Research Article

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Assessment of geosites as a basis for geotourism development: A case study of the Toplica District, Serbia

https://doi.org/10.1515/geo-2022-0589
received August 02, 2023; accepted November 22, 2023

Abstract: Toplica district represents an area in Southern Serbia with significant forms of geoheritage that have not been valorized yet. The aim of this pioneering study is to systematically analyze and evaluate all manifestations of the geodiversity in the Toplica district. Based on the geological importance, degree of attractiveness, and size, a total of six geosites were selected. The main goal of the study is to emphasize the insufficient utilization of huge geotourism potentials of the Toplica district and to determine the current geotourism development and geotourism potential of evaluated geosites. The geotourism suitability of each geosite is defined through comparative analysis. The Geosite Assessment Model (GAM) is used to assess the current state of the various elements of geodiversity in the study area. Positioning within the GAM matrix is defined by the values of the investigated parameters. Visualization of the distribution of the GAM indicators is an innovative approach for the interpretation of the obtained results. As a projection of the geotourism potential, the study presents the results of the traffic accessibility of geosites using the Geographic Information System (GIS)-based isochronous method. GIS and Digital Terrain Models are used in the visualization of the research area. The results of GAM apostrophize the current tourist value of Devil's City, while the isochron analysis of GIS highlights the great geotourism potential of publicly little-known and touristically unaffirmed geosites. The results represent a basis that can support the affirmation of geotourism, the improvement of existing, and the development of new geotourism strategies in the Toplica district.

Keywords: geodiversity, geosite assessment, GIS analysis, geotourism development, Toplica district, Serbia

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1 Introduction

Toplica district is an area with exceptional natural heritage values and significant geotourism resources. The research area has been recognized and confirmed as one of the most important spa areas in Serbia. The unique forms of geodiversity are the result of the effects of endogenous and exogenous geomorphological processes and the influence of climatic elements. The presence of these landforms in the Toplica district is significant, but they have been insufficiently scientifically researched, underutilized, and generally not included in the tourist offer. Their interpretation, valorization, and promotion can significantly influence the emergence of geotourism as a new aspect of the tourist offer in this area by providing an authentic and unforgettable experience for tourists. Geotourism is one of the alternative forms of modern tourism, which can enrich the tourist offer and have a stimulating effect on the extension of the tourist season of the Toplica district.

In recent years, there has been a rapid expansion of tourism interest in geological formations and landscapes [1]. Geoheritage and geotourism are concepts specifically focused on the diversity of geological and geomorphological landforms and landscapes. They are interconnected because geoheritage has become an irreplaceable part of the tourist offer of many countries. They include the protection and conservation of rare pedological, geological, and geomorphological phenomena, processes and formations, as well as cultural/archeological sites, mines, churches, or bridges (made of stone or natural materials), in order to create a complex cultural landscape and enhance the experience for tourists, thus increasing the geotouristic potential of sites and their effectiveness in engaging the public [2].

Geoheritage is a geotourism resource that could lead to the sustainable development of society and could contribute to information on geological and geomorphological characteristics, education, public awareness of geoconservation, and landscape protection [3]. Geosites have a unifying value, they are valorized as tourist motives by aesthetic, cultural, scientific, and educational values related to a given territory. Geotourism explicitly includes visits to geosites and is the most appropriate form of their sustainable use. The necessary preservation of natural heritage and associated cultural values to education, interpretation, and entertainment [4] are defined as the main objectives of geotourism. Qualitative and quantitative geodiversity assessment methods, make it possible to propose conservation plans (e.g., geoparks), to identify areas of interest (e.g., geological heritage), and to regulate their sustainable use (e.g., geotourism) [5].

A large number of different definitions of geotourism exist in literature. Dowling [6] observes geotourisam as a form of sustainable tourism with a primary focus on experiencing the earth's geological features in a way that fosters environmental and cultural understanding, appreciation, and conservation, and is locally beneficial [7]. Based on previous interpretations [8,9], Hose and Vasiljević [10] define the term geotourism as "the provision of interpretative and service facilities for geoheritage sites and geomorphosites and their encompassing topography, together with their associated *in-situ* and *ex-situ* artifacts, to constituency-build for their conservation by generating appreciation, learning and research by and for current and future generations" [11–13]. According to these findings, geotourism should be understood as a form of landscape (geological and geomorphological) and cultural sites that have natural and cultural value. The concept of geoheritage implies the preservation of geoheritage in order to use it in a sustainable way with the active participation of the local population.

The growing scientific interest in geoheritage has led to the development of numerous assessment methods. According to Reynard et al. [14], most of them can be divided into several groups. Early assessment models favored the assessment of scientific values only [15,16]. With the growing interest in geoheritage in scientific circles, socio-cultural attributes were also noticed, so that later assessment models extended the assessment to other values in addition to scientific criteria. They emphasize the need for protection and point out potential threats [17], evaluate socioeconomic and geocultural values [18], management values [19], quantitative (tourist and exploitation values) and qualitative criteria [20], ecological, aesthetic, historical, tourist, cultural, economic, and other values [14,21–23].

The more complex method Geosite Assessment Model (GAM) was developed as a combination of several methods with slight modifications. It was developed by Vujičić et al. [24] and evaluates scientific/educational, scenic/aesthetic, protection, functional, and tourist values. Visitors represent an important segment of tourism. Their opinions and attitudes are very important, and none of the previously mentioned models evaluate this segment. For this reason, Tomić and Božić [25], by improving the existing GAM, defined one of the most complex models – M-GAM. The advantages of using this model are related to the presence of tourists and familiarity of the general public with the places, which facilitates the collection of information, but this is also one of its disadvantages. The evaluation methodology and criteria strongly depend on the objective of the evaluation [14,26].

So far, scientific and professional studies on the subject of evaluation of the geoheritage of the Toplica district have covered only a modest number of sites. Most of them have never been scientifically considered and evaluated, while some have been evaluated several times in different studies. This is the first study that on systematical manner, tends to evaluate all representatives of geodiversity in the Toplica district, which reflecting its innovativeness and greatest scientific contribution.

The primary objective of this study is to show the insufficient use of the enormous geotourism potential of the Toplica district. The study is based on a comparative analysis of six selected geosites based on their attractiveness for geotourism development and the assumption that they can attract the attention of a large number of tourists. The current status of geotourism development is determined by the quantitative assessment of the geosites. The GAM is a well-defined method for this purpose. Since there are no organized tourist visits in all but one of the geosites studied, the assessment was conducted using the GAM. The evaluation method is based on the professional opinion of geoexperts, and the information was collected through surveys and field research. The aim of using this model is to define the current conditions and determine the current tourist value of each geosite. Numerical statistics provide information about the level of educational and aesthetic values, the level of protection, and the tourist suitability of sites. They show the strengths and weaknesses of geosites, the main areas of improvement, and the geosites that need more attention.

The values obtained with the GAM method provide the possibility to apply the interpolation method of Inverse

Distance Weighting (IDW). In previous studies, the numerical results of GAM were presented only in the form of graphs. The interpolation method will help in an innovative way to visualize, interpret, and analyze the numerical values of GAM. The maps show the spatial distribution of the value of the indicator groups as well as the distribution of the tourist value of the geosites.

In further course of research, the possibilities of the Geographical Information System (GIS) were used. The isochrone method is based on collected and processed data. It provides the possibility of visualization of spatial data of geosites within the existing traffic network. The algorithm is used to analyze, over the time distance on isochronous maps, the traffic-tourism accessibility as a conditional parameter for the design of the tourist offer. The objective is to evaluate the potential of geotourism development of each geosite and to show the tourism underutilization of the most accessible geosites. In this way, the analysis offers the possibility of a more effective projection of the tourist importance of each geosite and a better spatial organization of geotourism.

Through a comparative analysis of the results of the GAM method and the isochronous method, the overall suitability of each geosite for the development of geotourism, as well as its advantages and disadvantages, are defined. The obtained results represent a kind of basis for geotourism development strategies intended primarily for the tourism management bodies of the Toplica district. The study shows the great geotourism value of unused geosites. Through the study, a series of measures for the inclusion of geosites in the tourist offer is proposed, which will enable the confirmation of the unique geotourism product of the Toplica District.

2 Study area

The Toplica District is an administrative region of the Republic of Serbia located in the valley of the Toplica River, between 43.0–43.4°N and 21.4–21.58°E with an area of 2.231 km^2 [27]. The Toplica district includes the territory of the City of Prokuplje and three municipalities: Kuršumlija, Blace and Žitorađa. It represents the mountain-basin-valley microregion, a mesoregion in central-southern Serbia. The eastern border is formed by the South Morava River valley. To the west, the district includes the southeastern parts of the Kopaonik Mountains. The northern border runs along the highest peaks of Veliki and Mali Jastrebac Mountains, while the southern border follows the highest parts of the Radan-Vidojevica-Pasjača mountain system (Figure 1). The traffic position relies on the state road of category I, E-80, in the direction of Niš–Priština. About 20 km east of the district border, this road intersects with the international highway E-75 (corridors X and Xc), which is the main tourist route in Serbia. The Toplica District is a densely forested region with 57.7% of the area covered by forest [27] and only 10.9% is agricultural area [28]. About 12.3% of the area of the district consists of protected areas, mainly the Radan Nature Park.

The tecto-morphogenesis of the Toplica district is extremely complex. The Toplica Basin is a northeast-southwest trending intramontane tectonic depression [29]. It was formed under the influence of intense tectonic movements (shearing, uplift, faulting) followed by fluvial erosion. The central part of the district is filled with Neogen and Quaternary freshwater sediments with organogenic-marsh sediments and recent Holocene fauna in the vicinity of Blace [30].

The old block mountains, Jastrebac (1.942 m a.s.l.) in the northeast and north, and the Radan, Vidojevica-Pasjača mountain system in the south-southwest, consist mainly of Precambrian metamorphic rocks of the Serbian-Macedonian Massif (SMM) – biotite, quartz feldspar, gneiss, two mica-schist, and marble. To the southwest, the amphibolitic metamorphic base is intruded by Oligocene andesitic volcanic and volcaniclastic rocks of the Lece Magmatic Complex. It is the second-largest volcanic province in Serbia with an area of over 700 km^2 [31]. The western-northwestern part of the Toplica district consists of metamorphic base rocks – mostly phyllites and marbles of the Kopaonik Block and Ridge, overlayed by Oligo-Miocene volcanic pyroclastic rocks –- latite, quartz-latite, and dacite-andesite. West of the SMM is the Eastern Vardar Zone, which is a narrow ophiolite belt composed of continental and oceanic units, including Triassic and Jurassic ophiolites [32].

The thermomineral springs of the Toplica district represent an important tourist resource. Kuršumlijska Spa (water temperature 68°C) and Lukovska Spa (67°C) are located at the foot of the Kopaonik Mountains. They are among the warmest spas in Serbia, classified as hyperthermal due to the water temperature. Prolom Spa is located at the foot of Radan Mountain. The average water temperature of the springs is 31°C, classified as hypothermic. The location and the altitude at which they are situated make all three spas curative and climatic resorts. The considerable accommodation capacities and tourist offers of these spas provide the possibility of year-round tourist traffic. They are highly visited, among the most visited tourist resorts in Serbia. This represents an exceptional basis for the affirmation of geotourism in the Toplica district.

For the present work, six of the most representative geological and geomorphological sites of the Toplica

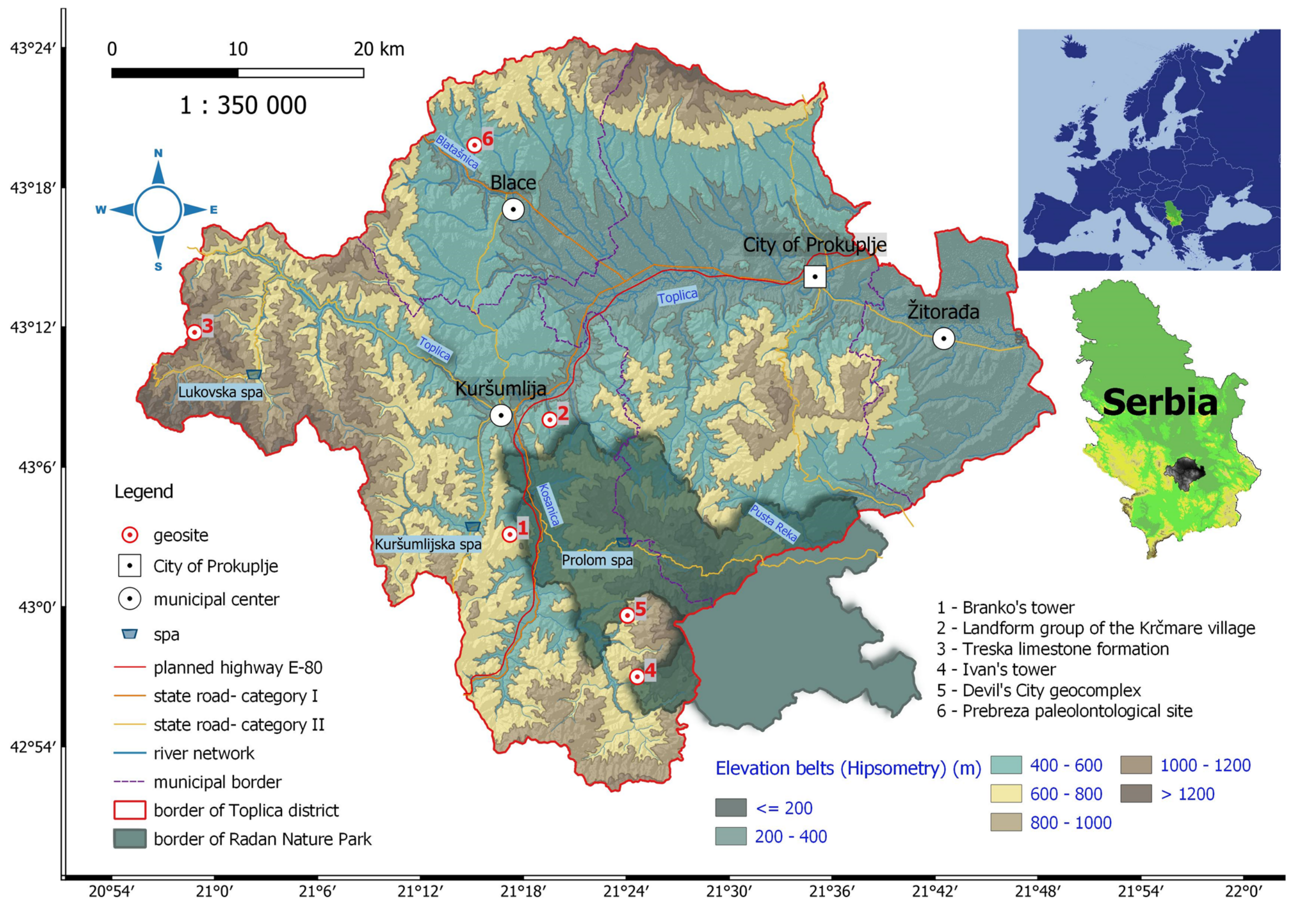

Figure 1: Geographical position of the Toplica District.

district were selected and described in Sections 2.1–2.6. Each site is given the designation "GS" and a sequence number from 1 to 6, where "GS" indicates the geosite. As shown in Figure 1, due to uneven distribution, four geosites in the southeastern part of the district can be defined as a cluster that gravitates towards the Kuršumlija area. There is only one geosite in the immediate vicinity of Blace, while Treska is located on the outskirts of the Toplica district. In several scientific studies, only GS-5 Devil's City was geo-ecologically and touristically valorized, while the other geosites were never the subject of scientific studies.

2.1 Branko's tower (GS-1)

The spectacular outcrop of columnar andesite basalt is located about 12 km south of Kuršumlija, about 1.5 km southwest of the village of Rudare, at 747 m a.s.l. (Figure 2(1)). It is located in the protected zone of the Radan Nature Park. The andesite-basalt pillars resemble a wall about 30 m long and up to 3 m high. This formation, which runs roughly in the direction of NNE-SSW, consists mainly of five-sided pillars, usually about 30 cm in diameter. The pillars are composed of hornblende-pyroxene andesite. The product is the second volcanic phase of the large Lece Magmatic Complex (LMC). The structure is actually a shallow dike-like intrusion. The columns are separated by joints or fractures that generally form when the lava shrinks, usually during cooling. They cut through the volcanic mound of hornblende andesite volcaniclastics, which are products of the first volcanic phase [33].

2.2 Landform group in flysch rocks near the village of Krčmare (GS-2)

Flysch is a dense marine sequence of turbidites and gravity mass flows embedded in the overthrust and fold belt of a growing orogenic belt [34]. To be recognized as flysch, the deposits must have appropriate lithologic and depositional characteristics. In the first case, it is the gradual deposition of suspended sediments from deep-water turbidites to shallow-water shales (clays and silts) and sandstones. At

Figure 2: (1) Spectacular andesite-basalt stone pillars at Branko's tower; (2) Flysh rock formation at the village of Krčmare; (3) Limestone massif and cave Treska; (4) Paleovolcanic dome and archeological site Ivan's tower; (5) Cone-shaped formation of volcanic stone pillars Devil's City; (6) Middle Miocene paleontological site Prebreza.

the base of the flysch sequence are coarse-grained sediments, breccias, and conglomerates. Differential erosion of flysch sediments, especially in the strata deviating from the main topographic surfaces, leads to the formation of very complex landscapes with specific landforms such as rocks in the form of pillars (stacks), cones, tables, mushrooms, haystacks, abri-scarps escarpments and rock shelters, isolated ridges, and boulder fields [35]. Vivid examples of reliefs created by selective weathering of Upper Cretaceous flysch breccias and conglomerates within the so-called Toplica flysch [30] are recognized in the village of Krčmare (right bank of the Toplica river, about 4 km from Kuršumlija). The figures are locally known as “Mara's petrified stacks.” The most vivid are Šiljak (sharp stone, a spike), Čučavac (squatting), and Kamalj (the stone) (Figure 2(2)), but there are also a number of head-like rock formations up to 1.5 m in diameter. It is carved into well-cemented conglomerates and is about 6 m high. Čučavac is a 3.5 m high rock without a base, which looks like a Dutch clog. The third relief figure, Kamalj, resembles a lying fossilized prehistoric animal.

2.3 Treska limestone formation (GS-3)

Treska limestone formation is located about 50 km northwest of Kuršumlija and about 20 km west of Lukovska Spa, between the villages of Seoce, Štava, and Trešnjica. Treska (1.439 m a.s.l.) consists of tectonized massive and sandy Triassic limestones (Figure 2(3)). It is one of the dominant peaks on the eastern slopes of the Kopaonik Mountains. Its appearance in the form of a double tooth makes it stand out from other mountain peaks. It is accessible only from the west side, and the ascent from the village of Štava is about 7 km long. It is characterized by difficult terrain, but also by exceptionally preserved biodiversity. It is especially attractive for mountaineers and lovers of geotourism.

The almost unknown and little explored Treska Cave is located at the foot of the southeastern part of the limestone massif. The estimated explored area of the cave is about 0.23 km^2, which is about 40% of its total area. It is relatively poor in speleothems. Preliminary investigations of the cave show that it consists of 11 galleries, but they are narrow and inaccessible. The entrance to the cave is now collapsed, so the cave remains unexplored and its total length is unknown.

2.4 Ivan's tower (GS-4)

Ivan's tower is a paleovolcanic dome (886 m a.s.l.) and a partially explored archeological site (Figure 2(4)). It is located on the western slopes of the Radan Mountains, 33 km south of Kuršumlija, in the immediate vicinity of the villages of Zagrađe and Ivan Kula. The paleovolcanic caldera is part of the LMC. The preserved archeological remains are related to a medieval fortress built on top of a paleovolcanic dome with a rectangular base and a height of 14 m. The area of 65.47 ha around Ivan's tower is protected by the second level of protection within the special geo(morpho)logical nature reserve "Kosanica-Đavolja varoš" [36]. The archeological remains of the medieval fortress have been protected by decree as a cultural monument since 1956 [37].

2.5 The Devil's City geocomplex (GS-5)

The Devil's City geocomplex is the best-preserved part of the LMC. The area of about 4.3 km^2 has been under protection since 1959. In 1995, it was declared as a Natural Monument of protection category I, and since 2009, it has been on the Tentative list of UNESCO. Besides the unique geomorphological phenomenon of earth figures, it also includes several different geosites (Figure 2(5)). It is located at an altitude of 700–720 m a.s.l., on Radan Mountains, about 29 km southeast of Kuršumlija.

The Devil's City is the most important geomorphological natural monument in Serbia, formed by erosion [38]. Striking erosional forms (a total of 202 earth/stone pillars, earth columns, soil/clay pyramids) are located between two gorges, the Devil's Gorge and the Hell's Gorge. Pyroclastic rocks are mostly represented by weakly bonded volcanic breccias and tuffs. These rocks are exposed as horizons ranging in thickness from a few meters to 100 m. Notable features of the Devil's City are the predominance of pyroclastic rocks over andesites and intense hydrothermal activity. Cone-shaped forms of poorly sorted volcanic material with large andesite caps reach heights of 2–15 m, widths of 4–6 m at the base, and heights of 1–2 m at the top. These ephemeral forms disintegrate relatively quickly when they lose their protective "cap" of andesite blocks [39].

Devil's City is also characterized by rare hydrological phenomena, springs with rare hydrochemical properties related to the last phases of volcanism. The first spring known as "Devil's Water" is extremely cold, acidic, and highly mineralized water [40] with radioactive content [41]. The second spring "Crveno Vrelo (Red Spring)" is less acidic but contains heavy metals, especially iron. The wider area of Devil's City is rich in ores (iron, aluminum, gold, and silver), and was part of a well-known mining area during the Middle Ages. The presence of several mining shafts are archaeological remains of mining from the thirteenth century.

2.6 Paleontological site of Prebreza (GS-6)

Several fossil sites exist in the Toplica district. The paleontological site "Prebreza" is one of the best preserved and most important European sites of vertebrates from the Middle Miocene (Figure 2(6)). It is located on the southwestern slopes of the Veliki Jastrebac Mountain, in the northwestern part of the Tertiary basin of Toplica, near Blace. The area has been protected since 1963. In 2009, it was declared as a special nature reserve and is protected by the Inventory of Geological Heritage of Serbia. The fossil remains of Prebreza are dated to the middle Miocene Badenian–Sarmatian [42]. The site was discovered by erosion of the coastal slopes of the Gluvi Potok (right tributary of the Blatašnica River). It extends on both sides of the watercourse in the form of a subvertical profile several hundred meters long. The geological structure of the Prebreza area consists of sandstones and clay sandstones with mica, covering pelite and tuff with coal.

3 Materials and methods

3.1 Data collection

In the initial phase, available literature and spatial planes were used as a source of spatial data. Digitized and georeferenced geologic maps 1:100,000 [30]; geomorphologic maps 1:300,000 [43], and military topographic maps 1:25,000 and 1:50,000 were used. By selecting different sources, we searched for symbols representing geosite features (cliffs, fractures, gorges). Geographic coordinates are defined by determined geosites. Available data via Google Earth and OpenStreetMaps applications in the research area were searched to create the preliminary GIS database. The focus was on finding photos of specific natural formations, locations, and viewpoints that have already been marked by climbers and geotourists. The free online database of the Information system of the immovable cultural property was also used (https://nasledje.gov.rs/index.cfm?jezik=Serbian_CIR) [44]. The location of geosites was marked in the field using GPS and mobile applications.

To reduce the number of sites to be checked in the field, pre-filtering was done based on geological significance, attractiveness, and size. Some of the geosites found proved to be less important, difficult to access or inaccessible, and of small size. Such sites were excluded from the GAM. In addition, the number was reduced by grouping them by location or similarity of origin. Finally, due to the complexity of the survey, six geosites were selected for analysis. A detailed report of the survey of geologic features was written for each geosite. Photographs of each geosite visited were taken.

3.2 Questionnaire designs

The application of the GAM was preceded by a survey in which a total of 52 people participated. The geospatial experts were carefully selected for their expertise in geography, geology, geoheritage, and geotourism. They are familiar with the research topic and the study area. The anonymity of the questionnaire preserved the credibility of the responses. The research was conducted in February and March 2023. Statistical calculation and visualization of the results were performed using SPSS 20 (Statistical Software for Social Sciences) and MC Excel. In preparing the questionnaire, the purpose of the research was first explained and each question and group of answers was simplified individually. The questionnaire is divided into two parts. The first part contains questions about the socio-demographic profiles of the participants (gender, age, place of residence, and education), as shown in Table 1. An important question for the study was related to the type of transport most often used on the journey to and during the stay in destinations where the participants could choose between different modes of transportation. In the second part of the questionnaire, each participant rated each of the 27 sub-indicators. A five-point Likert scale ranging from 0.00 to 1.00 was used for the rating (with 0.00 representing unimportant and 1.00 representing very important). The survey was conducted online, and the Google Forms application was used to design the questionnaire. The link to the questionnaire was sent to each participant's email address and can be found in the supplementary material section of the study. The aim was to have only geo-experts participate in the survey, thus ensuring the validity of the sample.

The questions included in the survey have already been tabulated in a large number of studies that use the GAM and/or M-GAM methods. Therefore, they are not tabulated again in this study. The values obtained by statistical calculations based on surveys and the final results of the geosite assessment are presented.

3.3 Geosite assessment model (GAM)

In order to present and quantitatively evaluate the macro and micro forms of relief in the Toplica district, the GAM developed by Vujičić et al. [24] was chosen. It is one of the most complex and well-defined methods. Numerical evaluation is based on surveys and field research. The modified version (M-GAM), developed by Tomić and Božić [25], is preceded by identical survey and field research. This method includes the evaluation and opinion of tourists, which often and decisively affects the final results of the

Table 1: Socio-demographic profile of the respondents

Geoexperts		
Gender	Male	52.8%
	Female	47.2%
Average age	19–59 years	91.7%
	More than 60	8.3%
Used form of transport	Car	83.3%
	Bus	16.7%
Place of living	AP Vojvodina	2.8%
	City of Belgrade	13.9%
	Šumadija and Western Serbia	11.1%
	South and East Serbia	72.2%
Education	MSc	44.4%
	Ph.D.	55.6%

assessment. Both models, through numerous studies, have already been applied in the evaluation of different areas of Serbia and neighboring countries [24,25,45–60]. Most of the research geosites of the Toplica district have not been publicly exposed, have not yet been geotouristically evaluated, and rarely been visited individually, so the GAM method proved to be adequate for this research.

In the analysis using the method GAM, two groups of values are evaluated. The first group, Main Scientific Values (MV), was created according to the natural characteristics of geosites. They consist of three groups of indicators – Scientific/educational value (VSE), Scenic/aesthetic value (VSA), and Protection value (VPr), with a total of 12 sub-indicators evenly distributed. For each geosite and each of the sub-indicators, the geospatial experts score one of the following numerical values: 0.00, 0.25, 0.50, 0.75, or 1.00. The total summary of these three groups of indicators is the final score for the MV (equation (1)).

$$\mathrm{MV} = \mathrm{VSE} + \mathrm{VSA} + \mathrm{VPr} = \sum_{i=1}^{12} \mathrm{SIMV}_i \quad \text{where } 0 \leq \mathrm{SIMV}_i \leq 1, \quad (1)$$

where SIMV_i represents the sub-indicators of the MV (i = 1, …, 12).

The second group, the Additional Values (AV), refers to the evaluation of the degree of a tourist-functional position of the geosites. They consist of two groups of indicators – Functional values (VFn) and Tourist values (VTr) – with a total of 15 sub-indicators, unevenly distributed into six and nine sub-indicators. Following the same principle, the same summation procedure is performed to obtain AV (equation (2)).

$$\mathrm{AV} = \mathrm{VFn} + \mathrm{VTr} = \sum_{j=1}^{15} \mathrm{SIAV}_i \quad \text{where} \quad 0 \leq \mathrm{SIAV}_i \leq 1, \quad (2)$$

where SIAV_i represent the sub-indicators of the AV (i = 1, …, 15).

According to the definition of the method GAM, the addition of the two groups of values gives the total result for each geosite (equation (3)).

$$\mathrm{GAM} = \mathrm{MV} + \mathrm{AV}. \quad (3)$$

A matrix divided into a total of nine fields was created for the graphical representation of the overall evaluation results. The H axis consists of the MV score, ranging from 1 to 12. The Y axis consists of the AV score, ranging from 1 to 15. Depending on the final result, a specific field of the matrix and the so-called "tourist value" is determined for each geosite. In order to better understand the values obtained, the standard classification (low, moderate, high) has been slightly modified. The level "moderate" is divided into "moderately high" and "moderately low" to highlight the tendency of geosites to have a high or low tourist value.

3.4 Data analysis

The remaining analyses were performed using the GIS. GIS and numerical modeling are becoming powerful tools [61] for inputting, editing, analyzing, creating, and improving spatial data. GIS Software package Quantum Geographical Information System 3.18. Zurich (QGIS) was used for data processing. For spatial analysis, the System for Automated Geoscientific Analyzes extension was used in the software. The methods of digitization, vectorization, and geo-referencing are used [27]. A raster grid with geo-referenced coordinates is downloaded. Then, the boundaries of the Toplica district were determined in vector format and connected to the locations of geosites within the district. The SRTM Digital Elevation Model (DEM) was also used. Using the GIS software, the boundaries of the Toplica district were cropped for processing purposes. Elevation zones were determined using QGIS within DEM. The IDW interpolation model was also used for geostatistical analysis and data modeling. Surface grids were created based on the defined geosite locations as well as the data obtained through the analysis of GAM. Using QGIS, the areas of the gravitational influence of the studied geosites were measured and analyzed based on the created raster representation.

Although there are several methods, the IDW method is preferred because it assumes that each measured point influences the locations that decrease with distance. This is one of the most commonly used deterministic interpolation methods for creating analytical distribution maps. It is considered a suitable method for the distribution of grouped points (clusters) in local space, such as the geosites under study. IDW is one of the spatial interpolation techniques that allows conversion of discrete measurements into a continuous spatial distribution. It is based on the assumption that neighboring values contribute more to the interpolated values than distant observations. For predicting values at any unmeasured location, IDW uses the measured values in the vicinity of the prediction location. It is based on the assumption that neighboring values contribute more to the interpolated values than distant observations. For predicting values at any unmeasured location, IDW uses the measured values in the vicinity of the prediction location. It is characterized by ease of use, clear and efficient interpretation of results [62], intuitiveness, and the "bull's eye" effect. The IDW interpolation method has not been used in the analysis of GAM. In the field of tourism, the method has been used with the implementation of GIS in the interpretation of the GIS-based tourist index [63], the analysis of social networks for tourists [64], the comparison of tourist images of the destination [65], the evaluation of the tourism potential of rural areas [66], the evaluation of the tourism suitability of wetlands [67], emotion mapping in urban areas [68], and sustainable tourism planning [69].

The general formula for IDW is as follows [70]:

$$Z = \frac{\sum_{i=1}^{n} \omega_i z_i}{\sum_{i=1}^{n} \omega_i}, \omega_i = \frac{1}{d_i^p}(2), \quad (4)$$

where Z represents the interpolated value; z_i is a known value; n is the total number of known values used in the interpolation; d_i is the distance between known and interpolated values; p is the power parameter where the weighting coefficient decreases as the distance between the interpolated points increases; the power parameter as an exponent of the distance between points, is defined by the most commonly used value (2) [71]. During the research, the calculated MV and AV of each geosite are used to convert into spatial values based on the IDW interpolation method. The overall results of GAM give a better overview of the tourist value of the place.

In the second part of the study, network analysis was used to analyze the traffic accessibility of geosites by determining their temporal range. Isochronous maps ("time-contour maps" or "travel-time maps") are based on the assumption that accessibility is a criterion that decisively influences tourist suitability. The criterion that primarily influences the tourist suitability of a geosite is its accessibility. The management of geotourism resources and the tourist development of geotopes are related to this criterion. Inaccessible sites require much more investment in infrastructure, which affects their tourism profitability. Due to the temporal distance, isochronous maps show the availability and analyze the space and points of interest (tourist infrastructure, tourist attractions, and geosites). The isochronous method of GIS has been applied in solving tourist traffic problems, determining traffic accessibility of attractions using GIS in Ukraine [72], analyzing the results of traffic accessibility of public transport in Warsaw, Poland [73], understanding the potential for the development of transit-oriented tourism [74], and analyzing the availability of roads to tourist destinations [75]. This method is also used in the multidimensional representation of natural and cultural heritage in Slovenia [76], visualization of tourism planning patterns [77], and identification of the most suitable mine sites for geotourism planning [78].

In the creation of the isochron maps, the geospatial data of the geosites in vector format and the road network of the OpenStreetMaps platform in vector format were used in one of the ORC (OpenRouteService) algorithms of the QGIS plugin.

Through the algorithm of the installed plugin, a set of polygons was created based on the road network around the given location. The measured polygons represent areas that can be reached within a certain distance in time. Travel times are calculated for each segment using average speed limits for different road types and considering different gradients or road surfaces. The parameters of the analysis were based on the results of the survey, which showed that more than 83% of the respondents use a car for tourist visits. The analyzed space has a local character; time intervals of 15 min were used. Geosites are evaluated by availability, from highly available to low available and unavailable (or slightly available), with moderately-high and moderately-low transition variants. The objective is to use a vector traffic network over a time radius to determine the traffic accessibility of geosites and analyze their suitability for tourist visits. In this way, it will be shown how isochron maps can be a gateway for more efficient geotourism organization and planning in the Toplica district.

4 Results

4.1 GAM numerical analysis

The previously described geosites of the Toplica district were evaluated using the GAM methodology. The results (Table 3) show the uniformity of indicator scores for the MV and AV of all geosites. The results also indicate a large mutual difference in the total GAM values between them. Such a relationship indicates a great potential but uneven tourism development of the studied area.

The ratings of the MV indicators presented in Table 3 highlight the Devil's City geosite. Undoubtedly, the best evaluated, with a high overall score (9.12), stands out with extremely high scores for Scientific/educational value (3.27). The consequence of sustainable tourism management is high scores for the Scenic/aesthetics and Protection sub-indicators (Table 2). Devil's City has a relatively small area, and the structure of the relief is limited, so it is not surprising that it is rated lowest in terms of Viewpoints.

Approximately equal ratings of all Main indicators, with better rated Scenic/aesthetic sub-indicators, are the result of Prebreza's geosite assessment. The limitation of the relief structure in this case also affects the low scores of

Table 2: Sub-indicator values given by geoexperts for each analyzed geosite – Branko's tower (GS-1); Landform group near the village of Krčmare (GS-2); Treska limestone formation (GS-3); Ivan's tower (GS-4); Devil's City (GS-5); Prebreza paleontological site (GS-6)

MV	GS-1	GS-2	GS-3	GS-4	GS-5	GS-6
Scientific/educational values (VSE)						
1. Rarity (SIMV1)	0.47	0.28	0.35	0.40	0.76	0.54
2. Representativeness (SIMV2)	0.44	0.35	0.44	0.51	0.85	0.64
3. Knowledge of geoscientific issues (SIMV3)	0.20	0.15	0.30	0.30	0.85	0.60
4. Level of interpretation (SIMV4)	0.37	0.37	0.49	0.51	0.81	0.63
Scenic/aesthetic (VSA)						
5. Viewpoints (SIMV5)	0.18	0.18	0.33	0.38	0.59	0.33
6. Surface (SIMV6)	0.33	0.25	0.46	0.42	0.83	0.56
7. Surrounding landscape and nature (SIMV7)	0.40	0.35	0.44	0.49	0.78	0.55
8. Environmental fitting of the sites (SIMV8)	0.75	0.60	0.68	0.78	0.79	0.72
Protection (VPr)						
9. Current condition (SIMV9)	0.38	0.33	0.42	0.38	0.74	0.54
10. Protection level (SIMV10)	0.10	0.12	0.11	0.38	0.78	0.50
11. Vulnerability (SIMV11)	0.42	0.38	0.44	0.39	0.60	0.49
12. Suitable number of visitors (SIMV12)	0.28	0.29	0.35	0.42	0.74	0.54
AV						
VFn						
13. Accessibility (SIAV1)	0.17	0.22	0.20	0.33	0.80	0.56
14. Additional natural values (SIAV2)	0.27	0.28	0.27	0.39	0.62	0.38
15. Additional anthropogenic values (SIAV3)	0.20	0.26	0.22	0.29	0.54	0.44
16. Vicinity of emissive center (SIAV4)	0.40	0.38	0.34	0.38	0.46	0.49
17. Vicinity of important road network (SIAV5)	0.40	0.42	0.34	0.44	0.65	0.50
18. Additional VFn (SIAV6)	0.12	0.12	0.14	0.17	0.52	0.34
Touristic values (VTr)						
19. Promotion (SIAV7)	0.17	0.15	0.20	0.27	0.80	0.47
20. Organized visits (SIAV8)	0.15	0.13	0.17	0.24	0.84	0.44
21. Vicinity of visitors' centers (SIAV9)	0.30	0.29	0.28	0.35	0.47	0.43
22. Interpretative panels (SIAV10)	0.19	0.11	0.14	0.16	0.71	0.48
23. Number of visitors (SIAV11)	0.13	0.19	0.19	0.19	0.69	0.31
24. Tourism infrastructure (SIAV12)	0.10	0.10	0.13	0.18	0.70	0.40
25. Tour guide service (SIAV13)	0.19	0.10	0.13	0.17	0.70	0.31
26. Hostelry service (SIAV14)	0.35	0.36	0.35	0.36	0.57	0.53
27. Restaurant service (SIAV15)	0.26	0.30	0.27	0.30	0.69	0.49

Table 3: Overall ranking of the analyzed geosites by GAM – Branko's tower (GS-1); Landform group near the village of Krčmare (GS-2); Treska limestone formation (GS-3); Ivan's tower (GS-4); Devil's City (GS-5); Prebreza paleontological site (GS-6)

Geosite	MV			∑	AV		∑	GAM	Field
	VSE	VSA	VPr		VFn	VTr			
GS-1	1.48	1.66	1.18	**4.32**	1.56	1.84	**3.40**	***7.72***	Z_{21}
GS-2	1.15	1.38	1.12	**3.65**	1.68	1.73	**3.41**	***7.06***	Z_{11}
GS-3	1.58	1.91	1.32	**4.81**	1.51	1.86	**3.37**	***8.18***	Z_{21}
GS-4	1.72	2.07	1.57	**5.36**	2.00	1.87	**3.87**	***9.23***	Z_{21}
GS-5	3.27	2.99	2.86	**9.12**	3.59	6.17	**9.76**	***18.88***	Z_{32}
GS-6	2.41	2.16	2.07	**6.64**	2.71	3.86	**6.57**	***13.21***	Z_{22}

The bold values are represents Σ(MV) = VSE + VSA + VPr; Σ(AV) = VFn + VTr; GAM = Σ(MV) + Σ(AV).

the sub-indicators for Viewpoint. On the other hand, the highly rated sub-indicator Environmental fitting of the sites is a result of protective measures. Three geosites, Ivan's tower (5.36), Treska (4.81), and Branko's tower (4.32), were given lower MV scores. These sites are rated better in terms of the Scenic/aesthetic sub-indicators. In relation to the Protection indicator, they were rated significantly lower. Thus, these are sites of exceptional aesthetic and landscape value, but they are poorly known to the public and only partially studied scientifically. This is confirmed by the extremely high rating of the Environmental fitting of Ivan's tower geosite. The lowest rated geosite is GS-2, with a low overall rating of the MV (3.65). The very low scores of the indicator of Environmental fitting of the sites and especially the extremely low scores related to Protection are evidence of its unrecognizability.

The AV contain important indicators of geotourism development. As can be seen from Table 3, Devil's City also stands out here with a high rating (9.76). This rating is a consequence of the high-rated indicators of Tourist values and VFn, especially the sub-indicator of Promotion. The geosite of Prebreza is in second place with an overall score of 6.57. The proximity of the municipal center of Blace has a significant impact on the higher rating of the Tourist values (3.86) compared to the VFn (2.71). This relationship also applies to the sub-indicators. The Accessibility and Road network sub-indicators were rated the highest, while the Number of visitors and Guide service were rated the lowest. The ratings indicate a high geotourism potential, but also its low utilization. The other geosites GS-1 to GS-4 are rated low in terms of AV. The ratings of all geosites are between 3 and 4, indicating low tourism recognizability and modest infrastructural investments.

After comparing the final results, the differences between the MV and AV become clearer through the positions of the 6 geosites in the GAM matrix (Figure 3). The best-valued geosite GS-5 Devil's City is also the best positioned, in the high-ranking field Z32 of the GAM matrix. The position indicates highly evaluated MV and moderately high evaluated AV. In total, the tourist value of this geosite is 18.88 (Table 3). In second place, according to the total score of GAM, is the site GS-6 Prebreza. The MV of moderately high level and the AV of moderately low level, position this geosite in the field Z22 of the GAM matrix. The overall tourism value, defined as moderately low, is scored as 13.21. The three geosites, GS-1, GS-3, and GS-4 are positioned in field Z21 of the matrix. Their MV are defined as moderately low, and AV are defined as low, which significantly affects their position in the GAM matrix. The overall rating of all geosites is about the same. The scores of the indicator groups of the geosite GS-4 Ivan's tower are slightly higher than the scores of the other geosites. Thus, it is best positioned in the Z21 area, the GAM matrix. The worst-rated geosite GS-2 is located in the Z11 field of the GAM matrix and has the lowest ratings of the indicator groups. Its tourist value can be defined as low.

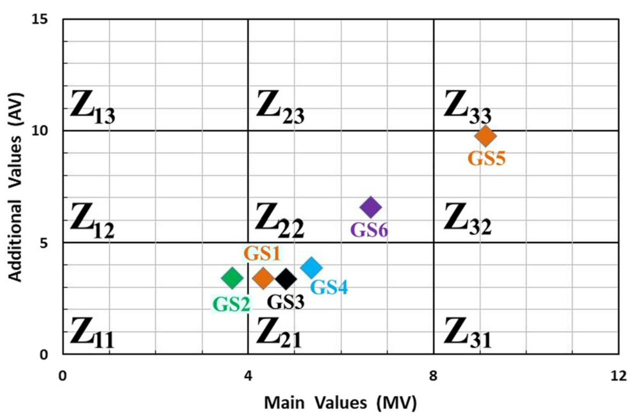

Figure 3: Scatterplot diagram of the GAM results – Branko's tower (GS-1); Landform group near the village of Krčmare (GS-2); Treska limestone formation (GS-3); Ivan's tower (GS-4); Devil's City (GS-5); Prebreza paleontological site (GS-6).

4.2 GAM geostatistical analysis

Based on the results of the numerical analysis of GAM, the values were interpolated into the surface raster. By visualizing the GAM indicator groups, a comparative distribution map was created (Figure 4). Since QGIS software also provides the ability to measure surfaces, it was used to

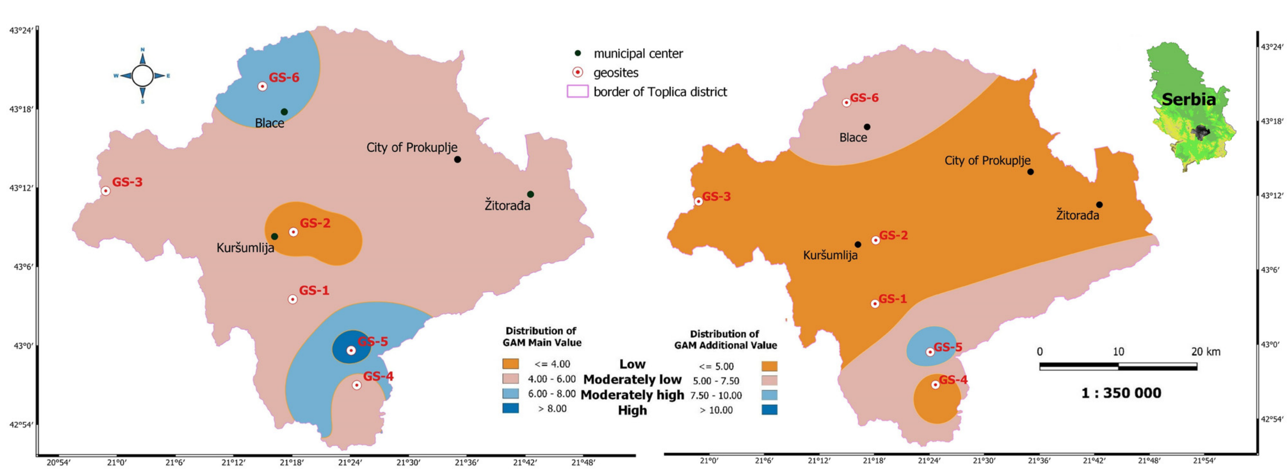

Figure 4: Distribution map of GAM values: Left – GAM MV; Right – GAM AV.

analyze the gravitational influence of geosites. The results of measuring the gravitational influence of geosites for MV, AV, and final GAM Tourist Values are presented in Table 4. Comparative examination of the interpolated areas in Figure 4 shows that both indicator groups almost equally participated in most of the geosites. There is a balance between scientific-educational and tourist-functional indicators.

According to Figure 4, two gravity centers are defined. They are located on different (opposite) parts of the interpolated area. It is more meaningful in terms of geosite Devil's City. The gravity range of the MV for this geosite is more expressive but has a smaller range of influence. As a result, there is a greater deviation in its ratings compared to the ratings of the other geosites. The measurement showed that the area is 224 km^2 (Table 4). The gravitational area for the AV of this geosite is much larger (520 km^2), but less meaningful because it has a smaller deviation of the GAM ratings. Another milder and less meaningful centroid is associated with the area of the gravitational influence of the geosite Prebreza. As a result of the smaller deviation of its ratings concerning the ratings of the neighboring geosites, its gravitational area for MV is smaller (171 km^2) – in terms of values, the value of GAM is on the lower limit of the moderately high level). The area of influence for AV is larger (364 km^2) because the scores of neighboring sites for this group of indicators are very low.

The deviation of the interpolated areas can be seen on Ivan's tower, as the values of the Main indicators are significantly higher than the values of the Additional indicators. The gravity area of influence is larger for the MV (95 km^2) than for the AV (40 km^2). This relationship is a consequence of the large differences in the GAM values (especially the AV) of these two neighboring geosites. The areas of the gravitational influence of other geosites overlap, so it can be assumed that they jointly participate in the interpolated area. This is particularly clear for the AV, where the three geosites GS-1, GS-2, and GS-3 form a common area between the two gravitational centers due to their low-scoring indicators. For the MV, the geosites Branko's tower and Treska, defined by the same distance segment, form a common gravitational influence area of 1,307 km^2. The worst evaluated gravity influence area of the geosite GS-2 is a single area of 108 km^2.

Based on Table 3, the total values of GAM were interpolated into the distribution map (Figure 5). On the map, separate areas of the geosites GS-1, GS-2, and GS-3 can be seen, then the common gravity area of the geosites GS-4 and GS-6, and the strongly pronounced gravity center of the geosite Devil's City. This ratio results from the total values of GAM (Table 3) and is a more plastic representation of the ratio in the GAM matrix. As a consequence of the best positioning in the GAM matrix, the area of gravitational influence of the geosite Devil's City (112 km^2) is related to the highest segments of the range (Figure 5). The common area of geosites GS-1 and GS-2 (337 km^2), and GS-3 (172 km^2), are the result of the lowest segment of the range – low defined tourist value (<9.00). Geosite GS-4 and GS-6, which are better positioned in the matrix GAM, belong to the moderately low segment of the range and form a common gravitational area (1,426 km^2).

Table 4: Area of gravitational influence of geosites (~km^2) – Branko's tower (GS-1); Landform group near village of Krčmare (GS-2); Treska limestone formation (GS-3); Ivan's tower (GS-4); Devil's City (GS-5); Prebreza paleontological site (GS-6)

	MV	AV	GAM
GS-1	1,633*	1,307*	337*
GS-2	108	1,307*	337*
GS-3	1,633*	1,307*	172
GS-4	95	40	1,426*
GS-5	224	520	112
GS-6	171	364	1,426*

*Equally participating in the common area.

4.3 Isochron analysis

Since most of the geosites gravitate to the area of the municipality center of Kuršumlija, it can be considered the carrier of geotourism development in the district. It was chosen as the starting point for the second part of the research. As a prediction for the improvement of the tourist offer of the study area, the isochron analytical map evaluates the geotourism potential of the sites through accessibility as the initial factor of geotourism activation. Similar analytical maps could be created for other municipal centers and tourist resorts of the Toplica district in order to expand the tourist offer and create geotourism routes.

The isochrone map based on the GIS algorithm was created in the area (Figure 6). It shows that the area of the Toplica district was divided into five differently colored isochron zones. The transportation and tourist accessibility of each of the six geosites is defined by its position in one of the isochron zones. Only one geosite was located within the first isochron zone. In the immediate vicinity of Kuršumlija, the Krčmare landform group is well below the maximum time interval of this zone (maximum 15 min). This site makes it highly accessible for tourists. On the border between the first and second isochrone zones, but with the

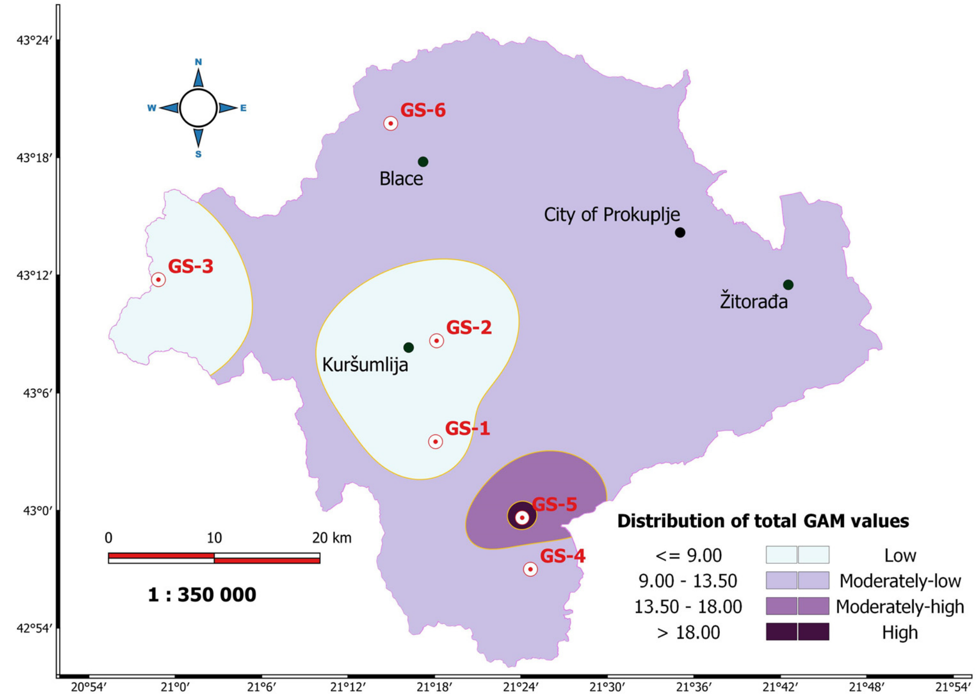

Figure 5: Distribution of the final GAM tourist values.

predominant belonging to the second zone, there is also a geosite, a Branko's tower. The location accessibility, determined by a maximum radius of 30 min, is defined as moderately high. The third isochrone zone includes two geosites, Devil's City and Prebreza. Although they are located in opposite parts of the district, their distance from Kuršumlija is almost the same. The temporal distance of not more than 45 min makes them moderately low accessible. According to the isochrone analysis, the most distant sites Treska and Ivan's tower are included in the fourth

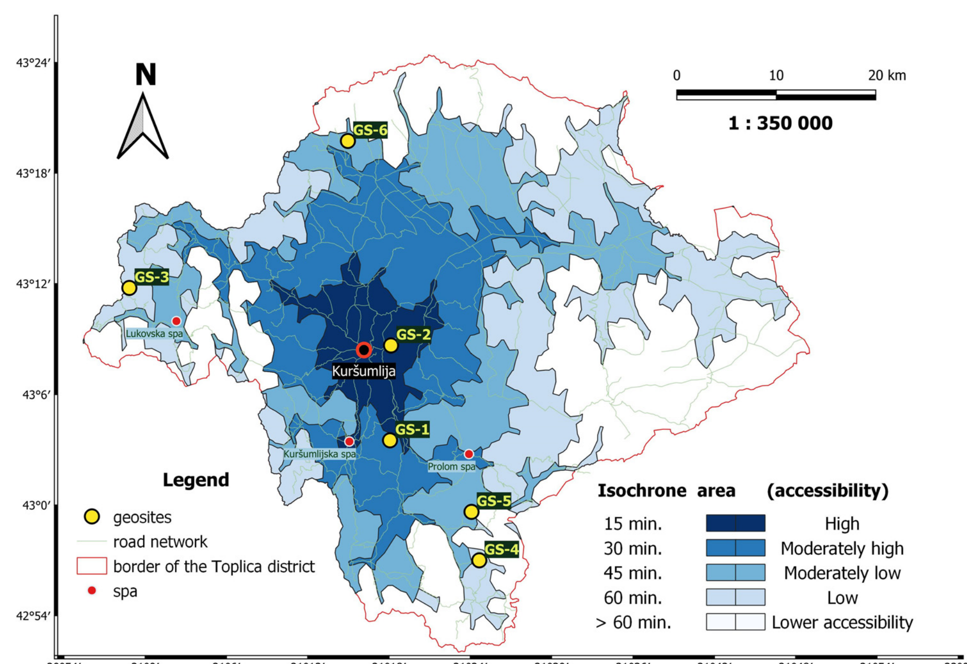

Figure 6: Perception of the tourist accessibility of geosites in the Toplica District.

isochrone zone with a maximum radius of 60 min. Equally distant from Kuršumlija and located at different ends of the Toplica district, their location could be classified as peripheral and their accessibility as low.

5 Discussion

Based on the objective evaluation of geoexperts through the GAM methodology, the results of the evaluation of the geotourism value of geosites were determined. The potential for geotourism development was evaluated using the analytical approach of isochron maps. By determining and comparing the results, the geotourism suitability of all six geosites of the Toplica district is defined: Branko's tower (GS-1), Landform group near the village of Krčmare (GS-2), Treska (GS-3), Ivan's tower (GS-4), Devil's City (GS-5), and Prebreza (GS-6).

Positioning in the Z21 field of the GAM matrix defines the low tourist value of the Branko's tower geosite (GS-1) as a result of the poorly evaluated AV. Conversely, positioning in the second isochrone zone defines accessibility as moderately high. This relationship indicates that this geosite is highly suitable for tourism and has significant geotourism potential. The geographic location near Kuršumlija Spa and Prolom Spa contributes positively to the geotourism potential, so this geosite can be described as "geotourism underutilized."

The positioning of the Krčmare landform group, in the first isochron zone, makes it highly accessible and therefore very suitable for tourist activities. Paradoxically, the GAM analysis rates for this geosite are the worst. They point out the total unfamiliarity of the geosite, the total lack of tourist information infrastructure, and promotional activities. Overall, the suitability of GS-2 for geotourism activities is exceptional. The geosite has a great geotourism potential, so it can be described as a completely "untapped potential."

Unlike the previous one, the Treska (GS-3) is evaluated with the lowest value in the results of both methods. Positioned in the Z21 field of the GAM matrix, the tourist value is considered as low. In the fourth isochrone zone, the accessibility is also classified as low. The general geotouristic suitability is significantly influenced by the proximity of Lukovska Spa as one of the receptive centers of the Toplica district. The scientific-educative-aesthetic value was noted, so the geosite Treska could be represented by the complementary tourist offer of the Spa. In this way, its tourist potential could be much better exploited.

The values of the GAM analysis of the geosite Ivan's tower (GS-4) highlight it as the best positioned in the Z21 field of the GAM matrix. Such a position defines its tourist value at the bottom of the moderately low level. The MV are significantly better rated than the AV. Due to the distance from Kuršumlija, it is located in the fourth isochrone zone. Its accessibility is rated as low. Geographically, this site is located near the Prolom Spa and near the highly rated Devil's City site (according to GAM results). These facts have a positive impact on the overall geotourism potential and significantly increase the suitability of this site for geotourism development. The qualitative and quantitative development of the tourist-functional infrastructure and appropriate promotional measures would make the best use of this geosite for the development of geotourism.

According to the GAM assessment, Devil's City (GS-5) is the best-evaluated geosite. Its positioning at the top of the Z32 field of the GAM matrix indicates its high tourist value. On the basis of the increased tourist value, the efficiency of the intensive implementation of tourist-functional measures and promotional activities can be seen. High scores of the sub-indicators MV and AV indicate an already established and recognizable geotourism complex with a defined tourist offer and active positioning in the tourist market of the Republic of Serbia. Further improvement of geotourism, according to the results, should be related to the expansion of the active tourist area and increasing the number of viewpoints. Due to the positioning in the third isochrone zone, the availability is classified as moderately low. Improvement of transport infrastructure and construction of access roads of higher category, would reduce the period of accessibility, which would further increase the geotourism potential of this geocomplex.

The second best ranked, according to GAM results, is Prebreza (GS-6). The MV, rated as moderately high, indicate its exceptional scientific and aesthetic importance and the recognition of the protected area. Other values were rated moderately low. As a result, there is insufficient tourist infrastructure and a low level of promotional activities. The overall tourism value of this geosite could be estimated at the upper limit of the moderately low level, with great potential for better evaluation through future research. As with the GS-5 transition, positioning in the third isochrone zone defines accessibility, so tourist convenience would be classified as moderately low. On the other hand, the proximity to Blace, one of the municipality centers, significantly increases the geotourism potential of this site. In terms of balanced geotourism development, it is necessary to take a series of infrastructural, organizational, and promotional measures to better exploit the geotourism potential of this geosite.

The models used vary considerably. GAM analysis involves numerical calculations and validity is ensured by the use of the software. It is considered one of the most practical methods for assessing geodiversity. It attempts to capture all aspects of geotourism. Certain limitations arise from the individuality and subjectivity of the assessment. The isochron method is a practical method that requires the use of GIS software and open source databases. It depends on their accuracy and precision, which are the limiting factors. Moreover, the methods overlap to some extent: (a) one of the sub-indicators of GAM refers to the evaluation of the classification of the road closest to the site in the spatial radius and (b) the isochron method takes a different approach. Practically, it considers accessibility through the time component, creating concentric polygons that can also be used for analytical purposes.

Comparison of results is complicated by the fact that only one of the geosite studied has been the subject of previous geotourism assessments. Using the GAM/M-GAM methodology, the Devil's City geocomplex was evaluated by comparing it with similar geological formations in the Balkan Peninsula [40] and in the USA [50]. In the mentioned studies it is placed in the Z22 field of the GAM matrix. The comparison of the results suggests that the tourist value of this geocomplex has increased significantly. The importance of this study lies in the fact that geological and geomorphological sites with different characteristics were evaluated for the first time at the regional level. In this way, the shortcomings of previous studies were successfully overcome.

At the regional level, it is difficult to identify identical results in terms of geoheritage assessment, but there are certain similarities. The results were analyzed and compared with those of national and foreign authors. Rock formations, massifs, and paleontological sites were evaluated using the methodology GAM/M-GAM in the areas of Fruška Gora mountain in Serbia [24] and Papuk Planina Geopark in Croatia [45], Drmno paleontological site in Serbia [46], gorges and canyons in Serbia [25,47], Bela Crkva Municipality (Serbia) [48], Kopaonik National Park [51,56], speleological sites in Slovenia [52], Bakony–Balaton Geopark in Hungary [54,57], Sokobanja Basin [55] and Stara Planina mountain in Serbia [58], Eastern Anatolia, Turkey [59], and East India [60]. Experience shows that geomorphological objects – gorges, canyons, plateaus, massifs, and paleontological sites – are significantly better evaluated and are located in the moderate and higher value fields of the GAM matrix. Geological and geomorphological sites (rock formations, caves, geological profiles) are found in fields with moderate and low values of the GAM matrix. Such results can be observed also in our study. The analysis of the values of the indicators and sub-indicators shows that the scientific-aesthetic values are significantly better evaluated in comparison with the functional-touristic values, which is consistent with the results of the study. The significantly worse evaluation of the traffic accessibility of the geosites represents a similar pattern to that identified in this research.

The application of the results can be manifold. The experience from the above studies shows that the results can be used in several aspects. Quantitative and qualitative improvement of functional and tourist infrastructure must be preceded by geoconservation. Functional-touristic formation includes local roads, hiking trails, direction signs, tourist information boards with the main features of the place and viewpoints. At the same time, it is possible to define the planned accommodation capacities and rest areas and prepare parking places for tourists. The second part of the application of the results refers to the planned actions for the design of the geotourism offer – the establishment of visitor centers, the organization of guide services and the elaboration of geotourism tours, and promotional activities that would form the final geotourism product. The isochron algorithm based on availability can be used in the formation of tourist routes. The studied geosites would thus be linked to form a unique, time-balanced geotourism product. Algorithm-based maps can be constructed to work on the interface of smart devices, which can be useful for tour operators and tourists in planning group or individual visits, defining cycling routes between geosites, and locating gastronomic services in geosite areas.

Future research may focus on developing new models for geoheritage assessment, better qualitative and quantitative research, and assessing the geodiversity of the area under study. Additional analysis and field research could include sites not covered in this study. By applying new methodological techniques, GIS, and remote sensing, the presented results can be improved and thus contribute comprehensively to future geospatial research. With greater spatial coverage and better quality of research, the geodiversity-rich area of the Toplica district would be better viewed.

6 Conclusion

The main aspect of this study is the evaluation and comparison of the current state and geotourism potential of the Toplica district, for the first time in whole, based on the selected geosites. Most of the geosites are moderately represented scientifically and have never been included in the geotourism assessment before. For the evaluation and assessment of the current geotourism value of the geosites, the method GAM was applied. The results confirmed the high MV and AV of the Devil's City geocomplex. Among the studied geosites, it is the only one that is recognized by the public, is active in tourism, is promoted to a significant extent, and is functional, so the highlighted results are to be expected. According to the results, the Prebreza paleontological site stands out, with a significantly better rated MV compared to the AV, as a result of the very low rated Tourist values. The analysis of the other geosites undoubtedly confirms their significant scientific and aesthetic values, but also very low evaluated AV as a result of anonymity for tourists and lack of tourist infrastructure. The GIS-based isochronous analysis indicated that the most accessible geosites GS-2 and GS-1 were also the lowest rated by the GAM analysis. Their accessibility, rated as high, makes them extremely suitable for geotourism activities, so they can be described as completely underutilized. At the same time, the highest rated geosites in the analysis of GAM were rated lowest in terms of accessibility. Improving the transport infrastructure would shorten the time interval of accessibility, which would significantly increase their geotourism potential.

The development of geotourism in Serbia is influenced by the fact that a small number of geosites are highly equipped for tourism dissemination purposes. Devil's City is one of the most equipped geosites for tourists. Its high value is also defined by all previous studies in which it was evaluated. The present study also confirms this. However, it is impossible to focus the developed geotourism only on one geosite. The aim of this study was to consider other sites that have not been used for intensive touristic promotion yet. The study confirms its scientific and aesthetic values. The results also show that the geosites with the highest accessibility are functionally totally inadequate or extremely poorly equipped and hardly known to the public, even by geoexperts who were included in the survey covered by this study.

The actions that should be taken in the first place must be related to a better and more detailed professional and scientific study of the geosites. Geological and geomorphological surveys at most geosites were carried out in the second half of the last century. New methodological, technical, and technological approaches offer the possibility to better understand these phenomena. The best example is the Devil's City, which is the subject of numerous studies and active projects, but it is necessary to study other geosites as well. Functional training must be preceded by geoconservation measures that reduce natural degradation and even minimize anthropogenic impacts on sites. The functional equipment of geosites would bring them closer to tourists. This mainly refers to local traffic communication, access roads, information boards, road signs, and layout of viewpoints. In this way, the research results can become the basis of regional policy and planning for the future development of geotourism, complementary to other forms of tourism represented in the research area.

According to the current situation, geotourism in the Toplica district is focused only on one site. The adaptation of other geosites would enrich and enhance the tourist offer of the Toplica district. By creating geotourism tours, geosites would become more attractive and visited by tourists. Its connection to a unique geotourism product is a support for the already established spa tourism. As the Toplica district is considered a depopulated area, economically dependent mainly on tourism, this way of using the sites is a direct support for the additional economic development of this area. The development of rural tourism would be accelerated, affecting the economic flows of the local population and reducing depopulation. A more diverse offer attracts tourists with different interests and affects the mass of tourist visits. Identification of new geo-sites will enable further development of geotourism and tourism recognition of geosites of the Toplica District at national and regional levels. In this way, the research results can become the basis of regional policy and planning for the future development of geotourism, complementary to other forms of tourism represented in the research area, and can be applicable to the territory of the entire Republic of Serbia.

Acknowledgements: This work was supported by the Ministry of Education, Science and Technological Development under contract number 451-03-68/2022-14/200091.

Funding information: This research received no external funding that has supported the work.

Author contributions: Conceptualization and methodology: M.I., A.V., and T.L.; GIS software and mapping: M.I. and A.V.; technical editing: M.I. and N.M.; field surveys: M.I. and V.B.; supervision: A.V.; All authors discussed the results and contributed to the final manuscript. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: Authors state no conflict of interest.

Supplemental materials: As supplemental material, we attached a link to our survey that was conducted as part of the GAM methodology: https://forms.gle/x1PKSEinv3f5ZT7y7.

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