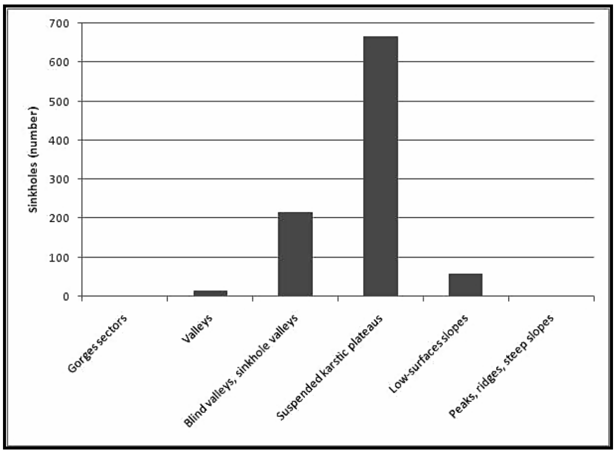

Figure 12. Sinkholes number situated in different landforms categories.

DEM analysis helped us to get an overview regarding karst geomorphology in the study area. The largest number of karstic depressions is situated on suspended plateaus, where surface drainage is missing, and also on areas occupied by sinkhole valleys or dry valleys (Fig.12).

5. DISCUSSIONS

A geomorphometric analysis could be considered as the first step in studying a karstic area from the geomorphological perspective, using digital data and GIS methods. For a validation we should use more accurate data, as aerial photos, high resolution DEMs and also field validation.

All parameters that were derived using DEM indicate that the study area is a highly karstificated one, with an evoluted karst, where slope, drainage density and drainage depth are morphometric parameters that are highly influenced by karstic evolution.

Analysing sinkholes with morphometric parameters, we noted that these karstic depressions are situated in areas where percolation water is retained for a longer period, as low-surface slopes, being favourable for dissolution.

In areas where the surface drainage is missing, as a consequence of underground drainage and the absence of fluvial processes are favourable for karstic depressions evolution.

The slope gradient, drainage depth and drainage density are those morphometric parameters which point out the karstic plateaus of the study area, by the values of these parameters and their spatial distribution.

Our DEM analysis confirms certain hypothesis regarding karst morphology: low-surfaces slopes are favourable for dissolution process; the disorganized drainage network is specifically for karstic areas; high density of karstic depressions on those karstic plateaus indicates a higher wetness value.

Suspended karstic plateaus present a planar aspect, surrounded by deep valleys, some of them with gorges aspect. On these plateaus sinkholes density is very high, all the morphometric parameters indicating values favourable for limestone dissolution.

6. CONCLUSIONS

DEM study is the beginning step in the geomorphological analysis for the karstic area of the Anina Mining Area. Using DEM in geomorphometry analysis applied to a karst area, we remark that there is a strong dependency on morphometric parameters and diagnostic karst feature, sinkholes.

The most representative karst features are developed for low-slope surfaces, in regions where surface drainage is missing and where the drainage depth presents small values.

Also, using certain indices like Topographic Wetness Index and Topographic Position Index (TPI), we observed that sinkholes are located in regions where humidity presents higher values (being known that in karst regions sinkholes are those points where the retention of water is for a long time) and also sinkholes in relation with the Topographic Position Index are predominantly situated on suspended karst plateaus.

We used karst depressions as sinkholes to have a first validation in our study area, by observing those classes of the morhometric parameters where these depressions were developed.

For the future approach, we intend to finish our study with several field observations, some of them being already made out, to observe if our terrain model is not generalising too much in certain areas.

Using computer analysis of terrain, there could appear some areas that are not classified quite exactly, if they extend beyond the boundary of the DEM. Despite the limitations of Digital Elevation Model, geomorphometric analysis provides a powerful tool to describe topographic attributes of a study area.

By practical point of view, connected to the applied geomorphology, this approach could be useful for natural resource management, the study area being part of two national parks, where limestone and karst landforms are prevalent.

It could be considered as the first step in the geomorphological description of the Anina Mining Area.

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