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PADIŞ - A GEOMORPHOMETRIC APPROACH

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Abstract: This study presents a unitary morphometric analysis for one of the most spectacular karst sectors in Romania: the closed basin Padiș – Cetățile Ponorului. 2 DEMs was used for this purpose, one derived from the interpolation of level curves and altimetry quotas from topographic maps, on scale 1 : 25000, and the second (generated from LiDAR data) was taken over from the National Agency for Cadastre and Land Registration (ANCPI). We have processed 6 morphometric parameters comparatively (hypsometry, slope, aspect and 3 types of curvatures : profil, plan and general curvature) to highlight the metric features of the relief in the studied area as accurately as possible. The results show that the surface relief in Padiș is mature, with an average altitude of 1268 m, in which prevail the slopes with moderate tilt (6 - 17°), predominantly sunny and semi-sunny. The relation between the general curvature values and the hydrogeologic features of the area explains the distribution of the sectors with underground water loss and also the disorganized distribution of the surface hydrographic network.

Key words: Padiș, morphometry, slope, aspect, curvatures

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INTRODUCTION

Padiș, one of the most spectacular sectors of the Apuseni Mountains, is probably the most known area from these mountains, knowledge offered by the numerous research studies done here and also by its widespread publicity online. A simple typing of the word ”Padiş” in Google Search Engine offers 29 600 results in 0.69 seconds.

Concerning the scientific knowledge of the karst in Padiş, it is noticeable a concentration of the research on three directions of interconnected approaches. The first one is lithostratigraphic and structural with studies that target the knowledge and effective mapping of the deposits in the area (Bleahu, 1957a; Bleahu, 1964; Patrulius et al., 1971; Ianovici et al., 1976; Lupu, D., 1975; Bordea and Bordea, 1982; Bleahu et al., 1985; Mantea, 1985). The second research direction is hydrogeological, focusing on the dynamics and geochemistry of the karst streams from the area. The studies of Viehmann (1966a,b), Vălenaș et al. (1982), Orășeanu et al. (1991), Orășeanu (1996, 2010)

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are important here. The third direction, predominantly geomorphological, is focused on the Padiș karst morphology with complex and well-documented studies that track the carbonation and dissolution mechanisms, the establishment of the present karst types, the assessment of the karst dynamics (Bleahu, 1957b; Bleahu, 1974; Viehmann et al., 1980; Viehmann, 1991; Vălenaș et al., 1977; Vălenaș, 1984; Cocean, 1985, 1990, 1992, 1993). Also included here are the studies that present the discoveries of new endokarst forms, most of them with very well-made maps (Vălenaș, 1977 – 1978, 1982; Damm, 1992; Damm and Moreh, 2001; Damm et al., 2004 – 2005).

Besides these, there are other studies that integrate the features of this mountainous area in presentations accessible for the wider audience (Bleahu and Bordea, 1967, 1974, 1981; Gaceu et al., 2012; Gaceu et al., 2013), that emphasize the touristic promotion of Padiș.

Morphometrically, the current studies are either punctual, meaning that for each karst unit a topographic survey was done, or the morphometric data were taken from Bleahu & Bordea's studies and completed with data from topographic maps. Here we also have to mention the morphometric processing that refers to Bătrâna Mountains (Badea et al., 2006) and Indrieș's (2010), that focuses on Padiș – Scărișoara Mountains.

Our study aims to present a unitary quantitative approach of Padiș – Cetățile Ponorului endorheic basin. Our main objective is the accurate obtaining of the basic morphometric parameters that characterize the area, based on good and very good quality of entry data.

STUDY AREA

The name ”Padiș – Cetățile Ponorului Endorheic Basin” does not leave any questions regarding the limits of the analysed area. In accordance with the reality in the field and out of respect for the aforementioned researchers, the limits of this area located in the central-northern part of Bihor Mountains (figure 1), were mapped in a classical way (on georeferenced topographic maps, scale 1: 25000) on the alignments of interfluves described very well by Bleahu and Bordea (1981), so we will not discuss them.

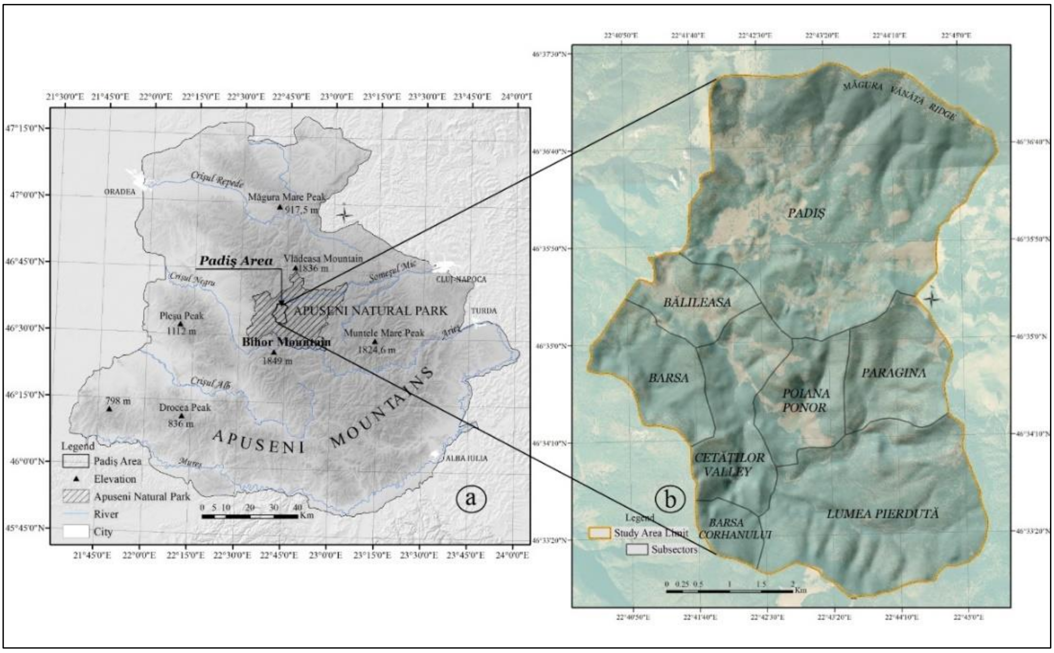

Figure 1. a) Study area location in Apuseni Mountains; b) Study Area with subsectors
(Source: Authors)

The surface that resulted after the delimitation covers 3593 ha (the above mentioned authors give the value of 36 km^2).

The endorheic character (noticed by Bleahu as early as 1953 – 1954, in ”Minutes of the meetints of the Geologic Committee”, published in 1957) and the division of the basin in 8 subsectors (map 1), are largely determined by the double alternation of layers of impermeable, non-karstificable rocks with layers of soluble rocks (limestone and dolomite).

The vegetation is coniferous (mainly spruce), broadleaf forests (beech) and secondary grassland. Inversions of vegetation often occur (the spruce is present on the plateau and especially on the bottom of humid sinkholes and the beech and the associated vegetation climb up the slopes), due to the persistent thermal inversion. The ecological management is provided by Apuseni Natural Park, as the studied area belongs to it.

MATERIALS AND METHODS

In this study we used 2 digital elevation models (DEMs) for the morphometric processing. The first one, called DEM_TOPO, was obtained through the interpolation of the elevation features (contour lines and altimetry quota corresponding to the most important peaks) digitized from the topographic maps 1:25000 (L-34-058-A-b; L-34-058-A-d; L-34-058-B-a; L-34-058-B-c), using Topo to Raster method, based on ANUDEM (Australian National University's Digital Elevation Model) locally adaptive elevation gridding procedure developed by Hutchinson (1989). The vertical accuracy of the entry data is 10 m (ensured by the 10 m equidistance between the contour lines), but for interpolation we selected a cell size of 15 m to reduce the so-called ”terracing” effect. The second elevation model, called DEM_LiDAR, was taken from ANCPI (National Agency for Cadastre and Land Registration), that offers an elevation model processed from LiDAR data, obtained during the Laki II project, that covers totally or partially 6 counties from Romania (Bihor, Arad, Alba, Hunedoara, Mureș, Harghita). The absolute vertical precision is 10 cm and the horizontal one is 30 cm. The data downloaded from Geoportal ANCPI have the resolution of 1m, and for the DEM extraction, after the mosaicking procedure of the grid-type rasters, a resampling was done at a resolution of 10 m. We mention the fact that for the extraction of both DEMs, it was used a buffer of 30 m to the limit – digitized polygon to ensure the best environment to run the used algorithms (sliding 3 x 3 or 5 x 5 cells window on raster). As a consequence, the surface of the study area for which we will do all the quantitatve reports is 3675 ha, the difference of 82 ha compared to the mapped limit being irrelevant from statistical point of view.

The morphometric parameters used in this study are part of the primary attributes category (Wilson and Gallant, 2000): hypsometry, slope, aspect and 3 types of curvatures (profil, plan and general curvature). To obtain them we tested comparatively 2 methods implemented in SAGA (System for Automated Geoscientific Analyses): Zevenbergen and Thorne’s (1987), with 9 polynominal parameters, and Florinsky’s (2009), with 10 polynominal parameters. For the testing, we used curvatures due to their sensitive behaviour. We mostly aimed at standard deviation and standard error to have acceptable values and the distribution of values at the cell level to offer a reasonable possibility of grouping them in territory. The results have shown that for the elevation data stored in DEM_TOPO, the behaviour of the algorithms derived from the 2 approaches is almost identical, but for DEM_LiDAR, meaning for data with very good resolution, it was noticed that Florinsky’s method is more suitable (figure 2) for our objective because it offers a better spatial uniformity of the values with a positive effect in the setting of the classes. As a result, all the morphometric processing in this study is based on Florinsky’s method.

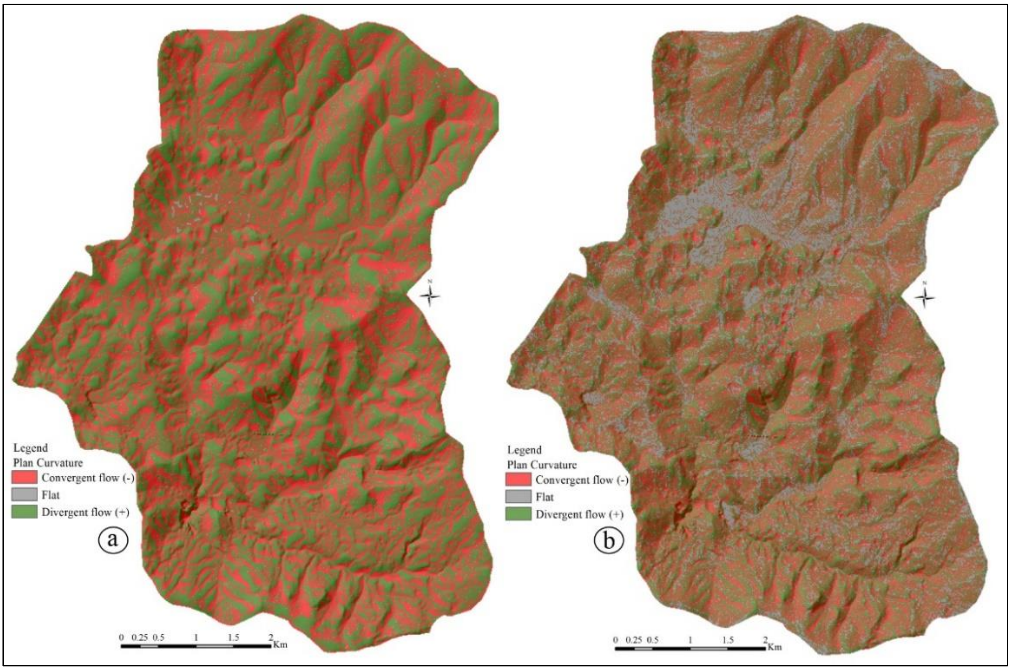

Figure 2. Plan Curvature from DEM_LiDAR obtained through: a) Florinsky method; b) Zevenbergen and Thorne method
(Source: Authors)

RESULTS AND DISCUSSION

Hypsometry

For the maximum and minimum altitude we kept the values from the topographic maps: 1641 m, in the NE corner of the sector, and 936 m in SV (Cetățile Ponorului). The average elevation for Padiș is 1268 m (value extracted from DEM_LiDAR).

Overall (figure 3), the altitude decreases in NW – SE direction and from W to E (towards Cetățile Ponorului and Barsa). Regarding the distribution of altitude ranges (table 1, figure 4), it is noticeable that 78 % of the analysed surface is between 936 m and 1350 m. The 1350 – 1450 m level has a ratio of only 14 %, and the highest level, with a ratio of 8 %, corresponds to the alignment of ridges that borders the plateau.

Table 1. The distribution of the Padiș area by altitude ranges
(Source: Authors)

	Altitude Ranges.					
	936 - 1150 m	1150.01 - 1250 m	1250. 01 - 1350 m	1350.01 - 1450 m	1450.01 - 1643 m	Total Area (ha)
Area from DEM_TOPO (ha)	632.50	1053.16	1194.84	507.76	287.28	3675.5
Area from DEM_LiDAR (ha)	603.72	1040.47	1211.26	521.05	298.92	3675.5

The explanation of this distribution of altitude values is given by the arrangement of the lithology in alternating strips, with strata that incline in the general direction NW - SE, which also influenced the direction of the underground drainage, with an obvious effect in accentuating the karst modeling for the SW part of the basin.

The comparative analysis of the altimetric intervals in the 2 DEMs (figure 4) shows an almost perfect similarity in terms of their spatial distribution. However, there is a 1% difference between the first and the second altimetric interval, an aspect that is best observed if you follow the passage from the Bălileasa uvala to the Cetăților Valley (figure 3).

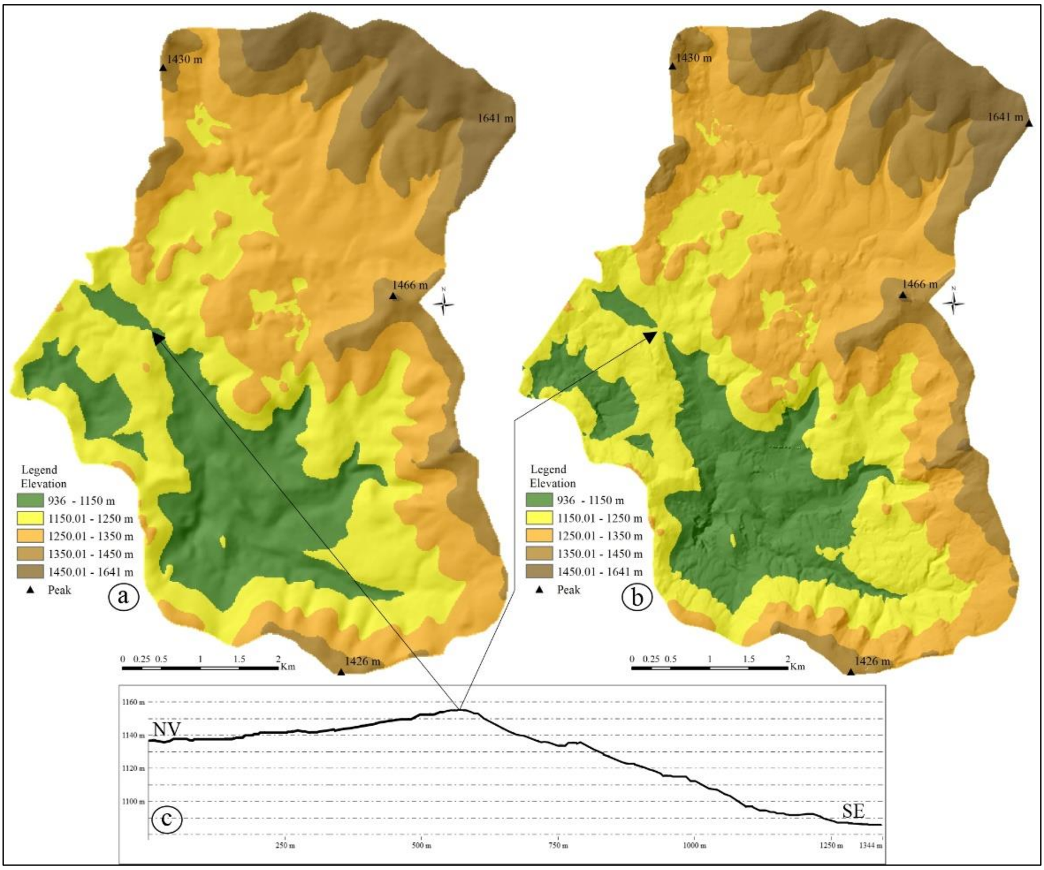

Figure 3. Hypsometry: a) Hypsometric raster based on DEM_TOPO. b) Hypsometric raster based on DEM_LiDAR. c) Longitudinal profile through the crossing sector between Bălileasa and Cetăților Valley (Source: Authors)

Table 2. Tabulated Area between surfaces of altitude ranges derived from DEM_TOPO and surfaces of altitude ranges derived from DEM_LiDAR (expressed in hectares)
(Source: Authors)

		936 - 1150 m	1150 - 1250 m	1250 - 1350 m	1350 - 1450 m	1450 - 1643 m
DEM_TOPO	936 - 1150 m	590.16	41.51	0	0	0
	1150 - 1250 m	14.14	978.27	58.96	0	0
	1250 - 1350 m	0	18.90	1142.40	31.24	0
	1350 - 1450 m	0	0	7.24	486.24	13.72
	1450 - 1643 m	0	0	0	2.07	283.50

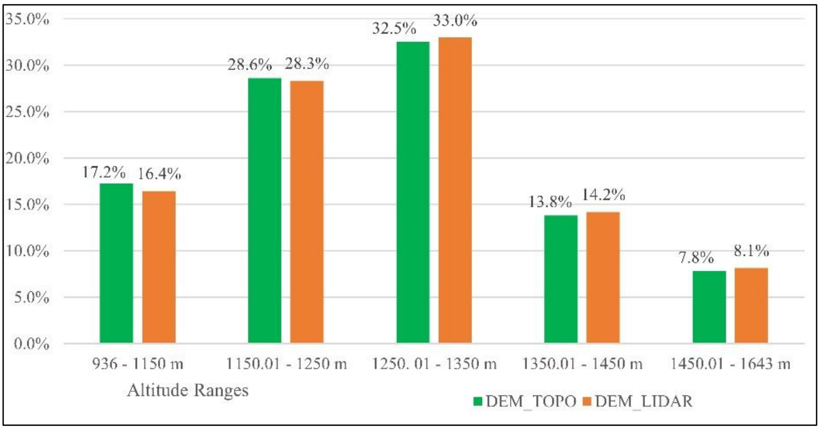

Figure 4. The percentage distribution of the area by altitude intervals
(Source: Authors)

For the rest of the altitude ranges, the differences in occupied surface and migrations from one hypsometric range to another are insignificant (table 2).

Slope

The slope classes and their spatial distribution (figure 5) express very well the plateau character of the northern compartment (Padiș Plateau), the quasi-horizontality of Bălileasa and the more rugged relief in the central and south-western part of the basin. Almost half (49 %) of the surface has a moderate slope, with values between 6 and 17° (table 3, figure 6), a very important fact for the achievement of a good infiltration of the surface water.

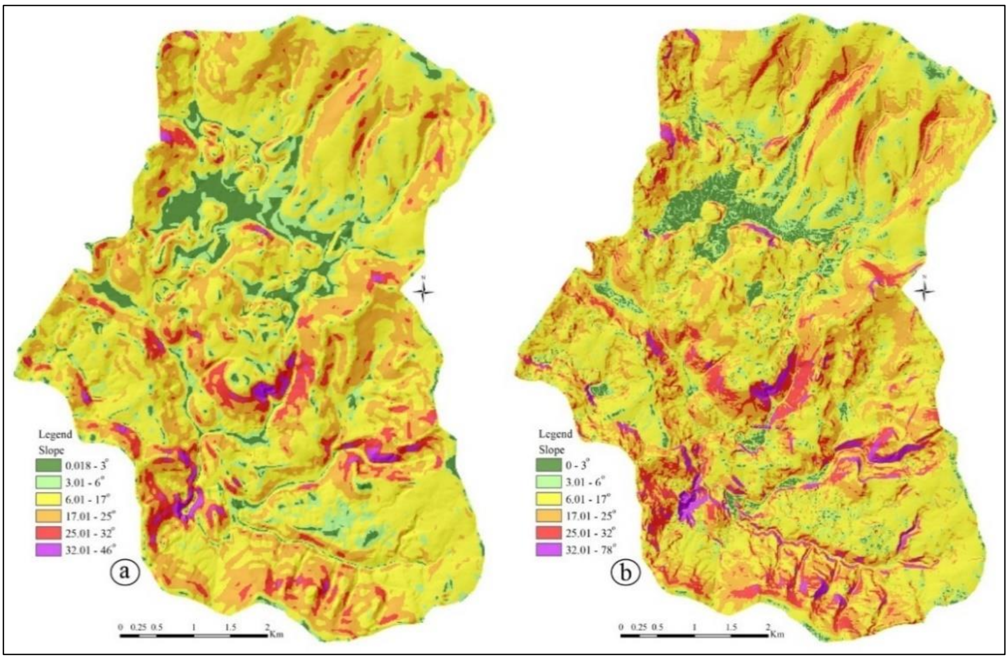

Figure 5. Slope based on: a) DEM_TOPO ; b) DEM_LiDAR
(Source: Authors)

The horizontal / quasi-horizontal and slightly tilted terrains represent 12 – 15 % of the total analysed surface, and the class over 32° covers 1 – 2.5 % of Padiș surface. The slope values that mark the petrographic and erosional abrupts (over 45°) are found in Cetățile Ponorului, Izbucul Ponorului, the right slope of Ursului valley towards the spring, the left slope of Seci (Glăvoiul) valley and in Pietrele Boghii. Only the slope raster derived from LiDAR has stored values over 70° tilt, while for the slope obtained from DEM_TOPO, the values stop at 46°.

Table 3. The distribution of the Padiș area by slope classes
(Source: Authors)

	Slope Classes						
	0 - 3°	3 - 6°	6 - 17°	17 -25°	25 - 32°	32 - 45/78°	Total Area
Area from DEM_TOPO (ha)	215.66	322.70	1815.93	1048.88	230.94	41.42	3675.5
Area from DEM_LiDAR (ha)	167.83	275.53	1796.78	1028.42	315.36	91.50	3675.5

As can be seen from figures 6, the only slope class where almost the same percentage weight is kept on both sets of results derived from DEM_TOPO and DEM_LiDAR, is the one of 6 - 17°. For the rest of the classes, the differences are between 1 and 3 % and are clearly conditioned by the greater variety of cell-level input data from DEM_LIDAR.

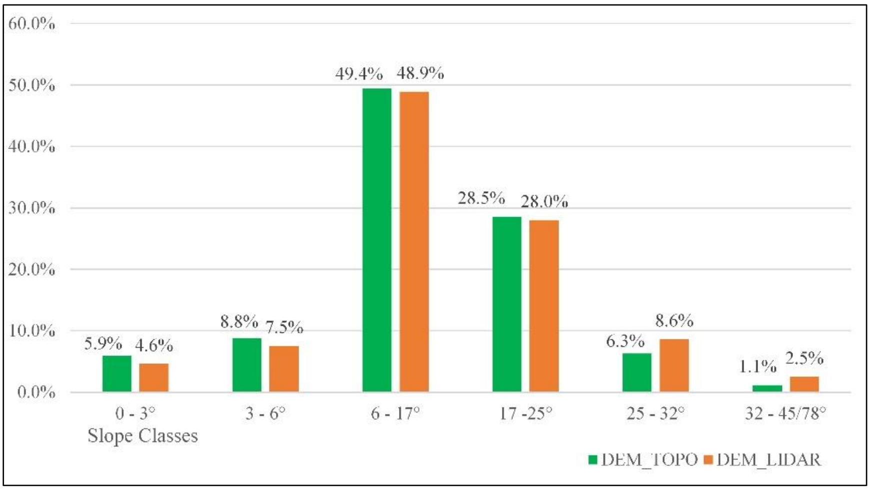

Figure 6. The percentage distribution of the area by slope classes
(Source: Authors)

Actually, if we analyse the spatial correspondence between the classes of the 2 rasters, we notice significant differences. For example, for the class 3 - 6° from DEM_TOPO, only 87 ha are kept in the same class for the data derived from DEM_LiDAR, and the rest migrate maily to the class 6 - 17° (table 4). For the class 25 - 32°, only 93 ha are kept in the same class as the slope raster derived from DEM_LiDAR. We draw attention that we talk about migrations of the surfaces of the rasters from one class to another, that is we should not confound the information from frigure 6 with that from table 4.

Table 4. Tabulated Area between slope classes areas derived from DEM_TOPO and slope classes areas derived from DEM_LiDAR (expressed in hectares)
(Source: Authors)

		0 - 3°	3 - 6°	6 - 17°	17 -25°	25 - 32°	32 - 45/78°
DEM_TOPO	0 - 3°	78.06	58.62	64.06	8.14	2.48	0.90
	3 - 6°	47.65	87.44	163.99	18.27	3.86	0.69
	6 - 17°	36.14	123.51	1224.33	359.01	55.24	16.55
	17 -25°	1.17	6.28	322.39	542.65	149.02	23.86
	25 - 32°	0.14	0.90	18.62	91.10	93.17	27.52
	32 - 45/78°	0.00	0.21	2.00	7.24	13.10	20.07

Aspect

In this study, the aspect rasters were classified to obtain the 4 standard classes (shady slopes, semi-shady slopes, semi-sunny slopes, sunny slopes), to which we add the horizontal terrains (figure 7). We mention that the rasters derived from any GIS soft for the aspect parameter (slope azimuth) highlight only the perfectly horizontal terrains (mathematically). If we want to highlight these terrains on aspect maps, with a correspondence with the horizontal terrains on slope maps, some processing is required presented by Blaga et al. (2014).

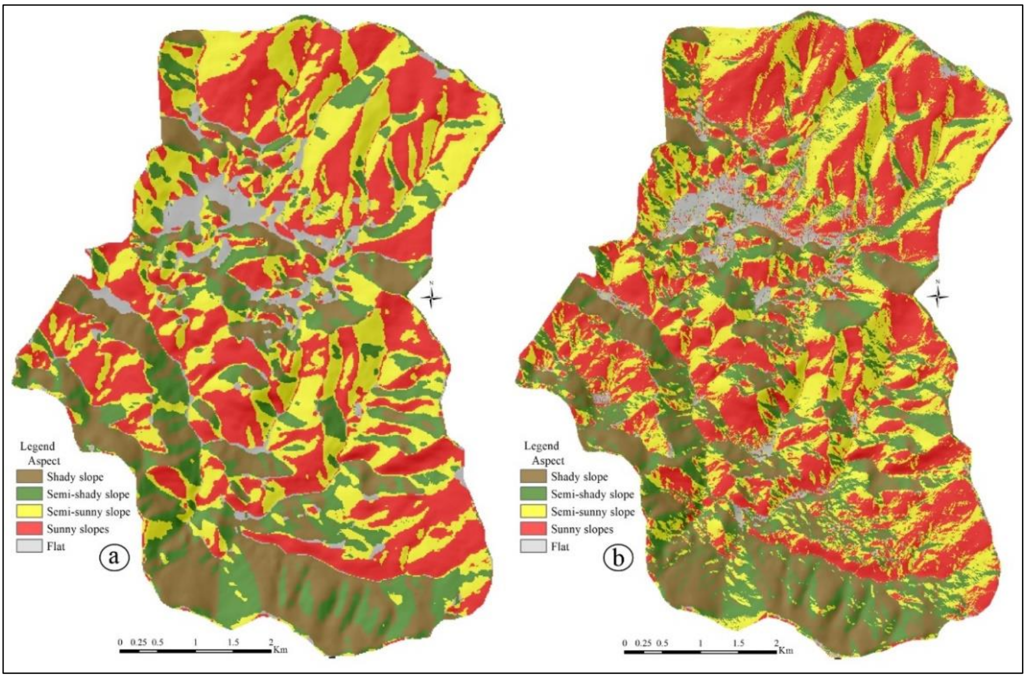

Figure 7. Aspect based on: a) DEM_TOPO; b) DEM_LiDAR
(Source: Authors)

The largest percentage of the total area of the basin belongs to sunny slopes (33%), followed by semi-sunny slopes with 28% (figure 6). The shady and semi-shady slopes together cover less than 1300 ha (table 5), being distributed spatially, mainly in the southern half of the area.

Table 5. The distribution of the Padiș area by sspect classes
(Source: Authors)

	Slope Aspect Classes					
	Shady slopes	Semi-shady slopes	Semi-sunny slopes	Sunny slopes	Flat	Total Area
Area from DEM_TOPO (ha)	595.91	670.12	1018.85	1174.89	215.66	3675.4
Area from DEM_LiDAR (ha)	583.46	689.63	1040.07	1194.43	167.83	3675.4

The comparative analysis of the surfaces related to the aspect slope classes derived from the 2 DEMs (figure 8), indicates an almost perfect quantitative correspondence, and it is normal to be so, because no matter how much information variety the LiDAR data bring, the slope azimuth can only be one for a hillslope (if the processing is done correctly).

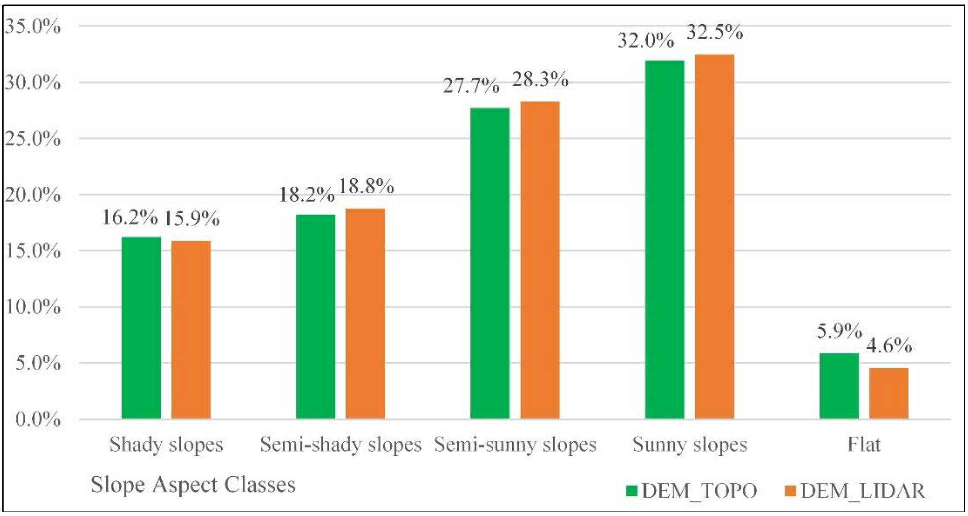

Figure 8. The percentage distribution of the area by slope aspect classes
(Source: Authors)

Land Surface Curvatures

Since 2012, the year of the publication of a study related to the significance of the curvatures (Blaga, 2012) up to now, the confusions related to their interpretation and implementation in GIS softs have still been present, although in this period a lot of well-documented articles on this topic have been published, as the one written by Minár, Evans and Jenčo in 2020. As the above mentioned authors say, there is a problem with the LiDAR data (they indirectly make this reference, meaning that they recommend smoothing and generalization of DEMs), related to the wide variety of Z (altitude) data at cell level and the implementation of the method of calculation in the GIS softs. Without going into details, (without forgetting our objective) we mention that this was the main reason why we chose Florinsky's algorithmization. **Profile Curvature**

It expresses the changing rate of the slope on the versant profile direction, along the flow alignments, perpendicular to the level curves, respectively. Morphologically, it indicates the convex (positive values in SAGA) and concave (negative values in SAGA) character of the slopes in the vertical plane (from the interfluves to the adjacent channels). From the point of view of runoff and erosion/deposition, it indicates sectors with high (convex areas) or low (concave areas) potential for accelerating runoff or decelerating runoff on slopes, and implicitly for intensifying erosion/deposition. The tolerance range for horizontal lands is ± 0.0001.

At the level of the entire basin, a balance is observed in the distribution and percentage of convex and concave areas (figure 9), with a slight increase for convex surfaces, which varies from 41 ha for the profile curvature from DEM_TOPO, to 161 ha for the profile curvature derived from DEM_LiDAR (table 6).

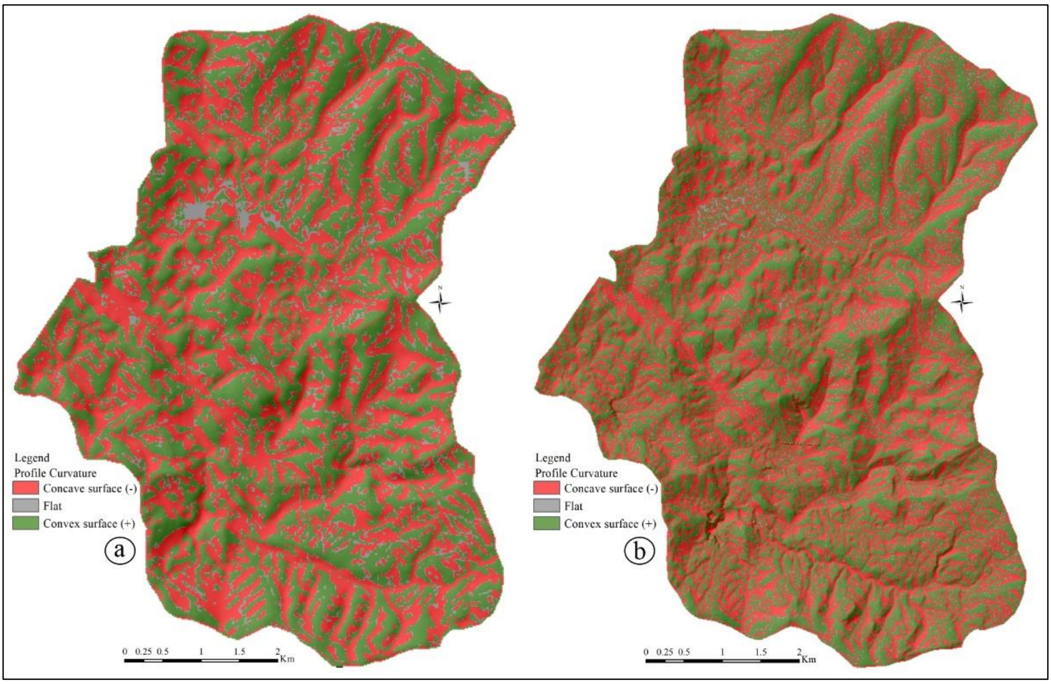

Figure 9. Profile Curvature based on: a) DEM_TOPO; b) DEM_LiDAR
(Source: Authors)

Table 6. The distribution of the Padiș area by profile curvature classes.
(Source: Authors)

	Profile Curvature Classes			
	Convex Area (+)	Concave Area (-)	Flat	Total Area
Area from DEM_TOPO (ha)	1694.30	1652.60	328.64	3675.5
Area from DEM_LiDAR (ha)	1817.13	1655.35	202.94	3675.4

Plan Curvature

In summary, it expresses the rate of change of the slope in a direction parallel to the isohypses, that is, it shows us the convex or concave character of the surfaces in this direction. It is essential in modeling runoff on slopes, because it indicates its convergent or divergent character, a fact already demonstrated by existing studies (Mitasova et al., 1995; Mitasova et al., 1996; Mitas and Mitasova, 1998), with the specification that in the mentioned studies the plan curvature is replaced by the tangential curvature that has the same significance. The analysis of the spatial and quantitative ditribution of the sectors with convergent and divergent runoff from the study area (figure 10, table 7) shows a balance similar to the one revealed for the values of the profile curvature.

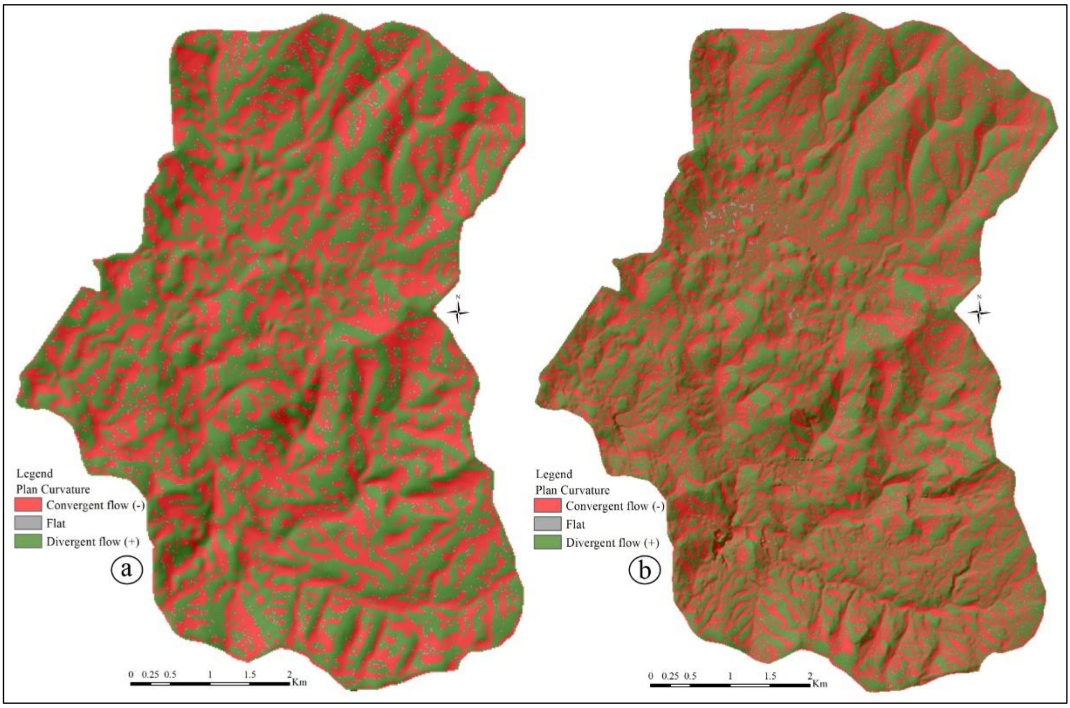

Figure 10. Plan Curvature based on: a) DEM_TOPO; b) DEM_LiDAR
(Source: Authors)

The sectors with convergent runoff cover 46 % (46.84 % / 46.02 % - DEM_TOPO / DEM_Lidar) of the total area, and those with divergent runoff cover 51 – 52 % of the entire area of Padiș plateau.

Table 6. The distribution of the Padiș area by plan curvature classes
(Source: Authors)

	Plan Curvature Classes			
	Convergent flow (-)	Divergent flow (+)	Flat	Total Area
Area from DEM_TOPO (ha)	1721.77	1884.85	68.92	3675.5
Area from DEM_LiDAR (ha)	1691.61	1931.90	51.91	3675.4

At the level of horizontal surfaces, despite the fact that the same tolerance range was kept (± 0.0001), it is noticeable a significant decrease compared to the data from the profile curvature, a fact that can be explained by the method of calculation.

General Curvature

Regardless of the algorithmization, it expresses the convex, concave or horizontal character of the forms of relief, in the sense that by the positive values (in SAGA) are identified the convex forms (slopes, interfluves, peaks) and by the negative ones (in SAGA) the concave forms (slopes, channels, depressions). The horizontal terrains have the same interpretation presented for the other 2 types of curvatures.

The convex surfaces represent 50 % of the territory, according to the processed data from DEM_TOPO, and 52 % from the data derived from DEM_LiDAR (figure 10, table 7), and the concave surfaces cover 47.5 % and 45.4 % respectively of the entire area. These percentages show us the maturity state of the relief in Padiș regarded as a whole and related to the scale of cyclical time.

Table 7. The distribution of the Padiș area by general curvature classes
(Source: Authors)

	General Curvature Classes			
	Convergent flow (-)	Divergent flow (+)	Flat	Total Area
Area from DEM_TOPO (ha)	1834.13	1748.03	93.38	3675.5
Area from DEM_LiDAR (ha)	1912.58	1671.35	91.49	3675.4

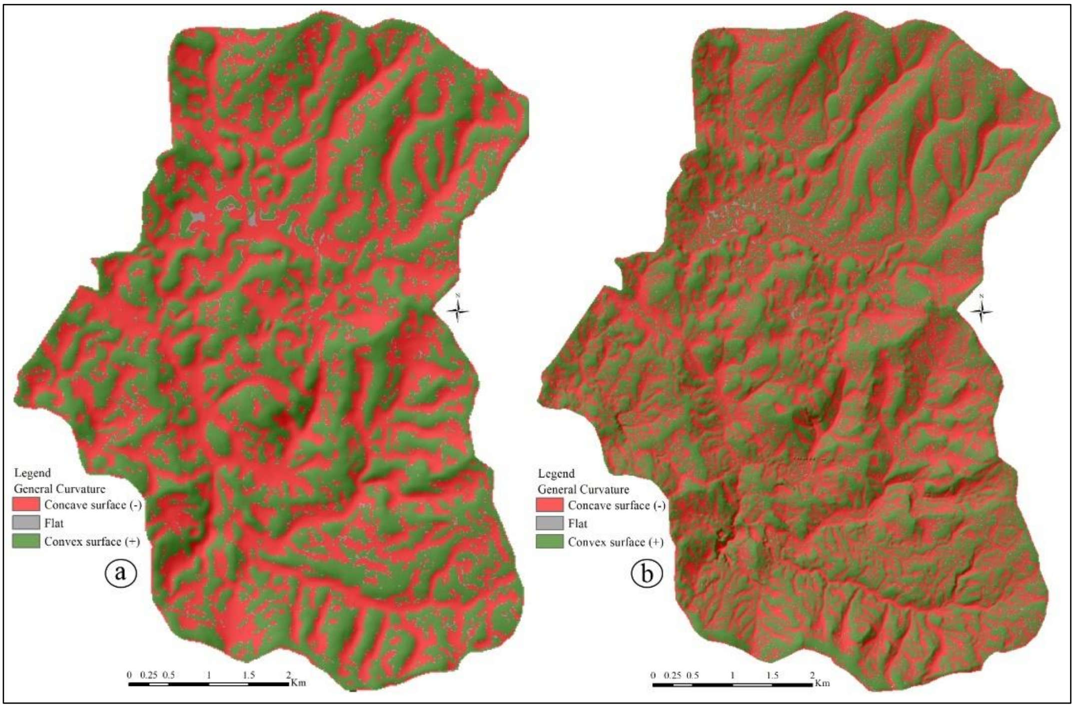

Figure 10. General Curvature based on: a) DEM_TOPO; b) DEM_LiDAR
(Source: Authors)

The information that can be extracted by relating the general curvature to the other geographical and geological territorial components can be more valuable than the specification of an evolution stage for the karst geomorphosystems from an area.

In figure 11 we presented together the hydrogeological features of the territory, the general curvature derived from DEM_TOPO and a hillshade generated from DEM_LiDAR. The hydrogeological map was drawn by Orășeanu (1996) for Bihor – Vlădeasa Mountains. We have only georeferenced the sector corresponding to Padiș with 9 control points taken from topographic maps 1: 25000.

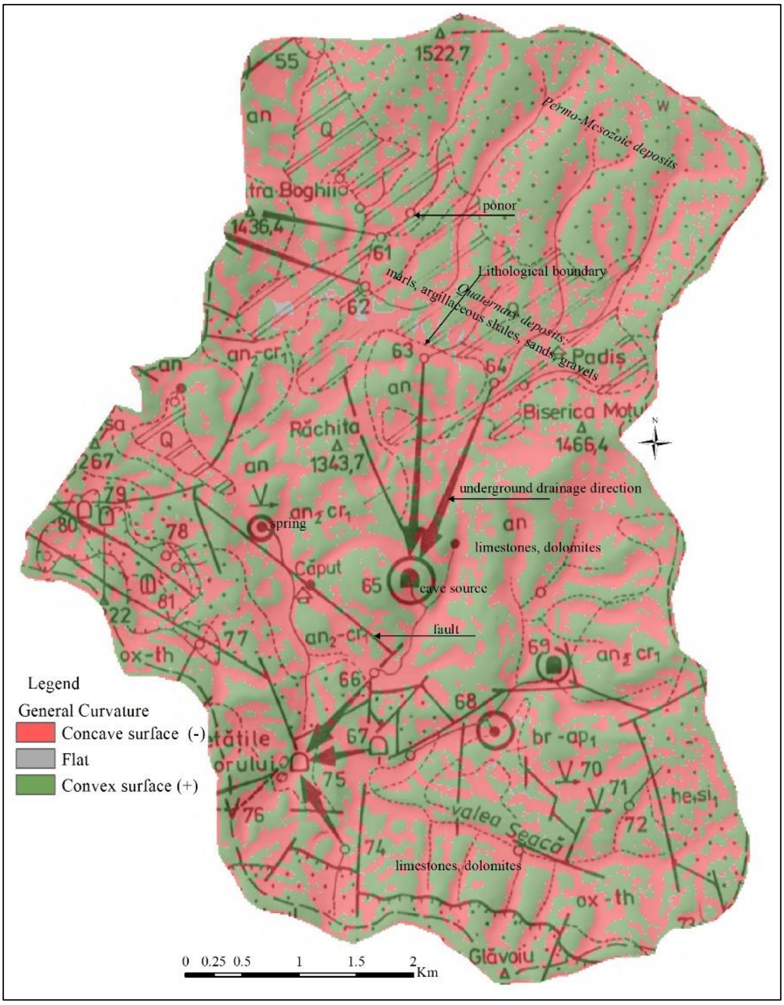

Figure 11. The hydrogeological features (Orășeanu, 1996) combined with the General Curvature in Padiș (Source: Authors)

If we follow closely the lithologic contact between Quaternary deposits (marls, argillaceous shales, sands, gravels) and karstificable rocks (limestones, dolomites) it is noticeable that there is a good correspondence with the alignment of the concave sectors from the area. In addition, if we look at the location of ponors with higher density on Padiș plateau, we can notice that they are located in the sectors with negative sign for the general curvature. Actually, this concave sinuous strip located at the contact between limestone and Quaternary sedimentary deposits corresponds to the alignment of underground water loss because the water loss takes place not only in ponors, but also diffusely. The same correspondence can be seen if we follow the location of the fault lines or the surface drainage network.

CONCLUSIONS

In this study we have done a unitary morphometric analysis of Padiș – Cetățile Ponorului basin using 6 primary morphometric parameters, essential for such a study.

The results show that we are in a mountainous sector, with a predominantly karst plateau morphology in the northern half, situated at an average altitude of 1268 m, in which prevail the surfaces with a moderate tilt (6 - 17°). All the types of curvature used express the maturity character of the surface relief, but this aspect could be caused by the direction of the main shaping agent (water) in the underground. Anyway, even the shaping stage of some local sectors, such as Cetățile Ponorului, in which the exokarst starts to combine with the endokarst, offers the same clues.

We believe that the potential of curvature parameters in relation to other morphological and geological features has not yet been fully exploited, and consequently, the future studies can highlight these aspects in more detail.

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