SocioBrains

ISSN 2367-5721, JOURNAL HOMEPAGE: WWW.SOCIOBRAINS.COM

INTERNATIONAL SCIENTIFIC REFEREED ONLINE JOURNAL WITH IMPACT FACTOR

ISSUE 59, JULY 2019

TERRAIN RUGGEDNESS ANALYSIS OF THE WESTERN RHODOPE MOUNTAINS (SOUTH BULGARIA)

Abstract: In recent decades, the increasingly widespread use of GIS technology in terrain modeling has given new and wider opportunities.Terrain ruggedness is one of most important morphographic features of the local topography and is widely used in modern GIS based geomorphology. Terrain ruggedness is a parameter that quantifies surface roughness through consideration of absolute elevations in the surrounding of a given raster cell. It plays an important role in determining how local positive and negative landforms interact with its environment. The scarcity of such type of research for the territory of the Western Rhodope Mountains determines the actuality of this study. The main goal of present research is to investigate and evaluate the relief ruggedness variability within the Western Rhodope Mountains based on the contemporary GIS technology. The research is based on a 30x30m spatial resolution global digital elevation model (DEM) extracted from ASTER missions. Elevation data are analyzed and visualized using free GIS software. The results obtained show low heterogeneity of the relief and largely confirm the traditional views of the morphographic pattern of the study region.

Author information:

Rosen Iliev
PhD
Institute for Space Research and Technology
Bulgarian Academy of Sciences
✉ ilievrosen@space.bas.bg
Bulgaria

Keywords:
Western Rhodopes, Terrain ruggedness, mountains, GIS, morphographic, Bulgaria

1. INTRODUCTION

The use of the contemporary geographic information technologies (digital image processing, GIS, global positioning systems (GPS)) in geomorphological research increased in the last decades. Digital Elevation Models (DEMs) provide an objective measure of surface elevation (or relief) and are therefore ideally suited to the parameterization of surface features (Evans 1980). The free Digital Elevation Models (DEMs) and satellite images cover large areas and lead to rapid development of algorithms for digital terrain analysis and methods for calculation of different local and combined terrain variabilities (e.g. Evans 1980; O'Callaghan, Mark 1984; Moore et al. 1991; Band 1993; Beven, Kirkby 1993; Shary et al. 2002; Pike et al. 2009; Hengl, Reuter 2009; Florinsky 2012; Conrad et al. 2015 and others), landform recognition and classification (e.g. Dikau 1989; Irvin et al. 1997; Blaschke, Drăguţ 2003; Prima et al. 2006; Iwahashi, Pike 2007; Olaya 2009; Pike et al. 2009; Drăgut, Eisank 2011; Grohmann et al. 2011; Evans 2012; Florinsky 2012; Schillaci 2015 and others). DEMs can also be used to describe the terrain ruggedness or surface roughness of areas. This parameters refers to the variability in elevation within a defined radius and is therefore very sensitive to the selected scale. It is used for the identification of coherent structures or underlying processes (Hobson 1972). Combined with other “traditional” geomorphological methods the GIS-based DEM analysis improves the complex terrain investigations.

The Rhodope Mountains (Rhodopes) is the largest mountain system in the eastern part of the Balkan Peninsula and cover an area in Southern Bulgaria and Northern Greece. They represent a complex mountain unit, made up of numerous ridges, kettles and deep river valleys. These peculiarities make it distinct from the other main positive morphounits in this part of the Balkans, namely Rila, Pirin, Slavyanka, Ograzhden, etc. (Tzankov et al. 2015, 2017). Гълъбов (1966) divided this complex mountain morphounit into the Western and Eastern Rhodopes. The boundary between them is marked from north to the south by the valleys of the Kayaliyka, Borovitsa and Varbitsa rivers.

The existing regional geomorphological studies about the study area are focused mostly on “traditional” complex field based geomorphological mapping and analysis. The issues about main morphographic features and geomorphological principles of regionalization of the Rhodope mountain massif are considered in detail by Яранов (1939, 1960), Гълъбов (1946, 1982), Гълъбов et al. (1956, 1972, Иванов (1959), Yaranoff (1963), Вапцаров et al. (1962, 1977, 1980, 1997), Канев (1967, 1977, 1983, 1989), Stefanov (1989), Георгиев (1991), Алексиев (2002, 2012), Стоилов (1995), Николов et al. (2013), Tzankov et al. (2015, 2017, 2018), etc.

The above cited studies represent complex geomorphological studies of the Rhodope Mountains and are based on well known "standart" geomorphological methods and approaches. Modern remote sensing (RS) methods and GIS-based terrain research of different parts of the Rhodope Mountains are poorly represented or absent. At present, there are only a few studies in Bulgarian geographic literature that use GIS and RS as methodological tool. Georgiev et al. (2004) and Желев (2013) used GIS for study and mapping of the volcanogenic structures within the Momchilgrad depression within the Eastern Rhodope Mountains. Черкезова (2012) used fuzzy logic method to recognize landforms within the region of the Ada Tepe (Krumovgrad) and Krumovitsa and Arda river valleys. Using SAGA-GIS Черкезова (2015) performs GIS based morphometric analysis of the territory of South Central and Southeastern Bulgaria including the area of the Rhodope Mountains. With the help of SAGA-GIS and ArcGIS 10.3 software in another study Черкезова (2018) explores the catchment area of the Krumovitsa River in the Eastern Rhodopes and analyzes the CORINE Land Cover features in the area.

The lack of sufficient GIS-based geomorphological research for the Bulgarian part of the Rhodope Mountains is one of the main arguments regarding the topicality of the proposed work. It creates real opportunities for development of a comprehensive approach for future regional topography analysis.

2. STUDY AREA

The Bulgarian part of the Western Rhodope Mountains (Longitude = 24.02 ° - 24.52 ° E and Latitude = 41.21 ° - 42.12 ° N) is the subject of the present study (Fig.1). The western border of the studied territory starts from the Ilinden-Exohi border checkpoint at the Bulgarian-Greek border, climbs to the northwest along the Mesta river valley and continues north along the valley of the river through the Gotse Delchev Kettle, the Momina Klisura gorge and reaches the Razlog Kettle. To the northwest of the village of Banya, the border goes up the valley of the Mesta River and its left tributary Dreshtenets, passes through the saddles Avramova (1295 m) and Yundola (1375 m) and along the Yadenitsa river valley (near the town of Belovo) reach the Maritsa River. To the north, the Western Rhodopes border with the Upper Thracian Plain, as the border starts from the town of Belovo and follows the northern foot of the mountain massif reaching the Zhalti kamak Ridge. The eastern border of the surveyed lands tracks the valleys of the Kayaliyka, Borovitsa and Arda rivers. The southern border coincides with the state border between the Republic of Bulgaria and the Republic of Greece. Within these limits, the surveyed area has a total area of about 7,500 km^2.

The Western Rhodopes are a complex system of mountain ridges and hills divided by deep river valleys. They have a medium mountainous and partly high mountain terrain pattern with a dense and deeply cut river network. The western part has an asymmetric orohydrographic structure with a well-defined block-ridge pattern. To the east of the meridian-oriented valley of the Vacha River lies the eastern part of the Western Rhodope Mountains. In the eastern direction from Kainchal peak (1815 m) the main hydrographic ridge is split from the valley of the Cherna River to the northeastern and southeastern branches.

In the western parts of the Rhodopes are located ones of the highest peaks within the mountain - Golyam Perelik (2191 m), Suytkya (2186 m), Persenk (2091 m), etc. These parts of the mountain Гълъбов (1966) mean "upper land". Different river valleys and deep gorges form the "bottom land". Some authors (Николов et al. 2013) further divide the Western Rhodopes into western (Batak-Dabrash) and eastern (Perelik-Prespa) part, with a border along the Vacha River Valley. They are mainly distinguished by some morphographic features.

The western part has a more compact massive mountain character. The hypsometric belt of 1000-1600 m occupies almost 2/3 (about 61%) of the total area. The main mountain ridges, from north to the south, are as follows: Alabak, Karkariya, Velizhka Mountain, Suytkya, Batak Mountain, Dabrash and Kainchal (Fig.1). Here are also located the Chepino and Batak kettles. In the eastern part, the 1000-1600 m hypsometric belt occupies only 44% of the area. Here are observed the mountain massifs of Chernatitsa (with the highest peak Golyam Perelik - 2191 m), Dobrostan, Radyuva Mountain, Prespa, Mursalitsa, Kainadin, Zhalti rid (Fig.1). The boundary between them runs along the valley of the Vacha River.

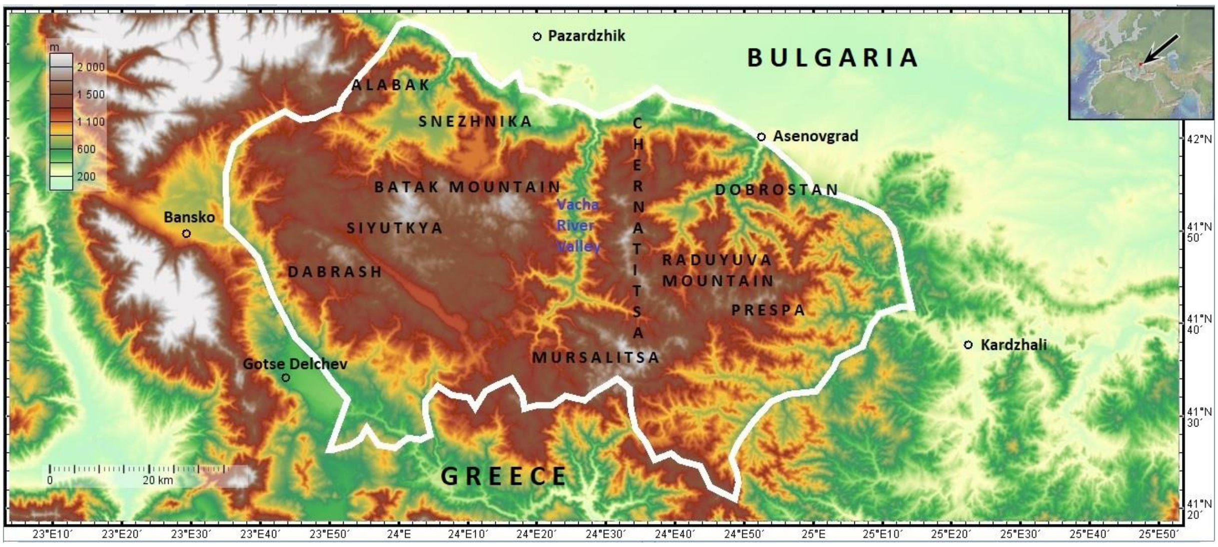

Fig.1 Geographic location of the study area with hypsographic scheme and main ridges and mountains

3. **DATA AND WORKING METHODS**

3.1 Digital elevation model (DEM) and software

The terrain ruggedness analysis of the studied territory was carried out on digital elevation model built from data acquired by Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) (Reuter et al. 2009). The ASTER GDEM V2 maintains the GeoTIFF format with 30x30 m spatial resolution and 1 x 1 degree tiles.

Digital elevation data were processed and visualised using SAGA-GIS (Conrad et al. 2015) and QGIS (Thiede et al. 2014) free software.

3.2 Terrain Ruggedness Index (TRI)

A range of methods have been developed for the definition, calculation and application of surface roughness (Grohmann et al. 2011). In geomorphometry (Olaya 2009; Pike et al. 2009) terrain ruggedness is described using surface elevation values and can be used to characterize landforms over a variety of different scales (Grohmann et al. 2011).

Riley et al. (1999) developed a Terrain Ruggedness Index (TRI) as a quantitative unit for GIS based terrain ruggedness analysis. The TRI provides a rapid, objective measure of terrain heterogenity

(Riley et al. 1999). This parameter is computed in the following way: from elevation of a central cell, for which the TRI value is calculated, elevation values of neighbouring cells are subtracted. The resultant differences are multiplied by themselves, summed up and squared once again (Riley et al. 1999), possibly to highlight morphological heterogeneity. TRI is expressed as

$$(\Sigma(zc–zi)^2)^2,$$

where zc is the elevation of a central cell and zi is the elevation of one of the eight neighbouring cells (i = 1,2, …, 8) (Rozycka et al. 2017).

The present work focuses upon the quantification of terrain ruggedness variability within the Western Rhodope Mountains based on digital elevation model (DEM) and using provided by Riley et al. (1999) Terrain Ruggedness Index (TRI).

4. RESULTS AND DISCUSSION

The results of terrain ruggedness analysis of the Western Rhodope Mountains are verbally reflected in Table 1. Regarding its "ruggedness" the relief in the Western Rhodope Mountains is divided into 5 classes.

Table 1 Classification of the Terrain Ruggedness Index (TRI) using the method of Riley et al. (1999) and the relative share of the individual classes in the surveyed area

Class	Description	Elevation (m)	Relative share of total area (%)
TRI0	Level	0-80	14,03
TRI1	Nearly level	81-116	25,71
TRI2	Slightly rugged	117-161	30,95
TRI3	Intermediately rugged	162-239	27,64
TRI4	Moderately rugged	>240	1,67

Table 1 shows that the surveyed area is characterized by level (TRI0)- nearly level (TRI1) to slightly (TRI2) -intermediately rugged (TRI3) terrain. Only 1,67% of the total area is moderately rugged (TRI4).

There is a strict geographic differentiation with regard to the spatial distribution of terrain ruggedness values (Fig.2).

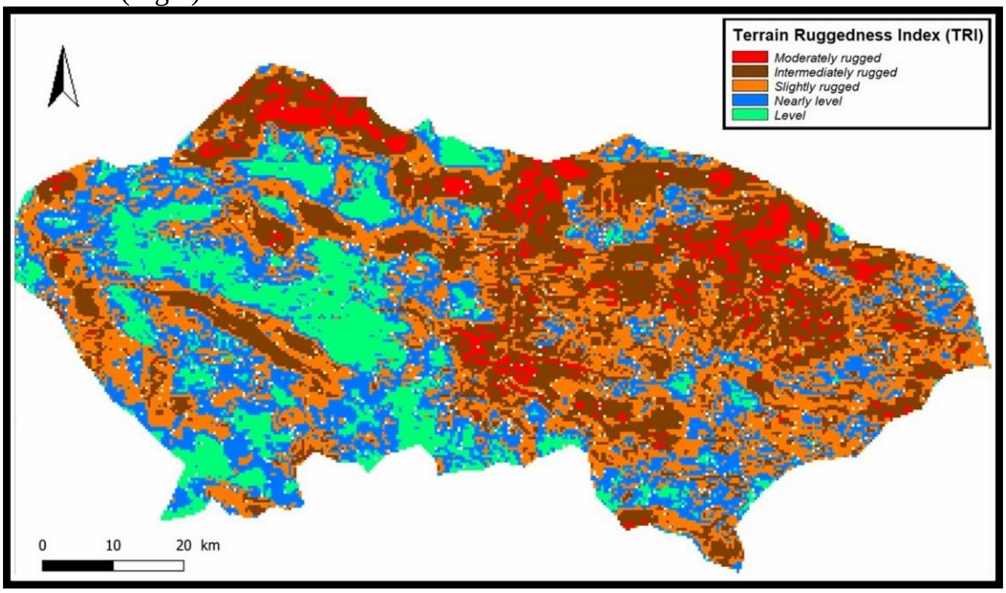

Fig.2 Terrain Ruggedness Index distribution across the Western Rhodope Mountains

From the enclosed map it is evident that the lands of Perelik-Prespa part (located to the east of the valley of the Vacha River) are characterized by higher TRI than those located to the west of the Vacha river valley (Batak-Dabrash part). In the eastern part of the studied area are situated the highest ridges of the mountain massif (Golyam Perelik peak - 2191 m).

Overall, the tendency for the terrain to be more rugged in the northern and northeastern parts of the surveyed territory is noticeable. Much of the western, central and especially southwestern parts of the Western Rhodope Mountains (its Bulgarian part) have a markedly flat topography.

5. CONCLUSION

Overall, the results obtained in the course of the present study show that the terrain of the Western Rhodope Mountains is characterized by low quantitative heterogeneity but with relatively high spatial heterogeneity. This results overlap with the generally accepted views on the morphographical pattern of the study area. Regarding the morphographic parameter "ruggedness", the relief of the studied region differs from that of the Eastern Rhodope Mountains. It is definitely more expressive and rugged.

On the one hand, the application of GIS-based digital research methods are a modern methodological tool for analysis and interpretation of the terrain variability within the study territory. The insufficient number of such studies determines one of the merits of the conducted research. On the other hand, the results obtained can be gathered as a good basis for future GIS based comparative terrain studies of the neighboring positive mountain morphounits (Rila, Pirin, etc.).

References:

1. Alexiev, G. 2002. Geomorphological zoning. In: Monograph Geography of Bulgaria, ForKom Press, Sofia, 104-105 (Bg)
2. Alexiev, G. 2012. Morphotectonics of the Balkan Peninsula. Andi-MG Press, Sofia, 291 p. (Bg)
3. Vaptsarov, I. 1962. Geomorphological studies of the northern Rhodope slope between Asenovgrad and Susam (Haskovo) with the adjacent part of the Thracian valley. Notifications of the Geological Institute at the Bulgarian Academy of Sciences, 6, 63-84 (Bg)
4. Vaptsarov, I. Mishev, K. 1977. Basic laws in the development of morphorstructures in Bulgaria. In: Problems of Geography, 1, 53-69 (Bg)
5. Vaptsarov, I. Dilinska, T. 1980. Morphostructural problems of the Rhodope massif. –In: Problems of Geography, 3, 59-63 (Bg)
6. Vaptsarov, I., Alexiev, G. and Vlaskov, V. 1997. Geomorphological zoning. In: Geography of Bulgaria. "Prof. M. Drinov " Press, Sofia, 103-105 (Bg)
7. Georgiev, M. 1991. Physical geography of Bulgaria. University press “St. Kliment Ohridski”, Sofia, 323-332 (Bg)
8. Galabov, Zh. 1946. Brief physiographic characteristic of Bulgaria. Fundamentals of Geology of Bulgaria, Annual of geological and mineralogical studies, A, 4, Sofia, 34-60. (Bg)
9. Galabov, Zh. (Editor), I. Ivanov, P. Penchev, K. Mishev, V. Nedelcheva 1956. Physical geography of Bulgaria. Publ. ″Narodna Prosveta″, Sofia, 344 p. (Bg)
10. Galabov, Zh. 1966. Rhodopes. In: Geography of Bulgaria, 1, Physical Geography, BAS Press, Sofia, 189-221 (Bg)
11. Galabov, Zh., Mishev, K. and Vaptsarov, I. 1972. Morphorestructural development of the northern Rhodope slope between the valleys of the Yadenitsa and Chepelarska rivers. Problems of Geography in Bulgaria, 3, BAS Press, Sofia, 5-29 (Bg)
12. Galabov, Zh. 1982. Geomorphological regions. In: Geography of Bulgaria. Publishing House ″Prof. Marin Drinov″, Sofia, 150-157 (Bg)
13. Ivanov, I. 1959. On some issues of geomorphological zoning of Bulgaria. -In: Notices of the Bulgarian Geographic Society, 2 (12), 157-159 (Bg)

14. Kanev, D. 1967. Geomorphology of the Chepino basin. -In: Annual of the Sofia University, 60, 2, Sofia (Bg)
15. Kanev, D. 1977. Morphostructural zones and areas in Bulgaria. -In: Annual of Sofia University ″St. Kliment Ohridski″, Sofia, 69, 2, 34-48 (Bg)
16. Kanev, D. 1983. General geomorphology. PH ″Science and Art″, Sofia, 307 p. (Bg)
17. Kanev, D. 1989. Geomorphology of Bulgaria. Publishing House "Kl. Ohridski" University, Sofia, 322 p. (Bg)
18. Nikolov, V., Yordanova, M. and Boteva, I. 2013. Mountains in Bulgaria. "Prof. Marin Drinov" Academic Press BAS, 3rd Edition, Sofia, 413 p. (Bg)
19. Stoilov, D. 1995. Geomorphological zoning. In: Encyclopedia of the Pirin region. v.I, Blagoevgrad, 202 p. (Bg)
20. Jelev, G. 2013. Study of the volcanic structures in the area of the Eastern Rhodopes through Remote Sensing and GIS. Abstract of the PhD thesis, ICIT-BAS, Sofia, 49 p. (Bg)
21. Tcherkezova, E. 2012. Multi-scale Fuzzy-Landform Classification of Arda, Varbitsa and Krumovitsa Watershed Basins (Eastern Rhodope Mountains, Southern Bulgaria). – In: Problems of Geography, 3-4, 106-116 (Bg)
22. Tcherkezova, E. 2015. Geomorphometric Analysis of South Central and Southeastern Bulgaria. – In: Problems of Geography, 3-4, 115-128 (Bg)
23. Tcherkezova, E. 2018. Analysis and Assesment of the Land Cover in the Area of the Krumovitsa River Basin, Eastern Rhodopes.− In: Problems of Geography, 1-2, 125-138 (Bg)
24. Yaranov, D. 1939. Contributions to the morphology of the Western Rhodopes. −In: Notifications of the Bulgarian Geographic Society, 7, 197-240 (BG)
25. Yaranov, D. 1960. Tectonics of Bulgaria. Technika Press, Sofia, 133 p. (Bg)
26. Band, L.E. 1993. Extraction of channel networks and topographic parameters from digital elevation data. −In: Channel network hydrology. John Wiley and Sons, 13-42
27. Beven, K.J. Kirkby, M.J. 1993. Channel network hydrology. John Wiley and Sons.
28. Blaschke, T. and Drăguț, L. 2003. Integration of GIS and object-based image analysis to model and visualize landscapes. −In: ISPRS workshop "Challenges in Geospatial Analysis, Integration and Visualization II", 8–9 September, 2003, Stuttgart, Germany, 18-23.
29. Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V. and Boehner, J. 2015. System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. −In: Geosci. Model Dev., 8, 1991-2007, doi:10.5194/gmd-8-1991-201
30. Dikau, R. 1989. The application of a digital relief model to landform analysis in geomorphology. Chapter 5. −In: Three dimensional applications in Geographical Information Systems. Taylor & Francis, London, New York, Philadelphia, 51-77
31. Drăgut, L., Eisank, C. 2011. Object representations at multiple scales from digital elevation models. −In: Geomorphology, 129, 183-189
32. Evans, I.S. 1980. An integrated system of terrain analysis and slope mapping. −In: Zeitschrift für Geomorphologie, N.F. Supplement band, 36, 274–295
33. Evans, I.S. 2012. Geomorphology and landform mapping: what is a landform? −In: Geomorphology, 137, 94-106
34. Grohmann, C.H., Smith, M.J,. and Riccomini, C. 2011. Multi-scale Analysis of Topographic Surface Roughness in the Midland Valley, Scotland. IEEE Transactions on Geoscience and Remote Sensing, 49, 1200-1213 DOI:10.1109/TGRS.2010.2053546
35. Irvin, B.J., Ventura, S.J. and Slater, B.K. 1997. Fuzzy and isodata classification of landform elements from digital terrain data in Pleasant Valley, Wisconsin. Geoderma, 77, 137-154

36. Iwahashi, J., Pike, R.J. 2007. Automated classifications of topography from DEMs by an unsupervised nested-means algorithm and a three-part geometric signature. −In: Geomorphology, 86, 3-4, 409-440
37. Florinsky I.V. 2012. Digital Terrain Analysis in Soil Science and Geology. Elsevier Academic Press, Oxford, UK. 379 p.
38. Hengl, T., Reuter, H.I. (Eds) 2009. Geomorphometry: Concepts, Software, Applications. In: Developments in Soil Science 33, Elsevier, Amsterdam, 121–140
39. Hobson, R.D. 1972. Surface roughness in topography: quantitative approach. In: Spatial Analysis in Geomorphology. Methuer, London, 225-245
40. Georgiev, V., Marinova, V. and Jelev, G. 2004. Morphostructures in Momchilgrad Depression (Eastern Rhodopes). −In: Annual of University of Mining and Geology, 47, 1, 69-74
41. Moore, I.D., Grayson, R.B., and Ladson, A.R. 1991. Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. −In: Hydrological Processes, 5, 3–30
42. O'Callaghan, J.F., and Mark, D.M. 1984. The extraction of drainage networks from digital elevation data. −In: Computer Vision, Graphics and Image Processing, 28, 323-344
43. Olaya, V. 2009. Basic Land-Surface Parameters. −In: Geomorphometry: Concepts, Software, Applications. Developments in Soil Science, Elsevier, 33, 141-169
44. Pike, R.J., Evans, I.S. and Hengl, T. 2009. Geomorphometry: a Brief Guide. −In: Geomorphometry: Concepts, Software, Applications. Developments in Soil Science, Elsevier, 33, 3-30
45. Prima, O.D.A., Echigo, A., Yokoyama, R. and Yoshid, T. 2006. Supervised landform classification of Northeast Honshu from DEM-derived thematic maps. −In: Geomorphology 78, ELSEVIER; 373–386
46. Reuter, H.I., Neison, A., Strobl, P., Mehl, W., and Jarvis, A. 2009. A first assessment of aster gdem tiles for absolute accuracy, relative accuracy and terrain parameters. −In: Geoscience and Remote Sensing Symposium, IEEE International, IGARSS 2009, 5, 240-243
47. Riley, S. J., DeGloria, S.D. and Elliot, R. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. −In: Intermountain Journal of Sciences, vol. 5, No. 1-4, 23-27.
48. Rozycka, M., Migon, P. and Michniewicz, A. 2017. Topographic wetness Index and Terrain Ruggedness Index in geomorphic characterisation of landslide terrains on examples from the Sudetes, SW Poland. −In: Zeitschrift für Geomorphologie, 61-80 DOI: 10.1127/zfg_suppl/2016/0328
49. Schillaci, C., Braun, A. and Kropáček, J. (Eds.) 2015. Terrain analysis and landform recognition. Geomorphological Techniques, Chap. 2.4.2, Sec. 4.2, British Society for Geomorphology, 1-18
50. Shary, P.A., Sharaya, L.S. and Mitusov, A.V. 2002. Fundamental quantitative methods of land surface analysis. −In: Geoderma 107, ELSEVIER, 1–32
51. Stefanov, P. 1989. Karst-morphological analysis and problems of the geomorphological development of the Dubrash part of the West Rhodopes. – In: Geographica Rhodopica. Kl.Ohridski University Press, Sofia, 9-13.
52. Thiede, R., Sutton, T., Düster, H., Sutton, M. 2014. Quantum GIS Training Manual. Locate Press, 388 p.
53. Tzankov, Tz., Iliev, R. 2015. Morphostructure of the Rhodopean Mountain Massif. Publishing House “Grafika-19”, Sofia, 48 p.
54. Tzankov, Tz., Stoyanov, Kr., Stankova, Sv., Iliev, R., Mitkov, I. and Aleksieva, T. 2017. Comparative analysis between the Rhodopean Mountain massif and the Rila-Pirin mountains range (South Bulgaria, North-East Greece). – In: Problems of Geography, 3, 12-17

55. Tzankov, Tz., Iliev, R., Stankova, Sv. and Mitkov, I. 2018. Centers of maximal contemporary elevation as a real criterion for the relief roughness assessment. – In: Problems of Geography, 3-4, 111-118
56. Yaranoff, D. 1963. La Neotectonique de la Bulgarie. – In: Revue de Geographie phisique et de Geologie dynamique, 5, 2, Paris, 75-83