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ORIGINAL ARTICLE

Quantitative Geodiversity Assessment of the Fruška Gora Mt. (North Serbia) by Using the Geodiversity Index

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Abstract
The Fruška Gora Mt., as a dominant orographic complex in the Pannonian plain, was selected for a pioneer geodiversity quantification study area due to its unique geology and soil properties. The methodology is based on the geodiversity quantification assessment approach of Serrano and Ruiz-Flaño (Geogr Helv 62:140–147, 2007). It employed a 500 × 500 m grid approach on several maps (lithological, geomorphological, topographical, and pedological) at scales of 1:50.000 to 1:300.000, together with a 30-m resolution digital elevation model for deriving sub-indices and a topographic roughness. The geodiversity index values (*Gd*) indicate that the highest geodiversity sites are found on the north, north-east and south-western part of the investigated mountain: in steep-sided valleys, along the horst and loess cliffs facing the Danube River. The obtained results are compared with the already recognized in situ geosite location network. This approach can be applied in the given area for geoheritage protection, conservation, and promotion at different levels (from local to national level). Following the results of this study, the criteria for the definition of conservation areas with abiotic significance should be considered, as there is no legal protection of any kind for the areas with the highest geodiversity index values outside the National Park area. Also, it is a potentially effective tool for supporting decision-making processes regarding the management and conservation of natural areas or regions at different scales with further possible applications in Serbia and elsewhere in Europe.

Keywords Geodiversity index · Mapping · Grid approach · Fruška Gora Mt.

Introduction

The geoconservation of an area's geological and geomorphological sites, which constitute its geodiversity, necessitates the development of appropriate inventories and the ranking of sites within them. The terms "geodiversity" and "geoconservation," insofar as they are pertinent to this study, have been defined and redefined especially from the mid-2000s (Gray 2004; Kozłowski 2004; Hose 2005; Serrano and Ruiz-Flaño 2007; Gray et al. 2013). Essentially the former is "…the natural variety of the Earth's surface, referring to geological and geomorphological aspects, soils and surface waters, as well as to other systems created as a result of both natural (endogenic and exogenic) processes and human activity" (Kozłowski et al. 2004, p.834), while the latter is the "… dynamic preservation and maintenance of geological and geomorphological sites, coupled with their associated collections of specimens and archive materials" (Hose 2005, p.29). However, geoconservation is much more than the mere endeavour of preserving geodiversity (Sharples 2002). It is also about enhancing and promoting geological and geomorphological features and sites, processes, and specimens (Burek and Prosser 2008) early national guidelines on such

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was published in the UK by English Nature (2006), a statutory conservation agency, to aid these outcomes. As a scientific and practical tool and approach, geoconservation has been useful in nature conservation, oriented explicitly towards territorial decision-making, planning, and educational outreach (Alexandrowicz and Kozłowski 1999; Stanley 2001; Gordon 2004; Kozłowski 2004; Serrano and Ruiz-Flaño 2007; Hjort and Luoto 2010; Pellitero et al. 2010; Gordon et al. 2012; Silva et al. 2013; Hjort et al. 2015; de Paula Silva et al. 2015; Araujo and Pereira 2018; Fernández et al. 2020). In order to provide this, Brilha et al. (2018) notes that geoconservation strategies are based on a sequence of steps (inventory, quantitative assessment, conservation, interpretation, promotion, and monitoring of sites) designed to achieve effective and operational management of geodiversity assets and geotourism. Regarding this, the respective author highlights that one of the main challenges facing geoconservation is the actual selection of those elements that should be conserved for the benefit of both present and future generations.

The majority of geoconservation studies have been dedicated to the processes of generating an inventory and assessing the associated geodiversity or geoheritage at various scales (Reynard and Brilha 2018); relevantly, "geoheritage" has been defined by ProGEO, in its contemporary promotional leaflet, as "… part of the natural heritage of a certain area constituted by geodiversity elements with particular geological value and hence worthy of safeguard for the benefit of present and future generations" (ProGEO 2017, p.2). Several authors agree that an inventory is the first and one of the most important steps of geoconservation and, consequently, that the identification and characterization of geosites are crucial for the success of geoconservation strategies (Brilha 2005 2016; Henriques et al. 2011; Brilha et al. 2018). Alternatively, quantitative assessment can be used as a tool both to contribute to geosite management and to reduce the degree of subjectivity associated with the selection of natural objects and features (Brilha 2016; Stepišnik and Trenchovska 2018; Brilha et al. 2018) Nevertheless, geodiversity assessment still is relatively subjective and depends on the knowledge and experience of the observer, and at the same time, it is selected and adapted to the object or phenomenon being analysed (Zwoliński et al. 2018). Identification, registration, and evaluation of geodiversity and then selection and conservation of valuable geoheritage sites and objects are a rather complex task (Maran Stevanović 2018) where most of these assessments have a descriptive approach and methodology. That is where objective analysis and quantitative methods find their purpose to minimize subjectiveness.

This study implemented a quantitative geodiversity assessment, which is considered to be an essential objective tool (Ruban 2017) because it requires good knowledge, by its facilitators, in the field of geosciences, multidisciplinary approach, scientific analysis, and application of various principles, methodologies, and techniques to derive such a quantitative geodiversity study on a local scale. Therefore, the scope of this study is the application of a geodiversity quantification method by using the geodiversity index, implemented in the National Park area of Fruška Gora Mt. (North Serbia) for the first time. Moreover, through derived indices and maps, the authors produced a set of tools for geoconservation and to assist in the protection and management of the study area (experiencing a number of challenges regarded to nature and geoconservation problems). For this purpose, the geodiversity index (*Gd*) was calculated following the methodology of Serrano and Ruiz-Flaño (2007), as it has proven to be the most suitable quantitative method in analogous research (e.g. Zwoliński et al. 2018).

Study Area

Fruška Gora Mt. is a low and isolated island mountain located in North Serbia, in the vicinity of Novi Sad, the capital of the autonomous province of Vojvodina (Fig. 1). It is situated on the right bank of the Danube River, as an east–west extending horst that separates the South Bačka depression and the Srem-Slavonian graben, approximately 80 km in length and 15 km width (Mesaroš et al. 2004; Lesić et al. 2007; Marović et al. 2007). The eastern and northern borders of the mountain are alluvial plains of the Sava and Danube Rivers, while the southern and western borders are constrained by loess plateaus in Srem (Fig. 1). Longitudinally, the Fruška Gora horst extends from east of the Danube to the Belgrade-Orlovat High (Marović et al. 2007). The horst and the loess plateaus present two morphostructures (Davidov et al. 2007). The highest peak is Crveni Čot (539 m.a.s.l), and it can be grouped within the Dinaric Alpine system (Mesaroš et al. 2004).

The geological history of the Fruška Gora Mt.'s geodiversity starts with the oldest metamorphic rocks of the Palaeozoic age, which are in tectonic contact with the Lower and Middle Triassic sediments (Lesić et al. 2007). The mountain formation began in the upper Cretaceous (100.5–66 Ma) when a horst started to emerge from the surrounding terrain, which was subjected to tectonic sinking. At the end of Sarmatian (11.63 ± 0.04 Ma), the uplift of the mountain belts around the Pannonian basin separated it from the rest of the Central Paratethys, a large epicontinental sea (Borgh et al. 2013). This caused the formation of Lake Pannon, an isolated lake, the bottom of which was filled with sediments transported by rivers, especially the palaeo-Danube (Radivojević et al. 2014; Horváth et al. 2015). The uplift of the Fruška Gora Mt. in the Pliocene–Quaternary (*ca.* 14–11 Ma) has reversed and shortened those structures formed in the Miocene (Matenco and Radivojević 2012). During the Pliocene (5.3–3.6 Ma), a regional fault formed and separated the uplifted structures of the Fruška Gora horst from the

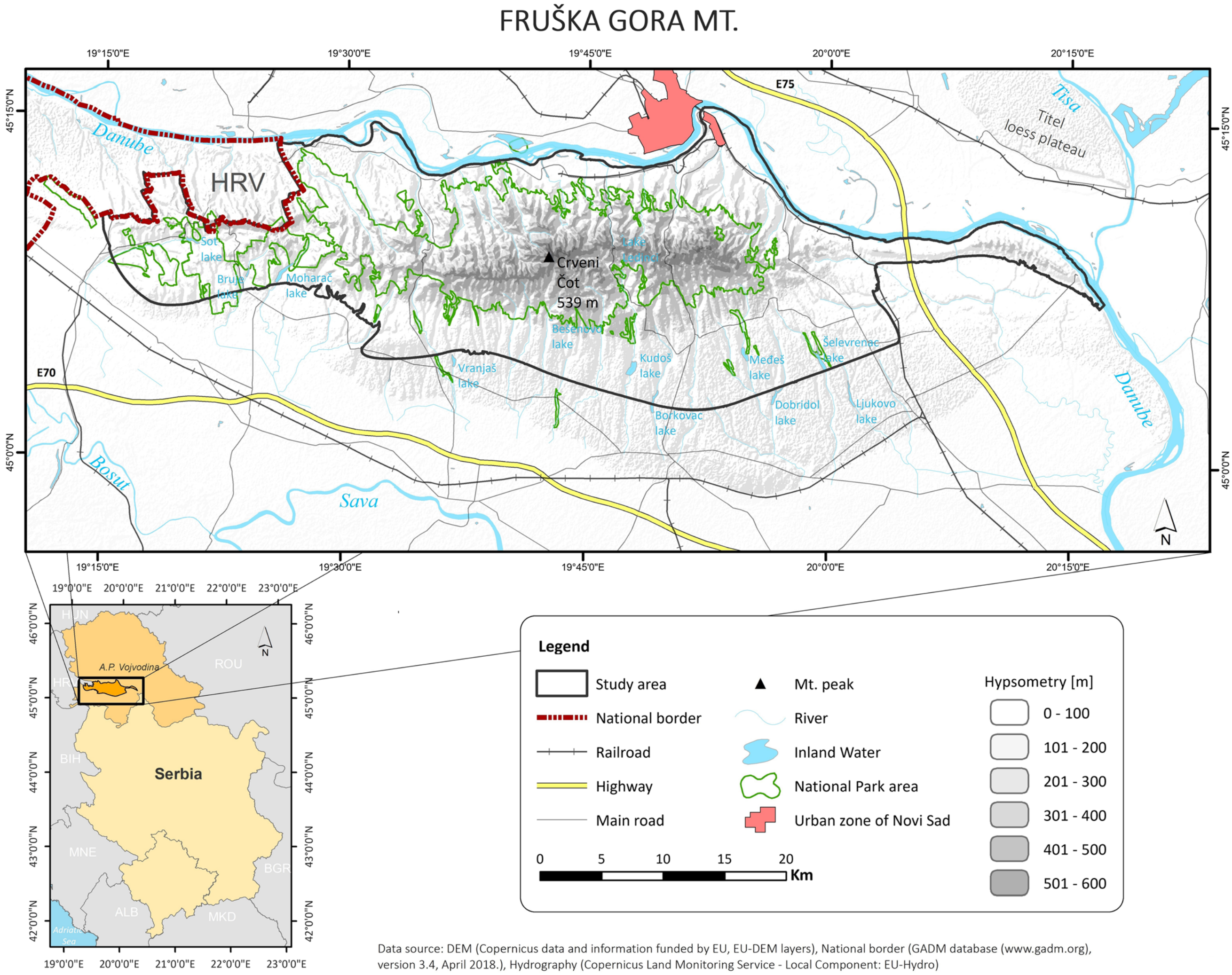

Fig. 1 The location of the study area

southern Bačka depression (Ganić et al. 2010). In the late Pleistocene (0.126 Ma) and the beginning of Holocene (0.011 Ma), an epeirogenic arch was formed, and at the same time, loess and alluvial sediments were deposited (Mesaroš et al. 2004).

The mountain is abundant in natural watercourses, with 28 streams draining the northern side (Danube basin) and 14 streams flowing down the mountain on the southern side (Sava basin). Also, there are a large number of constant, periodical, and occasional springs. Several artificial lakes on the southern side of the mountain serve for irrigation (water retention), flood prevention, and reduction of the torrents' impact and erosion processes (Pavić and Stojanović 2004). Based on the wetting characteristics, all soils on Fruška Gora Mt. can be divided into automorphic and hydromorphic soils. As the largest systematic soil unit in the Vojvodina, automorphic soils are dominant in this area too. The main characteristic of this soil is normal wetting under the influence of atmospheric precipitation, with their formation depending primarily on climate characteristics.

The National Park Fruška Gora is the oldest Serbian national park, established in 1960 (Petrović et al. 2013) with 25,393 ha of protected area (Vujičić et al. 2011; Vujko and Plavša 2014). This mountain represents one of the most diverse geological, pedological, and geomorphological areas in the Pannonian plain. It has been in the process of applying for admission to the UNESCO Geoparks Network since 2008 (Vasiljević 2015).

Previous work related to the investigation of Fruška Gora's geodiversity (Marković et al. 2001; Official Gazette of A.P. Vojvodina 2004; Vujičić et al. 2011; Petrović et al. 2013; Vasiljević 2015) has focused on a descriptive approach with lists of in situ geosites, as the smallest scale of geoheritage management. Some of the proposed geosites are officially under national concern since they are within the National Park territory (regime levels I and II). The only study of geodiversity quantification on the territory of Serbia was performed by Ilić et al. (2016); this was for an urban environment case study of the city of Belgrade. Therefore, this paper presents the first application of the geodiversity quantification method by using the geodiversity index, evaluated for the Fruška Gora Mt. (North Serbia), including the area of National Park Fruška Gora. It is intended that the derived indices and maps could serve as a potential tool for geoheritage-based landscape conservation and management on Fruška Gora Mt.

Materials and Methods

In this study, the geodiversity index is calculated following Serrano and Ruiz-Flaño's (2007) methodology with minor adaptations, due to the size of the study area. This method has been shown as one of the most suitable and frequently used quantitative methods in similar studies (e.g. Zwoliński et al. 2018), as it presents a potentially effective tool for supporting decision-making processes, with regard to the management and conservation of natural areas or regions at different scales. The methodology was initially proposed as (Eq. 1):

$$Gd = EgIR/lnS \quad (1)$$

where *Gd* stands as the geodiversity index, *Eg* as the number of different physical elements in the given unit, *IR* as the topographic roughness of the unit, *S* as the surface of the unit (km^2), and *ln* is the Napierian logarithm (Fig. 2).

As pointed out by Serrano and Ruiz-Flaño (2007), geodiversity increases with the number of elements and the representativeness of the geological environments in the study area. With an estimation of the various elements, quantitative assessment of geodiversity can be performed by applying mathematical criteria through an estimation model. This model is comprised of physical elements (geological, geomorphological, hydrological, pedological) and the topographical roughness of the given area. The coefficient of roughness includes a variety of orientations and slopes affecting physical processes. Elements of geodiversity encompass two main segments: elements (5 major and 11 sub-indices) and the number of unique elements (123 respectively) in the analysed area (Table 1).

The database was created following the digitization of geological (1:100.000), geomorphological (1:300.000), topographic (1:100.000), and pedological (1:50.000) maps (Fig. 3). The pedological (soil) dataset was harmonized with the World Reference Base for Soil Resources (WRB) classification system. Resolution for *Gd* was set to a 500 × 500 m grid, according to the study area size and the input data scale (Hjort and Luoto 2010). The compiled data were quantified and homogenized. Homogenization was performed on geological, geomorphological, and pedological datasets, to eliminate duplication of the same value polygons within each cell while counting them. Hydrology *Ed* was excluded from homogenization, in order to sum all surface water resources elements (Ilić et al. 2016; Araujo and Pereira 2018). Following the results of Pellitero et al. (2010), fossils and minerals were not included in *Ed* dataset due to the scale of the study area, which would give too much weight to these elements in the final result. Subtype indices for every *Eg* were calculated by unique polygon summarization. Red squares from Fig. 2 visualize how homogenization effects lithology subtype indices by reducing the value from 5 to 3. For topographical roughness (*IR*), we used EU-DEM as a hybrid product based on SRTM and ASTER GDEM data, fused by a weighted averaging approach with 30 m resolution/1 arc-second (Copernicus Land Pan-European 2016). *IR* is derived by calculation of the 3D vector analysis of slope and aspect (Hjort and Luoto 2010). This resolution was subsequently resampled from 30 to 500 m. The whole process, from map digitization, sub-indices, *IR*, and *Gd* index calculation to final visualization, was performed using the ArcGIS® software program.

It is also important to mention that all the digitized maps (layers) were produced in the GIS environment based on the published work of the respective national organizations and, hence, were validated to eliminate errors (such as topology and attributes). This approach was performed to guarantee the scientific integrity of the data and to avoid faults in the subsequent steps.

Results and Discussion

In total, 10 geodiversity elements, including 123 unique element values, were calculated through 2048 grids and presented as 8 geodiversity sub-indices, as well as the final *Gd*. Lithology and stratigraphy are the representative sub-indices of the geological diversity of the Fruška Gora Mt. with the values ranging from 1 to 8 and 1 to 6, respectively (Fig. 4a, b). The highest lithological (6–8) and stratigraphical diversity (6) is observed in the central part of the study area, where formations from the Palaeozoic to Cretaceous age can be identified (Fig. 3a). The core of Fruška Gora Mt. is comprised of Palaeozoic formations more than 300 Ma old, represented by different schists: sericite schists, phyllites, micaceous rocks, quartzite, shale, and marble, and other similar rocks (Pavić and Stojanović 2004; Petrović et al. 2013). Mesozoic sediments are represented by the Triassic red and grey sandstones, mica-schists, conglomerates, breccias, limestones, and the Upper Jurassic deep-water sediments. The Cretaceous sediments such as conglomerates, sandstones, dolomites, and flysch, deposited after a long break period, cover a central zone of the metamorphosed rocks (Mesaroš et al. 2004; Toljić et al. 2013).

High lithological and stratigraphic diversity (4–6) is also seen on the northern flank of the mountain in the Middle and

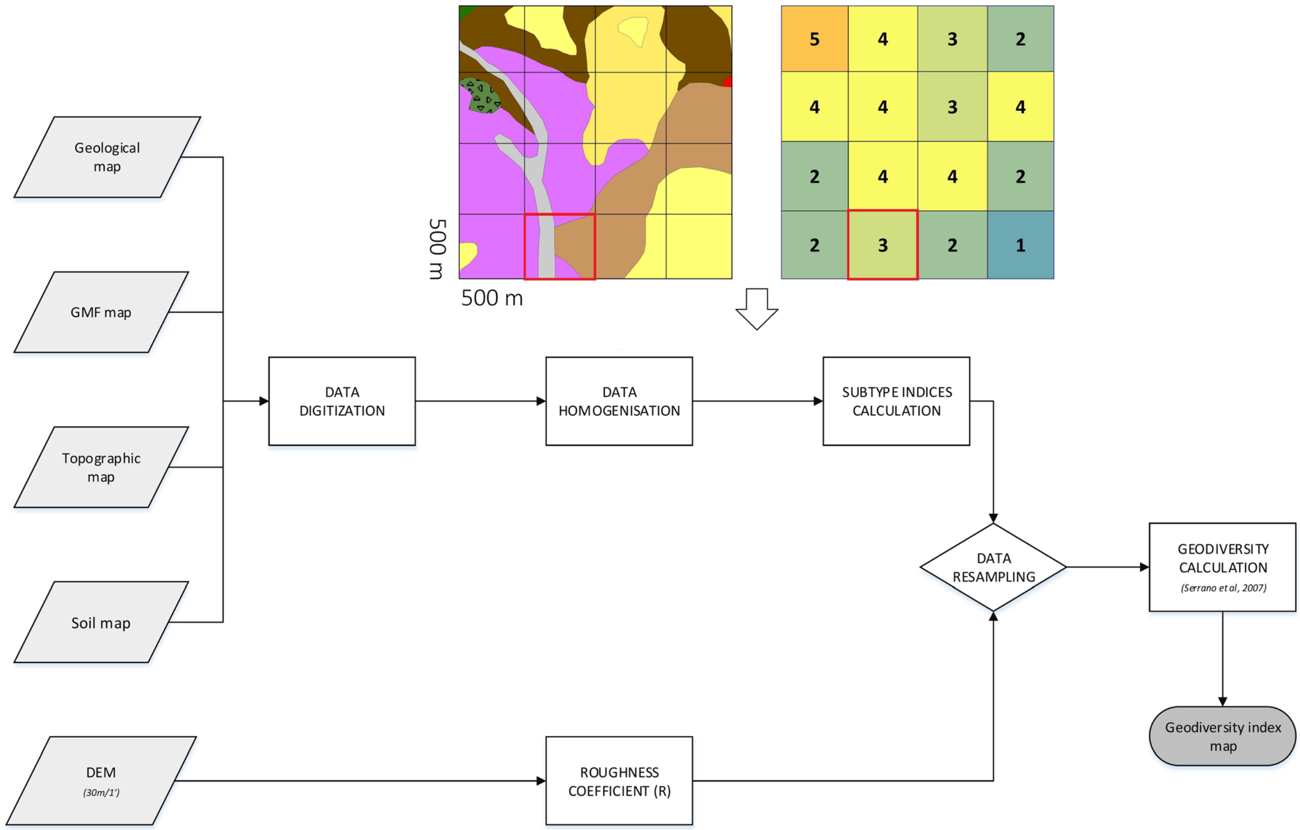

Fig. 2 Methodology workflow

Late Miocene sediments which include limestones, sands, and clays (Marjanović 2009; Ganić et al. 2010). In addition to sedimentary rocks on the northern flank, the Cenozoic is represented by dacites, andesites, and pyroclastic deposits originating from volcanic activity (Lesić et al. 2007). The latest Quaternary sediments can be found in the lower parts

Table 1 Elements of geodiversity (*Ed*)

Elements	No. of unique elements	Resolution	Data source
Topography roughness	-	30-m	DEM (Copernicus Land Pan-European 2016)
Geology		1:100.000	Basic geology map of Serbia (Čičulić-Trifunović and Rakić 1976; Čičulić-Trifunović and Galović 1984; Čičulić-Trifunović 1992)
Lithology	47		
Stratigraphy	6		
Geomorphology		1:300.000	Geomorphology map of Vojvodina (Košćal et al. 2005)
Morphogenetic system	24		
Erosion landforms	9		
Accumulation landforms	11		
Anthropogenic landforms	4		
Hydrology		1:100.000	Topographic map of Serbia (Military Geographical Institute of Serbia 1988)
Springs	1		
Rivers	1		
Lakes	1		
Soil		1:50.000	Soil map of Vojvodina (Nejgebauer et al. 1971)
Order	19		

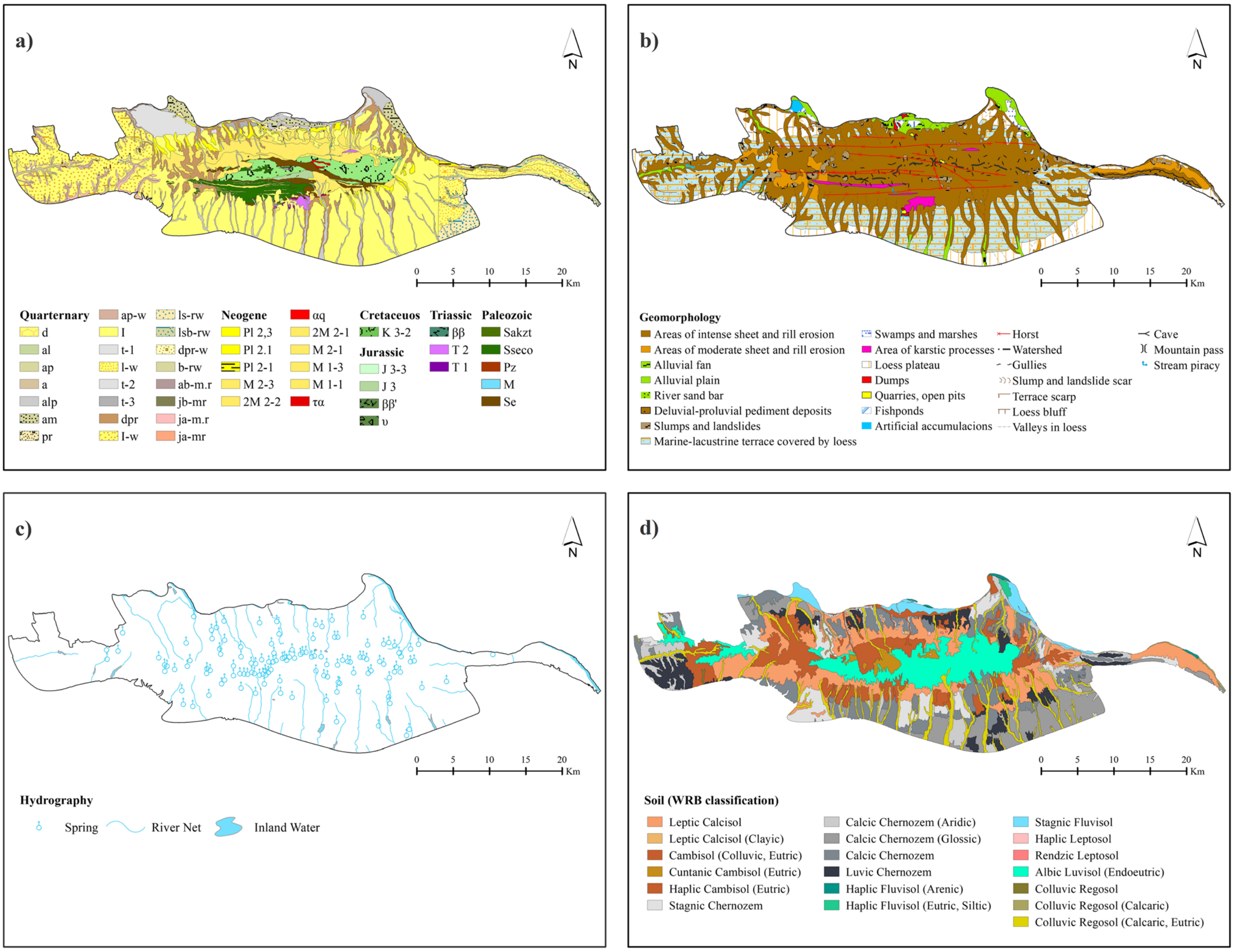

Fig. 3 Spatial distribution of **a** geology*, **b** geomorphology, **c** hydrology, and **d** soil of the Fruška Gora Mt. (*Lithology formation key for geology is given in the Appendix)

of the mountain; the most significant and the most widespread unit from this period is aeolian sediment — loess. The loess forms the cliffs facing the Danube River and covers the lower landscapes. The mountain is surrounded by two loess plateau areas, varying from 130 to 150 m.a.s.l. and 110 to 120 m.a.s.l., respectively (Vujko et al. 2017). The most recent units from the Quaternary period are fluvial deposits of permanent and periodical flows (Marjanović 2009; Petrović et al. 2013).

The geomorphological diversity is presented through 4 sub-indices: morphogenetic system, erosion, accumulation, and anthropogenic landforms (Fig. 4c–f). Morphogenic system values range from 1 to 6. The highest morphogenetic system diversity (5–6) is found in the south-west and north-eastern regions; this is where areas of intense and moderate sheet and rill erosion are congregating with loess, presented in the peripheral parts of the mountain, on its slopes and foothills (see Fig. 3b). Erosion landform sub-index distribution stands in inverse proportion with accumulation landforms: the highest values (3) are observed along the horst and loess cliffs facing the Danube River (Fig. 4d). The accumulation landforms are leading with the highest number of unique elements (Table 1), which also reflects the sub-indices' distribution ranging from 0 to 4 (Fig. 4e). Areas with zero values are, alternatively, the only positive values in anthropogenic landforms distribution (Fig. 4f).

The spring zones occur at four levels, with the highest one near the ridge, at an altitude of 420 m.a.s.l. and the lowest one at 280 m.a.s.l. (Mesaroš et al. 2004). This better explains the hydrology sub-indices' distribution which ranges from 0 to 6 (Fig. 4g) with the highest values (4–6) observed on the northern part of the mountain, where higher grid value follows the river network and spring zones.

The identified pedological sub-indices vary between 1 and 5 (Fig. 4h). The main representative of the weakly developed soils is Regosol, present on the stream valleys sides. Different types of chernozem such as calcic chernozem, stagnic

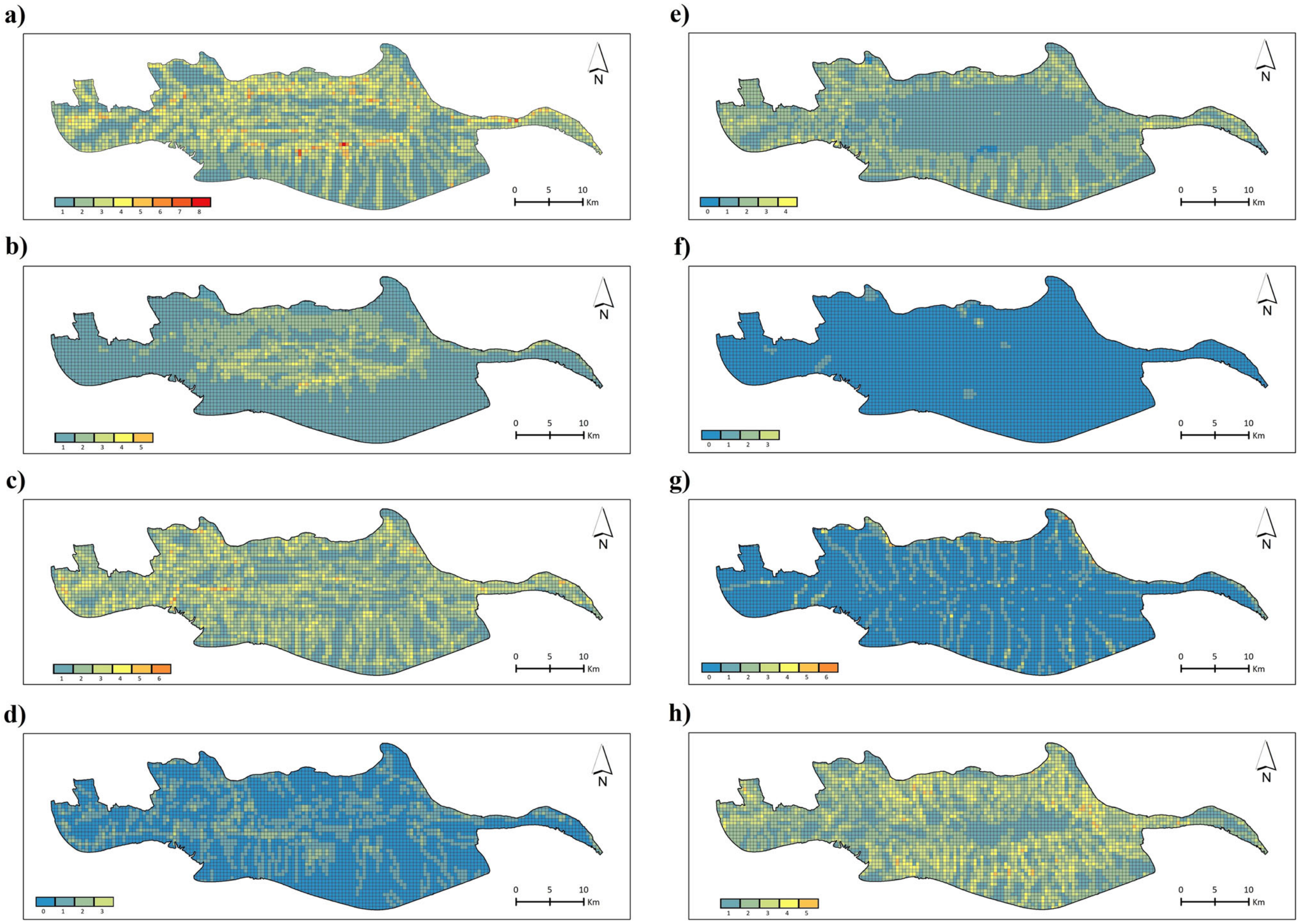

Fig. 4 Sub-indices spatial distribution for *Ed* **a** lithology, **b** chronostratigraphy, **c** morphogenetic system, **d** erosion landforms, **e** accumulation landforms, **f** anthropogenic landforms, **g** hydrologic elements, and **h** soil elements

chernozem, and luvic chernozem are widely distributed on the southern slopes of the Fruška Gora Mt., representing a class of humus-accumulative soils. To this class belongs leptic Calcisol which was identified mostly in the southern parts, but it is also occurring in the northern part of the Fruška Gora Mt. On the north side, soil types such as rendzic Leptosols and haplic Leptosols are distributed.

Also, different sub-types and varieties of the Cambisol (cutanic Cambisol and haplic Cambisol) have an essential distribution in the central and northern part of the Fruška Gora Mt. Albic Luvisol has been identified in the springhead area. Stagnic fluvisol and haplic fluvisol are most represented in the Danube valley (Nejgebauer et al. 1971; Miljković 1975; Davidov et al. 2007). The highest sub-indices' (4–5) values are seen on the north-eastern slopes of the mountain, and on the south, where humus-accumulative soils dominate.

Gd results can vary between 0 and ∞ (Pellitero et al. 2010), and in this study, they are presented within five classes: very low (0–2), low (2–3), moderate (3–4), high (4–5), and very high (5⩾). The result of the quantification of the 11 different geodiversity elements is given in Fig. 5. The highest values are obtained along the Danube's right bank and south from the watershed (see Fig. 3b), but the majority of the Fruška Gora Mt. has very low (72%) to low (24%) *Gd* values (Table 2). The National Park area shares these statistics with 70% of

Table 2 *Gd* distribution in National Park Fruška Gora and study area

Gd		National park area [%]	Study area [%]
Class	Value		
Very low	0–2	69.10	71.82
Low	2–3	27.20	23.82
Moderate	3–4	3.51	3.88
High	4–5	0.24	0.44
Very high	5⩾	0.00	0.03

the territory with very low and 27% of low *Gd*. The potential explanation for these results can be found not just in the low roughness coefficient of the Pannonian Plain, but also in lithological and pedological homogeneity with dominant alluviation (Ćalić et al. 2012). This stands as a fair explanation of why high and very high classes are located in parts of Fruška Gora were the high sub-indices values of lithology, morphogenetic system, and soil are overlapping (e.g. hotspot near geosite no. 9). Also, there are similar results obtained in the case of the Belgrade area, for the Pannonian part of the study area (Ilić et al. 2016), confirming that high *IR* is directly proportional to high *Gd* and vice versa (Serrano and Ruiz-Flaño 2009). Nevertheless, areas with lower geodiversity are not less important and should be also protected, but from the geotourism point of view, they are not so relevant.

According to Wimbledon (1996), a geosite can be a location, area, or territory in which it is possible to identify a geological or geomorphological interest for conservation. By analysing the produced *Gd* map (Fig. 5), it can be observed that the majority of in situ geosites recognized by the Institute for Nature Conservation of Serbia (Official Gazette of A.P. Vojvodina 2004) share low or medium geodiversity index locations (e.g. Stone block Orlovac). Geoheritage is not necessarily related to geodiversity, and individual geosites can have high geoheritage value but minimal diversity (Bétard and Peulvast 2019). Alternatively, it can be observed that many areas with high geodiversity do not have designated geosites, especially the eastern part of the mountain along the Danube bank and the western part of the mountain as well. This confirms that "geodiversity is a quantitative value and geoheritage is qualitative, sometimes assessed numerically, but always open to interpretation" (Pellitero et al. 2010, p. 173).

One of the aims of this study was to serve as a potential tool for the geoheritage-based landscape conservation and management of the Fruška Gora Mt. and National Park; however, it should be emphasized that having a good and detailed *Gd* map can reach its full potential only with the intensive cooperation between scholars and all stakeholders involved in the process of decision-making in nature conservation. The Provincial Secretariat for Energy and Mineral Resources in 2008 launched the initiative to join the Global and European Geopark Networks, from 2015 known as UNESCO Global Geoparks, but it was neither fully pursued nor achieved.

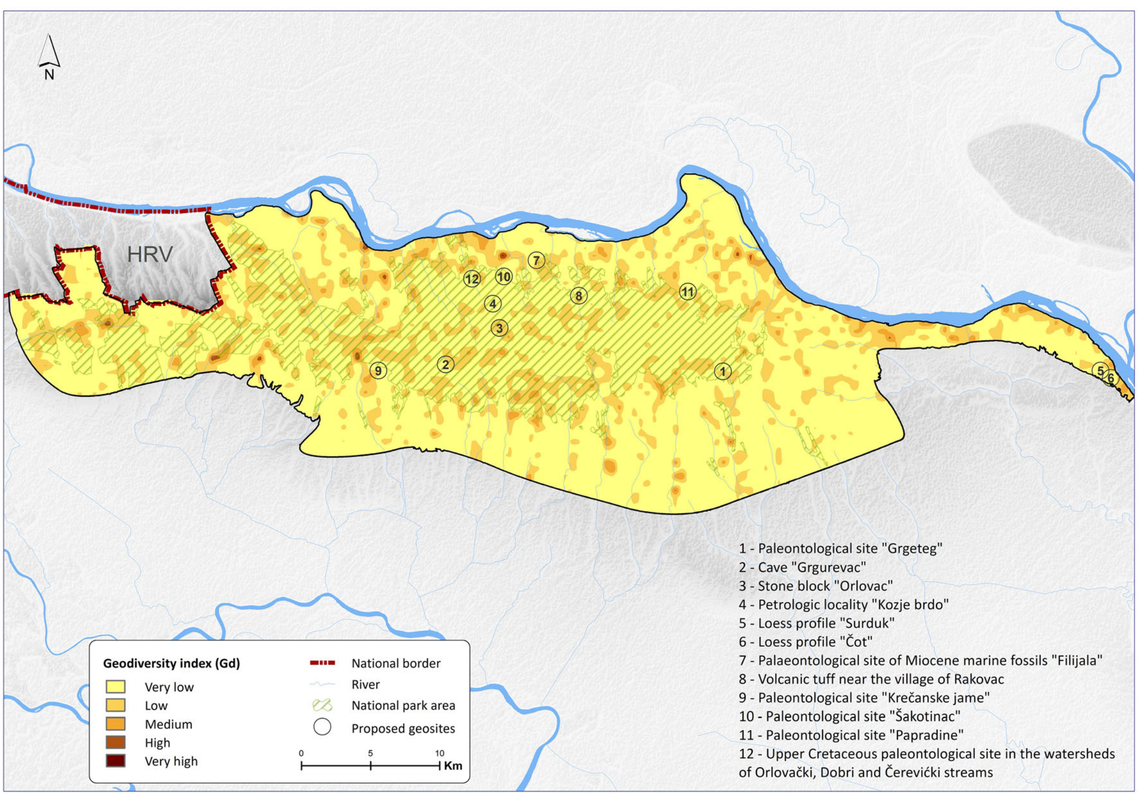

Fig. 5 *Gd* map of the Fruška Gora Mt. with marked geosites from the "Spatial plan of the special purpose area of the Fruška Gora until 2022" (Official Gazette of A.P. Vojvodina 2004)

Fig. 6 Loess profile “Surduk” located in the gully between Stari and Novi Slankamen village, Monument of Nature since 1975 (Photographs, T. Micić Ponjiger)

According to Vasiljević et al. (2016), the main reason for this lies in poor communication between crucial stakeholders and decision-makers, that is, the Vojvodina Šume (provincial public forest management company), the Institute for Nature Conservation, and the Fruška Gora National Park. As an example of managing one geosite, we will take the loess profile “Surduk” in the gully between the villages of Novi Slankamen and Stari Slankamen in the south-eastern outskirts of the Fruška Gora Mt. (Fig. 5, geosite 3; Fig. 6). Although it possesses very low/low *Gd* values, it has been protected as the Monument of Nature in 1975, as the first and the only protected geoheritage site of this kind in the former SFR Yugoslavia (as it contains valuable palaeoclimatic and palaeoenvironmental records of the Late Pleistocene). Since 2007, it has been classified within the first category for protection of the Republic of Serbia Natural Resources. Besides its geological importance, this geosite is also of archaeological significance due to the remains of a road from the Roman period (Vasiljević et al. 2011). Until today, little has been done to promote this location (as a European scale significance geosite), with only one interpretive panel (the text is in Serbian and English languages) before entering the gully. Inadequate infrastructure (roads, facilities) does not leave a good impression, bearing in mind that we are speaking about one of the most notable geosites of the Fruška Gora area (Vasiljević et al. 2011; Višnić et al. 2016). It is necessary to improve the management structure of the Fruška Gora Mt. and its administration plan, to attain a higher level of protection, promotion, and sustainable development.

Concluding Remarks

The constant growing importance of geodiversity preservation in territorial management requires maps that express and emphasize this concept. Providing a geodiversity map that could be used for strategic planning and management is of the utmost importance when it comes to the implementation of geoconservation activities. This study represents the first step in the evaluation and quantification of abiotic resources in the area of North Serbia, thus leading to the new proposals and open discussions to establish appropriate and effective methods for natural resources management. The majority of areas characterized by high geodiversity values sparsely occur in topographically heterogeneous landscapes along the northern slopes of the Fruška Gora Mt. and just outside the National park border. As there is no legal protection of any kind for the areas with the highest geodiversity index values, the criteria for the definition of conservation areas with abiotic significance should be considered in the future, following the results of this study. In this way, systematic evaluation of all elements of nature (biotic and abiotic), along with their connection with the social ones, would be taken into account before they are irreversibly affected. In this way, the natural values of the study area would be supported by contemporary geodiversity spatial information and then offered to decision-makers for implementation of sustainable land use and conservation management.

It is also important to underline that although the geodiversity index map can serve as a basis for creating planning and management strategies, it cannot be used for the protection of individual phenomena. In order to implement adequate geoconservation activities, it is necessary to conduct a detailed analysis of large-scale data associated with geosites in the given area. Since geosites have the potential to be acknowledged as both natural heritage and geotourism resources (with potential economic benefits), the management structure of the Fruška Gora Mt. should improve its administration plan and attain a higher level of conservation of geodiversity and sustainable development which could be applied to other localities on both regional and national levels.

Appendix

ERA	PERIOD	FORMATION	LITHOLOGY
Cenozoic	Quaternary	d	Diluvium: loess silty clay and sand (Holocene); overloaded loess; brown alevrit
		al	Sand, alevrit sand
		ap	Sandy-clay alevrit, alevrit sand, and alevrit clay
		a	Riverbed sediments: sand, overloaded loess, and organogenic-pond clay
		alp	Alluvium: sand, silt clay, and pebbles - faction of riverbed and floodplains (Holocene)
		am	Alluvium: organogenic-pond clay and sand (Holocene); clay alevrit, alevrit, and alevrit clay
		pr	Proluvial: pebbles, sand and clay - fluvial fans (Holocene)
		ap-w	Alevrit clay, sandy clay, clay alevrit and alevrit sand (Würm)
		I	Land loess (Pleistocene)
		t-1	First fluvial terrace (Pleistocene)
		I-w	Sand-clay alevrit, sandy alevrit, alevrit sand (Eolic sediments)
		t-2	Second fluvial terrace (Pleistocene)
		t-3	Third fluvial terrace (Pleistocene)
		dpr	Diluvial-proluvial sediments: pebbles, sand and red silty clay (Pleistocene)
		l-w	Sand-clay alevrit (Eolic sediments)
		ls-rw	Alevrit sand, sandy alevrit, sand, colluvial pebble (eolic-colluvial
		lsb-rw	Sand-clay alevrit, alevrit sand (loess and pond sediments)
		dpr-w	Diluvial-proluvial sediments: pebbles, sand, carbonate clay and red clay
		b-rw	Sand-clay alevrit, sandy alevrit, alevrit sand (pond faction)
		ab-m.r	Fluvial-lacustrine (pond) sediments: alevrit clay, alevrit sand and clay (Mindel-Riss)
		jb-mr	Sandy-clay alevrit, sandy alevrit, alevrit sand (lacustrine (pond) sediments)
		ja-m.r	Fluvial-lacustrine sediments: pebble, sand, alevrit sand and clay (Mindel-Riss)
		ja-mr	Fluvial-lacustrine sediments: pebbles, sand, red clay, brown carbonate clay,
	Neogene	Pl 2, 3	Fluvial-lacustrine sediments: clay, sand, and coal (Pliocene)
		Pl 2-1	Upper pontian sandstone, sand, marl
		Pl 1-1	Clay, sandy clay, sandy iron sandstone, coal clay
		M 2-3	White marl, clay, sandstone, and coal (Miocene)
		2M 2-2	Tortonian sandstone, marl, limestone, claystone
		αq	Dacite and andesite
		1M 2-2	Tortonian conglomerate, sandstone, claystone, limestone, tuff
		M 2-1	Conglomerate, sandstone, clay, and coal
		M 1-3	Conglomerate, sandstone, sand, and limestone
		M 1-1	Miocene conglomerate, sandstone, claystone, and coal
		τα	Latite
Mesozoic	Cretaceous	K 3-2	Cretaceous flysch, marl, breccia, sandstone
	Jurassic	J 3-3	Marly limestone, biogenic limestone, sandstone, claystone
		J 3	Slate, phyllite, quartzite and sandstone
		ββ'	Melaphyre
		ν	Gabbro
	Triassic	ββ	Diabase
		T 2	Claystone, limestone, dolomite and limestone breccia
		T 1	Sandstone, conglomerate, claystone and clay marl
Paleozoic	*	Sakzt	Actinolite - zoisite and glaucophane schist (blueschist)
		Sseco	Sericite and albit-chlorite schist, sercite quartzites, phyllite
		Pz	Quartz - sericite schist
		M	Metamorphosed limestone - marble
		Se	Serpentine

*These formations have only Era determined in the data source maps.

References

Alexandrowicz Z, Kozłowski K (1999) From selected geosites to geodiversity conservation: Polish example of a modern framework. In: Barettino D, Vallejo M, Gallego E (eds) Towards the balanced management and conservation of the geological heritage in the new millennium. Sociedad Geolögica de Espana, Madrid, pp 52–54

Araujo AM, Pereira DÍ (2018) A new methodological contribution for the geodiversity assessment: applicability to Ceará State (Brazil). Geoheritage 10:591–605. https://doi.org/10.1007/s12371-017-0250-3

Bétard F, Peulvast JP (2019) Geodiversity hotspots: concept, method and cartographic application for geoconservation purposes at a regional scale. Environ Manage 63:822–834. https://doi.org/10.1007/s00267-019-01168-5

Brilha J (2005) Património geológico e geoconservação. Palimage, Viseu

Brilha J (2016) Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage 8:119–134. https://doi.org/10.1007/s12371-014-0139-3

Brilha J, Gray M, Pereira DI, Pereira P (2018) Geodiversity: an integrative review as a contribution to the sustainable management of the whole of nature. Environ Sci Policy 86:19–28

Burek CV, Prosser CD (2008) The history of geoconservation: an introduction. Geol Soc Spec Publ 300:1–5. https://doi.org/10.1144/SP300.1

Ćalić J, Gaudenyi T, Milošević MV, Štrbac D, Milivojević M (2012) Geomorphometrical method for delineation of plains - case study of the south-eastern (Serbian) segment of the Pannonian plain. Carpathian J Earth Environ Sci 7:239–248

Čičulić-Trifunović M (1992) Sheet Inđija. In: Basic geology map of Serbia (in Serbian). Savezni geološki zavod, Belgrade

Čičulić-Trifunović M, Galović I (1984) Sheet Bačka Palanka. In: Basic geology map of Serbia (in Serbian). Savezni geološki zavod, Belgrade

Čičulić-Trifunović M, Rakić MO (1976) Sheet Novi Sad. In: Basic geology map of Serbia (in Serbian). Savezni geološki zavod, Belgrade

Copernicus Land Pan-European for E-D (2016) EU-DEM

Davidov D, Jovanović B, Milin M, Ćurčić S, Kleut M, Stefanović D M, Kovačević M D, Cindrić P, Kovač V, Romelić J, Marković S, Mikavica D, Gavrilović V, Raičević G, Butorac B, Habijan-Mikeš V, Đekić M, Božanić S, Poznanović D, Stojaković G, Josić L, Matić G, Gatalo A, Jeremić J (2007) Fruška gora. Zavod za udžbenike, Beograd

de Paula SJ, Rodrigues C, Pereira DI (2015) Mapping and analysis of geodiversity indices in the Xingu River Basin, Amazonia, Brazil. Geoheritage 7:337–350. https://doi.org/10.1007/s12371-014-0134-8

Fernández A, Fernández T, Pereira DI, Nieto LM (2020) Assessment of geodiversity in the southern part of the Central Iberian Zone (Jaén Province): usefulness for delimiting and managing natural protected areas. Geoheritage 12:20. https://doi.org/10.1007/s12371-020-00447-6

Ganić M, Rundić L, Knežević S, Cvetkov V (2010) The Upper Miocene Lake Pannon marl from the Filijala Open Pit (Beočin, northern Serbia): new geological and paleomagnetic data. Geol Anal Balk poluostrva 95–108https://doi.org/10.2298/GABP1071095G

Gordon J (2004) Geological conservation. In: Selley, R.G, Coks LRM& LP (ed) Encyclopedia of Geology. Amsterdam, Elsevier, pp 29–35

Gordon JE, Barron HF, Hansom JD, Thomas MF (2012) Engaging with geodiversity-why it matters. Proc Geol Assoc 123:1–6. https://doi.org/10.1016/j.pgeola.2011.08.002

Gray M (2004) Geodiversity: valuing and conserving abiotic nature. Wiley, Chichester

Gray M, Gordon JE, Brown EJ (2013) Geodiversity and the ecosystem approach: the contribution of geoscience in delivering integrated environmental management. Proc Geol Assoc 124:659–673. https://doi.org/10.1016/j.pgeola.2013.01.003

Henriques MH, dos Reis RP, Brilha J, Mota T (2011) Geoconservation as an emerging geoscience. Geoheritage 3:117–128. https://doi.org/10.1007/s12371-011-0039-8

Hjort J, Gordon JE, Gray M, Hunter ML (2015) Why geodiversity matters in valuing nature's stage. Conserv Biol 29:630–639. https://doi.org/10.1111/cobi.12510

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

Horváth F, Musitz B, Balázs A, Végh A, Uhrin A, Nádor A, Koroknai B, Pap N, Tóth T, Wórum G (2015) Evolution of the Pannonian basin and its geothermal resources. Geothermics 53:328–352. https://doi.org/10.1016/j.geothermics.2014.07.009

Hose TA (2005) Geo-tourism - appreciating the deep time of landscapes. In: Novelli M (ed) Niche tourism: contemporary issues, trends and cases. Elsevier Butterworth-Heinemann, Oxford, pp 27–37

Ilić M, Stojković S, Rundić L, Ćalić J, Sandić D (2016) Application of the geodiversity index for the assessment of geodiversity in urban areas: an example of the Belgrade city area, Serbia. Geol Croat 69:325–336. https://doi.org/10.4154/gc.2016.27

Košćal M, Milenković Lj, Mijatović M, Knežević M (2005) Geomorphology map of Vojvodina, 1:300.000. Geozavod-Gemini, Belgrade

Kozłowski S (2004) Geodiversity: the concept and scope of geodiversity. Prz Geol 58:833–837

Kozłowski S, Migaszewski ZM, Gałuszka A (2004) Znaczenie georóżnorodności w holistycznej wizji przyrody. Przegląd Geol 52:291–294

Lesić V, Márton E, Cvetkov V (2007) Paleomagnetic detection of Tertiary rotations in the Southern Pannonian Basin (Fruška Gora). Geol Carpathica 58:185–193

Maran Stevanović A (2018) Geodiversity and geoheritage from theory to practice. Natural History Museum in Belgrade, Belgrade

Marjanović M (2009) Landslide susceptibility modeling: a case study on Fruška gora Mountain, Serbia. Geomorphol Slovaca Bohem 9:29–42

Marković SB, Mijović D, Jovanović M, Kovačev N (2001) Geo-heritage sites of Fruška Gora Mountain. Prot Nat 53:131–138

Marović M, Toljić M, Rundić L, Milivojević J (2007) Neoalpine tectonics of Serbia. Serbian Geological Society, Belgrade

Matenco L, Radivojević D (2012) On the formation and evolution of the Pannonian Basin: constraints derived from the structure of the junction area between the Carpathians and Dinarides. Tectonics 31:n/a-n/a . https://doi.org/10.1029/2012TC003206

Mesaroš M, Marković SB, Mijović D, Jovanović M (2004) Physical geographic characteristics and geo-heritage of Fruska Gora mountain (Vojvodina, Serbia). Acta Geogr Szeged 38:148–157

Military Geographical Institute of Serbia (1988) Topographic map 1: 300.000 – sheets BačkaTopola, Novi Sad, Zrenjanin (in Serbian). Belgrade

Miljković N (1975) Zemljišta Fruške gore. Matica srpska, Novi Sad

Nejgebauer V, Živković B, Tanasijević Đ, Miljković N (1971) Soil map of Vojvodina, 1:50000. Institute for Agricultural Research, Novi Sad

ODPM, DEFRA, English Nature (2006) Planning for biodiversity and geological conservation – a guide to good practice. 69

Official Gazette of A.P. Vojvodina N 16/0 (2004) Spatial plan of special purpose area of Fruska gora until 2022

Pavić D, Stojanović V (2004) Fruska gora hydro-accumulation "Sot." Geogr Timisiensis 13:15–20

Pellitero R, González-Amuchastegui MJ, Ruiz-Flaño P, Serrano E (2010) Geodiversity and geomorphosite assessment applied to a natural protected area: the Ebro and Rudron Gorges Natural Park (Spain). Geoheritage 3:163–174. https://doi.org/10.1007/s12371-010-0022-9

Petrović MD, Vasiljević DA, Vujičić MD, Hose TA, Marković SB, Lukić T (2013) Global geopark and candidate-comparative analysis of Papuk Mountain (Croatia) and Fruška gora Mountain (Serbia) by using GAM. Carpathian J Earth Environ Sci 8:105–116

ProGEO (2017) Geodiversity, geoheritage & geoconservation: the ProGEO simple guide

Radivojević D, Magyar I, Ter Borgh M, Rundić L (2014) The Lake Pannon - Serbian side of the story. In: Cvetković V (ed) Proceedings of XVI Serbian Geological Congress. Serbian Academy of Sciences, Donji Milanovac, pp 54–60

Reynard E, Brilha J (2018) Geoheritage: a multidisciplinary and applied research topic. In: Reynard E, Brilha JBT-G (eds). Elsevier, pp 3–9

Ruban DA (2017) Geodiversity as a precious national resource: a note on the role of geoparks. Resour Policy 53:103–108. https://doi.org/10.1016/j.resourpol.2017.06.007

Serrano E, Ruiz-Flaño P (2009) Geomorphosites and geodiversity. In: Reynard E, Coratza P, RegoliniBissig G (eds) Geomorphosites. Pfeil, Munchen, pp 49–61

Serrano E, Ruiz-Flaño P (2007) Geodiversity. A theoretical and applied concept. Geogr Helv 62:140–147

Sharples C (2002) Concepts and principles of geoconservation. In: Publ. Electron. Tasmanian Park. Wildl. Serv. https://dpipwe.tas.gov.au/Documents/geoconservation.pdf. Accessed 17 Oct 2020

Silva JP, Pereira DI, Aguiar AM, Rodrigues C (2013) Geodiversity assessment of the Xingu drainage basin. J Maps 9:254–262. https://doi.org/10.1080/17445647.2013.775085

Stanley M (2001) Geodiversity strategy. Progeo News 1:6–9

Stepišnik U, Trenchovska A (2018) A new quantitative model for comprehensive geodiversity evaluation: the Škocjan Caves Regional Park, Slovenia. Geoheritage 10:39–48. https://doi.org/10.1007/s12371-017-0216-5

ter Borgh M, Vasiliev I, Stoica M, Knežević S, Matenco L, Krijgsman W, Rundić L, Cloetingh S (2013) The isolation of the Pannonian basin (Central Paratethys): new constraints from magnetostratigraphy and biostratigraphy. Glob Planet Change 103:99–118. https://doi.org/10.1016/j.gloplacha.2012.10.001

Toljić M, Matenco L, Ducea MN, Stojadinović U, Milivojević J, Đerić N (2013) The evolution of a key segment in the Europe-Adria collision: the Fruška Gora of northern Serbia. Glob Planet Change 103:39–62. https://doi.org/10.1016/j.gloplacha.2012.10.009

Vasiljević DA (2015) Geodiversity and geotourism of Vojvodina from aspects of conservation and tourism. Ph.D thesis. Department of geography, tourism and hotel management, Faculty of Sciences, University of Novi Sad

Vasiljević DA, Marković SB, Hose TA, Smalley I, O'Hara-Dhand K, Basarin B, Lukić T, Vujičić MD (2011) Loess towards (geo) tourism – proposed application on loess in Vojvodina region (north Serbia). Acta Geogr Slov 51:391–406. https://doi.org/10.3986/AGS51305

Vasiljević DA, Marković SB, Tomić N (2016) Geoheritage case study: the Danube Region in Serbia. In: Hose TA (ed) Geoheritage and geotourism: a European perspective. The Boydell Press, Woodbridge, pp 291–303

Višnić T, Spasojević B, Vujičić M (2016) The potential for geotourism development on the Srem Loess Plateau based on a preliminary geosite assessment model (GAM). Geoheritage 8:173–180. https://doi.org/10.1007/s12371-015-0149-9

Vujičić MD, Vasiljević DA, Marković SB, Hose TA, Lukić T, Hadžić O, Janićević S (2011) Preliminary geosite assessment model (gam) and its application on Fruška gora mountain, potential geotourism destination of Serbia. Acta Geogr Slov 51:361–376. https://doi.org/10.3986/AGS51303

Vujko A, Plavša J (2014) Evaluation of Fruška Gora National Park (Serbia) for sport and recreational tourism. Acta Geogr Slov 54:321–334. https://doi.org/10.3986/AGS54206

Vujko A, Plavša J, Petrović MD, Radovanović M, Gajić T (2017) Modelling of carrying capacity in National Park - Fruška Gora (Serbia) case study. Open Geosci 9:61–72. https://doi.org/10.1515/geo-2017-0005

Wimbledon WAP (1996) Geosites - a new conservation initiative. Episodes 19:87–88

Zwoliński Z, Najwer A, Giardino M (2018) Methods for assessing geodiversity. In: Reynard E, Brilha J (eds) Geoheritage: assessment, protection, and management. Elsevier, Amsterdam, pp 27–52