DEM based geomorphometric analyses of karst surface in the Republic of Macedonia

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Abstract— **Karst terrains in the Republic of Macedoniacover 12 % of its territory, generally as a number of separate karst areas with various sizes, most of which are located in the western and central parts of the country. Karst rocks are represented mostly by Triassic limestones and Precambrian marbles, with also parts composed of Paleozoic marbles and carbonate schists, Jurassic and Cretaceous limestones, Pleistocene tufa, tufaceous limestones and travertines and also Cretaceous gypsum and anhydrite. General morphometric characteristics of the karst surface were analyzed, with hypsometry, slope inclination and type, and aspect analyzed for both total karst surface and different karst rocks. Average elevation of karst terrains is 1100.4 m, reflective of the extension of karst terrains generally in mountainous regions, with limestone and marble having higher average elevations. As youngest rocks, tufaceous limestones, tufa & travertines are located mainly at lower elevations. Average slope (20.6°) is also significantly higher than mean slope of the entire country (15.4°), reflecting generally deeply incised fluvio-karstic landscapes and well preserved tectonic structures within the karst surface. Aspect analysis of karst surface shows generally even distribution between classes. Regarding slope type, large areas have linear downhill slope, especially in regards to the plan curvature. Beside that, convex terrains prevail with 28.9% for plan and 38.6% for profile curvature (with positive values for both). These results represent first attempt to analyze the general morphometric characteristics of the karst surface in Republic Macedonia. The outcome reveals certain specific characteristic of the karst surface, especially between different karst lithologies.**

I. INTRODUCTION

In the last few decades, aside from the specific study on karst characteristics and development, spatial extent of karst areas in Macedonia has been analyzed. The resulting data are based on traditional area measurementof karst rock outcrop extension from geological maps. Thus, according to Andonovski [1], karst area in the country occupies 9.6% from the total, while for Kolčakovski &Boškovska[2] it is 10.4%. Very recently, Temovski [3] calculated the extent of karst area in Macedonia in fine scale by vectorization of all types of karst rocks, at 12% as a final result. These studies deal only with extension of karst rock outcrops, with no other aspects of the karstic surface analyzed. Thus, until now no geomorphometric study was made on the whole karstic surface. This study presents first attempt to analyze the general morphometric characteristics of the karst surface in Republic Macedonia.Karst is a significant landscape feature in this country, with karst water resources representing important part of the water supply system in the country. Karst terrains in Macedonia are found inmore or less isolated, generally smaller areas (so called "karst oases" [4]), most of which are in the western and central parts of the country.They have numerous doline and karren features, few active karst poljes, large fluvio-karstic areas, numbers of karst beveled surfaces andmore than

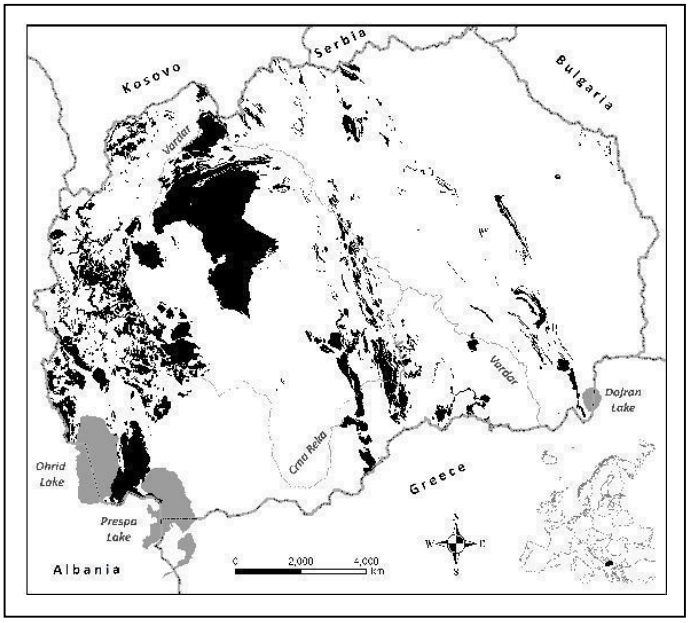

Figure 1.Extension of karst (black shade) in the Republic of Macedonia.

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400 documented caves. Karst rocks are represented mostly by Triassic limestones and Precambrian marbles, with also parts composed of Paleozoic marbles and carbonate schists, Jurassic and Cretaceous limestones, Pleistocene tufaceous limestones, tufa and travertines and also Cretaceous gypsum and anhydrite [3].

II. Methodology

Morphometric analyses were performed on vector data obtained by digitalization of karst rock outcrops from 100k General Geological Map of Macedonia. Map sheets containing karst rockswerefirstlygeo-referenced in national (Gauss Krugger)coordinate system. Digitalization of polygons was done in Global Mapper v.12 software, with database containing 11 fields for attributes of which 7 were extracted from the geological map (description, map source, symbol and 4 fields for age attributes), 3 were created with digitalization (area, island area, perimeter) and 1 was given according to the general classification of the karst rocks (limestone; marble; limestone, tufa & travertine; carbonate schist & marble; and gypsum & anhydrite). The obtained data, for the purpose of morphometric analysis, was later converted into UTM with WGS84 datum.

As a base for the geomorphometric analyses, 15m DEM of the Republic of Macedonia was used. This model is interpolated from 5m TIN-like detailed DEM of AREC-RM (Agency for Real Estate and Cadastre of the Republic of Macedonia), because of smoother surface and smaller file size. Currently, this is the best quality available DEM for the entire country with horizontal and vertical accuracy of +/- 2.2 m [5, 6].

Morphometric analyses of hypsometry, slope and aspect were performed using Spatial Analyst Tool in ArcGIS 10.1, and slope typein SAGA GIS v.2 modules.

III. Results and Discussion

Hypsometry

Average elevation of karst surface is 1100.4 m, with lowest value of 74.6 m and highest of 2743.9 m (Tab.1). The average elevation of the karst surface is well above the average elevation of the country at 829 m [7]. Distribution of elevation by 100 m classes shows major concentration between 500 and 1500 m, which is reflective of the extension of karst terrains generally in mountainous regions (Fig.2).

Analysis of hypsometry of various karst rock types shows that the distribution curve is mainly influenced by the major karst rocks, marble (51%) and limestone (43%), with peaks in classes of 800-900 and 900-100 m in marbles and classes of 1400-1500 and 1500-1600 m in limestones (Fig.2). Limestones have slightly higher average elevation (1192.1 m) than marbles (1045.4 m), generally found in mountainous areas in the western parts of the country. Marbles also cover mountainous areas in the western and central parts, but can also be found at lower elevations in the southern and eastern parts of the country.

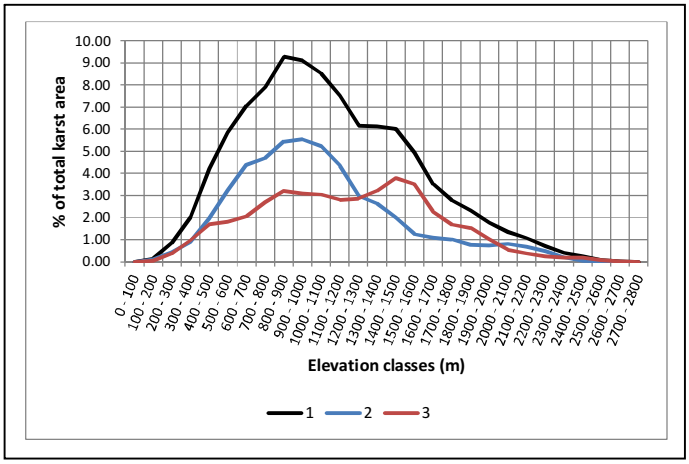

Figure 2.Area distribution by 100 m elevation classes of karst surface (1), marble outcrops (2) & limestone outcrops (3).

The other karst rocks cover much less surface (Fig. 3). Tufaceous limestones, tufa and travertines are the youngest karst rocks in Macedonia and are generally found at lower elevation, with lowest average elevation (593.7 m). Gypsum and anhydrites have the smallest area and can only be found along the deeply incised valley of Radika River, in the western part of the country. Carbonate schists & marbles and dolomites have wider vertical distribution, with average elevation of 1024.3 m and 1151 m respectively.Vertical distribution of the karst surface is a result of tectonic evolution of the area, with most of the karst rocks of Precambrian, Paleozoic and Mesozoic age, uplifted generally as part of horst structures. The tufaceous limestones, travertines and tufa are of Neogene and Quaternary age, deposited as continental deposits, mostly in lacustrine environments, and generallyare found at lower elevations, slightly elevated during the Quaternary.

TABLE 1.MAIN PARAMETERS (AREA, ELEVATION, SLOPE) OF KARST ROCKS.

Karst rocks	*% of total karst area*	*Elevation (m)*			*Slope (°)*		
		min.	*max.*	*avg.*	*min.*	*max.*	*avg.*
Marble	51.05	90	2607	1045.4	0	88.7	20.1
Limestone	43.36	74	2743	1192.1	0	88.7	20.5
Carbonate schist & marble	2.89	451	1965	1024.3	0	66.0	19.2
Tufaceous limestone, tufa & travertine	1.91	170	1057	593.7	0	51.1	9.7
Dolomite	0.76	368	1702	1151.0	0.12	52.6	23.2
Gypsum / anhydrite	0.07	577	1199	775.9	0	59.0	29.7
KARST	100.00	74	2743	1100.4	0	88.7	20.1

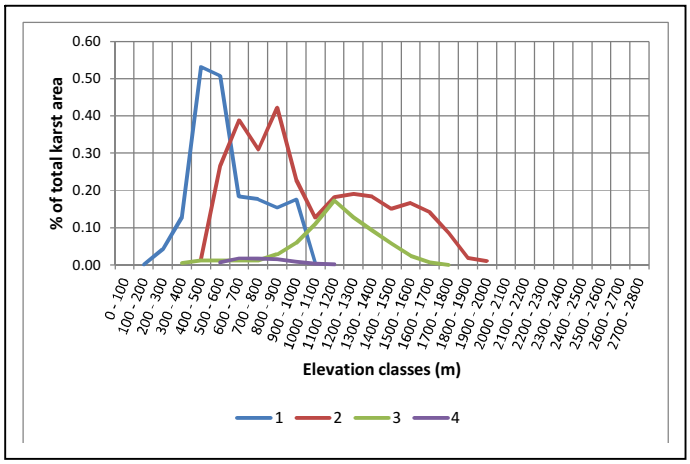

Figure 3. Area distribution by 100 m elevation classes of tufaceous limestone, tufa & travertine outcrops (1); carbonate schist & marble outcrops (2); dolomite outcrops (3); and gypsum & anhydrite outcrops (4).

In Macedonia, the amount of precipitation rises with altitude from about 500 mm on the lowest areas to 1200-1300 mm in high mountain parts (above 1500 m). It is opposite with temperatures which fall from 14°C to about 2-3°C. Thus, the karst weathering significantly increases especially above 1500 m, where limestone and marbles cover 591.5 km^2 or 16.2% of total karst area.

Slope

Average slope of the karst terrain in Macedonia is 20.6° or significantly higher than mean slope of the entire country which is 15.4° [5]. Only 35% of karst area has slope less than 20°, reflecting generally deeply incised fluvio-karstic landscapes and well preserved tectonic structures within the karst surface (Fig.4).

Marble and limestone have almost the same average slope with 20.1° and 20.5° respectively, while carbonate schist & marble have similar values at 19.2°. Gypsum & anhydrite and dolomite have the highest average slopes at 29.7° and 23.2°, generally due to deeply incised valleys. Tufaceous limestone, tufa and travertine have the lowest average slope inclination at 9.7°, which is mostly result to depositional low slopes, as most of these rocks are of lacustrine origin, have not been tectonically disturbed, and due to the karstic drainage have preserved their low slope surface.

Interestingly, the mean slope of karst terrains only slightly increase with altitude (unlike the overall terrain in the country) from 20.4° for areas under 1500 m to 21.3° for altitudes above 1500 m up to 2743 m. It is remarkable that highest values for slope angle have limestone and marble terrains (88.7°), while other rock types have more gentle peak slopes (up to 66°).

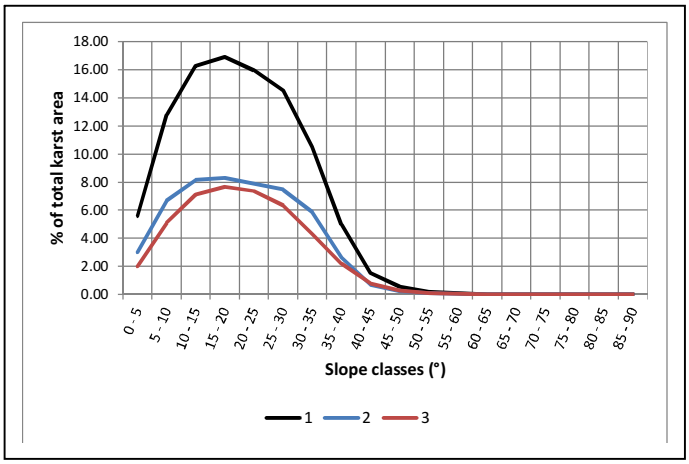

Figure 4. Area distribution by 5° slope classes of karst surface (1), marble outcrops (2) & limestone outcrops (3).

Also the area of slopes above 50° is much larger for limestone and marbles, mostly because of its hardness in comparisons to other, more erodible types of karst rocks. However, almost 1/3 of the karst terrain is flat or has slope under 15°, representing karst planation areas, karst polje bottoms etc. When compared with detailed 5m local DEM's, on these almost flat areas, small to medium-scale sinkholes frequently appear.

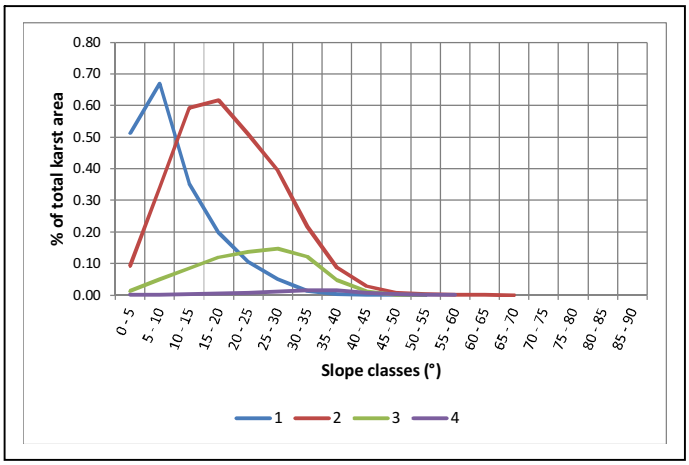

Figure 5. Area distribution by5° slope classes of tufaceous limestone, tufa & travertine outcrops (1); carbonate schist & marble outcrops (2); dolomite outcrops (3); and gypsum & anhydrite outcrops (4).

Aspect

Aspect analysis of karst surface shows generally even distribution between classes, with eastern (67.5-112.5°) and western (247.5-292.5°) expositions having slightly higher percentage.

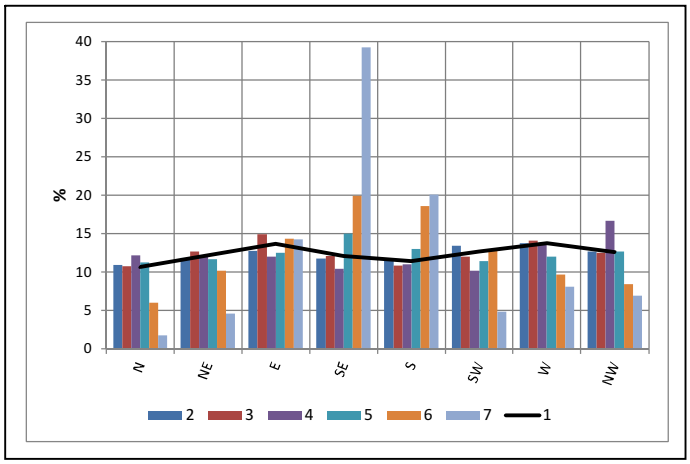

Figure 6.Area distribution of karst surface by 45° aspect classes: 1 – total karst area, 2 – marble, 3 – limestone, 4 – tufaceous limestone, tufa & travertine, 5 – carbonate schist & marble, 6 – dolomite, 7 – gypsum & anhydrite.

Similar distribution is found for most of the karst rocks, except dolomite and especially gypsum & anhydrite, where southern and southwestern expositions prevail. This is due to the local extension of these outcrops, mostly on valley sides with southern and southwestern aspect. As they represent less than 1% of the karst rock outcrops, this is not reflected on the total karst terrains aspect distribution.

When generalized to only north and south aspects, these two have exactly 50% each. However, small differences by altitude appear, where in lower karst terrains up to 1500 m, northern aspects prevail (50.3 %), while in higher terrains, southern aspects dominate (50.9%).Similar small differences are found in relation of aspects to the slope classes. Thus, terrains with steep slope (higher than 30°) are more inclined to south (50.7%), especially toward south-west and south-east. As a result, they are more exposed to temperature amplitudes and mechanical weathering.

Plan and profile curvature

Plan and profile curvature are calculated in SAGA GIS software, where negative values indicate concave slopes and positive values correspond to the convex terrains (peaks, ridges etc.). Values near zero indicate linear slopes [8]. As results in Table 2 shows, in karst terrains large areas have linear downhill slope, especially in regard to the plan curvature. Except of that, convex terrains prevail with 28.9% for plan and 38.6% for profile curvature (with positive values for both). This is normal, because the karst terrains composed of hard rocks, usually outcrop into the landscape as a ridges, crests, large stones etc.

According to the calculations, in lower altitudes (up to 1500 m), concave curvature dominates, while in higher it is opposite.

TABLE 2. PLAN AND PROFILE CURVATURE OF KARST TERRAINS.

Plan curvature	*Area (%)*	*Profile curvature*	*Area (%)*
<-0.01	14.0	<-0.001	23.2
-0.01 to -0.005	9.3	-0.001 to -0.0005	9.5
-0.005 to 0.005	47.8	-0.0005 to 0.0005	28.7
0.005 to 0.01	15.0	0.0005to0.001	9.4
>0.001	13.9	>0.001	29.2

IV. CONCLUSION

This research represent first attempt to analyze the general morphometric characteristics of the karst surface in the Republic of Macedonia. The outcome reveals certain specific characteristic of the karst surface, especially between different karst lithologies. Slope can be an important indicator of karst surface, as dolines will not develop on steep hillsides with more than about 20° [9]. Hypsometry of karst surface can also provide correlation to climatic characteristics (ex. precipitation, temperature) that control karst development, with most of the karstic terrains in Republic of Macedonia found in mountainous areas.Furthermore, with combination of selected geomorphometric parameters, fine-scale automated classification of karst features can be made [10].

REFERENCES

[1] Andonovski T., 1981. “Survey of underground karst forms in the SR of Macedonia”. 8th Yugoslav Congress of Speleology, Belgrade, 207-213.

[2] Kolčakovski D., Boškovska G., 2007. “Extension and age of carbonate rocks in the Republic of Macedonia”. Bulletin of Physical Geography, No.3-4, Skopje, 77-82.

[3] Temovski M., 2012. “Extension of karst rock outcrops in Republic of Macedonia”. Geographical Reviews, Skopje, 46, 21-35

[4] Manakovik D., 1980. “L’hydrographiekarstique en formed’oasis en Macedoine”. CongresYougoslave de speleology 7, Titograd, 293-309

[5] Milevski I., 2014. “Slope Values Accuracy vs Resolution of the Digital Elevation Models (Example of the Republic of Macedonia)”. Proceedings of 5th ICC-GIS Conference; Eds: Bandrova T &Konecny M., Vol. 2, Varna, 568-575.

[6] Milevski I., Gorin S., Markoski M., Radevski I., 2013. “Comparison of Accuracy of DEM’s Available for the Republic of Macedonia”. Proceedings from the 3rd International Geographic Symposium - GEOMED 2013, Antalya, 165-172

[7] Andonovski T., 1995. “Characteristics of relief in the Republic of Macedonia”, Geographical Reviews, Skopje, 30, 5-12.

[8] Dikau, R., 1989. “The application of a digital relief model to landform analysis”. In: Raper, J.F. (Ed.). Three dimensional applications in Geographical Information Systems. Taylor and Francis, London, pp. 51–77.

[9] Ford & Williams, 2007. “Karst hydrogeology and geomorphology”. 2nd ed., Wiley, 562 pp.

[10] Liang, F., and Y. Du., 2013. "An automated method to extract typical karst landform entities from contour lines on topographic maps". Geomorphometry 2013. Nanjing, China.