MORPHOMETRIC ELEMENTS OF TERRAIN MORPHOLOGY IN THE REPUBLIC OF MACEDONIA AND THEIR INFLUENCE ON SOIL EROSION

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Abstract

As a consequence of suitable natural factors and increased human impact in the space, Republic of Macedonia is characterized by high rates of soil erosion (among the highest in Europe). On this relatively small area (25.713 km^2), we have real mosaic and variations of natural factors: geology, geomorphology, climate, hydrology, vegetation, soil stucture as well as high variations in population density and human activity. From mentioned factors, terrain morphology has significant direct or indirect influence to soil erosion processes. Namely topography of Macedonia is characterized by high absolute and relative altitude differences (lowest point 44.5 m and highest peak 2753 m), then average to high slopes dominantly with south inclination, great vertical relief dissection etc. Because of the significance for soil erosion processes, we performed detailed morphometric analysis of several topographic elements: hypsometry, slopes (slope angle, slope curvature), terrain aspect (inclinations) and vertical relief. Furthermore, complex cluster classification of topographic elements is made according to their influence on soil erosion processes. Every topographic factor is indicated in the view of the implication on erosion potential.

Key words: geomorphometry, cluster analysis, soil erosion

INTRODUCTION

Republic of Macedonia has high intensity of soil erosion processes which is evident from simply terrain prospecting (field analysis) or from already made soil erosion map (Djordjević *et al*., 1993) which indicates a mean specific sediment production of about 680 $m^3 \cdot km^{-2} \cdot yr^{-1}$. There are many factors for such high erosion, partly based on natural conditions and partly of human activity in past and modern time.

Among the natural factors of soil erosion, topography has great importance. On gentle slopes or flats, soil erosion is low or accumulation prevails, while opposite is on terrain with high slopes. Hypsometry has indirect influence thought climate, type of vegetation cover and intensity of human activity. Also, inclination has considerable effect, because on this (north) latitude, soil erosion is stronger on south sides since of greater temperature amplitudes, lower precipitations, poorer vegetation, greater human impact etc. (Lazarević, 1975).

Mentioned examples show that analysis of topography may suggest soil erosion potential of an area. Certainly, some topographic parameters have greatest effect on soil erosion than others, so it is necessary right selection of terrain attributes. For that purpose we perform detailed analysis of some erosion-related geomorphometric elements of the Republic of Macedonia.

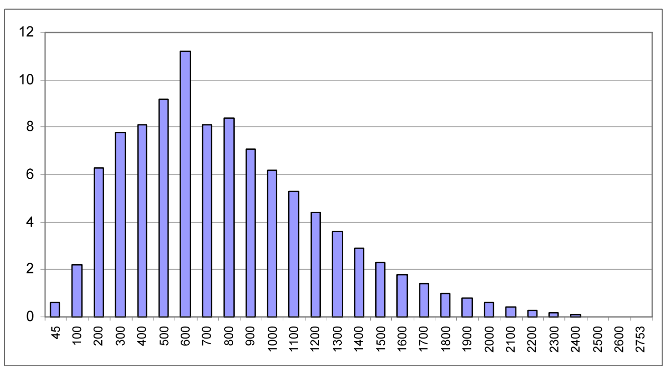
Previously, there are several works considering some geomorphometric parameters of Republic of Macedonia like hypsometry, slope angles, aspects and relief (Manaković *et al.,* 1986; Andonovski, 1995; Markoski, 1995; Manaković *et al.,* 1998). These analysis and data's are acquired with classical (manual) cartometry procedures with some subjective disadvantages.

In our analysis we use latest software techniques together with 3"SRTM DEM (version 2 of CGIAR-CSI; Jarvis, A. *et al*., 2006). This is a free near global DEM (covering latitudes from 60N to 56S) with acceptable resolution and quality. Worldwide research suggest that vertical and horizontal errors of this model are tolerant (Gamache, 2004; Gonçalves & Fernandes, 2004; Milevski, 2005; Koch *et al*., 2006), and good enough for medium-scale geomorphometry procedures. Because of international coverage, there are possibility for comparisons of results with other areas and countries. However, from 3"DEM model is extracted quadrant covering Republic of Macedonia, after which original resolution of 3" is reinterpolated to UTM coordinates and squares of 70 m, and about 5 millions points (pixels). Such resolution is just optimal for entire country, keeping in balance computer performance, file size as well as output results. Previously prepared DEM, is then processed with latest available software. Among huge choice of free and commercial software for DEM analysis, were used SAGA GIS v.1.2, 2.0, MicroDEM v.10, and Golden Software Surfer v.8.

In this analysis are included standard (basic) soil erosion-related morphometric elements: hypsometry, slopes, aspects, profile and plan curvature, terrain convergence and vertical relief. On the end, special procedure of cluster analysis of slopes and curvatures is performed.

Hypsometry

Republic of Macedonia lay between 45 m (Vardar riverbed on the Greece border), and Golem Korab peak (2753 m), which is vertical difference of 2708 m. Taking the sea level like basis, overall 27 hypsometric zones by 100 m can be arrange, and their area is figure on graph 1.



Graph 1. Hypsometry of the Republic of Macedonia in%, by 100 m altitude zones.

From Graph 1 is evident that greatest area of the country (44%) lye between 500–1000 m above sea level. Below 500 m is an area of 25%, and above 1000 m is 31% of entire area. Such hypsometry with dominant elevation of 500–1000 m, exactly correspond with high erosion potential. Namely, in that range here we have low mean annual precipitation (450–650 mm) with events of intensive rains, vegetation is poor and sparse (slim raindrop protection), human activity and land use is significant. On higher elevation, above 1000 m, precipitations generally rise (about 40–50 mm/100 m; Lazarevski, 1993), with higher potential for pluvial erosion, but on other side, vegetation cover is denser offering greater protection against raindrop erosion.

According to altitude of all 5.187.139 70 m DEM points, outcome that Republic of Macedonia has average elevation of 832 m, which is highest of all Balkan Peninsula countries.

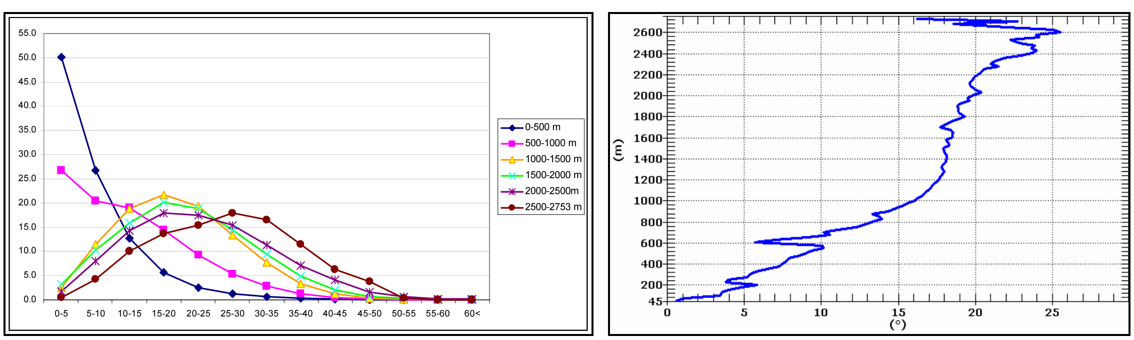
Terrain slopes

Slopes have great influence on soil erosion intensity, in a way that with slope, kinetic energy of surface water increase, as well as erosion rate (Gavrilović, 1972), which is formulated in some equations of erosion modeling (Morgan, 1995).

Terrain slopes of Republic of Macedonia are obtained with MicroDEM software. Because of resolution related underestimation, slope values are corrected with empiric index in form $\alpha = \alpha \cdot [1+(\alpha/150)]$. Followed analysis suggest that moderate slopes (10–30°) prevail, covering an area of 42.4%. Usually those are mountain, depression and valley sides, often on their bottom in the contact with flats. If other factors are suitable (geology, vegetation), on these slopes sheet and gully erosion, as well as some types of landslides occur. Terrains with lower slopes (2–10°), related with thin pluvial erosion and small stratigenic landslides, cover area of 29.8%, and depositional flat areas (0–2°) cover 13.6%. It must be point-out that step slopes (above 30°), related with deep valleys, fault sides, escarpments etc, reach significant area of 7.1%. Those areas have potential for linear erosion, landslides and rock falls.

Table 1. Terrain slopes (corrected) of the Republic of Macedonia derived from 3"SRTM DEM

Slope	Above °		Below °		Between °	
°	km²	%	km²	%	km²	%
0	25713.0	100.0	0.0	0.0	2284.6	8.9
1	23428.4	91.1	2284.6	8.9	1202.7	4.7
2	22225.7	86.4	3487.3	13.6	926.4	3.6
3	21299.3	82.8	4413.7	17.2	934.4	3.6
4	20364.9	79.2	5348.1	20.8	969.7	3.8
5	19395.2	75.4	6317.8	24.6	4844.3	18.8
10	14550.9	56.6	11162.1	43.4	4384.2	17.1
15	10166.7	39.5	15546.3	60.5	3705.6	14.4
20	6461.1	25.1	19252.0	74.9	2791.9	10.9
25	3669.2	14.3	22043.8	85.7	1833.2	7.1
30	1836.0	7.1	23877.0	92.9	1063.3	4.1
35	772.8	3.0	24940.3	97.0	491.0	1.9
40	281.8	1.1	25431.3	98.9	186.4	0.7
45	95.4	0.4	25617.7	99.6	61.5	0.2
50	33.8	0.1	25679.2	99.9	20.7	0.1
55<	13.1	0.1	25699.9	99.9	13.1	0.1



Graph 2. Elevation-slope plots of: A. 500 m elevation zones in%; B. mean slope curve

From elevation-slope relation on graph 2, outcome that slopes in Republic of Macedonia have general tendency of rising with elevation. Greatest gradient of mean slope curve is recorded up to 1200 m altitude (1.5°/100 m), suggesting steepest slope change and highest erosion potential (which is evident from field research). Overall, mean slope of all country is high, i.e. 13.5°.

Terrain aspects

Terrain aspect (inclination) is another morphometric element influencing soil erosion processes. Our analysis of 3”DEM, show that in Republic of Macedonia SW-W (26.4%) and E-NE (26.1%) aspects prevails. This is result of Dinaric direction (NW-SE) of main structural landforms (mountains, valleys, basins), especially in the west and central part of the country. In general (without flat areas), west aspects are greater (27.4%), than east (25.8), south (24.8%), and north (21.9%) aspects. So terrains with south inclination are larger than terrains with north inclination. South-sided terrains are exposed to higher weathering (because of solar radiation, temperature amplitudes, dryness, deforestation) and more eroded than north terrains.

Table 2. Terrain aspects of the Republic of Macedonia, from 3”SRTM DEM

Terrain aspects		Area	
Aspect	Aspect deg.	km^2	in%
N	337.5-22.5	2689.0	10.5
NE	22.5-67.5	3168.1	12.3
E	67.5-112.5	3559.6	13.8
SE	112.5-157.5	3066.2	11.9
S	157.5-202.5	3035.7	11.8
SW	202.5-247.5	3427.7	13.3
W	247.5-292.5	3363.3	13.1
NW	292.5-337.5	2620.5	10.2
Water surface		425.3	1.7
Flats <1°		357.7	1.4
All		25713.0	100.0

Profile curvature

Profile (vertical) curvature is terrain curvature in steepest slope direction. This is very significant topographic element that show which process tends to be dominant, erosion or deposition. On convex terrains erosion is likely to prevails, and on concave deposition. Amount of these processes depend of degree of convexity or concavity.

Profile curvature of Republic of Macedonia (as well as plan curvature) is calculated with Surfer v.8 (in unit rad/100m), where negative values indicate convex and positive values concave areas. Analysis shows that in Republic of Macedonia concave terrains cover greater surface (43.9%), because of dominance of large depressions and valleys (Table 3). In that sense, concave and highly concave are near 11.5% of total area, representing deep depressions and valley bottoms with increased deposition. On the other side, convex areas cover 38.3%, representing ridges, crests, peaks and other forms related with erosion processes. Areas with flat profile curvature (13.8%), usually are erosional, especially on steepest slope angle.

In Republic of Macedonia, profile curvature change with altitude and relief structures, similar like slopes. Concave terrains dominate below 1000 m, and convex terrains are above this altitude where erosion is principal process.

Plan curvature

Plan (horizontal) curvature is normal to profile curvature, and represent terrain curvature along contour (aspect). Terrains with convex plan curvature indicate dispersion of surface waters (initiation of sheet, rill and gully erosion), and terrains with concave plan curvature indicate contribution-aggregation (concentration) of surface waters, thus elevated processes of deposition (fan, alluvial areas). According to DEM calculations, in Republic of Macedonia prevail terrains with convex plan curvature (42.7%) in respect to concave plan curvature (38.7%). But latest have greater fraction of highly and extremely concave curvature showing terrains with high deposition (Table 3). Unlike profile curvature, altitudinal change of plan curvature is insignificant.

Table 3. Profile and plan curvature of terrain in the Republic of Macedonia

Description	Profile curvature			Plan curvature		
	Value	km^2	%	Value	km^2	%
extremely convex	–0.018 to –0.008	–	–	–0.18 to –0.08	15.51	0.06
highly convex	–0.008 to –0.004	51.35	0.20	–0.08 to –0.04	97.78	0.38
convex	–0.004 to –0.001	2686.4	10.45	–0.04 to –0.02	2070.65	8.05
slightly convex	–0.001 to –0.0001	7121.91	27.70	–0.01 to –0.001	8797.42	34.21
flat	–0.0001 to 0.0001	3555.89	13.83	–0.001 to 0.001	3783.78	14.72
slightly concave	0.0001 to 0.001	8347.00	32.46	0.001 to 0.01	7594.11	29.53
concave	0.001 to 0.004	2796.68	10.88	0.01 to 0.04	2212.10	8.60
highly concave	0.004 to 0.008	147.41	0.57	0.04 to 0.08	118.06	0.46
extremely concave	0.008 to 0.012	1.73	0.01	0.08 to 0.18	17.19	0.07
other	–	1004.63	3.91	–	1006.40	3.91
all	–	25713.00	100.00	–	25713.00	100.00

Terrain convergence

Terrain convergence (divergence) is similar parameter to plan and profile curvature but is more "pronounced" in values. It is derived from module local morphometry incorporated in SAGA GIS software, where usually serve for catchments extraction and divide delineation, as well as specific landforms classification (Olaya, 2004).

Values for terrain convergence of the Republic of Macedonia range from –91.6 (max concave terrains with surface water concentration) to 94.1 (max. convex terrains with surface water dispersion). In this analysis, terrains with slopes smaller than 1°, have zero convergence.

Results of convergence analysis (aspect-based) show that larger area have divergent-convex terrains (crests, peaks, ridges, upper slopes) with values greater than 2 (42.4%). Convergent-concave terrains (depressions, valleys, lower slopes) cover 40.1%. The rest of about 17.5% belongs to the terrains with generally flat convergence. From our experience, greater erosion potential has terrains with curvature index between –25 to –10 and 10 to 30, which cover around 35% of entire country area. These values, in practice often overlap with areas of significant erosion rates, especially if other soil erosion factors (like soft rocks and sparse vegetation) are suitable.

Terrain relief

Terrain relief is a morphometric parameter which shows maximal altitudinal differences of some area, ordinary box size of 1 km^2. This parameter is in correlation with intensity of tectonic movements and dynamics of geomorphological processes in analyzed area. Higher relief indicates greater erosion potential (relief energy, according to Marković, 1983).

Terrain relief in Republic of Macedonia is obtained thought square boxes areas (of 1 km^2) analysis, in MicroDEM v.10. Values are between 0 m·km^{-2} (flats) in larger depressions and 1150 m·km^{-2} for Nezilovski Karpi escarpment on south side of Jakupitca Mountain.

Calculations indicate that greatest area occupied terrains with moderate relief (100-300 m), covering 50.3%. Those are generally edge mountain areas contacting with near depressions, or dissected with valleys, and often characterized with strong pluvial erosion and denudation. It is important to outline that terrains with high relief (300–800 m), cover significant 24.3%, representing inner mountain areas dissected with deep fault-incised valleys. Real flats with relief 0–10 m, cover only 5.5%, representing inner areas of large depressions (basins). In one word, terrain relief has strong erosion potential, characterizing with great vertical dissection and minor flats.

Table 5. Terrain relief of the Republic of Macedonia in m/km^2

Relief	Above m		Below m		Between m	
	km^2	%	km^2	%	km^2	%
0 m	25,713.0	100.0	0.0	0.0	1409.9	5.5
10 m	24,303.1	94.5	1,409.9	5.5	645.2	2.5
20 m	23,657.8	92.0	2,055.2	8.0	433.7	1.7
30 m	23,224.1	90.3	2,488.9	9.7	420.1	1.6
40 m	22,804.1	88.7	2,908.9	11.3	527.0	2.0
50 m	22,297.0	86.7	3,416.0	13.3	3,109.4	12.1
100 m	19,187.5	74.6	6,525.5	25.4	12,938.8	50.3
300 m	6,248.7	24.3	19,464.3	75.7	5,487.8	21.3
500 m	760.8	3.0	24,952.2	97.0	753.0	3.0
800 m <	7.9	0.0	25,705.1	100.0	7.9	0.0

Cluster classification

Previously analyzed parameters are in group of so-called simple local morphometry. But like individual parameters they don't provide clear picture of topographic erosion potential. For this purpose, more often complex terrain classification is used. In the past several decades, researches introduced numerous models of terrain classification (Wood, 1996; Romstad, 2001; Miliaresis, 2002; Drăgut & Blaschke, 2006). Each model has some advantages and disadvantages, but the main goal of all them is to classify terrain is small number of as much is possible homogenous classes. In our procedure, 9 classes cluster classification thought SAGA discretisation module is used, where Hill-Climbing Rubin (1967) algorithm automatically classify most homogenous terrain units from several grid layers (topography parameters). From numerous possible parameters (slopes, curvature, aspects, LS index, wetness, relief etc.), slope angle, profile and planar curvature was selected. The results are given in Table 6. It is obvious that cluster classes with high erosion potential (steep convex or flat steep slope) dominate, which is evident from map on fig. 1D. Usually those are mid and lower mountain areas (bottoms), around depressions.

Table 6. Cluster classes of slope and curvature classification of Republic of Macedonia

Cluster	Slope	Plan Curv.	Prof. Curv.	Variance	Area km^2	Area%	Description	Process
0	15.42	–0.00088	–0.00393	477121.22	914.8	3.6	vall. bottom	high dep.
1	10.93	–0.00057	–0.00087	532508.89	4016.4	15.6	mid slope	slim eros.
2	2.59	–0.00004	–0.00003	332564.47	7267.9	28.3	flats	equilibr.
3	23.82	0.00101	0.00026	537491.42	2844.1	11.1	steep v. side	high eros.
4	10.91	0.00085	0.00052	511139.59	4189.6	16.3	mid slope	erosion
5	13.57	–0.00370	–0.00099	461106.10	1312.8	5.1	river beds	high dep.
6	23.47	–0.00109	–0.00042	510494.60	2494.8	9.7	steep conc.	high eros.
7	14.60	0.00093	0.00284	484135.38	1282.5	5.0	crests, peaks	surf. eros.
8	16.45	0.00345	0.00112	458395.76	1389.9	5.4	upp. convex	erosion

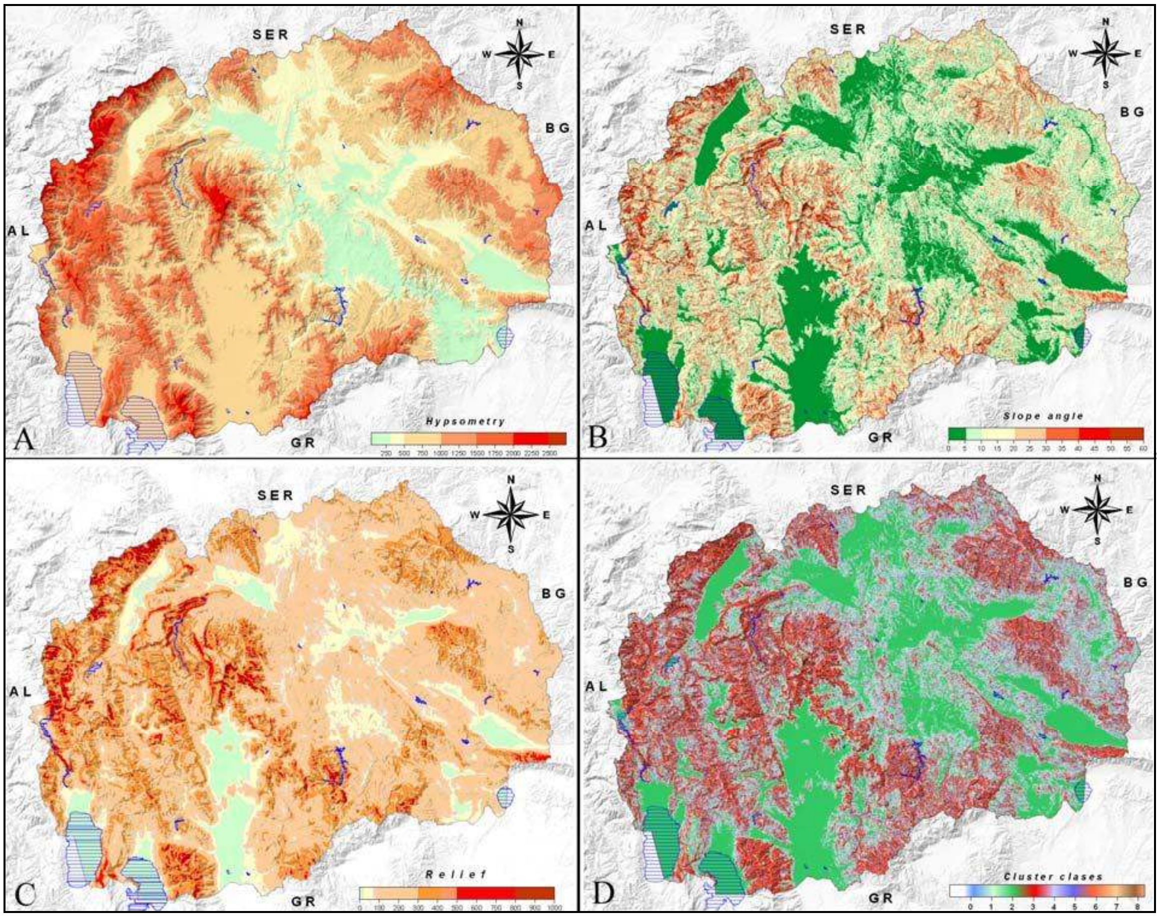


Fig. 1. Maps of A. hypsometry, B. slopes, C. relief and D. slope-curvature terrain clusters

CONCLUSION

In this paper are exposed some geomorphometric elements of Republic of Macedonia, directly or indirectly related with soil erosion processes. Greater attention is put to basic morphometry indices: hypsometry, slopes, aspects, profile and planar curvature and terrain relief. Aside of these, in analysis of soil erosion often is used LS factor and wetness index, two very significant parameters, but usually applicable on smaller areas. However, it is clear that all factors matching high topographic erosion potential, especially slopes and curvatures, which is clearer from their cluster classification. Properly used (quantified) in adequate equation (method of Gavrilović, USLE, etc.), these topographic indices, combined with derivative grids for precipitation, lithology, vegetation (from satellite imagery) and land use, can indicate acceptable values of annual erosion rate (Milevski, 2001).

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