360
GEOME 2
Manuscript received: January 20, 2020
Accepted: May 4, 2020

Geologica Macedonica, Vol. **34**, No. 1, pp. 51–66 (2020)
In print: ISSN 0352 – 1206
On line: ISSN 1857 – 8586
UDC: 528.412:004.4]:551.26(497.723)

Original scientific paper

GEOMATICS AND GIS BASED SYSTEM FOR GEODIVERSITY INVENTORY AND EVALUATION APPLIED IN KRATOVO

Aleksandra Trenčovska

Geological Survey of Slovenia, Dimičeva 14, 1000 Ljubljana, Slovenia
aleksandra.trenchovska@geo-zs.si

A b s t r a c t: The paper presents geomatics – GIS based system for inventory and evaluation of geodiversity. It is composed in a simple way including three phases with various methods used in a specified order. In accordance with this it is objective, repeatable and applicable at different landscapes and different surface size areas. The system was applied in the Kratovo area which is located within the largest paleovolcanic area in North Macedonia. Geodiversity elements were obtained through GPS supported morphographic field mapping, remote sensing method, and statistical analyses. The inventory of geodiversity elements on a spatial unit was performed with approach developed during this research. For this purpose, the Block Statistics tool, and statistical analyses of maximum and variety in ArcMap were utilized. Geodiversity index was calculated by multiplying two layers: number of different geodiversity elements within the spatial units and terrain ruggedness index of the spatial units. In order to facilitate the application in tourism, education and nature conservation the geodiversity index was classified in three classes: low, medium and high. The results of the method showed that three major units with high geodiversity index are present at the study area or 9.95% of the surface. At the west part where the high geodiversity index was detected geomorphological site Kuklica is located. Medium geodiversity index is on the 37.33% and low index on the 51.77% of the study area.

Key words: quantitative method; GIS; geomatics; geodiversity; Kratovo; Republic of North Macedonia

1. INTRODUCTION

The diversity of our planet is wide from a different point of views. To provide comprehensive explanation of its diversity and functioning, various scientific fields interweave and supplement (Gray, 2013). One of them is earth science which provides an integrated, quantitative and interdisciplinary approach to the study of abiotic and biotic sphere among others (Goudie, 2006; Rafferty, 2012). The omittable part of all is interminable human's interaction with nature which leads to exploit and modify environmental resources (Gray, 2008, 2013). Therefore, legal protection and conservation can ensure longer existence of diverse landscapes (Gray, 2013) and endangered species (Maclaurin and Sterelny 2008).

Over the last few decades, the nature protection was primarily focused on biotic sphere or biodiversity. This was particularly highlighted after the United Nations Conference on Environment and Development (UNCED), also known as „The Rio Summit of 1992", when scientific community committed to improve biodiversity enhancement and protection (Myers, et al. 2000; Jenkins, et al. 2013). Although, the abiotic protection within geology and geomorphology occurred at the end of the XIXth century by establishing the first geologic reserves Siebengebirge and Yellowstone national parks. A special attention for abiotic nature was devoted in Tasmania, Australia, where the geodiversity term appeared for the first time at geological and geomorphological studies. The term was coined by analogy of the term »biodiversity« (Gray, 2013). The last, geodiversity was mentioned at the IUCN World Conservation Congress in Hawaii in the resolution 091 – Conservation of moveable geological heritage, and in a few other adopted resolutions (IUCN 2016). In fact, the scientific interest for geodiversity and geoheritage is increasing.

Until today, variety of articles appeared which discuss the geodiversity definition and theory, the geodiversity elements and their inventory and evaluation as well as the connections to tourism and geoheritage. In addition, articles with different methods for inventory and evaluation of geodiversity elements exist. The qualitative and qualitative-quantitative ones merged various criteria, which are divided into scientific and additional values in most of the cases (Zouros, 2007; Reynard et al., 2007; Panizza and Mennella, 2007; Pereira et al., 2007, 2015; Pereira and Pereira, 2010; Fernández et al., 2014; Clivaz and Reynard, 2018). Scientific values assess the basic value of the elements in terms of rareness, representativeness, paleogeographical values etc. Additional values are usually introduced to emphasise results application in tourism, education or nature protection filed (Reynard et al., 2007). All these methods provide qualitative description assessment based on subjective estimation criteria. Their main aim is to improve or establish new management within already protected areas.

The opposite of letter, the quantitative methods utilize digital spatial data, geomatics and geographic information systems. It is notable that the geodiversity elements and their spatial distribution are treated to define geodiversity index and numerical explanation (Zwoliński, 2009; Hjort and Luoto, 2010, 2012; Pellitero et al., 2011; de Paula Silva et al., 2014; Melelli, 2014; Ravanel et al., 2014; Stepišnik and Repe, 2015; Argyriou et al., 2016; Araujo and Pereira, 2017; Melelli et al., 2017; Forte et al., 2018; Bétard and Peulvast, 2019; da Silva et al., 2019). We already have a range of new methods which must to be improved in future research (Muciviuna et al., 2019).

Geomatics, GIS and systematic problem solving are widespread in scientific fields where the geodata collection and management is relevant (Regolini-Bissig and Reynard, 2010; Warfield, 2003). Also, they are used in geodiveristy inventory and evaluation (Regolini-Bissig and Reynard, 2010). Geomatics are an integrated approach to selecting the instruments and techniques for collecting, organizing and visualizing spatial georeferenced data (Gomarasca, 2009). The established database can be useful to evaluate spatial large areas for which field work is timeconsuming and sometimes even impossible (Gomarasca, 2009; Regolini-Bissig and Reynard, 2010). On the other side GIS are software devices equipped with many processing and representation tools that enable managing digital elevation models, 3D and model creations, and other analyses (Gomarasca, 2009). The advantage of the systems and consequently systematic problem solving is their high organization, structure with purpose and interconnected and interdependent elements. Systems have precisely defined incomes, dynamics, and outcomes (Warfield, 2003). Therefore, the connection of geomatics, GIS and a systematic problem solving can allow comprehensive geodiversity examining.

The main aim of this paper is to present geomatics – GIS based system for inventory and evaluation of geodiversity. It consists three phases and welldefined methods and techniques to ensure the objectivity and applicability at different landscapes and different study area size. One of the objectives was to define the exact number of different geodiversity elements on a spatial unit. For this reason, we developed an inventory method using the Block Statistics tool with two different statistical analyses. The final geodiversity index calculation was made with the application of modified equation (Trenčovska, 2016) at the first proposed by Serrano and Ruiz-Flaño (2007). The system was applied in the Kratovo area within the largest paleovolcanic area in North Macedonia.

2. MATERIALS AND METHODS

2.1. *Regional settings*

The Kratovo-Zletovo paleovolcanic area is situated in north-eastern part of North Macedonia (Fig. 1). It covers 970 km^2, thus is one of the largest in the country and the Balkans (Stojanov, Serafimovski, 1990; Serafimovski, 1993). It spreads at northwest–southeast direction in a length of 60 km and width of 30 km. In general, the bedrock comprises volcanic rocks (basalt, andesite, dacite, tuffs, pyroclastic material). Volcanic rocks are transformed with numerous faults, which in some places cross each other; there are also deposits of lead and zinc ore (Hristov et al., 1969; Serafimovski, 1993).

The geodiversity study area is located at the north-eastern part of Kratovo-Zletovo paleovolcanic area and covers 82 km^2. It is situated among two geotectonic units. The west slopes of Osogovo Mountain which are located on the east and northeast belong to the Serb-Macedonian geotectonic unit; the rest of the study area is part of Vardar geotectonic unit (Hristov et al., 1969; Serafimovski, 1993). .

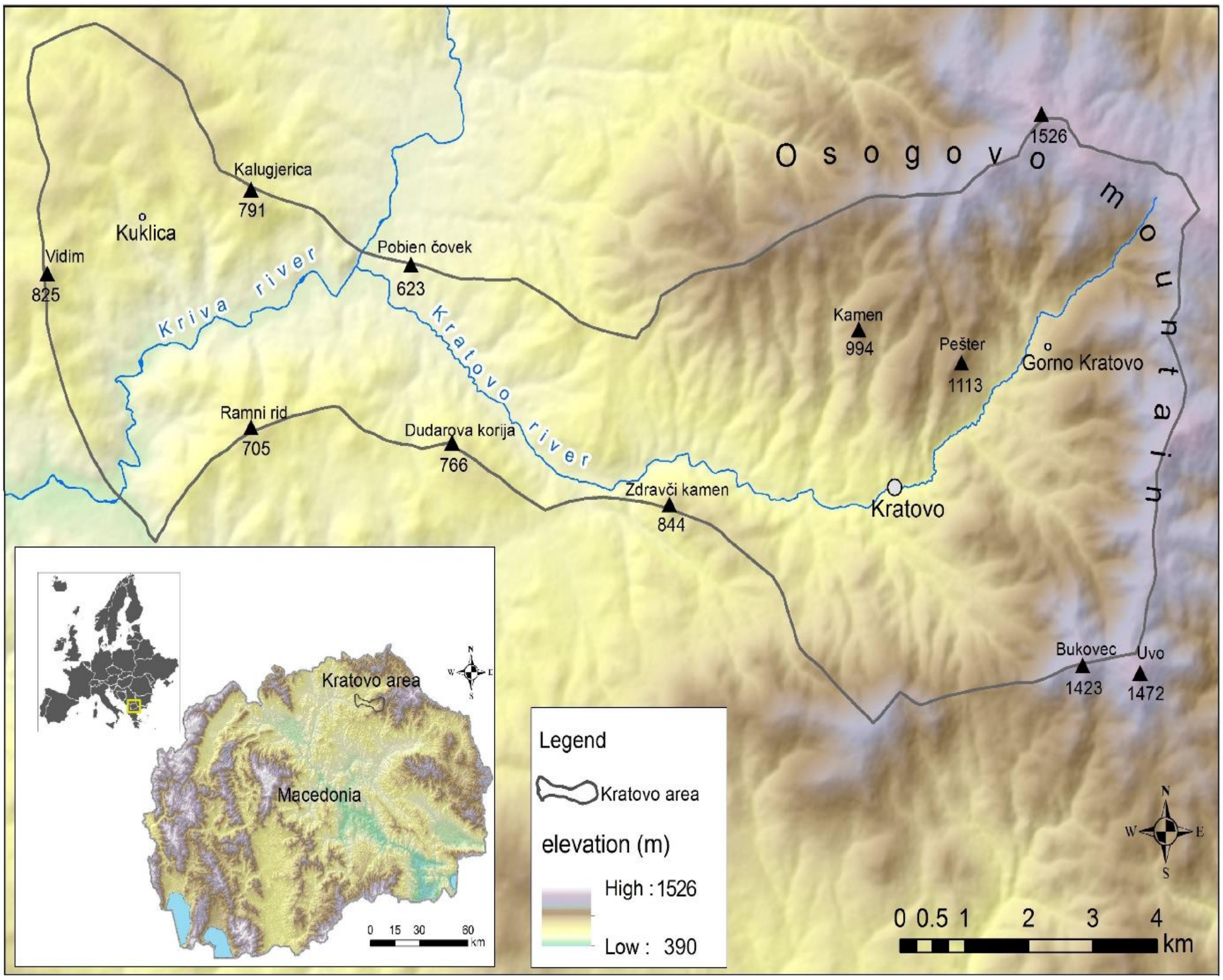

Fig. 1. Location of the study area

It was researched the entire valley of Kratovo River and the middle part of the Kriva River valley. The slopes were researched from the valley bottoms up to the nearby mountains and hills ridges. The most specific are paleovolcanic landforms such as volcanic bombs, lava flows and volcanic necks

Different landforms appear across the area formed because of the diversity of geological structure, rainfall and climatic regime, the relief fragmentation, hydrological conditions, and anthropogenic impacts.

The terrain is highly dissected with numerous gullies and badlands due to high erosion and denudation dynamics. Moreover, there are several locations where the 2 m to 5 m andesitic tuffs beneath the surface are transformed in earth pyramids landforms. Within the study area there is a protected geomorphological locality where prominent landforms are the earth pyramids. It is called Kuklica and covers 0.3 km^2 (Milevski, 2000). The entire study area is not protected with policy.

2.2. *Geodiversity inventory and evaluation system*

The geomatics – GIS based system for inventory and evaluation of geodiversity is composed of three phases. The geodiversity elements were chosen on the basis of main physical features of the study area and prior field study. Within the research were used morphographic and geologic maps as well as a map of terrain ruggedness index derived from 1" SRTM digital elevation model (USGS, 2015) and statistical analyses. All produced maps and methods were performed using ESRI ArcGIS software, version 10.3.1 (Figure 2). The whole statistical analyses were made for a spatial unit in a square shape with the size of 240 × 240 m to ensure objectivity and possibility to compare the results. Thus, the area was automatically divided into 1772 equal size spatial units.

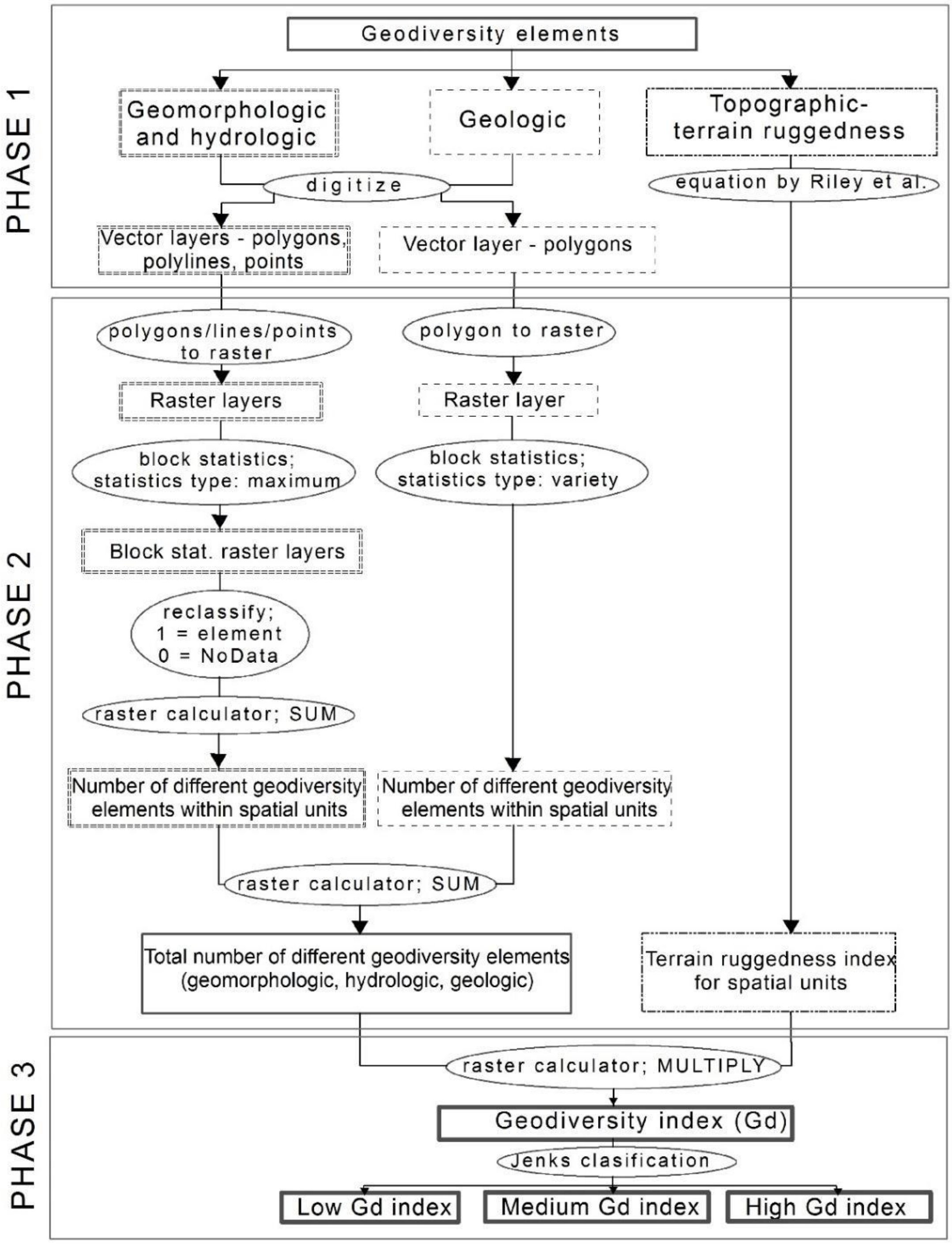

Fig. 2. Detailed scheme of geomatics – GIS based system for inventory and evaluation of geodiversity

2.2.1. Phase 1: *Choosing and mapping the geodiversity elements*

The geodiversity elements for detailed research were chosen on the basis of the scientific literature (Serrano and Ruiz-Flaño, 2007; Gray, 2013), cartographic material at various scales, digital aerial imagery (Real Estate Cadastre Agency of the Republic of Macedonia, 2015), remote sensing data and prior filed study. Namely, the following geodiversity elements were included: the geomorphologic, geologic, hydrologic and topographic.

All geomorphologic and hydrologic geodiversity elements were documented by combination of several methods (GPS supported morphographic field mapping (Pavlopoulos et al., 2009), remote sensing, previous studies (Serafimovski, 1993) and digitalization. In this category were included all different types of geomorphologic and hydrologic elements with purpose to define the number of different geodiversity elements in the spatial units. On the other side, the geologic geodiversity elements were documented just with digitalization based on the general geological map – sheet Kratovo ("Osnovna geološka karta SFRJ. List K 34–69, Kratovo, 1:100.000", 1974).

The topographic geodiversity element was included through the terrain ruggedness index calculation using the equation by Riley et al. (1999) which reflect the change in elevation. The change of elevation also affects the variety of orientations, slopes and radiation affecting soil, hydrological and geomorphological processes (Serrano and Ruiz-Flaño, 2007). All digitalizing geodiversity elements were represented in vector format with polylines, polygons and points within two maps. While the morphographic map consists 19 vector layers that overlap at certain locations and create NoData value areas, the geologic map has only one vector layer where geologic geodiversity elements are in a continuous order. The first phase results are input data for the next phases. From them it is possible to determine spatial distribution (e.g. density, pattern distribution) and the total number of different geodiversity elements (geomorphologic, hydrologic, geologic).

2.2.2. Phase 2: *Inventory of different geodiversity elements on a spatial unit*

The method for inventory of different geodiversity elements on a spatial unit is based on the analysis performed with Block Statistics tool within Neighborhood toolset. Therefore, all vector layers from the previous phase were transformed in raster format, otherwise the functioning of the tool is impossible (ESRI, 2016a). After that, only for the raster layers of the morphographic map the statistical analyses of maximum were performed in order to determine whether the element is present within the spatial units. For the geologic raster layer was performed the statistical analyses of variety with the same purpose. It was followed with reclassifying and summing the raster layers from the block statistical analyses with the Raster calculator tool. As a result, the map of exact number of different geodiversity elements on a spatial unit was obtained.

2.2.3. Phase 3: *Calculation of terrain ruggedness and geodiversity index*

The first step in this phase was the calculation of terrain ruggedness index based on the equation by Riley et al. (1999). It was used 1"SRTM 30 m digital elevation model from USGS database (USGS 2015). The terrain ruggedness index was calculated for a spatial unit of a square with size of 240 m to match with the layer of different number of geodiversity elements obtained in the first phase. The equation can be used at different scales (Riley et al., 1999) which is important for the final geodiversity index calculation.

The second step was to calculate the geodiversity index based on the modified formula (Trenčovska, 2016), which prior was proposed by Serrano and Ruiz-Flaño (2007):

$$Gd = Eg \cdot R,$$

where Eg is the number of different geodiversity elements within a spatial unit and R is terrain ruggedness index on a spatial unit. The both layers were multiplied at the Raster Calculator tool with the aim to determine the geodiversity index within the entire study area. Geodiversity index was divided into three classes, low, medium and high on the bases of Jenks classification (Jenks and Caspall, 1971).

3. RESULTS

The study area that covers 82 km^2 was divided into 1772 equal spatial units in the shape of a 240 × 240 m square size. For each spatial unit was determined the exact number of different geodiversity elements, the terrain ruggedness index and geodiversity index. Three different thematic maps were generated through the system processes.

The chosen geodiversity elements for the research were defined on the basis of the scientific literature, cartographic data and prior field survey. It was detected 16 different geomorphologic geodiversity elements and only 2 hydrologic which are distributed discontinuously over the entire study area (Figure 3). There are 12 different geologic geodiversity elements with continuous distribution (Figure 4). Thus, the number of different geodiversity elements mapped at the study area is 30 and the total number of all geodiversity elements is 498.

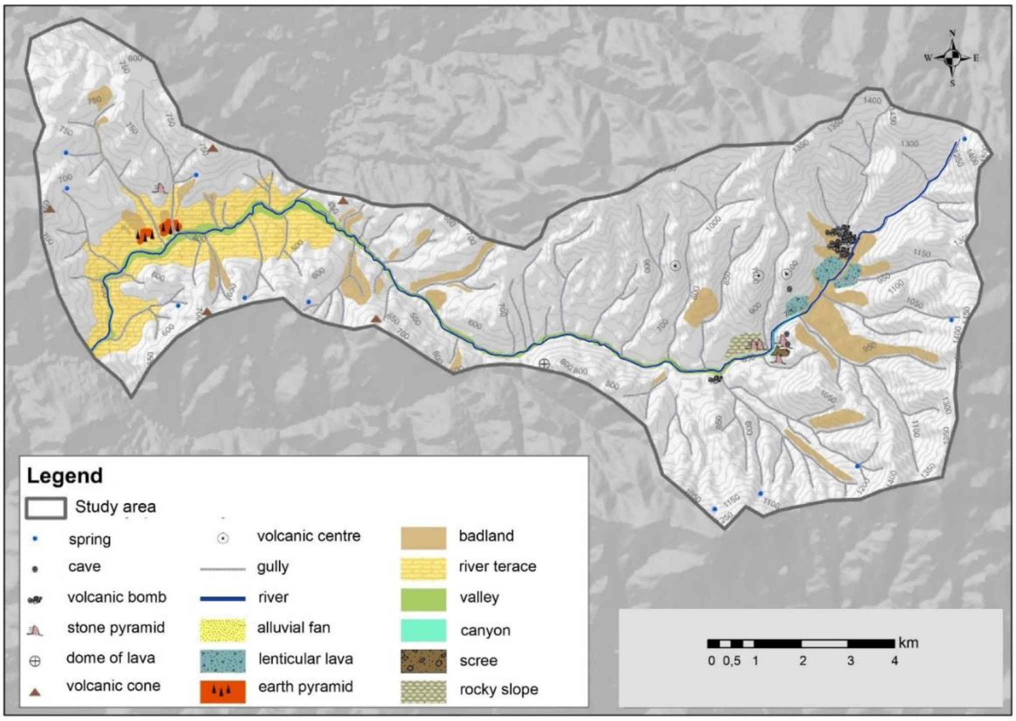

Fig. 3. Map of the geodiversity elements (geomorphic and hydrologic)

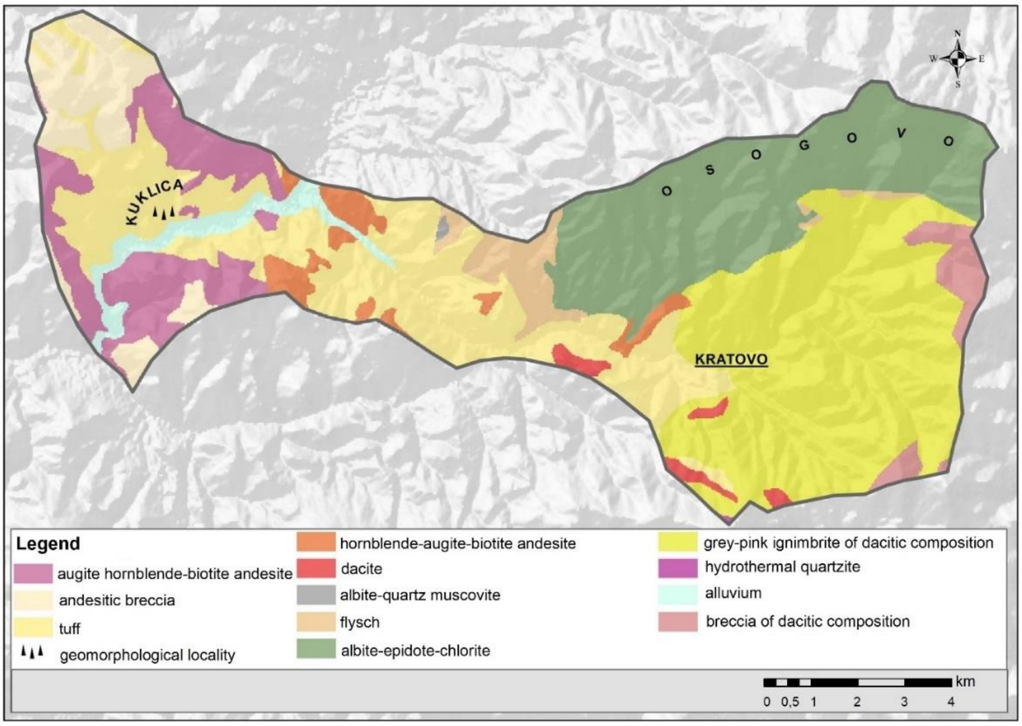

Fig. 4. Geological map of the study area (by OGK SFRJ, 1974)

The number of different geodiversity elements (geomorphologic, hydrologic, geologic) within the spatial units was defined by performing statistical analyses within the Block Statistic tool. It varied from one to nine (Figure 5). Most of the spatial units had one different geodiversity element while just one of them had the highest value of nine. About 70 % of the study area has one or two different geodiversity elements. The spatial units with the highest number of different geodiversity elements are located at the western part of the area at the valley of Kriva River.

Terrain ruggedness index represents a quantitative objective assessment of surface heterogeneity (Riley et al., 1999) which can enhance result comparability among different areas. Calculation was based on a Riley et al. (1999) equation and 30 m digital elevation model (USGS, 2015). It ranges on a value index scale from 62 to 619 (Figure 6). The spatial units with a high index are positioned on the east at the higher altitudes of Osogovo Mountains. Also, the high index values are on the steep slopes of the hills and mountains on both the east and the west parts of the study area. The low index appears on the valley bottoms and at the high altitudes of the hills and mountains but in a small area.

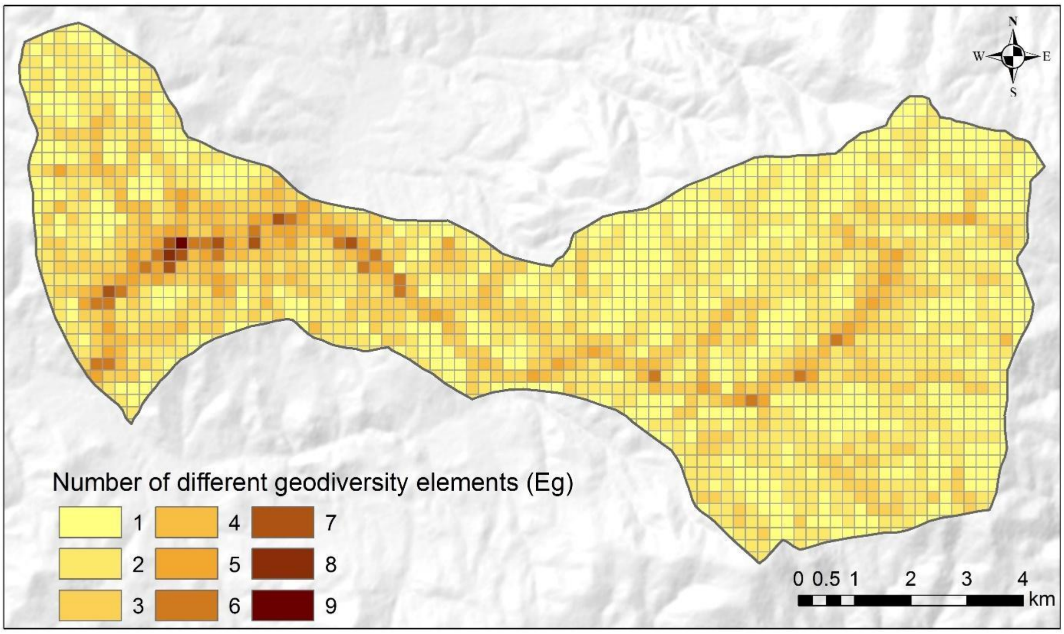

Fig. 5. Map of the number of different geodiversity elements within the 240 × 240 m sized spatial units

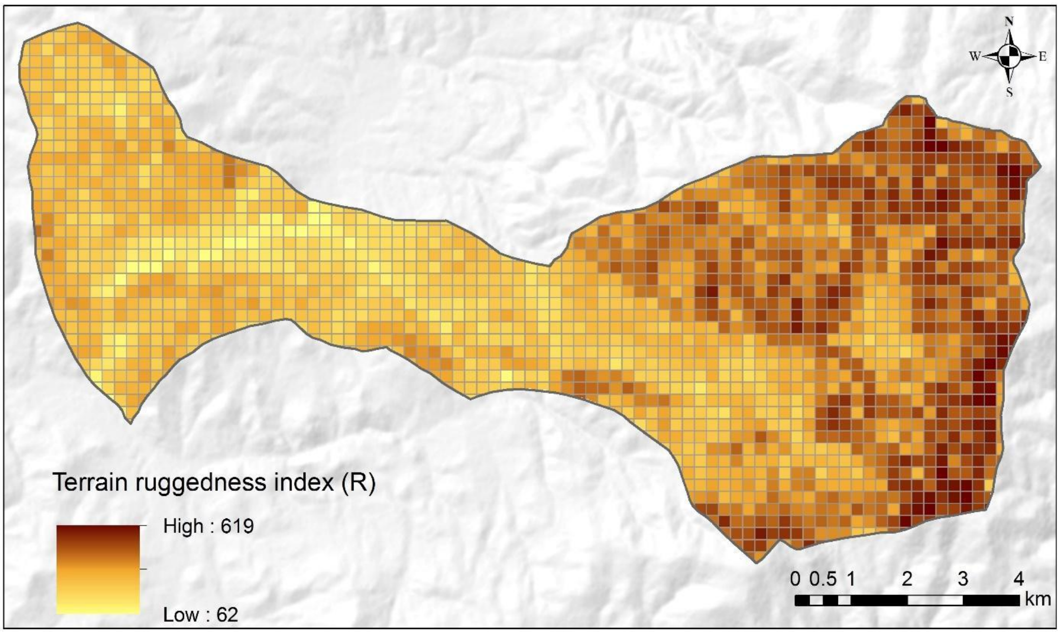

Fig. 6. Map of terrain ruggedness index of the 240 × 240 m sized spatial units

The geodiversity index is a result of the geomatics and GIS within the established system. It was obtained by multiplying the digital layers of the number of different geodiversity elements and the terrain ruggedness index on the spatial unit. The values of the index are ranged between 62 and 5571. They were divided on low, medium and high geodiversity index values (Table. 1) according to the natural Jenks method (Jenks and Caspall, 1971). In order to provide better visualization and interpretation of the geodiversity index values homogenous areas were created. (Figure 7).

Table 1

Surface area and percentage of geodiversity index values in the Kratovo

Geodiversity index	Area (km^2)	Ratio (%)
Low	42.64	51.77
Medium	31.16	37.83
High	8.20	9.95

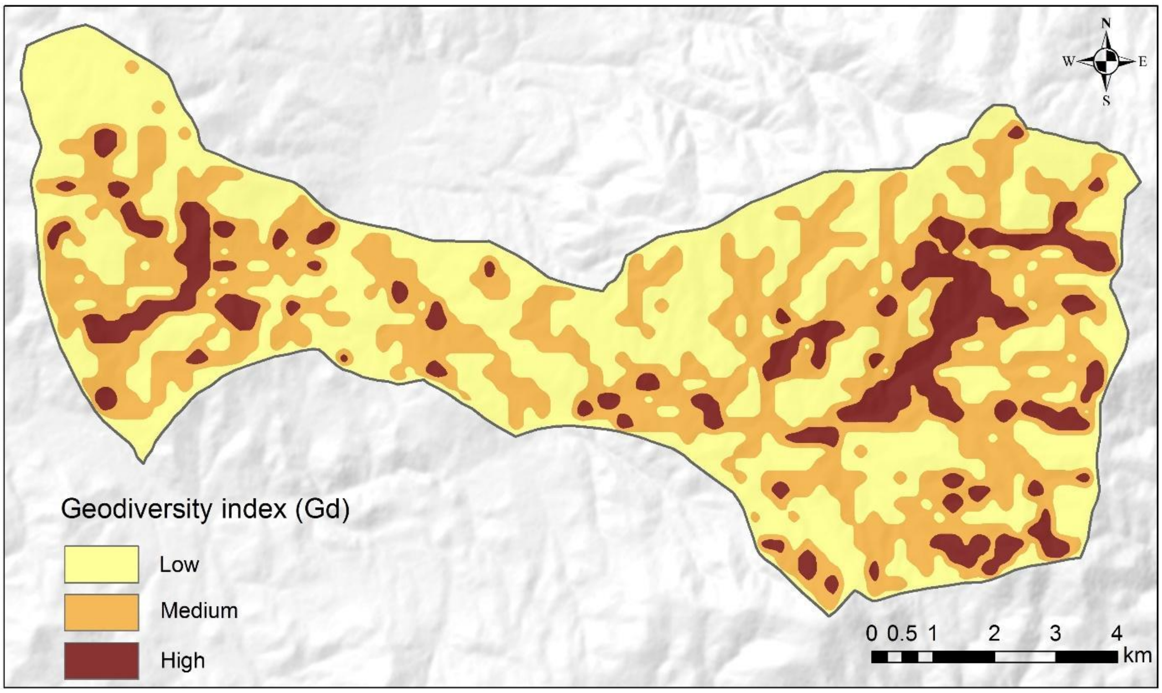

Fig. 7. Map of geodiversity index of Kratovo area classified in three classes

Areas with low and medium geodiversity index are distributed quite evenly throughout the entire study area. Low index areas are most in common in the central part of the southern slopes of the Osogovo Mountain both at higher and lower altitudes. Another major area of low index is located northwest of the village of Kuklica (Figure 8 (C)). Medium index areas are located widespread through the entire study area and kind of follow slopes with gullies and geologic geodiversity elements spatial distribution (Figure 8 (B)).

The areas of high geodiversity index appear at three major areas. They are also defined as geodiversity hot spots, and there can be found from six to nine different geodiversity elements. The first high geodiversity index location is in the geomorphological locality "Kuklica" and its surroundings, which includes small part of the Kriva River valley (Figure 9). In this area were documented the following geodiversity elements: earth and stone pyramids, erosive hot spots, gullies, a river terrace, alluvial fans, a bottom valley and a river. Only two types of lithological elements appear: tuffs and alluvial. Earth pyramids cover about 0.30 km^2 on the right side of the Kriva River terrace which is very eroded at this place (Milevski, 2000). The Kuklica locality is protected with a legal status as a natural monument in 2008 ("Zakon za proglasuvanje na lokalitetot 'Kuklica' za spomenik na prirodata", 2008). As such is the only protected abiotic part of nature in the entire research area.

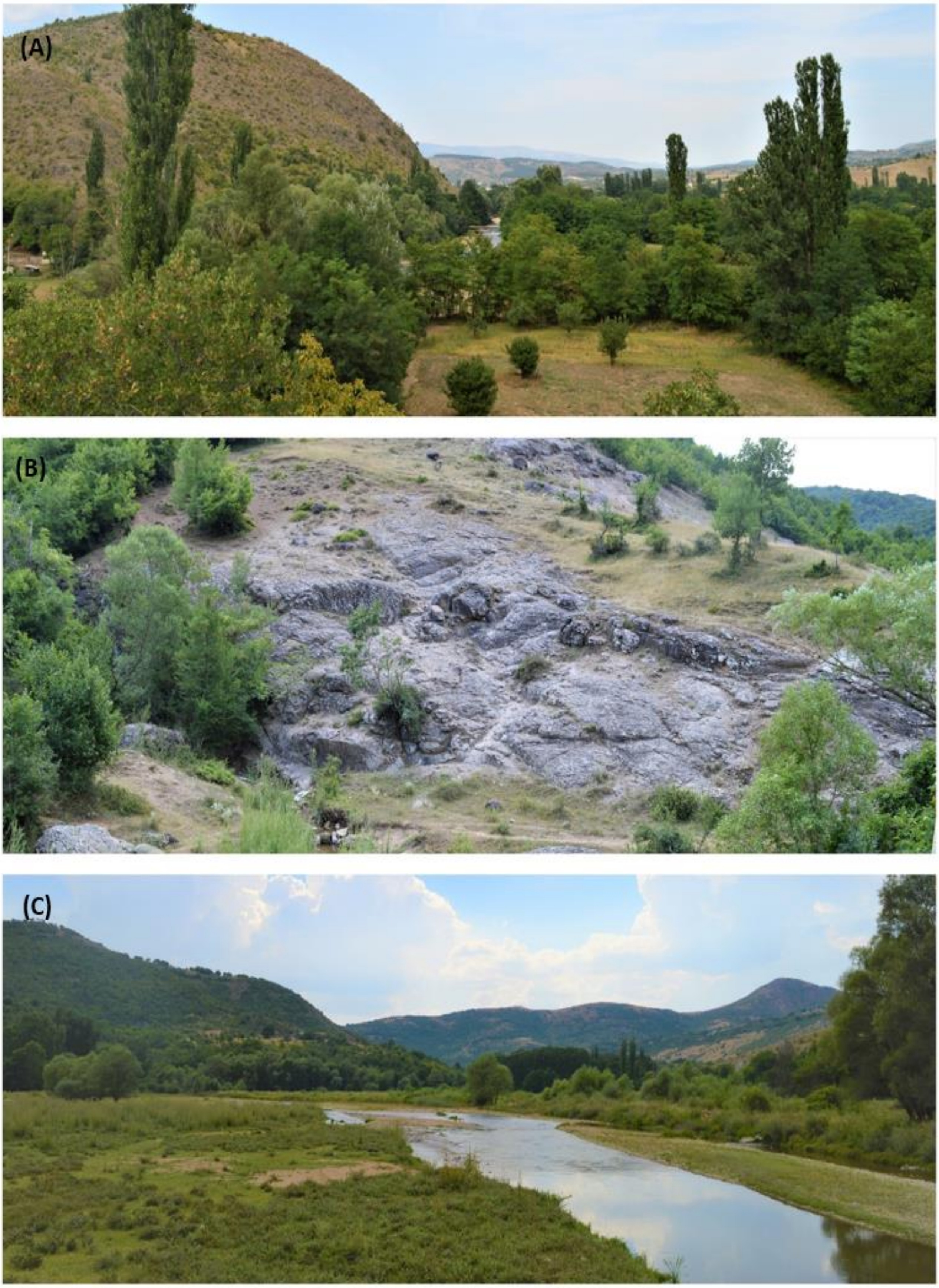

Fig. 8. Relief forms within the areas of mid and low geodiversity index: (A) hill, (B) slope, (C) river with background hill

Fig. 9. Geomorphological locality "Kuklica"

The second area of high geodiversity index begins at surroundings of Kratovo and spreads towards northeast to the village of Gorno Kratovo. There are appearing volcanic bombs (Figure 10(D)), badlands, gullies, lava flows, stone pyramids, caves, scree, canyon (Figure 10(E)), the river (Figure 10(B)), and the former volcanic centers Kamen and Pešter (Figure 10(A)). There is present just one of the geologic geodiversity elements, namely the graypink ignimbrite with dacite composition (Hristov et al., 1969; Serafimovski, 1993). Within this area, the intertwined paleovolcanic and fluvial features are the most notable on the surface. There is no legally nature protected areas, although the diversity is very high. However, the results of this paper can be a step forward to its protection in the future.

The third major area is directly above the second location. As such is the smallest of the three with a high geodiversity index. Here again on the surface area is noted the interconnection of several geodiversity elements like gullies, river and three different geologic geodiversity elements (slate, dacite breccia and flysch). The other high geodiversity index locations cover small surface areas and appear in separate spots through the study area.

This occurs as a result of the contact of different geological geodiversity elements on a small area. The diversity of these small high geodiversity areas is not reflected on the surface like a relief form. As such they are relevant from scientific perspective.

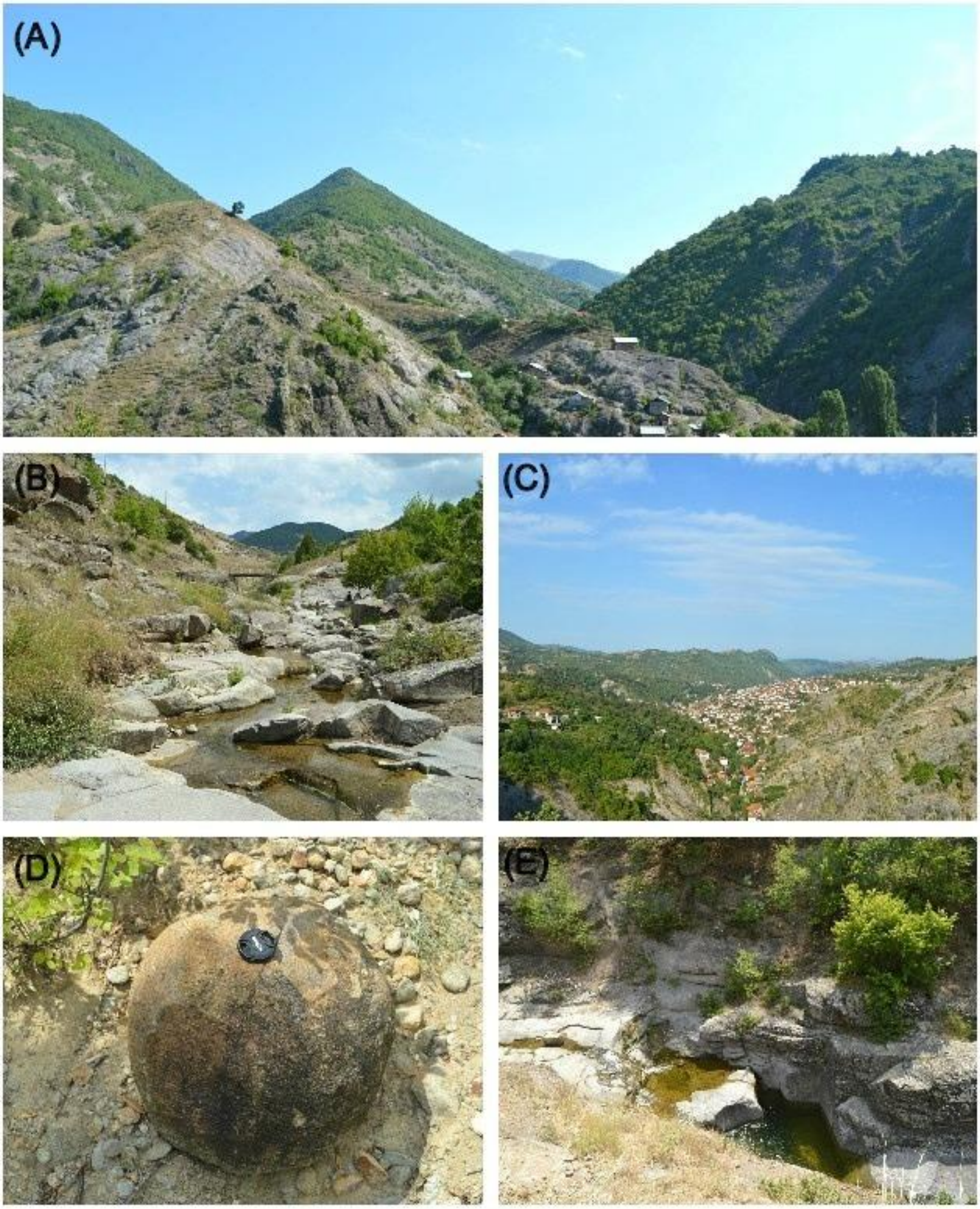

Fig. 10. Relief forms within the areas of high geodiversity index: (A) volcanic center, (B) river, (C) ridge in the south part, (D) volcanic bomb and (E) canyon on the east side of the study area

4. DISCUSSION

The geodiversity concept within the field of geography has evolved over the last two decades. It includes inventory and evaluation of abiotic nature elements (Gray, 2013). During this time, many dif ferent methods for inventory and evaluation were proposed. Initially most of them were with a qualitative nature due to improvement of management at the actual protected areas. The criteria and processes for inventory and evaluation of geodiversity elements differ among the methods and the result is usually presented descriptively (Zouros, 2007; Reynard et al., 2007; Panizza and Mennella, 2007; Pereira et al., 2007, 2015; Pereira and Pereira, 2010; Fernández et al., 2014; Clivaz and Reynard, 2018). The principal problem of these methods is their subjectivity and tough comparison of results among different areas. The process of identification and inventory of geodiversity elements is questionable if it is carried out by different evaluators. The results obtained can be useful to increase tourist or educational potential within actual protected areas.

In the last decade, on the field of geodiversity surveys emerged also quantitative methods and usage of geomatics and GIS (Zwoliński, 2009; Hjort and Luoto, 2010, 2012; Pellitero et al., 2011; Melelli, 2014; de Paula Silva et al., 2014; Ravanel et al., 2014; Stepišnik and Repe, 2015; Argyriou et al., 2016; Araujo and Pereira, 2017; Melelli et al., 2017; Forte et al., 2018; Bétard and Peulvast, 2019; da Silva et al., 2019). Their advantage is precise and accurate interpretation of numerical results, the repeatability of the processes and the use of large databases, which can be processed in a relatively short time. Moreover, they allow monitoring and forecast of geodiversity loss or extension in a time as well as result comparison among different study areas. These articles also highlight the application of geomatics, various tools and techniques within geographic information systems, remote sensing methods, statistical analyses and GPS method. In general, the inventory and evaluation processes are carried out on the basis of geodiversity elements selection and its distribution within the study areas in combination with the terrain ruggedness. All these processes lead to establishment of the geodiversity index and most diverse areas, or geodiversity "hot spots" (Ruban, 2010).

A common characteristic of the existing quantitative methods is the spatial unit size and design which varies among the articles depending of the authors decisions. Also, the authors used different geodiversity elements as input data and a variety of tools and processes order for the statistical analyses. This can cause problems in the reapply of the methods and results comparison among different areas. The focal statistics tool applied by Melelli (2014) performs a neighborhood operation that computes an output raster where the value for each output cell is a function of the values of all the input cells that are in a specified neighborhood around that location (ESRI, 2016b). Thus, the accurate number of different geodiversity elements within a spatial unit cannot be defined. Other methods used summing (Hjort and Luoto 2010) or subtracting (de Paula Silva et al., 2014) processes for the geodiversity elements, but without specific information for utilized tools.

The geomatics GIS based system, which is presented, offers a new way for geodiversity inventtory and evaluation. It is composed of three phases which consists a set of methods, procedures and techniques arranged in an exact order. From each phase, it is evident an intermediate result, which is used in the next phase. These features of our system enabled objectivity, controlling the interim data and results. Moreover, the repeatability of the system to other study areas, regardless of the landscape type and the study area size, is facilitated. It was tried to upgrade already recognized advantages of the methods used so far and to remove their shortcomings with a new inventory method of geodiversity elements which was developed at this research. The objectivity of our system is highlighted by carrying out the inventory and evaluation for the system of spatial units. The entire study area was automatically divided into 1772 equalsized spatial units in a square with a size of 240 × 240 m. The size of the units was determined on a base of the size of the entire study area, several test analyses with smaller or larger unit sizes and DEM resolution. In further research will be necessary to establish correspondence among the spatial unit size, the number of geodiversity elements taken into consideration and the surface size of the study areas.

Geodiversity calculation needs to take scale and hierarchy issues into account, which makes comparison among study areas only possible if the same scale is used. The scale is also important in application phases of the results in real management, because areas subject to protection turn out to be entire regions or squares as extensive as several municipalities. This is obviously also dependent on the scale of the country, so large countries like Brazil may be able to afford management on such broad scales, although frequency studies can be suggested to compare areas with the same geodiversity index (Pellitero et al., 2015). The method presented in the article would be a significant benefit for the next geodiversity research as well as to extent it on regional and even global scale.

The geodiversity elements were digitized in order to create the digital morphographic and geologic map. Some of the geomorphologic and hydrologic geodiversity elements from the morphographic map overlapped and at the same time generated areas with NoData value. On the other side, the geological geodiversity elements spread continuously and without NoData value areas. It has been found that it is significant to determine the mentioned features of digitized elements to choose the adequate statistical analysis within the Block statistics tool. Consequently, were chosen two statistical analyses to identify the different geodiversity elements within the spatial units. Obtained GPS positions of the geodiversity elements helped to align field mapping data with the shaded relief map, which has been used for a base of the digital final maps.

The Block Statistics analyses in the second phase offer innovative method to inventory and establish the exact number of different geodiversity elements within a spatial unit. The Block Statistics tool allows calculating statistics for each spatial unit or block based on the value of the input raster cell data. Blocks are not overlapped, and the value of each input raster cell is considered only once to calculate the statistics of the block. The statistical analyses which can be performed are the average, most, maximum, median, minimum, minority, range, standard deviation, sum and difference (ESRI, 2016a). For each different geomorphological and hydrologic geodiversity element converted in a raster format was determined the presence within the spatial unit with Block Statistics tool and the statistical analysis of maximum. For the geological geodiversity elements was used the same tool and the statistical analyses of diversity. With both statistics was obtained the number of the different geodiversity elements within the spatial unit. Different statistics were used as the spatial distribution of geomorphologic and hydrologic geodiversity elements in nature is different from that of geologic. Geomorphologic and hydrologic elements are discontinuous and may also overlap while geological appear more continuously.

To calculate the terrain ruggedness index have been used different methods and equations so far (Melton, 1965; Riley et al., 1999; Jenness, 2004; Nellemann et al., 2007; Grohmann, 2015; Trevisani and Rocca, 2015). In this research, was used the equation suggested by Riley et al., (1999) as applicable in a different spatial scale. The input data was the 1″ SRTM 30 m digital elevation model from USGS database (USGS, 2015). Considering the size of the entire study area and the results, we believe that its accuracy was satisfactory. In the case of smaller areas, we assume it will be needed more detailed digital elevation model.

The geodiversity index was calculated on the basis of modified equation (Trenčovska, 2016) developed by Serrano and Ruiz-Flaño (2007). The modification was needed because of the new inventory method developed in the second phase. After the calculation of *Eg* and *R* for the equal spatial units, the natural logarithm of the surface of spatial unit was taken away. The natural logarithm at the original formula was used because the spatial units for inventory and evaluation of geodiversity elements were of different sizes. With the aim the geodiversity index to be useful in tourism, education, or management of protected areas it has been automatically divided into three classes according to the method of natural Jenks classes (Jenks and Caspall, 1971). Consequently, the most diverse geodiversity areas or hot spots were obtained.

Our system is used on a local scale for inventory and evaluation of different geodiversity elements within a spatial unit. Its usage at regional and global level should be tested. According to the objective system design and application of geomatics and GIS we considered that it can also be useful in other professional fields inside and outside of the geography, where the number of different elements/processes/phenomenon at spatial unit are relevant. Such usage can be experimented in the future. Also, it is necessary to determine the size of spatial unit for research at different scales and try to automate repetitive processes within the system using some programing language or building a model in GIS software.

5. CONCLUSION

The article offers new geomatics – GIS based system for inventory and evaluation of geodiversity. The system is designed of three phases and different methods in an exactly defined order. The Kratovo geodiversity index calculation was based on several geographical digital data. There were used the geomorphological, hydrological, geological and topographical geodiversity elements obtained with field work, remote sensing method, GPS, GIS mapping and statistical analysis. The system includes a new method for inventory of the different geodiversity elements within a spatial unit. It was developed within the research to facilitate the calculation of geodiversity index. The geodiversity index is a result of multiplying the digital raster layers of the number of different geodiversity elements within the spatial unit and the terrain ruggedness index at the spatial unit. It was classified into three classes low, medium and high, and has an interdisciplinary application in tourism, education and nature conservation. Further work can contribute to a complete automatization of the processes and methods within the system and extension of the geodiversity research at regional and even global scale.

REFERENCES

Araujo, M. A., Pereira, I. D. (2017): A new methodological contribution for the geodiversity assessment: Applicability to Ceará State (Brazil). *Geoheritage* **10**, 591–605.

Argyriou. A. V., Sarris, A., Teeuw, R. M. (2016): Using geoinformatics and geomorphometrics to quantify the geodiversity of Crete, Greece. *Int. J. Appl. Earth Obs. Geoinf*. **51**, 47–59. DOI:10.1016/j.jag.2016.04.006. DOI: 10.1007/s1237101702503.

Bétard, F., Peulvast, J. P. (2019): Geodiversity hotspots: concept, method and cartographic application for geoconservation purposes at a regional scale. *Environmental Management*, **63**, 822–834. DOI: 10.1007/s00267019011685

Clivaz, M., Reynard, E. (2018): How to integrate invisible geomorphosites in an inventory: A case study in the Rhone river valley (Switzerland). *Geoheritage*, **10**, 527–541. DOI: 10.1007/s1237101702227.

da Silva, M. L. N., Mascimento, M.., Mansur, K. L. (2019): Quantitative assessments of geodiversity in the area of the Seridó Geopark Project, Northeast Brazil: Grid and centroid analysis. *Geoheritage*, **11**, 1177–1186. DOI: 10.1007/s1237101900368z.

de Paula Silva, J., Rodrigues, C., Pereira, D. I. (2014): Mapping and analysis of geodiversity indices in the Xingu river basin, Amazonia, Brazil. *Geoheritage* **7**, 337–350. DOI:10.1007/s1237101401348.

ESRI (2016a): *Block Statistics*. http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/block-statistics.htm. Accessed 23 December 2016.

ESRI (2016b): *How Focal Statistics Works*. http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-focalstatistics-works.htm. Accessed 23 December 2016.

Fernández, M. P., Timón, D. L., Marín, R. G. (2014): Geosites inventory in the Geopark Villuercas-Ibores-Jara (Extremadura, Spain): A Proposal for a new classification. *Geoheritage* **6**, 17–27. DOI:10.1007/s1237101300882.

Forte, J. P., Brilha. J., Pereira, D. I., Nolasco, M. (2018): Kernel density applied to the quantitative assessment of geodiversity. *Geoheritage*, **10**, 205–217. DOI: 10.1007/s12 37101802823.

Gomarasca, M. A. (2009): *Basics of Geomatics*. Springer. https://doi.org/10.1007/9781402090141.

Goudie, A. S. (2006): *Encyclopedia of Geomorphology*. Routledge.

Gray, M. (2008): Geodiversity: developing the paradigm. *Proc. Geol. Assoc*. **119**, 287–298. DOI:10.1016/S00167878(08)803070.

Gray, M. (2013): *Geodiversity: Valuing and Conserving Abiotic Nature*, 2nd ed. Wiley–Blackwell, Chichester.

Grohmann, C. H. (2015): Effects of spatial resolution on slope and aspect derivation for regional-scale analysis. *Comput. Geosci*. **77**, 111–117. DOI: 10.1016/j.cageo.2015. 02.003.

Hjort, J., Luoto, M. (2012): Can geodiversity be predicted from space? *Geomorphology* **153–154**, 74–80. DOI: 10.10 16/j.geomorph.2012.02.010.

Hjort, J., Luoto, M. (2010): Geodiversity of high-latitude landscapes in northern Finland. *Geomorphology* **115**, 109–116. DOI: 10.1016/j.geomorph.2009.09.039.

Hristov, S., Karajovanovikj, M., Jančevski, J., Ivanova, B. (1969): *Tolkuvač za listovite Kratovo i Kjustendil*. Zvezni geološki zavod, Beograd.

IUCN (2016): 091 – *Conservation of moveable geological heritage*. https://portals.iucn.org/congress/motion/091 Accessed 23 December 2016.

Jenkins, C. N., Pimm, S. L., Joppa, L. N. (2013): Global patterns of terrestrial vertebrate diversity and conservation. *PNAS* **110**, 1–10. DOI: 10.1073/pnas.1302251110

Jenks, G. F., Caspall, F. C. (1971): Error on choroplethic maps: definition, measurement, reduction. *Ann. Assoc. Am. Geogr*. **61**, 217–244. DOI: 10.1111/j.14678306.1971.tb00 779.x.

Jenness J. S. (2004): Calculating landscape surface area from digital elevation models. *Wildl. Soc. Bull*. **32**, 829–839. DOI: 10.2193/00917648(2004)032[0829: CLSAFD]2.0.CO;2.

Kolčakovski, D., (2004). *Fizička geografija na Republika Makedonija*. Univerzitet Sv. Kiril i Metodij, Skopje.

Kolčakovski, D. (2006): *Geomorfologija*. Nacionalna i univerzitetska biblioteka Sv. Kliment Ohridski, Skopje.

Maclaurin, J., Sterelny, K. (2008): *What Is Biodiversity?* The University of Chicago, United States of America.

Melelli, L. (2014): Geodiversity: A New quantitative index for natural protected areas enhancement. *Geoj. Tour. Geosites* **13**, 27–37.

Melelli, L., Vergari, F., Liucci, L., del Monte, M. (2017): Geomorphodiversity index: Quantifying the diversity of landforms and physical landscape. *Science of the Total Environment*, **584–585**, 701–714. d DOI: 10.1016/j.scitoten v.2017.01.101.

Melton, M. A. (1965): The Geomorphic and paleoclimatic significance of alluvial deposits in Southern Arizona. *J. Geol*. **73**, 1–38. DOI:10.2307/30066379

Milevski, I. (2000): Zemjani piramidi vo Kuklica – Kratovsko, *Geografski razgledi,* kn. 35, Skopje, 13–28.

Milevski, I. (2006): Palaeovolcanic landforms in the western part of Osogovo massif. *Geographical review,* No. **40**, Skopje, pp. 47–67.

Milevski, I. (2010): Geomorphological characteristics of Kratovo-Zletovo palaeovolcanic area. *Proceedings of the XIX Congress of CBGA2010,* Scientific Annals of the School of Geology, Aristotle University, Thessaloniki, Greece, pp. 475–482,

Mucivuna, V. C., Reynard, E., Garcia, M. G. M. (2019): Geomorphosites assessment methods: Comparative analysis and typology. *Geoheritage*. **11**. 1799–1815, DOI:10.1007/s1237101900394x.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fronseca G. A. B., Kent, J. (2000): Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858.

Nellemann, C., Støen, OG., Kindberg, J., Swenson, J. E., Vistnes, I., Ericsson, G., Katajisto, J., Kaltenborn, B. P., Martin, J., Ordiz, A. (2007): Terrain use by an expanding brown bear population in relation to age, recreational resorts and human settlements. *Biol. Conserv*. **138**, 157–165. DOI:10.1016/j.biocon.2007.04.011.

Osnovna geološka karta SFRJ. 1:100.000, 1974. List K,34–69, Kratovo.

Panizza, V., Mennella, M. (2007): Assessing geomorphosites used for rock climbing. The example of Monteleone Rocca Doria (Sardinia, Italy). *Geogr. Helv*. **62**, 181–191.

Pavlopoulos, K., Evelpidou. N., Vassilopoulos, A. (2009): *Mapping Geomorphological Environments*. Springer. DOI:10.1007/9783642019500.

Pellitero, R., González-Amuchastegui, M. J., Ruiz-Flaño, P., Serrano, E. (2011): Geodiversity and geomorphosite assessment applied to a natural protected area: The Ebro and Rudron Gorges Natural Park (Spain). *Geoheritage* **3**, 163–174. DOI:10.1007/s1237101000229.

Pellitero, R., Manosso, F. C., Serrano, E. (2015): Mid and large-scale geodiversity calculation in fuentes carrionas (nw Spain) and serra do cadeado (Paraná, Brazil): methodology and application for land management. *Geografiska Annaler: Series A, Physical Geography* **97**, 2, 2019–235.

Pereira, D. I., Pereira. P., Brilha, J., Cunha, P. P. (2015): The Iberian massif landscape and fluvial network in Portugal: A geoheritage inventory based on the scientific value. *Proc. Geol. Assoc*. **126**, 252–265. DOI: 10.1016/j.pg eola.2015.01.003.

Pereira, P., Pereira, D., Caetanno Alves, M. I. (2007): Geomorphosite assesment in Montesinho Natural Park (Portugal). *Geogr. Helv*. 62, 159–168.

Pereira, P., Pereira, D. (2010): Methodological guidelines for geomorphosite assessment. *Geomorphol. Process. Environ*. 215–222. DOI: 10.4000/geomorphologie.7942.

Rafferty, J. P. (2012): *Geological Science*. DOI: 10.1017/ CBO9781107415324.004.

Ravanel, L., Bodin, X., Deline, P. (2014): Using terrestrial laser scanning for the recognition and promotion of High-Alpine geomorphosites. *Geoheritage* **6**, 129–140. DOI: 10. 1007/s1237101401041.

Real Estate Cadastre Agency of the Republic of Macedonia (2015): *Cartographic Products*. http://ossp.katastar.gov.mk/OSSP/. Accessed 15 July 2015.

Regolini-Bissig, G., Reynard, E. (2010): *Mapping Geoheritage*, Institut de geographie.

Reynard, E., Fontana, G., Kozlik, L., Scapozza, C. (2007): A method for assessing “scientific” and “additional values” of geomorphosites. *Geogr. Helv*. **62**, 148–158. DOI:10.5194/gh621482007.

Riley, S. J., DeGloria, S. D., Elliot, R. (1999): A Terrain ruggedness index that qauntifies topographic heterogeneity. *Intermt. J. Sci*. Vol. **5**, No. 3–4, pp 23–27 DOI:citeulikearticleid:8858430.

Ruban, D. A. (2010): Quantification of geodiversity and its loss. *Proc. Geol. Assoc*. **121**, 326–333. DOI:10.1016/j.pge ola.2010.07.002.

Serafimovski, T. (1993): *Structural Metallogenic Characteristics of the Lece-Chakidiki zone: Types of Mineral Deposits and Distribution*. Special edition of RGF Štip, No 1, 328 p.

Serrano, E., Ruiz-Flaño, P. (2007): Geodiversity. A theoretical and applied concept, *Geographica Helvetica,* Jg. **62**, 140–147.

Serrano, E., Ruiz-Flaño, P., Arroyo, P. (2009): Geodiversity assessment in a rural landscape: Tiermes-Caracena area (Soria, Spain). *Mem. Descr. Cart. Geol. d'It*. **LXXXVII**, 173–179.

Stojanov, R., Serafimovski, T. (1990): Vulkanizam vo zletovsko-kratovskata oblast. *XII kongres na geolozite na Jugoslavija, Ohrid*, Kn. 2, 424–441.

Stepišnik, U., Repe, B. (2015): *Identifikacija vročih točk geodiverzitete na primeru Krajinskega parka Rakov Škocjan*. Dela 2015, 45–62. DOI:10.4312/dela.44.3.4562

Trenčovska, A. (2016): *Inventarizacija in vrednotenje geodiverzitete na območju Kratova, Makedonija*. University of Ljubljana, Ljubljana.

Trevisani, S., Rocca, M. (2015): MAD: Robust image texture analysis for applications in high resolution geomorphometry. *Comput. Geosci.* **81**, 78–92. DOI: 10.1016/j. cag eo.2015.04.003.

USGS (2015): *Earth Explorer*. https://earthexplorer.usgs. gov/ Accessed 20 October 2015.

Warfield, J. N. (2003): A Proposal for systems science. *Syst. Res. Behav. Sci*. **20**, 507–520. DOI:10.1002/sres.528.

Zouros, N. C. (2007): Geomorphosite assessment and management in protected areas of Greece. Case study of the Lesvos island – coastal geomorphosites. *Geogr. Helv.* **62**, pp. 169–180. DOI:10.5194/gh621692007.

Zwoliński, Z. (2009): The routine of landform geodiversity map design for the Polish Carpathian Mts. In: E. Rojan, A. Łajczak (eds), *Geoecology of the Euroasiatic Alpids. Landform Analysis* **11**, pp. 79–87.

Р е з и м е

ИНВЕНТАРИЗАЦИЈА И ЕВАЛУАЦИЈА НА ГЕОДИВЕРЗИТЕТОТ ВО КРАТОВО СО ПРИМЕНА НА ГЕОГРАФСКИ ИНФОРМАЦИСКИ СИСТЕМИ И ГЕОМАТИКА

Александра Тренчовска

Геолошки завод на Словенија, Димичева 14, 1000 Љубљана, Словенија
aleksandra.trenchovska@geozs.si

Клучни зборови: квантитативни методи; ГИС; геоматика; геодиверзитет; Кратово; Република Северна Македонија

Во трудот е претставен геоматски систем базиран на ГИС (географски информациски систем) за инвентаризација и евалуација на геодиверзитетот. Системот е составен на едноставен начин, вклучувајќи три фази со различни методи користени по одреден редослед. Во согласност со ова, тој е објективен, повторлив и применлив на различни предели и области со различни површини. Системот е применет во кратовското подрачје што се наоѓа во рамките на најголемиот палеовулкански предел во Република Северна Македонија. Елементите на геодиверзитетот се добиени преку GPS поддржано морфографско теренско картирање, метод за далечинско препознавање и статистички анализи. Инвентаризацијата на елементите на геодиверзитетот на просторната единица е извршена со алатката за блок-статистика (Block Statistics) и статистичките анализи за максимум (Maximum) и разновидност (Variety) во програмскиот софтвер ArcMap. Индексот на геодиверзитетот е пресметан со множење на два растерски слоја: број на различни елементи на геодиверзитетот во просторни единици и индекс на раздвиженост на теренот на просторни единици. Со цел да се олесни примената на резултатите во туризмот, образованието и зачувувањето на природата, индексот на геодиверзитетот е класифициран во три класи: ниска, средна и висока. Резултатите покажаа дека три главни единици со висок индекс на геодиверзитет се присутни на проучуваното подрачје во Кратово, односно 9,95% од вкупната површина. Во западниот дел, каде што е присутен висок индекс на геодиверзитет се наоѓа и геоморфолошкиот, локалитет Куклица. Индексот на среден геодиверзитет е забележан на 37,33%, а на низок на 51,77% од површината на проучуваното подрачје.