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Geodiversity assessment by application of geoinformation approach (on the example of Golo Bardo Mountain, Western Bulgaria)

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Abstract

Geodiversity is considered as a complex indicator of the abiotic environment. On the example of information about Golo Bardo Mountain (Western Bulgaria), the article emphasizes the need to develop methods for quantitative assessment of the geodiversity of an area to minimize the subjective nature of the assessment by defining clear criteria that can be quantified. The complex geodiversity assessment of the investigated area was made based on the analysis of lithology, soils, topographic features and drainage network. The analysis is done in a GIS environment. Topographic settings are analysed on the base of digital elevation model with a cell size of 30 m using Spatial Analyst Tools. The elevation model is used for calculating the terrain roughness, slope gradients and aspects of the slopes. Geological component is evaluated considering the petrographic composition of the area. The variety of the abiotic components is calculated by application of grid method (cell size 1000 x 1000 m), using Focal statistics tool, neighborhood type “Variety”. Fuzzy logic is suggested to be used for comparison of areas located in different regions and with different landscape conditions.
The results of the geodiversity assessment show that most of the area of the Golo Bardo mountain has moderate geodiversity index. The method used in the article gives reliable results with minimal subjectivity, that can be used for assessment of the distribution of the geodiversity on a particular area and allow to compare different territorial units. The results obtained in the current study show good correlation between areas with high and moderate geodiversity index, and areas with high biodiversity values. The applied methodology and the visualization of the geodiversity index allow for easy understanding of geodiversity by a wide range of stakeholders, even non-geoscientists, and can be successfully applied in the planning of geotourism activities.

Keywords: *geodiversity, terrain roughness, GIS, focal statistics, grid method*

Rezumat. Evaluarea geodiversităţii prin aplicarea unei abordări geoinformatice (asupra exemplului Muntelui Golo Bardo, Bulgaria de Vest)

Geodiversitatea este considerată un indicator complex al mediului abiotic. Pornind de la exemplul informațiilor despre Muntele Golo Bardo (Bulgaria de Vest), articolul subliniază necesitatea dezvoltării unor metode de evaluare cantitativă a geodiversității unei zone pentru a minimiza caracterul subiectiv al evaluării prin definirea unor criterii clare care pot fi cuantificate. Evaluarea complexă a geodiversităţii zonei investigate a fost realizată pe baza analizei litologiei, solurilor, caracteristicilor topografice şi reţelei de drenaj. Analiza se face într-un mediu SIG. Caracteristicile topografice sunt analizate pe baza modelului digital de elevație cu o dimensiune a celulei de 30 m folosind Spatial Analyst Tools. Modelul elevației este utilizat pentru calcularea rugozității terenului, a pantelor și a caracteristicilor acestora. Componenta geologică este evaluată având în vedere compoziţia petrografică a zonei. Varietatea componentelor abiotice este calculată prin aplicarea metodei caroiajului (dimensiunea celulei 1000 x 1000 m), folosind instrumentul de statistică focală (Focal statistics tool), tipul neighborhood „Varietate”. Se sugerează utilizarea logicii fuzzy pentru compararea zonelor situate în diferite regiuni și cu diferite condiții de peisaj.
Rezultatele evaluării geodiversității arată că cea mai mare parte a zonei muntelui Golo Bardo are un indice de geodiversitate mediu. Metoda folosită în articol oferă rezultate fiabile cu subiectivitate minimă, care pot fi utilizate pentru evaluarea distribuției geodiversității pe o anumită zonă și permit compararea diferitelor unități teritoriale. Rezultatele obținute în studiul de față arată o bună corelație între zonele cu indice de geodiversitate ridicat și moderat și zonele cu valori mari de biodiversitate. Metodologia aplicată și vizualizarea indicelui de geodiversitate permit înțelegerea ușoară a geodiversității de către o gamă largă de părți interesate, nu numai cercetători în domeniul științelor naturii, și pot fi aplicate cu succes în planificarea activităților de geoturism.

Cuvinte-cheie: *geodiversitate, rugozitatea terenului, SIG, statistici focale, metoda caroiajului*

Introduction

Generally, geodiversity is defined as a set of abiotic components of the environment. This term has been used by geologists and geomorphologists since 1990s as an indicator about the variety of the abiotic environment. It was introduced mainly as an opposite to the term biodiversity and used to emphasize the importance of abiotic components. The definition of geodiversity is considered in many publications and is presented in different approaches – descriptive, analytical, holistic, etc. (Sharples, 1993; Kiernan, 1996; Eberhard, 1997; Gray, 2004; Kozlowski, 2004, Serrano & Ruiz-Flano, 2007, etc.). The development of the concept shows expanding the scope from a synonym of geological and geomorphological diversity to a wider scope of a generalizing concept, including also hydro-morphometric indicators, soils and partly land use. Despite the differences in interpretation, geodiversity is considered as a complex indicator of the abiotic environment or a corresponding abiotic equivalent of biodiversity (Soms, 2017).

Different approaches and indicators are used for evaluation of geodiversity: qualitative, quantitative, combined qualitative and quantitative. In many cases the qualitative parameters are quantitatively rated taking into account the authors' view and experience as well as the practice presented in the literature (Coratza & Giusti, 2005; Reynard et al., 2007; Brilha, 2015). The quantitative approach is characterized by less expressed subjectivity of the assessment, but requires the processing of a significant amount of digital information (graphic and attributive), the application of mathematical and statistical methods. In this relation geographic information systems (GIS) provide gereat opportunity (Santos et al., 2017; Soms, 2017; Ferrando et al., 2021; Chrobak et al., 2021). On the other hand, the results of this approach depend on the choice of the components of the evaluation and the method of classification, which are determined by the researcher/expert performing the evaluation.

This outlines the need for elaborating methods for quantitative assessment of geodiversity of a given area so that to minimize the subjective character of the assessment by setting clear criteria which can be quantitatively expressed. Though the term is used since 1990, standardized methods for geodiversity assessment have not yet been established. The review of the publication about assessment of geodiversity shows that mainly four components have been taken into evaluation: geological, geomorphological, hydrological and pedological (Ilić et al., 2016, Zwoliński et al., 2016, Ferrando et al., 2021). Some of the authors also consider land use / land cover (Pătroescu & Niculae, 2010; Chrobak et al., 2021; Ferrando et al., 2021). There are differences in the approach of determining the particular units for calculating the geodiversity index but the most often used is the grid method. The size of the grid is different and depends on the scale of the map and the size of the area of interest. In order to minimize the subjectivity of assessment, analytic hierarchy process (AHP) is applied (Chrobak et al. 2021; Ferrando et al., 2021). Despite the fact that determining the weights of the different components of geodiversity is arguable and depends on the experience and the view of the researcher, application of AHP gives reliable results, taking into account the interrelations between abiotic components.

Regarding to the above, the aim of the current study is to contribute to minimizing the subjectivity of geodiversity assessment by application of geoinformation approach with emphasize on the relations between the geological, geomorphological, hydrological and pedological components as well as application of fuzzy logic for determining the classes of geodiversity assessment, which can be used in comparisons between areas with different location and different landscape conditions.

Area of interest

The current study is carried out for the area of the Golo Bardo mountain, located in the western part of Bulgaria (Fig. 1). This is a low mountainous area, with the highest peak Vetrushka, 1158 m (northwestern part of the mountain). Golo Bardo extends from northwest to the southeast direction and has a length of 25 km and 5-6 km width. The ridge surface is narrow and the mountain slopes are predominantly slightly sloping and are cut by streams. Slope gradients between 5 and 15 degrees take nearly 49% of the studied area, 18.8% are areas sloping between 15 and 30 degrees, while flat (0-3°) and nearly flat (3-5°) surfaces take respectively 17% and 14.6%. The mountain is drained mainly by the left tributaries of the river Struma which flows through the west – northwest foothills of the mountain.

Regarding the tectonic features of Golo Bardo mountain and its position in the tectonic zonation of Bulgaria, the mountain is located on the border of three structural zones: Kraishte, Srednogorie and Rhodopes. Bonchev (1971) refers the area of Golo Bardo to the Kraishtidi structural zone. Dabovski et al. (2009) determines the region as a part of the Lyubash-Golo Bardo unit of the Srednogorie zone. According to Ivanov (2017) it is a natural continuation of the Luzhnitsa tectonic unit of the Kraishte zone. Stratigraphically, the area of Golo Bardo is quite diverse. Quaternary, Neogene, Paleogene, Upper Cretaceous, Jurassic-Lower Cretaceous, Jurassic, Triassic, Permian, Devonian, Paleozoic and Neoproterozoic-Lower Paleozoic rocks are revealed. Mesozoic sediments, which are not metamorphosed within the study area, predominate. It is assumed that they are affected by several alpine folding phases, but the exact number of phases, their regional scope and timing are debatable. Considering petrographic aspects, the sedimentary rocks in the study area are represented by argillites, siltstones, sandstones, gravelites, calcareous sandstones, sandy limestones, clayey limestones, marls, limestones, breccias, conglomerates, flysch sediments. The magmatic and metamorphic rocks in the area are represented by gabbro, gabbro diorites, diorites, metagabbros to metadiorites, metabasites, amphibolites, amphibole and green shales, double mica gneisses and migmatites, biotite gneisses, muscovite gneisses, garnet-muscovite shales.

Sediments like clay, sands and boulders are also spread in many parts of the study area. Generally, the considered rocks and sediments can be grouped into the following groups: consolidated carbonate rocks; consolidated carbonate and non-carbonate rocks;

consolidated non-carbonate rocks, tuffs, flish, intrusive, metamorphic rocks, proluvial and deluvial, and alluvial deposits (Fig. 2). Wide areas of carbonate rocks are a prerequisite for development of karst relief.

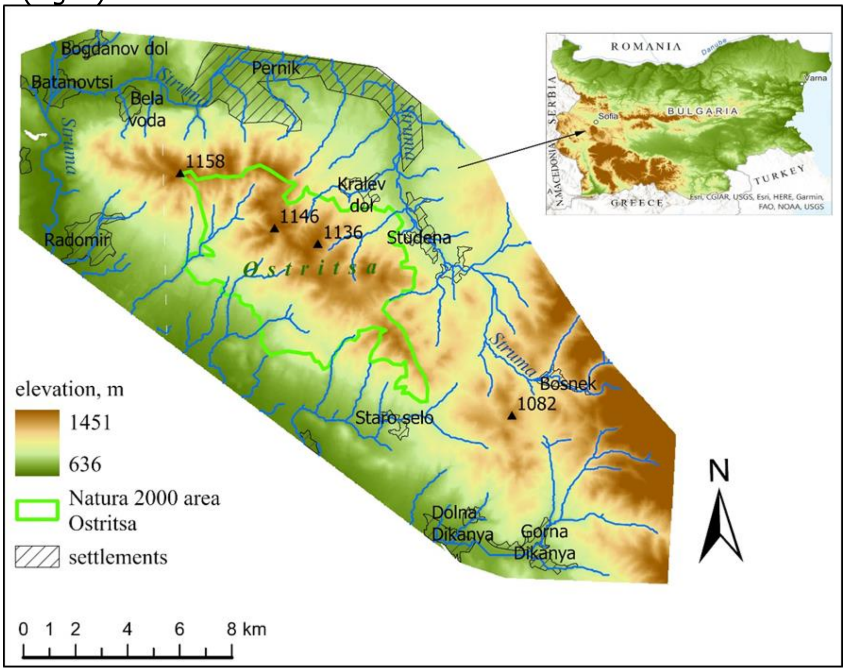

Fig. 1: Study area (terrain data is obtained by United States Geological Survey, Earth Resources Observation and Science Center. (2014). Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global data [Data set]. https://doi.org/10.5066/F7PR7TFT)

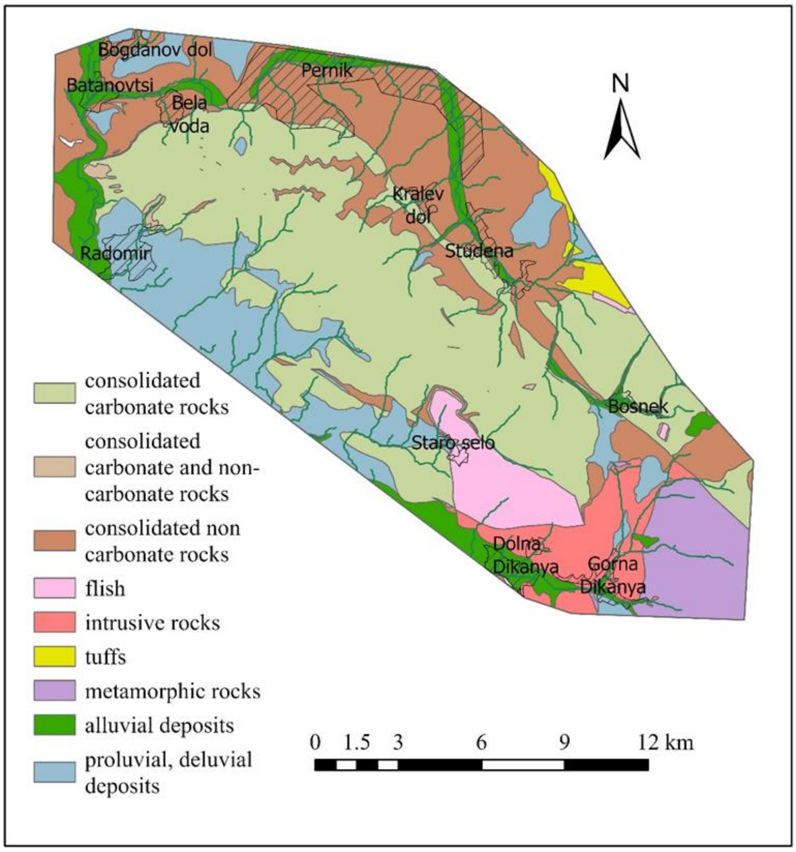

Fig. 2: Petrographic map of the study area (after Milanov et al., 2006; Antonov et al., 2011a, 2011b, 2011c, with amendments)

Soils are presented by, Chromic Cambisols, Chromic Luvisols, Cambisols, Vertisols, Fluvisols and Rendzinas (FAO, 1990). More than 50% (57.5%) of the mountain area are covered by Rendzinas and nearly half of this areas are loamy. The wide distribution of Rendzinas is closely related to the distribution of carbonate rocks. Relatively wide are covered by Chromic Luvisols (around 24% of the study area). They are distributed on the low slopes of Golo Bardo mountain and mainly on the southern and southwestern slopes this soil type has well expressed clayey composition. Nearly 6% of the mountain area are covered by Eroded Chromic Luvisols. Fluvisols take around 7% of the study area and are formed in the valley bottom of the river Struma.

Natural vegetation in Golo Bardo mountain area is presented by forest, pasture and grasslands and bushes. Forests cover 24,5% of the area of interest where 46% of forests are broad-leaed and 42% are coniferous. Natura 2000 area (Council Directive 92/43/EEC), named Ostritsa, is determined in the central high part of the mountain. There is one natural rezerve Ostritsa, established for protection of valuable plant specimens. Other protected area - Kashkavalya, located in the south-eastern part of the mountain and outside of Natura 2000 is also established for protection of conservation-significant plant species.

Data and methodology

In the current study, the geodiversity of the area of interest is evaluated by analysis of lithology, soils, topographic features and drainage network. The complex geodiversity (Gd) assessment is calculated taking into consideration the formula proposed by Serrano and Ruiz-Flano (2007):

$$Gd = \frac{Eg * R}{Ln\, S},$$

where Eg is the number of abiotic elements in the area of interest/spatial unit, R is coefficient of roughness, S is area of the unit (sqkm); Ln = natural logarithm.

The analysis of the lithological settings is done on the base of geological map at a scale of 1:50 000 (Milanov et al., 2006; Antonov et al., 2011a, 2011b, 2011c) and field research. Regarding the origin of the rocks and their physical and mechanical properties, the following groups are determined: consolidated carbonate; consolidated carbonate and non-carbonate; consolidated non-carbonate, tuffs, flish, intrusive, metamorphic, proluvial and deluvial, and alluvial deposits (Fig. 2).

For evaluating the variety of soils, a soil map at a scale 1:400 000 is used (ISSAPP "N. Poushkarov"). Regarding the small area of Golo Bardo mauntain and the generalization of the content of the geological map performed to determine the groups of rocks taken into account in the analysis of lithological features, the used soil map provides sufficiently detailed information about soil diversity analysis, which is comparable to the information about the rock composition of the area of interest.

Topographic settings are analysed on the base of digital elevation model (DEM) with a cell size of 30 m (SRTM). The elevation model is used for calculating the terrain roughness index (TRI), for calculating the slope gradients and aspects of the slopes. Terrain roughness is considered as relative metric based on local neighbourhood of a given pixel and, in this regard, it is used to identify landscape patterns corresponding to environmental factors (Otto et al., 2018). The following formula is applied:

$$TRI = \frac{DEM_{smooth} - DEM_{min}}{DEM_{max} - DEM_{min}}$$

where: DEM_{smooth} is a smoothed elevation raster; DEM_{min} is minimum elevation raster; DEM_{max} is maximum elevation raster.

The above parameters of DEM are calculated in ArcGIS Pro (ESRI Inc, 2021) environment using Focal Statistics analysis. In the current study we accepted rectangle method for determining the area of neighbourhood and set a size of 1000x1000 m.

Slope and aspect rasters are generated on the base of DEM (ArcGIS Pro Spatial Analyst Tools). The slope gradients are calculated in degrees and classified in the following classes: 0-2; 2-5; 5-15; 15-30; 30-4 and >45. Aspect raster is created using eight directions model and also flat surfaces are determined.

The number of abiotic elements in the area of interest is determined by Focal Statistic tool (ArcGIS Pro), Neighborhood – Rectangle, size 1000 x 1000 m, Statistics type – Variety. The variety layers, generated for lithology, soils, slope, aspect and drainage network are summed to obtain the complex coefficient of variety (Eg) and then multiplied by roughness index (TRI) which we used for roughness coefficient (R).

Geodiversity index raster is classified in 3 classes: low, moderate and high, using equal interval method. This method presents the geodiversity like a relative indicator for the different parts of the study area and the extend of the intervals depends on the minimal and maximal values of the geodiversity index, calculated for the considered area of interest. The determined classes of low, moderate and high geodiversity are valid only for the particular area and cannot be referred to the other area with different landscape conditions. In order to be comparable with different areas we suggest using fuzzy logic (Fuzzy Membership tool of ArcGIS Pro Overlay analysis) by which values of geodiversity index raster are scaled from 0 to 1. Membership type "Large" is applied, by which large values of the input raster have high membership in the fuzzy set. After fuzzification the output raster is classified in 3 classes: low (0 – 0.33); moderate (0.331 – 0.67) and high (0.671 – 1). In this way, the values of geodiversity index will vary between 0 and 1 in each one of the considered areas/regions, and the classes of geodiversity will have one and the same intervals, regardless the peculiarities of the areas.

Results and disscusions

The geodiversity index is calculated based of the maps of the variety of abiotic components, shown on Fig. 3. This approach is considered in many publications, despite the fact that there are differences in the spatial variables – abiotic components (geological, geomorphological, hydrological and soils) used for calculating the number of abiotic elements (Pereira et al., 2013; Stoms, 2017, Chrobak et al., 2021; Manosso et al., 2021).

In the current study, the variety is calculated per area of 1 sqkm. The highest variability is observed on the raster of aspects – from 4 to 9 spatial units per 1 sqkm and in nearly 90% of the study area the calculated number of units is 9. This is an indicator for higher values of horizontal dissection of the relief and dense drainage network. The aspect of slopes together with slope gradients and elevation influence on local climate conditions and mainly on the distribution of solar radiations, air temperature and precipitation. In this relation, it is an important conditioning factor for geomorphological processes and variety ot the relief. Relatively equal is the variety of slopes and lithology. Maximal value of spatial units per 1 sqkm for both factors is 6 but the values are unevenly distributed on the mountain area and the pattern of the rasters shows a bit higher variety of the lithology (Fig. 3). The variety of the soil cover is between 1 and 5. Generally, southern and western parts of the mountain have higher values of soil variety. This partly corresponds to the variety of lithological component and the differences are determined by the influence of vegetation and local climate.

The variety of hydrologic component is determined on the base of availability or absence of streams and in this relation, it is presented in two classes. The pattern of the distribution of both classes shows that two elements per 1 sqkm are observed on 71% of the area of the mountain and on the other part the number of spatial units is 1 per 1 sqkm.

The roughness coefficient for the area of Golo Bardo mountain varies between 0.03 to 0.79. The values are the smallest in the larger bottoms of the river valleys and increase with the increasing of the elevation, and also in the areas with denser stream network. Regarding the calculation of the roughness coefficient in different publication it can be concluded that there is no uniform methodology for calculating the terrain roughness. For example, Grohmann et al. (2011) consider standard deviation of residual topography (Melelli, 2014) takes into account surface area and planimetric area, Stepišnik et al. (2017) use elevation differences, Chelariu & Hapciuc (2017) accept slope gradient for determining the terrain roughness. In the current study, we calculated the terrain roughness on the base of elevation differences, which can be considered as an indicator for the energy of the relief, and in this relation for the variety of the landscapes. We consider that when slope gradients are used for calculating the variety of the abiotic components (Eg), taking into account slope in calculating the roughness can enhance the importance of slope gradient in the complex geodiversity assessment.

Complex geodiversity index is calculated by multiplying the sum of components varieties and roughness coefficient. The surface distribution of the values is presented on Fig. 4. Most of the area of Golo Bardo mountain (80.7%) has moderate geodiversity index. Areas with low and high geodiversity take around 9.7%, each one. High geodiversity is observed in the south-eastern part of the mountain, where they can be related to the high variety of lithology and high values of roughness. High geodiversity values in high central and northwestern part of the mountain are mainly related to the high variety of slopes, as well as of roughness coefficient. Fuzzification of geodiversity raster, in the current case, causes small changes in the spatial pattern and the redistribution of the values of the geodiversity but as a whole the location of the classes of low, moderate and high geodiversity index is preserved. After fuzzification areas with moderate geodiversity index are decreased to 69.3% of the mountain, while areas with low and high geodiversity are increased, respectively to 17.2% and 13.5%. Despite the observed differences fuzzification can give reliable results when two or more regions with different landscape conditions are compared, providing equal intervals of the geodiversity classes.

Comparing the spatial distribution of the geodiversity index with the land cover/land use data (CORINE) shows that the largest part of the areas with high geodiversity is covered by forests, followed by areas with shrubs and rare vegetation, and pastures. Areas with low geodiversity are taken mainly by agricultural and urban areas (Table 1).

Nature protected areas are located mainly in spatial units with moderate and high geodiversity index. Most of the part of Natura 2000 protected area Ostritsa (77%) has moderate geodiversity, 21% present a high geodiversity index and 2% possess low geodiversity.

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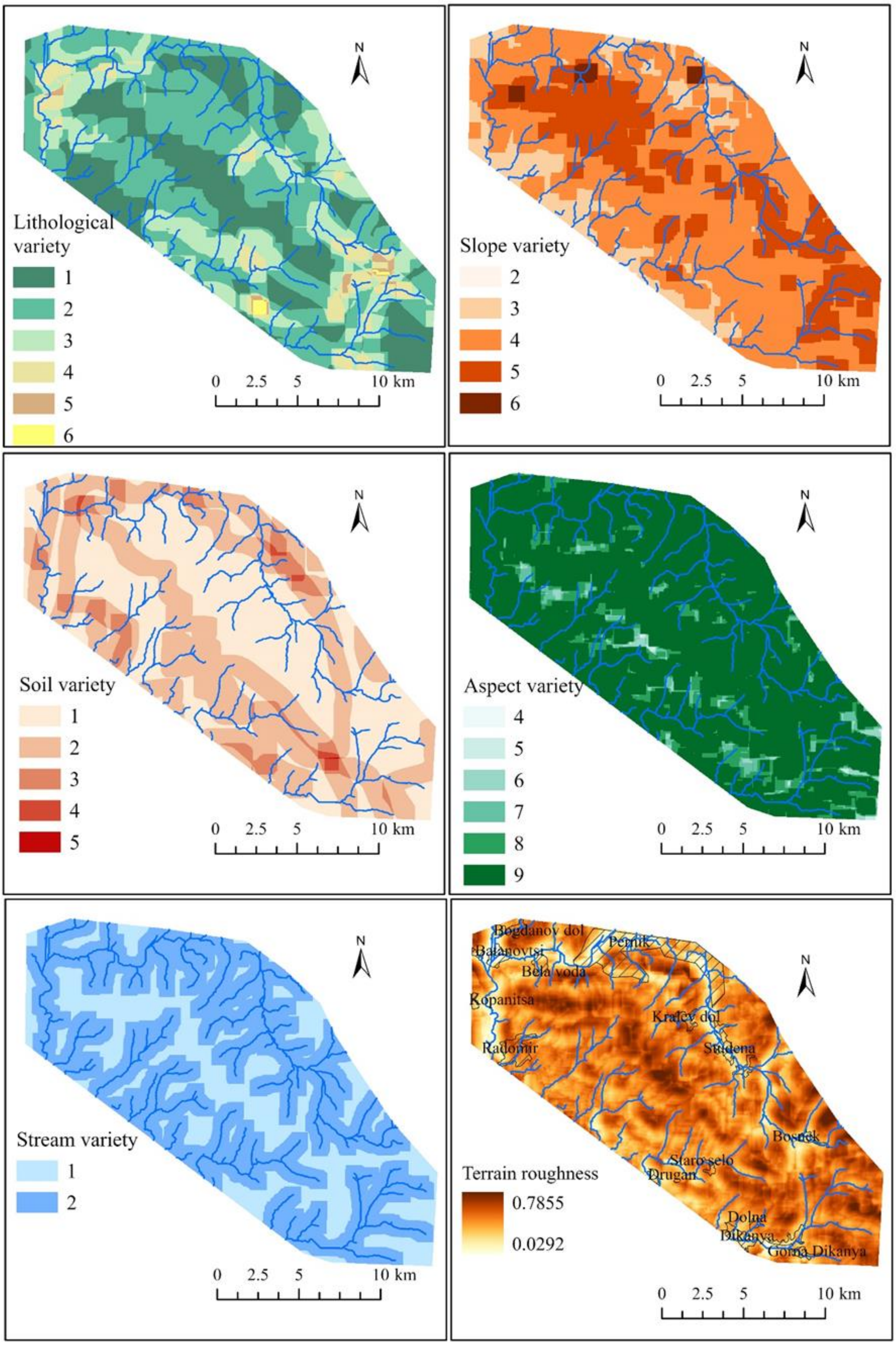

Fig. 3: Variety of abiotic components at Golo Bardo mountain area

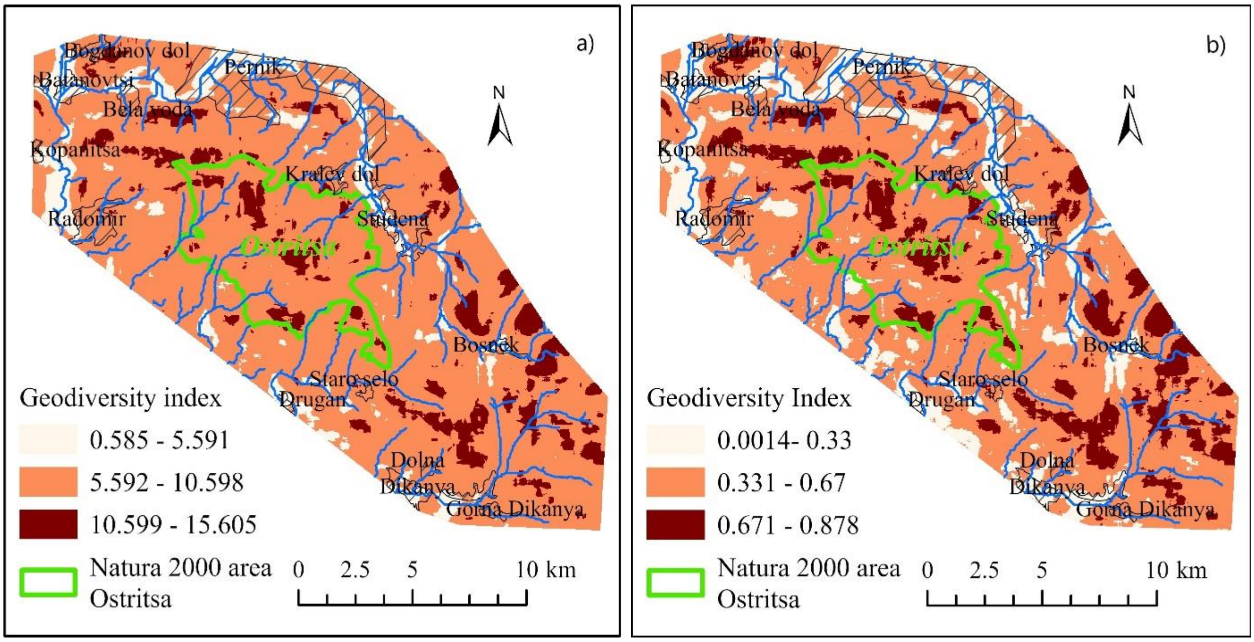

Fig. 4: Spatial distribution of the geodiversity index a) values of geodiversity, classified by equal intervals method; b) fuzzyfication of geodiversity raster, membership type "Large"

Table 1: Distribution of land use/land cover types in percent of the classes of geodiversity index

	Geodiversity index		
Land use / land cover	**Low**	**Moderate**	**High**
Urban areas	37.62	9.04	0.42
Mineral extraction sites	4.93	3.40	2.14
Agricultural lands	44.66	29.30	12.69
Pastures and natural grassland	7.08	19.14	20.61
Forests	2.15	25.00	42.38
Rare vegetation and shrubs	0.81	12.97	20.85
Bare rocks		0.35	0.14
Water bodies	2.76	0.80	0.77

Conclusions

The geodiversity index is calculated for the area of Golo Bardo mountain by applying the grid method and determined size of grid 1000 x 1000 sqm. Four abiotic components are considered: geological (petrographic composition), geomorphological (slope, aspect and elevation differences), hydrological (presence and absence of streams) and pedological (soil types). The obtained values for the raster of geodiversity are classified into three classes: low, moderate and high. Equal intervals classification method is used. According to this method, most of the area of the mountain has moderate geodiversity index. The method gives reliable results with minimal subjectivity, that can be used for assessment of the distribution of the geodiversity on a particular area and allow to compare different parts of this area. This can contribute to better territorial planning. On the other side, application of equal intervals classification is not appropriate for comparison of areas, located in different regions with different landscape conditions. In this case, using fuzzy logic gives better results by assigning values between 0 and 1 of the input geodiversity raster, indicating the strength of a membership in a given set.

The values of the geodiversity index, calculated for this particular study area show that most of the Golo Bardo area has moderate geodiversity. There is a good correlation between areas with high and moderate geodiversity and nature protected areas.

Using of geoinformation tools for calculating geodiversity index and application of quantitative approach minimize subjectivity of the assessment but it has to be taken into account that the results closely depend on the resolution of the initial DEM used for evaluation of the topographic features as well as on the degree of detail of the data about other abiotic components. The choice of the abiotic components and indicators used for the calculation of geodiversity index is debatable and depends on the expert's experience. Despite this imperfection of the process

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of the assessment of geodiversity, the applied methodology provides an opportunity for fast assessment of geocomponents and can significantly contribute to better spatial planning and identification of areas with potential for geotourism development. Future research should focus on assessing the impact of data resolution and standardization geodiversity assessment.

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