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ORIGINAL ARTICLE

Evaluation of Geo-sites in the Podrinje-Valjevo Mountains with Respect to Geo-tourism Development

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Abstract
The Podrinje-Valjevo Mountains (located in Western Serbia) constitute the longest mountain range in Serbia and possess numerous and diverse geo-heritage sites. In prior research, this region has been poorly investigated in terms of evaluating its geo-sites for geo-tourism potential. The aim of this paper is to evaluate and compare protected geo-sites in the Podrinje-Valjevo Mountains in order to determine their current state and potential for future geo-tourism development. This is done by applying the modified geo-site assessment model (M-GAM). Eight geo-sites were analysed and evaluated: Kovačevića Cave, Trešnjica Gorge, Taor Springs, Gradac Gorge, Crna River Gorge, Petnica Cave, Ribnica Gorge, and Ribnica Cave. The research results show the analysed geo-sites possess substantial geo-tourism development potential for making the Podrinje-Valjevo Mountains a geo-tourism destination. However, there is a lot of room for improvement of additional values such as promotion, tourist infrastructure, visitor centres, tour guide services, and interpretative panels. The results also show that there are certain differences between the evaluation of hydrological and speleological geo-sites within a region. Therefore, in order to comparatively analyse with maximum relevance, it is proposed to use the model to evaluate the same type of geo-sites.

Keywords Geo-tourism · Geo-sites · Evaluation · Podrinje-Valjevo Mountains · Western Serbia

Introduction

In order to minimize the long-term negative effects of mass tourism, specific forms of tourism are being developed. They have become synonymous with sustainable tourism development due to the importance and conservation of natural and cultural tourist values (Järviluoma 1992; Dearden and Harron 1994; Triarchi and Karamanis 2017). In scientific literature, geo-tourism is observed and researched as one of the specific, i.e. sustainable forms of tourism (Robinson and Novelli 2005; Dowling 2011).

Geo-tourism was first defined by Thomas Hose in the early 1990s (Hose 1995); therefore, this type of tourism is considered a relatively new phenomenon. Since then, the original definition of geo-tourism has been supplemented and modified several times (Dowling and Newsome 2006; Gray 2008; Newsome and Dowling 2010; Hose and Vasiljević 2012). A very detailed and comprehensive definition was provided by Newsome and Dowling (2010). They defined geo-tourism as "a form of natural area tourism that specifically focuses on geology and landscape. It promotes tourism to geo-sites, the conservation of geo-diversity, and an understanding of Earth sciences through appreciation and learning. This is achieved through independent visits to geological features, use of geo-trails and view points, guided tours, geo-activities, and patronage of geo-site visitor centres." It follows from this definition that geo-tourism is based on geo-diversity, with its intrinsic, cultural, aesthetic, economic, functional, and scientific values (Gray 2004). Dowling (2011) points out that geo-tourism is based on five fundamental principles, of which the first three are the key determinants of geo-tourism: the geological basis (primarily geo-heritage sites), sustainability, education (through geo-interpretation), benefit for the local community, and tourist satisfaction.

Over the last two decades, this type of tourism has seen remarkable growth in the global tourism market (Dowling and Newsome 2017; Ólafsdóttir 2019), with the main goal being to ensure tourism development while simultaneously initiating conservation and/or protection of geo-heritage at the same time (Newsome et al. 2012). Moreover, the

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importance of geo-ethics and its inclusion in comprehensive geo-tourism development has been increasingly emphasized as a framework for ensuring actions more respectful towards geo-heritage and human needs (Peppoloni and Di Capua 2016). It is also a path for sustainable development and responsible management of geo-sites (Vasconcelos et al. 2016). Geo-ethics is seen as one of the best ways to create social awareness about the value of geo-heritage and geo-diversity, and to prevent human-induced geo-site degradation (Vasconcelos et al. 2016; Antić et al. 2020a).

Geo-tourism is a very useful tool to promote the concepts of geo-sites' values, educating tourists, and sustainable development, and to foster an understanding of geology and geomorphological processes. However, before a particular tourist destination receives the prefix "geo", a thorough assessment of the condition and value of its geo-sites is necessary. This gives a clear picture of the activities that should be undertaken in order to ensure adequate geo-site tourism development and management (Vujičić et al. 2011).

Every year, the number of articles dealing with the identification and assessment of geo-sites and their inclusion in tourist flows is increasing (Bruschi and Cendrero 2005, 2009; Pralong 2005; Pereira et al. 2007; Reynard et al. 2007; Zouros 2007; Vujičić et al. 2011; Fassoulas et al. 2012; Bollati et al. 2013; Tomić and Božić 2014; Brilha 2016; Suzuki and Takagi 2018). A large number of Serbian geo-sites have been studied in terms of their geo-tourist activation. Most geo-sites research was conducted in Eastern Serbia (Tomić 2011; Božić et al. 2014; Tomić and Božić 2014; Božić and Tomić 2015; Antić and Tomić 2017; Antić et al. 2019, 2020c; Tomić et al. 2019; Bratić et al. 2020), Northern Serbia (Vujičić et al. 2011; Boškov et al. 2015; Višnić et al. 2016), and Western Serbia (Božić et al. 2014; Božić and Tomić 2015; Vuković and Antić 2019; Antić et al. 2020b). Although some parts of Western Serbia have been researched in terms of geo-tourism development, the region of Podrinje-Valjevo Mountains (North-western Serbia) has been poorly investigated. So far, one paper dealing with the analysis and assessment of caves in Western Serbia's Valjevo karst area (Antić et al. 2020b) and one investigating the Gradac river's gorge for geo-tourism development have been published (Milenković et al. 2020).

Karst terrains, as an integral part of geo-heritage, represent various geo-touristic attractions. Due to its specific features, scientific interest in the karst areas (caves, gorges, canyons, etc.) for geo-tourism development has increased during the last few years (Tičar et al. 2018; Telbisz et al. 2019, 2020; Telbisz and Mari 2020; Valente et al. 2020). The Podrinje-Valjevo Mountains region is partly a karst area and, as Vuković and Antić (2019) noted, the karst regions in Serbia have immense speleo- and geo-tourism potential. Taking into account that Podrinje-Valjevo Mountains geo-tourism potential has been poorly investigated, the aims of this paper was to evaluate and compare protected geo-sites in this region in order to determine their current state and future geo-tourism development potential. Seven protected geo-sites were evaluated for this paper: Kovačevića Cave, Trešnjica Gorge, Gradac Gorge, Crna River Gorge, Petnica Cave, Ribnica Gorge, and Ribnica Cave. The evaluation also covered Taor Springs (currently not protected but are undergoing a long protection process) which have geo-tourism development potential.

The null hypothesis is that the Podrinje-Valjevo Mountains are interesting due to their natural features of relief as well as their numerous and varied geo-sites, all of which can be used for geo-tourism development. The author's hypothesis states the mountains will be a geo-tourism destination because they possess attractive geo-sites (with geo-tourism development potential) and they can be properly organized and promoted for geo-tourism.

Area of Study

The Podrinje-Valjevo Mountains encompass parts of North-western Serbia (Fig. 1). With a length of 117 km, they constitute the longest mountain range in Serbia. Going from west to east, the mountains stretch as follows: Gučevo, Boranja, Jagodnja, Sokolska, Medvednik, Jablanik, Povlen, and Maljen. Although they do not have a high altitude (779–1347 m), many years of endogenous and exogenous processes have created various geomorphological forms of relief in the range.

The *Kovačevića cave* (*GS_1*) is located in the Kovačevići hamlet, on the right side of the Kovačevića river valley (Fig. 2). According to the cave channels' morphology and their spatial relationship, it is a relatively complex speleological object that was developed in limestones of the Palaeozoic age. It consists of four parts: the entrance, the main channel, the bath channel, and the mud channel. The entrance consists of two openings at a height of 17 and 20 m from the riverbed. The lower entrance is 8 m wide, and the higher 21 m, while their heights are 1 m and 3 m, respectively. The total investigated length of the main channel and all side channels is 985 m, making it one of the longest and most significant caves in Western Serbia. One that stands out is a stalagmite of milky white crystalline calcite (about 5 m high) that is a symbol of the Kovačevića cave. The cave is a habitat of a bat colony and 12 species of arthropod fauna. It is of paleontological and archaeological significance because 6 representatives of different genera of mammals (Pleistocene and recent age) as well as pottery remains were found in it. It was declared a natural monument in 1975 (Kličković et al. 2007).

The *Trešnjica river's gorge* (*GS_2*) is located in Western Serbia, not far away from Ljubovija. The watercourse is

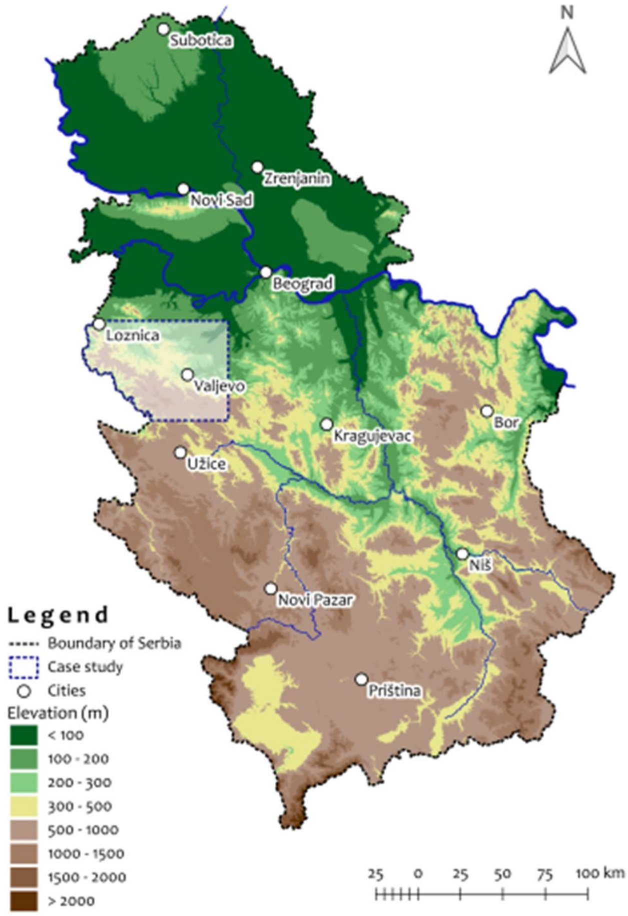

Fig. 1 Location of Podrinje-Valjevo Mountains

formed by several contact karst springs on the slopes of the Povlen Mountain (at 1180 m above sea level) and it flows into the Drina a few kilometres downstream from Bačevci. The total length of the stream is 22.4 km. Trešnjica basin's relief is formed by various rocks that mainly belong to older geological formations such as Palaeozoic shales, Triassic and Cretaceous limestones, serpentinites, and diabases. The middle of Trešnjica's limestone basin (about 1000 m high) has built an imposing gorge valley (about 7 km long) with steep sides that are 500 m deep in certain places (Spasojević 1979). Trešnjica is peculiar because it is the habitat of a rare species of vulture: the griffon (*Gyps fulvus*). In order to preserve the griffon population, natural rarities, geomorphological forms of relief, and valuable ethno-heritage, Trešnjica's gorge has been placed under protection as a natural asset of exceptional importance and it is classified as a special nature reserve (Decree on protection of Special Nature Reserve "Trešnjica river gorge" 1995).

The *Taor springs* (GS_3) belong to the Skrapež river basin (Fig. 3). They formed on the fault and the contact between the Triassic limestones and the serpentine. They erupt from a cave at the bottom of the limestone section, first creating a stream, and then large rapids and waterfalls. The water contains significant amounts of dissolved lime materials and, during swelling, precipitates significant amounts of tufa (Vasović 2003). They are a good example of tufa accumulation in Serbia but the entire complex was degraded because the springs were used for supplying water to the Kosjerić municipality at the end of the last century. The springs' functional values are significantly impaired by anthropogenic influence and a large number of water mills are no longer operational. The springs' source is no longer abundant, thereby impairing the aesthetic appearance of the waterfalls (Đurđić 2015).

The *Gradac river's gorge* (GS_4) is 22.7 km long and was formed between the Povlen and Maljen mountains. Geomorphological peculiarity is seen in the form of a pronounced meandering of the valley's lower part. The river valley is characterized by the appearance of clamped meanders and meandering limestone capes. At these places, the valley becomes quite narrow at the bottom (5–20 m). The gorge is about 150–200 m deep relative to the riverbed. The gorge's deepest part (over 300 m) lies between the villages of Bačevci and Gornja Leskovica as well as between Brangović and Lelić. The gorge's sides are steep (in some places, completely vertical) and limestone cliffs can be seen. These cliffs usually descend to the valley's bottom in the form of rocky walls. The riverbed has a different morphology. Its fall is smaller in the gorge's wide parts and larger in the narrow ones, and the flow is significantly faster. In some places, the river has waterfalls and deep whirlpools; the most famous is "Kraljev vir" (Simić 2008). The river Gradac's gorge has been protected as a landscape of exceptional features since 2001 (Institute for Nature Conservation of Serbia 2020).

The *Crna river's gorge* (GS_5) is located on Maljen Mountain (near a tourist place called Divčibare). It has been protected as a strict nature reserve (with an area of 60 ha) since 1868. The protected area encompasses the sides of the river's gorge and its branches (that have been transformed into narrow rocky ridges). The complex is full of special flora and vegetation (white and black pine, birch, fir, oak sessile, etc.) and attractive elements of relief (Vasović 2003).

The *Petnica cave* (GS_6) is located 7.5 km south-east of the city of Valjevo. Its geological basis is made of Middle Triassic limestones and it has 11 speleo-morphological parts (made up of halls, canals, and other elements of underground relief). Its total length is 580 m (making it the most spacious cave in the Valjevo karst) and it is divided into two parts: the Upper and the Lower Cave. The Lower Cave is a part of the largest hall (also known as the Concert Hall) of the Upper Cave. The concert hall's ceiling is pierced with two large openings so that the hall has dim daylight. It was extremely rich in stalactites and stalagmites but after the ceiling was pierced, its formation was interrupted. The Lower Cave is characterized by a constant flow of water called Banja.

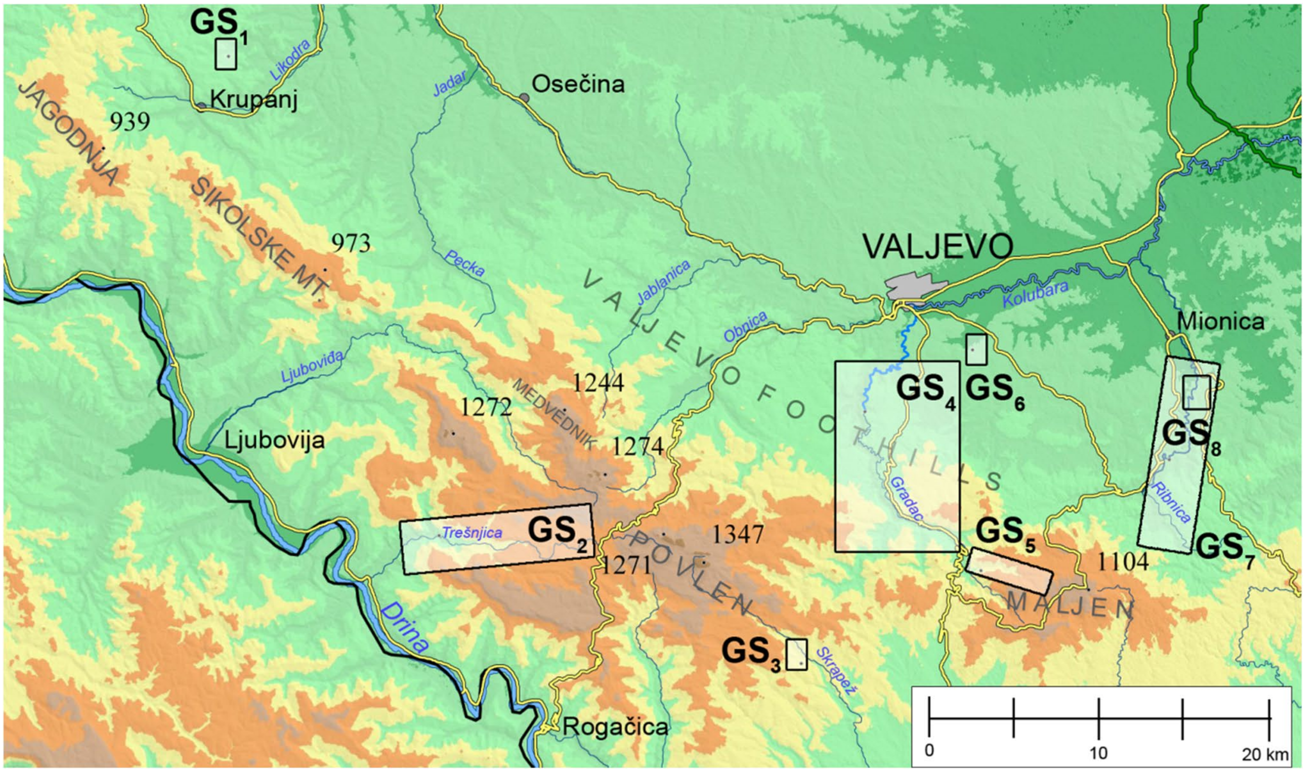

Fig. 2 Podrinje-Valjevo Mountains Geo-sites Map

Fig. 3 (1) Taor Springs. (2) Ribnica Gorge. (3) Petnica Cave. (4) Gradac Gorge. (5) Ribnica Cave (photos: Author 2020)

It is actually an intermittent spring with an average flow of 280 l/s (Vasović 2003). The karst spring of Banja is an interesting and rare hydrological phenomenon and the way it works has not been figured out to this day (Simić 2008). The Petnica cave is also an important archaeological site because scientific research has determined it was Palaeolithic man's habitat. Due to its geomorphological, hydrographic, archaeological-paleontological, and other features, it was proclaimed a natural monument in 1950 and it has great scientific and educational significance (Vasović 2003).

The *Ribnica river's gorge* (GS_7) belongs to the Kolubara basin and it is a part of the Valjevo karst (Stanojević 2009). Depending on local geological and geomorphological conditions, the valley narrows and widens, and its sides have steeper or milder slopes. Its entire basin is a transition from hilly to mountainous relief. The basin is mainly composed of marls, sandy limestones, clays, and sandstones. The river has cut a meandering gorge valley with a length of 10 km and a depth of over 200 m. It is made up of limestones from the Lower, Upper, and Triassic Cretaceous periods. The main feature of the gorge valley's karst relief is 12 caves that are arranged at different heights (Lazarević 1996).

The *Ribnica cave* (GS_8) is located on the Ribnica river's left bank (opposite the Ribnica church). The cave's entrance is a triangle (with a maximum length of 20 m and a height of 16 m) and behind it is a spacious hall that is 20 m wide. There are two siphon channels where the cave ends and a small stream occasionally flows through one of them. The cave is 127 m long and its Great Hall is covered with soil, blocks of limestone, and gravel. On the ceiling are rare stalactites and many sharp-edged depressions, formed by the decline of rocky blocks (Simić 2008). There are 14 species of bats in the cave, which is an extremely rare occurrence (Vasović 2003). Since 1999, 28 ha of the Ribnica river's valley and cave has been placed under protection as a natural monument of exceptional importance (Decision on the protection of Natural Monument Ribnica 1999).

Methodology

In order to identify the potential for geo-tourism development in a particular area, it is necessary to assess the value and current condition of its geo-sites (Boškov et al. 2015). This paper uses a modified geo-site assessment model (M-GAM) developed by Tomić and Božić (2014) for evaluating eight geo-sites of the Podrinje-Valjevo Mountains. This method is based on the Geo-site Assessment Model (GAM) created by Vujičić et al. (2011) and the Importance factor (*Im*) first introduced by Tomić (2011). In addition, the model represents an amalgam of former geo-site assessment methods (Bruschi and Cendrero 2005; Coratza and Giusti 2005; Pralong 2005; Serrano and González-Trueba 2005; Pereira et al. 2007; Reynard et al. 2007; Zouros 2007; Reynard 2008; Erhartič 2010; Tomić 2011). Unlike previous methods, where all grades were given by experts, the M-GAM includes not only expert opinion but also that of tourists regarding the importance of each sub-indicator in the assessment process. More reliable and accurate results are thus obtained (Tomić and Božić 2014). The validity of this model is confirmed by its successful application in geo-site assessment scientific research of the past few years (Božić et al. 2014; Božić and Tomić 2015; Boškov et al. 2015; Tomić et al. 2015, 2019, 2020, 2021; Antić and Tomić 2017, 2019; Jonić 2018; Pál and Albert 2018, 2021; Tičar et al. 2018; Vukoičić et al. 2018; Antić et al. 2019, 2020b, c; Vuković and Antić 2019; Bratić et al. 2020).

The M-GAM consists of two groups of indicators: Main Values (*MV*) and Additional Values (*AV*). The Main Values are divided into three groups of indicators: Scientific/Educational Values (*VSE*), Landscape/Aesthetic Values (*VSA*), and Protection (*VPr*), forming a total of 12 sub-indicators. The Additional Values are divided into two groups of indicators: Functional Values (*VFn*) and Tourist Values (*VTr*), with a total of 15 sub-indicators being formed (Table 1). The M-GAM is obtained by adding the Main and Additional Values: $M\text{-}GAM = MV + AV$. The Main Values are obtained by adding three indicators: $MV = VSE + VSA + VPr$, while the Additional Values are obtained by adding two indicators: $AV = VFr + VTr$. Since each group of indicators consists of a number of sub-indicators, the following equations of Main and Additional Values are derived:

$$MV = VSE + VSA + VPr \equiv \sum_{i=1}^{12} SIMV_i, \text{ where } 0 \le SIMV_i \le 1$$
$$AV = VFn + VTr \equiv \sum_{j=1}^{15} SIAV_i, \text{ where } 0 \le SIAV_j \le 1$$

where $SIMV_i$ represents 12 sub-indicators of Main Values ($i = 1,\ldots,12$) and $SIAV_j$ represents 15 sub-indicators of Additional Values ($j = 1,\ldots,15$).

In the M-GAM, as stated before, tourists take part in the assessment process via a survey that asks them to rate the importance (*Im*) of all 27 sub-indicators (0.00, 0.25, 0.50, 0.75, 1.00). Once all the ratings are collected, each sub-indicator's average value is determined and its final value is the importance factor (*Im*). Then, the product of the importance factor (*Im*) and the value determined by experts (0.00, 0.25, 0.50, 0.75, 1.00) is derived (Tomić and Božić 2014). Therefore, all sub-indicators are given a rating (between 0.00 and 1.00) by experts and tourists, thus giving more objective and accurate final results (Table 2).

The importance factor (*Im*) is defined as follows:

$$Im = \frac{\sum_{k=1}^{K} Iv_k}{\mathrm{K}}$$

where Iv_k represents the assessment of one visitor for each sub-indicator, and K represents the total number of

Table 1 The modified geo-site assessment model (M-GAM) structure

Indicators/sub-indicators	Description
Main values (MV)	
Scientific/Educational values (VSE)	
1. Rarity ($SIMV_1$)	Number of closest identical sites
2. Representativeness ($SIMV_2$)	Didactic and exemplary characteristics of the site due to its own quality and general configuration
3. Knowledge on geoscientific issues ($SIMV_3$)	Number of written papers in acknowledged journals, thesis, presentations and other publications
4. Level of interpretation ($SIMV_4$)	Level of interpretive possibilities on geological and geomorphologic processes, phenomena and shapes and level of scientific knowledge
Scenic/Aesthetic values (VSA)	
5. Viewpoints ($SIMV_5$)	Number of viewpoints accessible by a pedestrian pathway. Each must present a particular angle of view and be situated less than 1 km from the site
6. Surface ($SIMV_6$)	Whole surface of the site. Each site is considered in quantitative relation to other sites
7. Surrounding landscape and nature ($SIMV_7$)	Panoramic view quality, presence of water and vegetation, absence of human-induced deterioration, vicinity of urban area, etc
8. Environmental fitting of sites ($SIMV_8$)	Level of contrast to the nature, contrast of colours, appearance of shapes, etc
Protection (VPr)	
9. Current condition ($SIMV_9$)	Current state of geo-site
10. Protection level ($SIMV_{10}$)	Protection by local or regional groups, national government, international organizations, etc
11. Vulnerability ($SIMV_{11}$)	Vulnerability level of geo-site
12. Suitable number of visitors ($SIMV_{12}$)	Proposed number of visitors on the site at the same time, according to surface area, vulnerability and current state of geo-site
Additional values (AV)	
Functional values (VFn)	
13. Accessibility ($SIAV_1$)	Possibilities of approaching to the site
14. Additional natural values ($SIAV_2$)	Number of additional natural values in the radius of 5 km (geo-sites also included)
15. Additional anthropogenic values ($SIAV_3$)	Number of additional anthropogenic values in the radius of 5 km
16. Vicinity of emissive centres ($SIAV_4$)	Closeness of emissive centres
17. Vicinity of important road network ($SIAV_5$)	Closeness of important road networks in the radius of 20 km
18. Additional functional values ($SIAV_6$)	Parking lots, gas stations, mechanics, etc
Touristic values (VTr)	
19. Promotion ($SIAV_7$)	Level and number of promotional resources
20. Organized visits ($SIAV_8$)	Annual number of organized visits to the geo-site
21. Vicinity of visitors centres ($SIAV_9$)	Closeness of visitor centre to the geo-site
22. Interpretative panels ($SIAV_{10}$)	Interpretative characteristics of text and graphics, material quality, size, fitting to surroundings, etc
23. Number of visitors ($SIAV_{11}$)	Annual number of visitors
24. Tourism infrastructure ($SIAV_{12}$)	Level of additional infrastructure for tourist (pedestrian pathways, resting places, garbage cans, toilets, etc.)
25. Tour guide service ($SIAV_{13}$)	If exists, expertise level, knowledge of foreign language(s), interpretative skills, etc
26. Hostelry service ($SIAV_{14}$)	Hostelry service close to geo-site
27. Restaurant service ($SIAV_{15}$)	Restaurant service close to geo-site

Table 1 (continued)

Indicators/sub-indicators	Description				
Grades (0–1)					
	0.00	0.25	0.50	0.75	1.00
1	Common	Regional	National	International	The only occurrence
2	None	Low	Moderate	High	Utmost
3	None	Local publications	Regional publications	Nacional publications	International publications
4	None	Moderate level of processes but hard to explain to non-experts	Good example of processes but hard to explain to non-experts	Moderate level of processes but easy to explain to common visitor	Good example of processes and easy to explain to common visitor
5	None	1	2 to 3	4 to 6	More than 6
6	Small	–	Medium	–	Large
7	–	Low	Medium	High	Utmost
8	Unfitting	–	Neutral	–	Fitting
9	Totally damaged (as a result of human activities)	Highly damaged (as a result of natural processes)	Medium damaged (with essential geomorphologic features preserved)	Slightly damaged	No damage
10	None	Local	Regional	National	International
11	Irreversible (with possibility of total loss)	High (could be easily damaged)	Medium (could be damaged by natural processes or human activities)	Low (could be damaged only by human activities)	None
12	0	0 to 10	10 to 20	20 to 50	More than 50
13	Inaccessible	Low (on foot with special equipment and expert guide tours)	Medium (by bicycle and other means of man-powered transport)	High (by car)	Utmost (by bus)
14	None	1	2 to 3	4 to 6	More than 6
15	None	1	2 to 3	4 to 6	More than 6
16	More than 100 km	100 to 50 km	50 to 25 km	25 to 5 km	Less than 5 km
17	None	Local	Regional	National	International
18	None	Low	Medium	High	Utmost
19	None	Local	Regional	National	International
20	None	Less than 12 per year	12 to 24 per year	24 to 48 per year	More than 48 per year
21	More than 50 km	50 to 20 km	20 to 5 km	5 to 1 km	Less than 1 km
22	None	Low quality	Medium quality	High quality	Utmost quality
23	None	Low (less than 5000)	Medium (5001 to 10,000)	High (10,001 to 100,000)	Utmost (more than 100,000)
24	None	Low	Medium	High	Utmost
25	None	Low	Medium	High	Utmost
26	More than 50 km	25–50 km	10–25 km	5–10 km	Less than 5 km
27	More than 25 km	10–25 km	10–5 km	1–5 km	Less than 1 km

Source: Vujičić et al. (2011)

Table 2 Sub-indicator values given by experts for analysed geo-sites

Indicators/sub-indicators	Values given by experts								*Im*	Total value							
	GS_1	GS_2	GS_3	GS_4	GS_5	GS_6	GS_7	GS_8		GS_1	GS_2	GS_3	GS_4	GS_5	GS_6	GS_7	GS_8
Scientific/educational values (VSE)																	
Rarity ($SIMV_1$)	0.25	0.50	0.50	0.50	0.25	0.25	0.00	0.25	0.89	0.22	0.44	0.44	0.44	0.22	0.22	0.00	0.22
Representativeness ($SIMV_2$)	0.25	0.75	0.50	0.50	0.50	0.50	0.25	0.25	0.79	0.19	0.59	0.39	0.39	0.39	0.39	0.19	0.19
Knowledge on geoscientific issues ($SIMV_3$)	0.75	0.75	0.50	0.75	0.50	1.00	0.50	1.00	0.45	0.33	0.33	0.22	0.33	0.22	0.45	0.22	0.45
Level of interpretation ($SIMV_4$)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.85	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Scenic/aesthetic values (VSA)																	
Viewpoints ($SIMV_5$)	0.00	0.75	0.75	0.75	0.75	0.50	0.50	0.25	0.79	0.00	0.59	0.59	0.59	0.59	0.39	0.39	0.19
Surface ($SIMV_6$)	0.25	1.00	0.50	1.00	0.75	0.25	0.75	0.00	0.54	0.13	0.54	0.27	0.54	0.40	0.13	0.40	0.00
Surrounding landscape and nature ($SIMV_7$)	1.00	1.00	1.00	1.00	1.00	0.75	0.75	0.75	0.95	0.95	0.95	0.95	0.95	0.95	0.71	0.71	0.71
Environmental fitting of sites ($SIMV_8$)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Protection (VPr)																	
Current condition ($SIMV_9$)	1.00	1.00	0.50	0.75	1.00	0.75	0.75	1.00	0.83	0.83	0.83	0.41	0.62	0.83	0.62	0.62	0.83
Protection level ($SIMV_{10}$)	0.75	0.75	0.25	0.75	0.75	0.75	0.75	0.75	0.76	0.57	0.57	0.19	0.57	0.57	0.57	0.57	0.57
Vulnerability ($SIMV_{11}$)	0.75	0.75	0.00	0.75	0.75	0.50	0.75	0.50	0.58	0.43	0.43	0.00	0.43	0.43	0.29	0.43	0.29
Suitable number of visitors ($SIMV_{12}$)	0.25	1.00	0.75	1.00	1.00	0.75	1.00	0.75	0.42	0.10	0.42	0.31	0.42	0.42	0.31	0.42	0.31
Functional values (VFn)																	
Accessibility ($SIAV_1$)	0.25	1.00	0.75	1.00	1.00	1.00	1.00	1.00	0.75	0.18	0.75	0.56	0.75	0.75	0.75	0.75	0.75
Additional natural values ($SIAV_2$)	0.00	0.50	0.25	1.00	0.50	0.75	0.50	0.50	0.71	0.00	0.35	0.17	0.71	0.35	0.53	0.35	0.35
Additional anthropogenic values ($SIAV_3$)	0.00	0.25	0.25	0.75	0.25	0.75	0.50	0.25	0.70	0.00	0.17	0.17	0.52	0.17	0.52	0.35	0.17
Vicinity of emissive centres ($SIAV_4$)	0.25	0.25	0.50	0.75	0.50	0.75	0.50	0.50	0.48	0.12	0.12	0.24	0.36	0.24	0.36	0.24	0.24
Vicinity of important road network ($SIAV_5$)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.62	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Additional functional values ($SIAV_6$)	0.00	0.25	0.00	0.50	1.00	1.00	0.25	0.25	0.59	0.00	0.14	0.00	0.29	0.59	0.59	0.14	0.14
Touristic values (VTr)																	
Promotion ($SIAV_7$)	0.00	0.50	0.50	0.50	0.50	0.50	0.25	0.25	0.85	0.00	0.42	0.42	0.42	0.42	0.42	0.21	0.21
Organized visits ($SIAV_8$)	0.00	0.75	0.50	0.75	0.50	0.25	0.00	0.25	0.56	0.00	0.42	0.28	0.42	0.28	0.14	0.00	0.14
Vicinity of visitors centres ($SIAV_9$)	0.00	0.00	0.00	0.25	0.25	0.25	0.75	0.75	0.87	0.00	0.00	0.00	0.22	0.22	0.22	0.65	0.65
Interpretative panels ($SIAV_{10}$)	0.25	0.25	0.50	0.50	0.25	0.50	0.00	0.00	0.81	0.20	0.20	0.40	0.40	0.20	0.40	0.00	0.00
Number of visitors ($SIAV_{11}$)	0.25	0.25	0.25	0.75	0.50	0.25	0.25	0.25	0.43	0.11	0.11	0.11	0.32	0.21	0.11	0.11	0.11
Tourism infrastructure ($SIAV_{12}$)	0.00	0.25	0.50	0.50	0.25	0.25	0.00	0.25	0.73	0.00	0.18	0.36	0.36	0.18	0.18	0.00	0.18
Tour guide service ($SIAV_{13}$)	0.00	0.25	0.25	0.25	0.25	0.25	0.75	0.75	0.87	0.00	0.21	0.21	0.21	0.21	0.21	0.65	0.65
Hostelry service ($SIAV_{14}$)	0.75	0.75	1.00	0.75	1.00	1.00	1.00	1.00	0.73	0.55	0.55	0.73	0.55	0.73	0.73	0.73	0.73
Restaurant service ($SIAV_{15}$)	0.50	0.50	0.25	1.00	0.75	1.00	0.75	0.75	0.78	0.39	0.39	0.19	0.78	0.58	0.78	0.58	0.58

GS_1, Kovačevića Cave; GS_2, Trešnjica Gorge; GS_3, Taor Springs; GS_4, Gradac Gorge; GS_5, Crna River Gorge; GS_6, Petnica Cave; GS_7, Ribnica Gorge; GS_8, Ribnica Cave visitors. *Im* parameter can have any value in the range from 0.00 to 1.00 (Tomić and Božić 2014).

Taking into account all of the above, the M-GAM equation is defined as:

$$M - GAM = MV + AV$$

$$MV = \sum_{i=1}^{n} Im_{i*MVi}$$

$$AV = \sum_{i=1}^{n} Im_{j*AVj}$$

When the evaluation of geo-sites is performed by the both experts and tourists, a matrix of Main (X axis) and Additional (Y axis) Values is formed. It contains 9 fields marked with $Z(i,j)$, $(i,j = 1,2,3)$ and it indicates the current state of geo-sites (Fig. 4).

Božić and Tomić (2015) conducted a research based on two different geo-tourism market segments, determining the importance factor (*Im*) for each sub-indicator through a survey. As it can be applied for researching other geo-sites, the values of the importance factor (*Im*) have been adopted for this paper.

For the purpose of this paper, collecting data on the current status of eight geo-sites of the Podrinje-Valjevo Mountains was based on the available literature, through field research, by contacting local tourism organizations (Tourist Organization of Valjevo, Tourist Organization of Ljubovija, Tourist Organization of Mionica), mountaineering societies, non-profit organizations (Environmental Movement “Frame of Life”), and profit organizations (Wild Serbia Travel Agency).

Results and Discussion

The objectives of the paper were to investigate and compare protected geo-sites in the Podrinje-Valjevo Mountains in terms of their current state and potential for the geo-tourism development. The null hypothesis and the author’s hypothesis are fully confirmed by this research. The results of evaluating the eight geo-sites of the Podrinje-Valjevo Mountains are shown in Tables 2 and 3, and Fig. 4. Most of the geo-sites are located in the Z_{22} cell (Gradac Gorge, Crna River Gorge, Petnica Cave, Ribnica Gorge, Ribnica Cave), while three geo-sites are located in the Z_{21} cell (Kovačevića Cave, Taor Springs, Trešnjica Gorge). This research revealed some differences between the evaluation results of hydrological and speleological geo-sites.

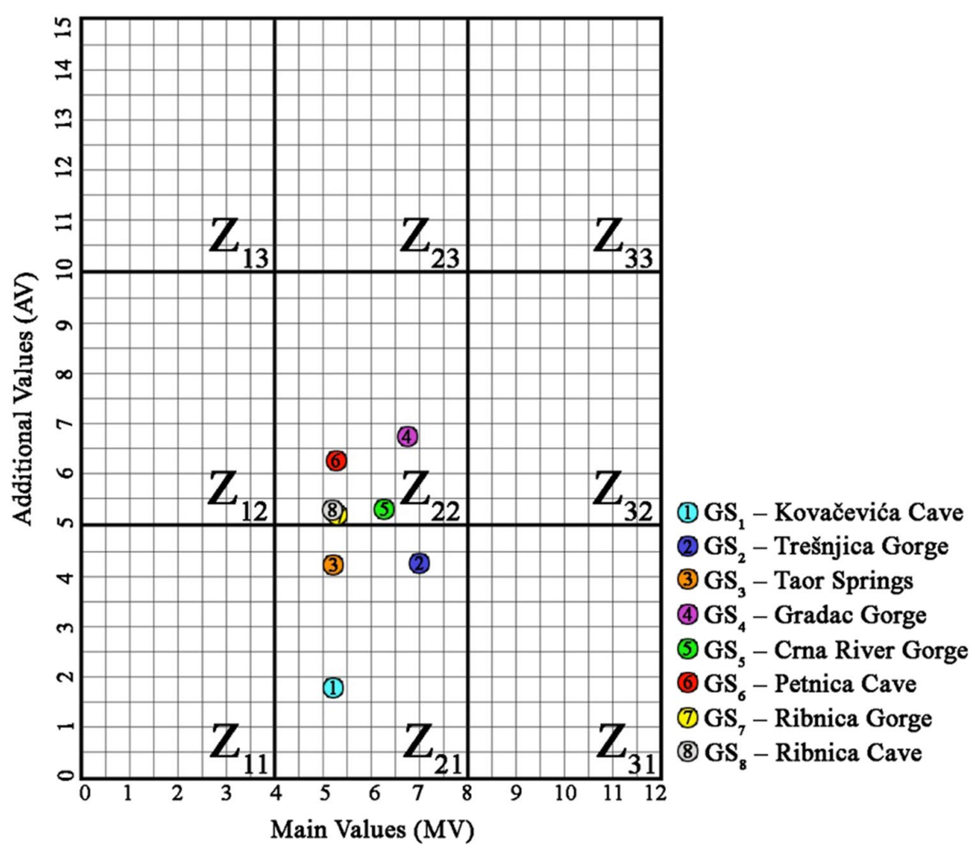

Fig. 4 Geo-site position in the M-GAM matrix

Table 3 Analysed geo-sites ranked by M-GAM

Geo-sites	Values				
	Main Values VSE + VSA + VPr	Overall	Additional Values VFn + VTr	Overall	Field
GS_1 — Kovačevića Cave	1.37 + 1.76 + 1.93	5.06	0.61 + 1.25	1.86	Z_{21}
GS_2 — Trešnjica Gorge	1.99 + 2.76 + 2.25	7.00	1.84 + 2.48	4.32	Z_{21}
GS_3 — Taor Springs	1.68 + 2.49 + 0.91	5.08	1.45 + 2.70	4.15	Z_{21}
GS_4 — Gradac Gorge	1.79 + 2.76 + 2.04	6.59	2.94 + 3.68	6.62	Z_{22}
GS_5 — Crna River Gorge	1.46 + 2.62 + 2.25	6.33	2.41 + 3.03	5.44	Z_{22}
GS_6 — Petnica Cave	1.69 + 1.91 + 1.79	5.39	3.06 + 3.19	6.25	Z_{22}
GS_7 — Ribnica Gorge	1.04 + 2.18 + 2.04	5.26	2.14 + 2.93	5.07	Z_{22}
GS_8 — Ribnica Cave	1.49 + 1.58 + 2.00	5.07	1.96 + 3.25	5.21	Z_{22}

After summing up the results of scientific/educational values, the Trešnjica river's gorge was rated highest while the lowest values were assigned to the Ribnica river's gorge. There are many gorges and caves in the whole region due to it being a mountainous and partly karst area. Hence, in terms of rarity, the highest values were assigned to the Trešnjica and Gradac rivers' gorges and the Taor springs. The main reason for this is related to their geological and geomorphological features as well as the surface they cover. Due to the significant distribution of Triassic and Cretaceous limestones that influenced the formation of steep cliffs (Spasojević 1979), the Trešnjica river's gorge has peculiar representativeness. It is also the griffon vulture's habitat. The significance and representation of this geo-site are enhanced because the bird nests only in the Uvac special nature reserve area and in the Trešnjica river's gorge. The suitability for geo-tourism development emphasizes that all investigated geo-sites have a moderate level of geomorphological processes that can be easily explained to a common visitor.

When it comes to scenic/aesthetic values, all geo-sites fit extremely well into their surrounding environment. However, by analysing the values obtained for the sub-indicator "viewpoints", certain differences in the values between hydrological and speleological geo-sites were noticed. The analysed hydrological geo-sites are mostly gorges of river valleys and the terrain configuration allows reaching certain viewpoints from which the geo-sites can be observed. In contrast, most of the analysed caves do not have an area large enough to single out locations within them (from which cave dripstone can be observed). Certain differences between hydrological and speleological geo-sites were also noted in the "surface" sub-indicator. Speleological geo-sites generally occupy a much smaller area than hydrological ones and it directly affects the values to be assigned.

Even though the aim of the paper was to investigate geo-sites with some degree of protection (one of the main value indicators), it does not show great fluctuations in the valuation of selected geo-sites. The current condition of most geo-sites was assigned the highest values. However, the negative human impact that directly reflects on the current condition of certain geo-sites should be emphasized. The Taor springs' current condition is a repercussion of many years of negative anthropogenic impact. The springs started to be used in the 1980s to supply water to Kosjerić and it resulted in long-term changes in the water level (most abundant during spring and thus most attractive for tourists), the intensity of erosion, and the aesthetic degradation of the environment (Golić and Joksimović 2017). Furthermore, the local population illegally exploits the springs' tufa accumulation which disrupts the relief structure, and due to the springs' reduced abundance, the tufa creation process has been hampered. Due to lack of protection and proximity to the city of Valjevo, the Petnica cave is often a gathering place not only for tourists but also for unscrupulous citizens. This is reflected in the disturbance of its geological and geomorphological features (graffiti on the outer and inner cave walls is especially noticeable). Moreover, the Gradac and Ribnica rivers' gorges are located near larger settlements and are often being visited by locals (especially picnickers) and tourists who do not have much awareness of preserving natural values. They impair aesthetic values and degrade the rivers' flows by dumping waste. Therefore, a slight damage to the mentioned geo-sites by the reckless behaviour of visitors was noticed.

The Taor springs have a 0.25 protection level because they are informally treated as a natural monument (protected at the local level). The remaining geo-sites are protected at the national level (0.75). Failure to implement legal regulations for protecting Taor Springs results in endangering their essential features and thus directly affects geo-site sensitivity. Although most geo-sites have a high value for the "sensitivity" sub-indicator, it is not the case with Taor Springs. If the problem of Kosjerić's water supply is not solved in the near future, the Taor springs will face the threat of completely losing their main values. Generally, the suitable number of tourists for a geo-site is in direct correlation with its surface area. However, this research did not show large fluctuations among the analysed geo-sites because most of them are large enough to hold 20 to 50 tourists without impairing their natural values. The only exception is the Kovačevića cave as it is not big enough to accommodate more than a few tourists at the same time.

Analysing the additional values revealed significant differences between the geo-sites. The Gradac river's gorge and the Petnica cave occupy a dominant position thanks to good geo-tourist location and proximity to Valjevo while Kovačevića Cave is valued the least due to lack of both functional and tourist values. Although access to Kovačevića Cave is possible by bus, speleological equipment and expert guidance are needed to visit the cave. Accessibility to other geo-sites is very favourable. It is worth emphasizing that even though the Taor springs' accessibility is well assessed, the road leading from the city of Valjevo is in extremely poor condition and that is why it takes almost 2 h to reach them. Therefore, as geo-site accessibility is very important for tourists (0.75), the local government should set aside money to fund road improvements. The Gradac river's gorge leads in terms of additional natural values. There are many underground karst landforms in it. Numerous caves were built by the river itself while other caves are remnants of former cave systems (Vasović 2003). The most famous among them are the Degurićka and Baćina caves. The valley of Gradac river's gorge also has a medieval monastery (Ćelije), remains of the "Jerina's town" medieval fortress, the Ilovačića watermill, and a hydroelectric power plant. These single out this gorge in terms of additional anthropogenic values.

The Petnica cave and the Gradac river's gorge stand out in terms of proximity to emissive centres because they are located close to Valjevo. Other geo-sites do not have such a favourable position related to proximity to emissive centres and they are connected to emissive centres via roads of regional importance. It should certainly be noted that due to the recently opened section of the "Miloš Veliki" highway, four geo-sites located in the study area's northeast section (Ribnica Gorge, Ribnica Cave, Petnica Cave, and Gradac Gorge) are more accessible to tourists coming from Belgrade. Additional functional values are generally unfavourable for most geo-sites. The exceptional value of this sub-indicator was given to the Crna river's gorge and the Petnica cave. The Crna river's gorge is located on the Maljen Mountain's slopes, not far from Divčibare's tourist resort. Divčibare has a long tradition of tourism and it is known for having suitable conditions for recreational skiing and other winter sports. On the other hand, the Petnica cave is located in the immediate vicinity of a larger urban settlement in Serbia (the city of Valjevo), providing extremely easy access to gas stations, parking lots, car service, etc.

Promotional activities for the researched geo-sites are carried out mainly at the local and regional levels, except for Kovačevića Cave which does not have any promotional activities. Taor Springs used to be on the front pages of numerous brochures of the former Yugoslavia Tourist Organization. They erupt from a cave located at the bottom of a limestone section, creating numerous waterfalls and cascades, which make them extremely different and scenic relative to other springs in this region. However, promotion of the Taor springs has been reduced to the regional level because their aesthetic values were disturbed by human irresponsibility. For the "organized visits" and "number of visitors" sub-indicators, the information was collected from local tourism organizations because there are no official statistics. The Trešnjica and Gradac rivers' gorges have the most organized visits (between 24 and 48) while the Ribnica river's gorge and the Kovačevića cave have the least. This is because geo-sites with a larger surface and attractive geomorphological features are more attractive for tourists. In addition, the Trešnjica and Gradac rivers' gorges are mountaineering destinations visited mostly by mountaineering associations. Due to the geographical position, easy accessibility, attractive relief features, and nearby cultural values, the Gradac river's gorge has the most tourist visits relative to other geo-sites.

Most geo-sites do not have visitor centres. The exceptions are the Ribnica river's gorge and the Ribnica cave. Although it is not a real visitor centre, there is a Stone Museum (founded in 2013 by biologist Predrag Petrović) in the immediate vicinity of these two geo-sites (Fig. 5). The museum houses more than 300 geological exhibits (dating from the Middle Devonian to the Upper Cretaceous) from the immediate vicinity of the Ribnica river (https://www.turistickisvet.com/news/tourism/muzej-kamena-kod-mionice---eksponati-stari-nekoliko-miliona-godina-1.html). It is a unique museum in the Republic of Serbia because it was established by individual initiative and it offers tourists an exceptional range of educational and practical activities. The Stone Museum especially promotes educating the youth about the importance and preservation of geo-diversity and it often initiates the involvement of experts in researching geo-heritage. The main goal of the museum is to point out the richness and importance of Serbia's north-western geoheritage and to promote it through exhibitions and organized workshops (http://okvirzivota.org.rs/).

The geo-sites do not have dedicated tour guide services but they — except for Kovačevića Cave — do have locals who act as informal guides for tourists. They are hired by local tourism organizations exclusively for planned and organized visits. The exceptions are the Ribnica river's gorge and the Ribnica cave (located near the Stone Museum) because the museum's employees often lead tours (that do not necessarily have to be planned). This is the main reason why the above geo-sites received a higher value for the "guide service" sub-indicator as compared to other geo-sites. Extremely low-quality interpretive panels characterize most

Fig. 5 Stone Museum (source: 1 — http://okvirzivota.org.rs/; 2 — https://www.opanak.rs/muzej-kamena-u-mionici/; 3 — https://www.turistickisvet.com/news/tourism/muzej-kamena-kod-mionice---eksponati-stari-nekoliko-miliona-godina-1.html)

geo-sites while those of medium quality are found in the Gradac river's gorge, the Taor springs, and the Petnica cave. The Ribnica river's gorge and the Ribnica cave do not have interpretive panels. Most geo-sites have poor- to medium-quality tourism infrastructure. Hiking trails, rest benches, and garbage cans are present in the Gradac river's gorge and the Taor springs. Accommodation services are extremely favourable for all geo-sites because of urban area proximity (Valjevo) or rural settlements offering such services (Donji Taor). When it comes to restaurant services, the situation is most unfavourable for Taor Springs while Petnica Cave and Gradac river's gorge are valued highest.

In their paper about cave tourism in the Valjevo karst area, Antić et al. (2020b) applied M-GAM to analyse four caves, two of which (Petnica and Ribnica) are explored in this paper. Comparing the results of both research papers highlights certain differences in the evaluation process. In this paper, Petnica and Ribnica Caves are given higher values for the "knowledge on geoscientific issues" sub-indicator. The main reason behind this improvement is related to the research of these geo-sites in terms of cave tourism and their recent publication in an international journal (Antić et al. 2020b). In addition, certain deviations in the assessment of tourist values were noticed, especially when it comes to the Ribnica cave. As mentioned previously, there is a Stone Museum (in the immediate vicinity of the Ribnica cave) containing a huge collection of the area's geological history and the museum's employees often lead tours. For this reason, the values of some sub-indicators ("vicinity of visitors centre" and "tour guide service") in this paper are better when compared to those in Antić et al. (2020b). Furthermore, the Stone Museum promotes Valjevo's geo-heritage and, along with the Ribnica cave, is a destination for student excursions. Consequently, the additional values increased and automatically shifted the cave's matrix location (from cells Z_{21} to Z_{22}).

Conclusion

This research created an insight into the current state and possibilities for geo-tourism development of eight geo-sites in the Podrinje-Valjevo Mountains by applying the M-GAM. The results indicate that the analysed geo-sites possess substantial geo-tourism potential for making the Podrinje-Valjevo Mountains a geo-tourism destination. However, there is a lot of room for improvement of additional values. This primarily refers to the lack of additional functional values, tourist infrastructure, interpretative panels, visitor centres in the most attractive geo-sites, and a tour guide service which should be available to any individual who decides to visit a particular geo-site.

Promotional activities are at a low level and should be improved and expanded to the national level. This can be achieved by better organization of websites containing more geo-site information, better presentation at tourism fairs, more informative and creative brochures, and detailed maps for self-guided tourists. Moreover, as geo-education and geo-interpretation are considered crucial in the affirmation of geo-tourism and its development (Dowling 2013), organizing interactive workshops and education for tourists of different profiles and ages would significantly increase tourists' awareness about sustainable development and the importance and values of these geo-sites. Given that virtual tours are considered an important means of promotion in order to inform and attract tourists, local tourism organizations in this region should introduce geo-site virtual tours. Involvement of the local population in interpretive activities and placement of domestic products can also help this region in becoming a geo-tourist destination. Additionally, setting up more creative and informative interpretive panels of geo-sites' values (geological, geomorphological, speleological, hydrological, climatological, biogeographical, and cultural) that contain responsible tourist behaviour would result in a lot geo-heritage benefits (especially for self-guided tourists).

The Ribnica river's gorge and the Ribnica cave are a good example of how an area can be revived geologically via individual initiative. The Stone Museum enriches the space and provides tourists with geo-site chronology. Educational activities and workshops for tourists are organized by this museum and it is considered an important trigger for geo-tourism development. Furthermore, this museum, created by a person who is fond of biology and geology, is an outstanding example of good practice in incentivizing geo-tourism development at the local level. However, in order to make these geo-sites more familiar to tourists, more active and focused promotion by all geo-tourism stakeholders is necessary. On the contrary, the most attractive geo-sites lack visitor centres and official tour guide services that enable their geological and geomorphological features to be presented to tourists.

Through the conducted research, the advantages and limitations of geo-tourism development in eight geo-sites of the Podrinje-Valjevo Mountains were noticed. The main geological values emerged as a result of many years of endogenous and exogenous processes and they can not be visibly changed in the short term. However, the additional values depend exclusively on the engagement and initiative of local state authorities and individuals. Therefore, recognizing the importance of spatial planning to and around geo-sites will enhance tourism infrastructure as well as the local economy and community involvement. In order to not impair the basic values of the geo-sites (and thus the entire region), it is very important that geo-tourism in this region develops in a planned manner and in accordance with sustainable practices. With an approach that integrates the organization of geo-tourism and its management (including cooperation between public and private sectors), a number of positive effects could be expected in the future.

While researching and summarizing the results, it is noticed that the M-GAM application provides insight into the current state of the studied area in general. However, certain weaknesses of this model were observed when applied to the analysis of different geo-sites in one region. In the case of this research, some differences between hydrological and speleological geo-sites became apparent. As a rule, hydrological geo-sites, unlike speleological geo-sites, cover a larger — often enormous — area, thereby enabling greater suitable number of tourists and providing more viewpoints. With this in mind, future research using M-GAM should be applied exclusively to the same type of geo-sites so that comparative analysis can be performed with maximum relevance.

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Data availability See references.

Code Availability Not applicable.

Declarations

Conflict of Interest Not applicable.

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