SocioBrains
**ISSN 2367-5721**, JOURNAL HOMEPAGE: WWW.SOCIOBRAINS.COM
**INTERNATIONAL SCIENTIFIC REFEREED ONLINE JOURNAL WITH IMPACT FACTOR**
ISSUE 65, JANUARY 2020

# TERRAIN SURFACE COMPLEXITY OF THE WESTERN RHODOPE MOUNTAINS (SOUTH BULGARIA)

**Abstract:** Terrain surface complexity is one of the fundamental parameters in contemporary digital geomorphometry. There are several methods of describing the terrain surface worldwide. They give a generalized description of the local terrain morphology entirely using Geographic Information Systems (GIS) aprroach. The present study examines the terrain surface complexity within the Bulgarian part of the Western Rhodope Mountains (41.21° - 42.12° N; 24.02° - 24.52° E) based on popular unsupervised nested-means algorithm. For this purpose, the terrain surface of the study area is classified and analyzed using advanced spatial statistics and terrain classification techniques. The results obtained show that the topography of the study area is represented by four terrain categories.

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**Keywords:**
Rhodopes, mountain, nested-means, terrain surface, classification, GIS

## INTRODUCTION

Quantitative analysis of the land surface is defined by the term geomorphometry, a highly active research field within geomorphology (Hengl and Reuter, 2009). Its focus is on the quantification of land surface parameters and the detection of objects from digital elevation data. In turn geomorphometry as a research area builds a theoretical foundation and serves as a bridge between GIS and geomorphology (Dikau, 1996). Advances in computer technology, new spatial analytical methods and the increasing availability of digital elevation data have re-oriented geomorphometry (Pike, 1999) and promoted the development of computer algorithms for calculating geomorphometric properties of the Earth‘s surface. Geomorphometry aims to identify and describe discrete landforms and their morphological characteristic. The fundamental operation in geomorphometry appear the extraction of features from DEMs. DEMs provide an objective measure of surface elevation (or relief) and therefore are 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 landform recognition and classification (e.g. Dikau, 1989; Irvin et al., 1997; Guisan, 1999; Weiss, 2001; Blaschke and Drăguţ, 2003; Prima et al., 2006; Iwahashi and Pike, 2007; Olaya, 2009; Pike et al., 2009; Drăgut and Eisank, 2011; Grohmann et al., 2011; Evans, 2012; Florinsky, 2012; De Reu et al., 2013; Schillaci, 2015; Mokkaram, 2015; etc).

With respect to the territory of the Rhodope Mountains, GIS-based studies have a relatively short history. In Bulgarian geographic literature only a few studies related to GIS and Remote Sensing (RS) approach can be found. Georgiev et al. (2004) and Jelev (2013) used GIS for study and mapping of the volcanogenic structures within the Momchilgrad depression in the Eastern Rhodopes. Tcherkezova (2012) based on fuzzy logic method recognized landforms within the region of the Ada Tepe

(Krumovgrad) and river valleys of Krumovitsa and Arda. The same author (2015) performs GIS based morphometric analysis of the territory of South Central and Southeastern Bulgaria (including the area of the Rhodope Mountains). In another study Tcherkezova (2018) explores the catchment area of the Krumovitsa River in the Eastern Rhodopes and analyzed the CORINE Land Cover features in the area. Iliev (2019) also using the GIS approach analyzed the ruggedness of the terrain within the Bulgarian Western Rhodopes.

The purpose of this study is to analyze and classify terrain surface within the Western Rhodope Mountains using nested-means algorithm (Iwahashi and Pike, 2007). Based on Digital Elevation Model (DEM) from ASTER GDEM V2 (Reuter et al., 2009) the terrain of the study area is classified and four terrain classes are extracted.

## 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. Some authors (Nikolov 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.

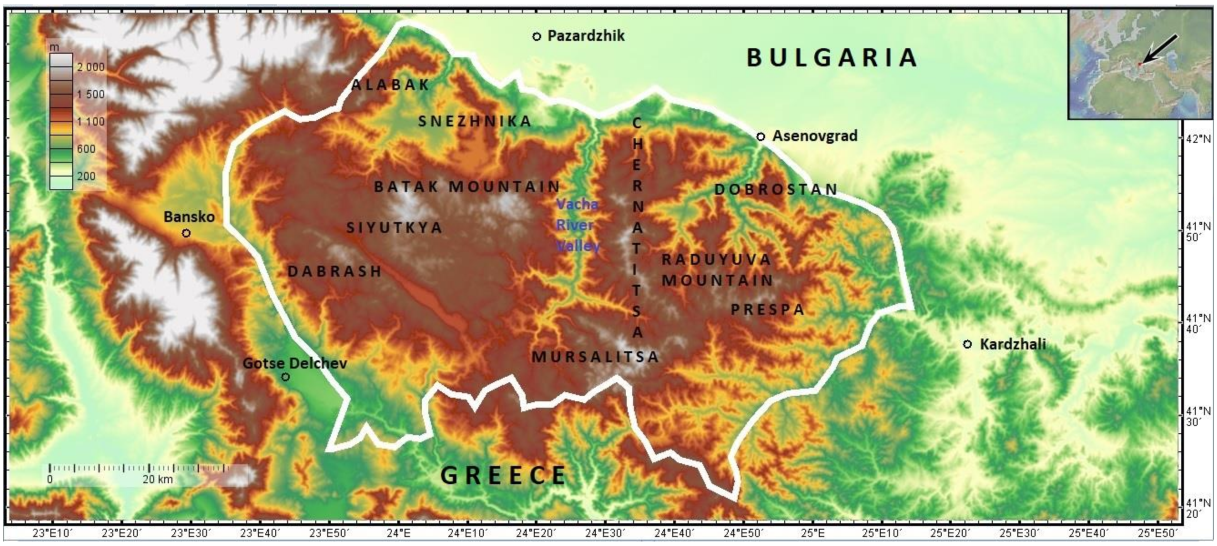


**Fig.1** Geographic position of the study area with hypsographic scheme and main ridges and mountains

## DATA AND WORKING METHODS

### Unsupervised nested-means algorithm for terrain classification

In the present study the analysis of the terrain within the study area was performed using the „nested-means algorithm" initially developed by Iwahashi and Pike (2007). The terrain classification procedure is based on three surface parameters:

(1) terrain surface texture (Fig.2) - spatial frequency of positive and negative landforms;

(2) surface convexity (Fig.3) - spatial frequency of convex/concave locations;

(3) slope gradient (Fig.4) - spatial changes of slope values;

Thresholds of classification were defined to be graduated values using successively averages of the total slope, the gentler half, the gentlest quarter, and the gentlest quarter-half. This follows a common geomorphological map style in which mountainous steep slopes tend to be lumped together while plains are divided into details. Thresholds of slope gradient for the nested-means method do not decrease linearly like those of surface texture and local convexity, but decrease logarithmically (Iwahashi and Pike, 2007).

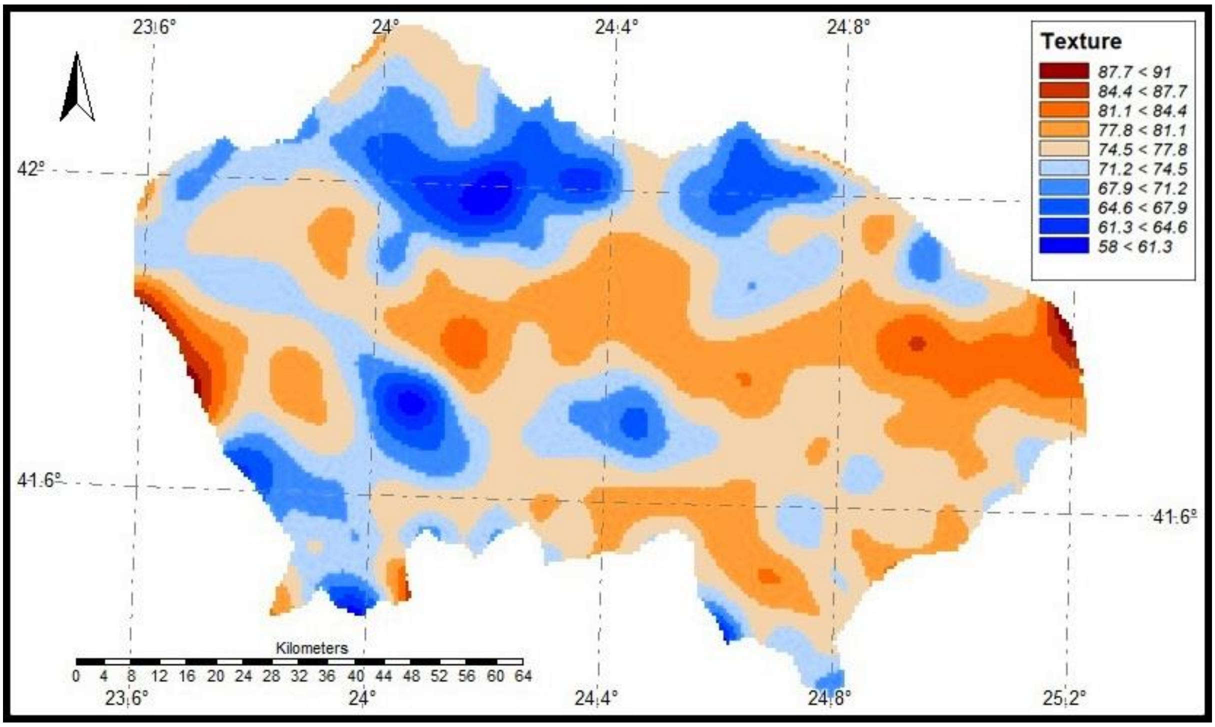


**Fig.2** Surface texture of the study area

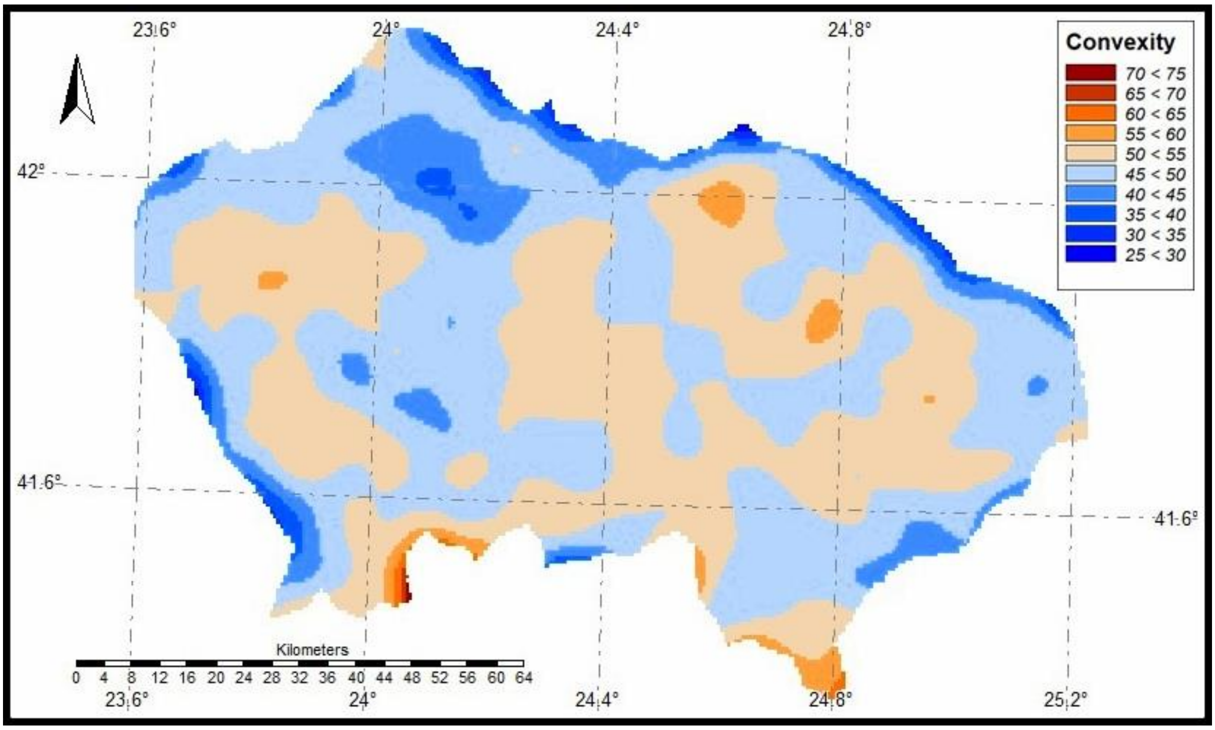


**Fig.3** Surface convexity of the study area

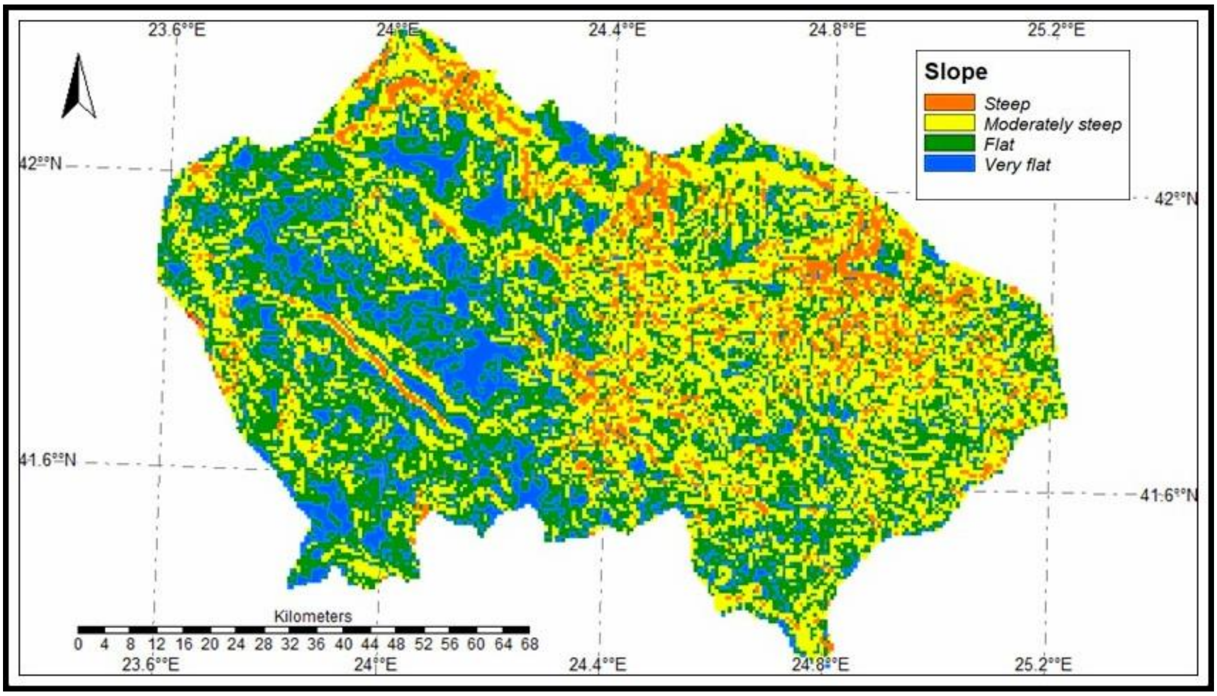


**Fig.4** Slope gradient of the study area

These three parameters are combined using the mean of each parameter as a dividing measure into an 8, 12 or 16 categories of the terrain. For maximum accuracy in this study 16 terrain categories approach is used. Each terrain surface class is estimated based on whether the pixels values for each parameter exceed the mean of that parameter.

**Digital Elevation Model (DEM) and software**

Terrain analysis of the study area was performed using digital elevation data acquired by Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) (Reuter et al., 2009). The elevation data are available in GeoTIFF format and is available at 30x30 m pixel size.

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

## RESULTS AND DISCUSSION

The results obtained in the course of the study are presented in Table 1. The main conclusions and interpretations are discussed below.

**Table 1** Terrain surface classification within the study area. The numbering of the terrain categories is in accordance with the original nomenclature of Iwahashi and Pike (2007)

| Terrain Category № | Description | Area (km$^2$) | Relative share of total area (%) |
|---|---|---|---|
| 1 | very steep slope, fine texture, high convexity | 3983 | 52.8 |
| 5 | steep slope, fine texture, high convexity | 1962 | 26.0 |
| 9 | moderate slope, fine texture, high convexity | 915 | 12.1 |
| 16 | gentle slope, coarse texture, low convexity | 688 | 9.1 |

The results in the table show a variable terrain, dominated by Terrain Category 1 (very steep slope, fine texture, high convexity) (52.8% of total area). In combination with Terrain Category 5 (26.0% of total area), it can be concluded that the terrain surface in the study area is generally characterized by extreme values. The other two terrain categories №9 (12.1% of total area) and №16 (9.1% of total area) complete the topography complexity. As a whole the terrain surface is very variable.

In spatial terms (Fig.5), the four terrain surface categories are separated in distinctive belts. Terrain Class 1 occupies mostly the inner parts of the mountain massif (with exception of the river valleys) and marks the most prominent ridges. Classes 5 and 16 are located mainly on the edges of the mountain or along the valleys of the main river arteries. Terrain Class 9 has highly fragmentary distribution and marks the bottom of kettles and river valleys. In general, the terrain is variable and is characterized by a well-defined geographical determination.

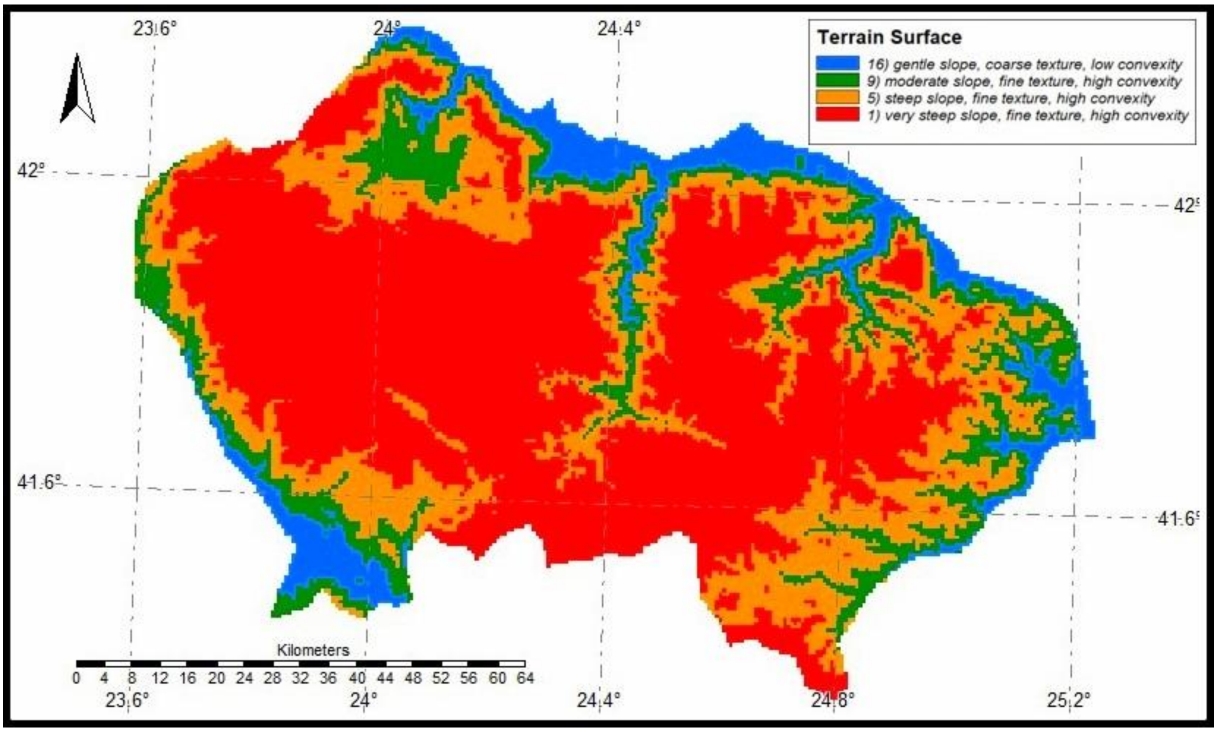


**Fig.5** Spatial distribution of terrain surface categories within the study area

**CONCLUSION**

In the presented study, a GIS (Geographic Information Systems) based analysis of the complexity of the terrain within the Bulgarian Western Rhodopes was performed. A popular terrain analysis algorithm was used for this purpose. Four terrain classes were extracted. The results obtained showed that the terrain within the study area was dominated by extreme values. Based on the GIS approach, in the future the presented results could serve as a good basis for other digital terrain studies.

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