Research Article

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# Loess and geotourism potential of the Braničevo District (NE Serbia): From overexploitation to paleoclimate interpretation

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**Abstract:** The use of loess as a resource for paleoclimatic research is quite well established. In Serbia, a significant number of loess sequences have been preserved in old brickyards. The results of the previously conducted research indicate extremely valuable data that enable a better understanding of the mid- to late Pleistocene climatic evolution in this part of Europe, as well as human dispersal from Africa to Europe via the so-called Danubian migration corridor. The aim of this study is to evaluate the geotourism potentials of the loess profiles in Požarevac (northeastern Serbia). The goal is to determine their geotourism potential for paleoclimate interpretation. The Modified Geoheritage Assessment Model method has identified exceptional geotourism potentials that can be implemented in the tourism market. Paleoclimatic data can serve as indicators for the development of scientific visitor centers for the promotion and popularization of paleoclimate science and museums, which will affirm sustainable socio-economic development through multidisciplinary interpretation. By combining geological, paleoclimatic, archaeological, biological, and other values that reveal natural and anthropogenic events from the distant past, it is possible to create a very competitive geotourism destination, whose sustainability can be passed on to future generations.

**Keywords:** loess, paleoclimatic interpretation, sustainable geotourism, Braničevo District (Serbia)

## 1 Introduction

Approximately 10% of the continental surface is covered by loess and loess-like sediments [1]. Because of its physical and geochemical properties, throughout human history, loess has been exploited for a variety of purposes ranging from agriculture [2], raw material for brick production [3,4], or even housing [5,6] in most regions where it is found. Apart from its "practical" use, loess has also great importance in the reconstruction of the past climate, because of its continuous deposition. The loess–palaeosol sequences (LPSs) are considered to be a valuable terrestrial archive, suitable for detailed investigations, which provide a better understanding of glacial–interglacial variability [7,8] for the last ~2.6 million years (Quaternary period) [9,10]. The oldest loess accumulations in Europe are located in the Danube River Valley [11–13]. Most of the studies about loess, conducted in Serbia, put focus on the loess plateaus situated in the Vojvodina region, northern Serbia. The reasons for this were multiple: continuity, thickness, and accumulation of this sediment, making the paleoenvironmental research far more complete. These studies lead to significant results, which contributed to a better understanding of climate changes during the Pleistocene [14,15]. However, apart from these well-studied LPSs, there are numerous marginal sections situated in the northeastern part of Serbia [12,16–19].

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Here, loess deposits drape the westward slopes of the Carpathian–Balkan Mountain chain and provide a useful insight into the climate dynamics of this region [12,17,20].

In the past 3 decades, new trends in tourism were developed, particularly oriented toward a proximate connection with abiotic elements of nature [21]. Loess represents an important geomorphic landscape that preserves significant data on paleoclimatic and paleoenvironmental changes on the surface of the Earth [22–24]. As geotourism disseminates Earth's science, these elements of the landscape are important assets for the development of nature-based tourism and they have the potential to become attractive geotourism destinations [25]. The connection between geotourism and loess sections is a recent idea that is continuously spreading worldwide [26]. The importance of loess profiles and the tourism potential of the loess landscape, as well as the possibilities of its inclusion in tourism, are presented by several authors in Serbia [25–31], Poland [21,22,32], Italy [33], and China [34,35].

Tourism in loess regions is still a rare phenomenon in the world [26], mainly because this valuable geoheritage is largely ignored by tourism stakeholders, and consequently, the tourist offer is still very limited [21]. One of the best practices in the world is demonstrated by the Luochuan Loess Geopark (the first loess geopark in China and in the world), which is mostly focused on the promotion of loess geomorphic landscapes. The geopark is well known for its LPSs and loess landscape formations such as loess columns, loess walls, and loess bridges. This geopark has great scientific and aesthetic values, and it attracts many tourists because of the well-developed and diverse loess landscape [35]. Likewise, loess sections are well presented in Huoshi Chai, Kungdongshan, Jingtai, Yellow River geoparks of China [36], and the White Dear Plateau (Chines Loess Plateau) [13]. Besides China, there are also some practices in Austria (the Krems-Wachtberg and Willendorf Paleolithic sites, Strazing loess profile), the UK (English Riviera Geopark), and Novohrad-Nógrád Geopark (Hungary – Slovakia) [28].

In Serbia, a project was initiated in 2008 by the Municipality of Inđija, which is still in its initial phase, due to the lack of funding. This project, named "Loessland," was intended to be set at the "Čot" loess profile, along the Danube River near the village of Stari Slankamen. The envisioned loess-themed museum, with a modern multifunctional visitor and research center, is planned to have an educational, scientific, and touristic function [37]. Recent landslide activation in 2022, on the 50 m tall loess cliff, definitely prolonged the first steps toward the Loessland creation, as the municipality focuses on new problems related to the stabilization of moved terrain.

The aim of this study was to investigate the geotourism potentials of the LPSs in the Braničevo District, in northeastern Serbia, which can be transformed into significant socio-economic values. The study was conducted using geotourism evaluation via the Modified Geoheritage Assessment Model (M-GAM) method. However, only three sites are currently available for further studies, as the Nosak LPS was levelled during the operation of the Drmno coal mine. Thus, Nosak will not be included in the evaluation process. In addition to the Braničevo District, there are numerous LPSs in other parts of Serbia, which have been studied for the purpose of paleoclimatic research and also have certain geotourism potentials. However, one of the advantages of this region is the existing archaeological and paleontological park Viminacium (located near the former Nosak LPS), which is already (to some degree) touristically and educationally utilized, making it a solid base for further development. Moreover, the inclusion of paleoclimatic interpretation, as an integral part of the tourist content of the city of Požarevac and its surroundings, would provide further scientific and educational information, which would satisfy already existing tourists who visit the archaeological and paleontological park Viminacium. Given the evidently rich geological resources used for paleoclimatic reconstruction, the potential for geotourism affirmation of this area is reflected in the potential for the establishment of sustainable scientific and educational interpretive values that can be highly positioned in the tourism market. Using the M-GAM method, the current state and perspectives of geotourism development will be determined on the basis of three loess profiles (Kisiljevo, Požarevac A and B), i.e., two geotourism sites.

## 2 Study area

Loess is aeolian sediment that can act as a detailed archive of past climate and environments [38]. Because it is one of few types of sediment that is deposited directly from the atmosphere on land, loess is special as a record of Quaternary climate change [39]. It is a product of polygenetic origin formed by weathering and pedogenesis in semiarid areas in grasslands and forested steppes and is a deposition of silt and clay triggered and caused by wind erosion, with full of minerals and in general, drains water very well. Loess is easily cultivated for planting seeds. Pedogenetic processes may take place in three different ways: (1) epigenesis, an accumulation of a mineral mass without loess properties, with high silt and lime content; (2) syngenesis, the accumulation of a mineral mass that is mainly of eolian origin; and (3) protogenesis, the accumulated mineral matter already has all the main loess properties because transport occurred subsequent to weathering and soil formation [40,41]. Loess deposits include sandy loam, loamy

sand, loamy loam, clayey loam, and loam altered during the soil formation process. These deposits are often mixed with other types of sediment that include loess loam, loess silt, loess-bearing rock debris, and layered loess.

Loess is rather ill-consolidated sediment of low compressive strength. It is stable, however, as long as it remains dry. Parting surfaces are vertical because capillary incrustations of lime developed around the roots of a grassy plant cover, lend a vertical texture to loess [42]. Loess usually erodes very slowly. As seen in China within the Watershed of the Yellow River, the Loess Plateau has been cultivated for centuries, but it is still used for agriculture today, and the erosion processes of land degradation did not exclude this area from agricultural production. On the other hand, loess is suspended in the water coloring the waters in the rivers and it is a well-known fact that the Yellow River gets its name from the coloring of loess material from the nearby plains.

Wind erosion as a process of land degradation is mostly recorded in deserts and coastal dunes and beaches, but also on the mountain peaks exposed to strong winds. Some wind erosion is recorded in the area under the Loess Plateau. Wind erosion is causing land degradation and problems to the plants to some extent in certain land conditions in agricultural areas. Type of land use is very important for the protection of loess from wind erosion, and those plots of land can be prevented by keeping the ground covered with plants. Contrary to loess, some dry and bare soils are more easily blown away by the wind. Wetting decreases cohesion between grains by two-thirds, and the angle of internal friction also decreases. Groundwater flow in loess will carry away fine, insoluble mineral particles, and this mechanical separation in loess can be accompanied by the solution of mineral particles. This process gives rise to depressions, sinkholes, loess wells, and collapse ravines and is much accelerated by gully erosion.

The Braničevo District is located in the northeastern parts of Serbia, about 60 km southeastern of the capital city of Belgrade. The administrative center and the largest city of this territory is Požarevac (latitude 44°37′ and longitude 21°11′), which is situated between three major rivers: Danube, Velika Morava, and Mlava. Approximately 12 km north of Požarevac lays Viminacium, an ancient Roman city and military camp, which represents one of the most unique archaeological sites in Serbia and is widely recognized as a valuable touristic attraction of this region [43–46].

The early geological and geomorphological studies around the city of Požarevac were conducted in the late 19th century [47]. Neogene sediments, which separate the modern alluvial plains of the Velika Morava and Mlava Rivers, form the uplifted geological structure Požarevačka greda (PG), on which the loess sediments are preserved and protected from fluvial erosion. According to the Central Paratethys stratigraphy [48], the Pannonian sands lay over the brackish lower Sarmatian clayey sands. The Pontian sands with coal layers are present in the north of the PG. Although they are about 150 m thick, they are tilted toward the Velika Morava River and are covered by its alluvial sediments [49]. PG is more than 100 m higher than the surrounding river terraces and presents a remarkable landscape on the eastern side of the city of Požarevac. Some smaller streams cut the PG perpendicularly and form alluvial fans as they enter lower terrain. In the northernmost part of the study area, on the right Danube Bank, the geological setting is very different. Neogene sediments cover the Devonian crystalline schist, which lies in the base of this structure [50] and reaches a height of 272 m a.s.l. near the Ram village. The position of the loess geosites Kisiljevo, Požarevac A, and Požarevac B investigated in this study is presented in Figure 1.

## 2.1 Kisiljevo loess–paleosol profile

**GS1 –** Kisiljevo (latitude 44°44′0″, longitude 21°25′0″) is the easternmost LPS in the Carpathian Basin so far investigated (Figure 2) [19]. It is named after the village it is located in. Not so many loess profiles are located in such diverse surrounding. The profile is exposed cca. 1 km south of the lake named *Srebrno jezero* (Silver Lake). After the building of the Iron Gate I Hydroelectric Power Station, to protect the village of Kisiljevo from the rising water level of the Danube River, this part of the river bed was artificially separated from the Danube River main course, becoming the Silver Lake. It exists today in a former river bed, shaped like the natural oxbow lake [51]. A few kilometers west of Kisiljevo is Zatonje sandy area, and about 25 km eastern from it, starts the Danube gorge. The loess section is 11 m thick of which the upper 8 m of the profile was investigated by means of environmental magnetic analyses, pedostratigraphy, and quartz optically stimulated luminescence (OLS) dating. According to the published ages [19], the profile accumulated during the last 32 ± 3 ky. The loess section in Kisiljevo probably covered a much wider area, but it was most likely reduced to the present dimensions by fluvial erosion. The profile is unique because it was revealed that the Kisiljevo LPS preserves some of the most extensive loess accumulation during the Holocene and Marine Isotope Stage (MIS) 2 thus far discovered in this part of Europe [19]. Such high accumulation rates are usually not observed in the well-investigated loess profiles in the Vojvodina region

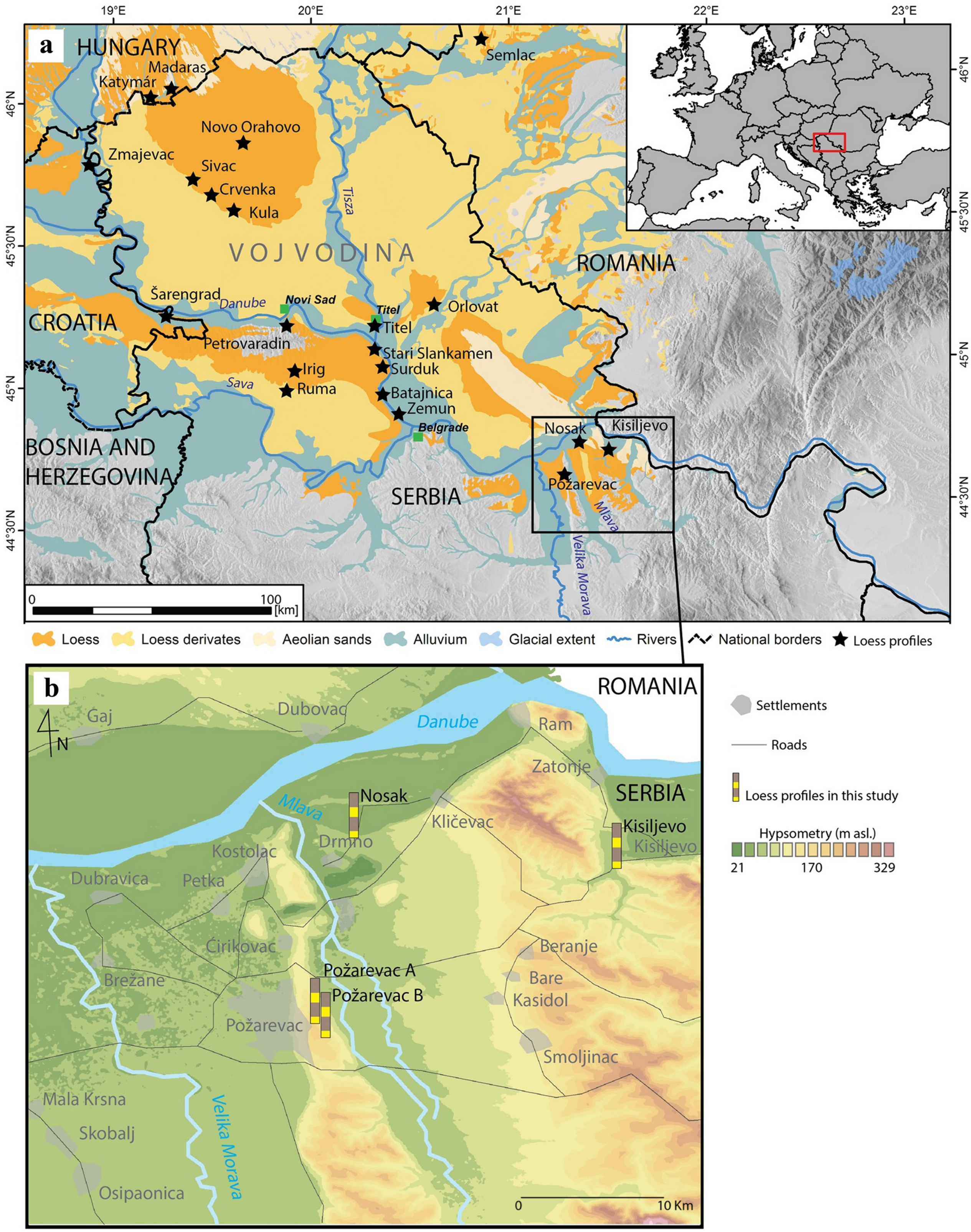


**Figure 1:** (a) Distribution of loess, loess derivatives, aeolian sand, and alluvium is shown according to Lehmkuhl et al. [52]. The LGM glacial extent and Digital Elevation Model shown according to Ehlers et al. [53] and JAXA EORC [54], respectively. Modified from Perić et al. [17] and (b) position of the evaluated sites near Požarevac city.

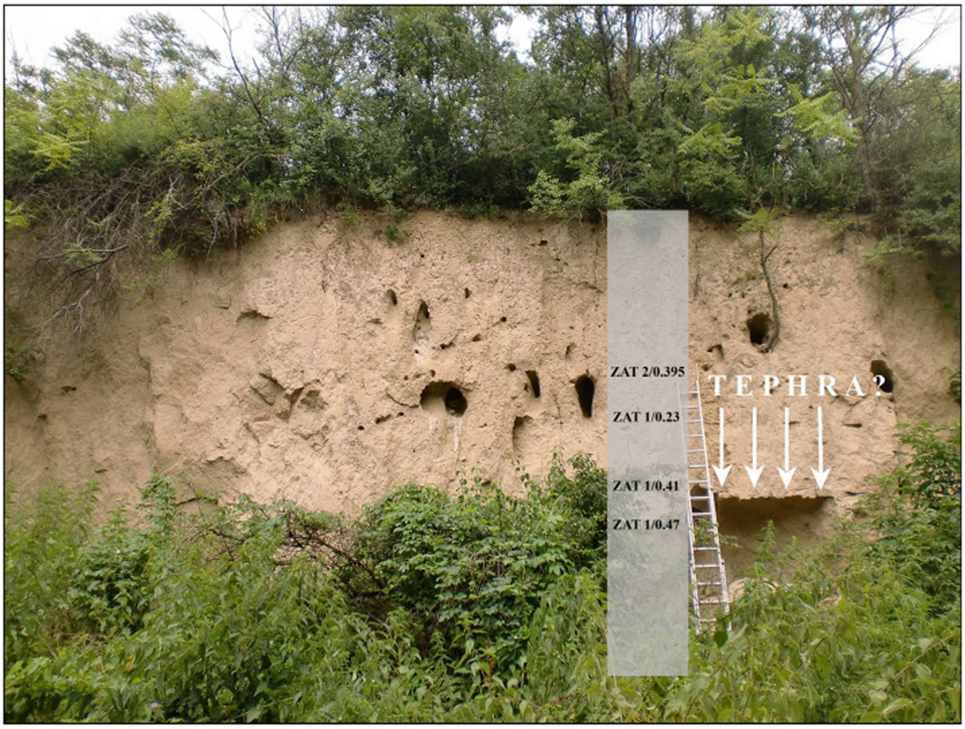


**Figure 2:** Kisiljevo loess–paleosol profile (Source: Perić et al. [19]).

(north Serbia). This implies that the atmospheric mineral dust activity in this region during the last cca. 12 ka was considerably higher than that according to the accepted model and that the Holocene climate was much more variable than previously assumed. Another surprising finding was the absence of MIS3 soil formation, which is not common for the Pannonian loess [19].

## 2.2 Požarevac A and B loess–paleosol profiles

GS2 – The Požarevac A and B loess–paleosol profiles (Figure 3) are located at the PG brickyard (latitude 44°37.755′, longitude 21°12.245′). Profile A is 9.35 m high, and B is 6.35 m. Together, they cover the last four glacial–interglacial cycles, and they are, therefore, the oldest of all the geosites in this study. At both profiles, the penultimate glacial loess is only 50 cm thick, and the antepenultimate is twice as thick. They have been studied for magnetic susceptibility, malacology, amino acid racemization, and grain size. Additionally, a luminescence-based chronology has been constructed, which suggests that the two profiles were formed during the last 264 ± 24 ky [18,55–57]. This profile is the only LPS in this region to have obtained July paleo temperatures (°C) based on malaco fauna assemblage covering the last 350 ky, using the malaco-paleothermometer method [58]. This implies that the longest existing record of unique paleotemperature in Serbia covers the Braničevo District. Paleo-ecological context based on published results is very detailed, which adds to the value of the geosite. Relatively warm temperatures that were obtained even in the glacial conditions make this location a refugium for thermophilous species. Older loess horizons are thin, and younger loesses are thicker. Still, younger loess is thinner in Požarevac, compared to the same layers in Nosak or Kisiljevo LPS. This can be explained by the southward migration of the main source of aeolian material, which is the Danube River. Nosak and Kisiljevo LPS had a higher accumulation rate for the Last Glacial, and Požarevac lags due to their closeness to the Danube [16].

Near Požarevac, there was also Nosak LPS, which was levelled during the operation of the Drmno coal mine. Thus, Nosak will not be included in the evaluation process. It was famous for the number of bones from Pleistocene mammals (300 and more), which were found in the Paleo river not more than 1.3 m deep. Due to the importance of found bones, the first paleontological park is made not far away from the place where they were found and was opened for tourism in 2014 [57].

**Figure 3:** Požarevac A and B loess–paleosol profiles (Photo: Aleksandar Antić).

## 3 Overexploitation, brickyards, and temporal environmental dynamics

Loess is seen as a construction material and was exploited in numerous brickyards in northern Serbia, but also in the vicinity of the city of Požarevac. It was noted in earlier research [28] that unlike more durable limestone or magmatic rocks, loess and Quaternary deposits can easily be removed, (bio)turbated, exploited, and the original loess geomorphology ruined. This is why geosites related to such fine-grained sediment are very prone to natural or human-induced erosion, and their "life expectancy" is shorter compared to geosites in other types of rocks. One of the characteristics of the loess is that it collapses vertically, leaving cliffs of newly exposed LPS behind it. These cliffs can today be seen on the right bank of the Danube River in Serbia, along with many houses built on and under the cliff. Having in mind the human activities around the loess profile, Marković et al. [59] published a proposal for cliff conservation where they wrote how the exploitation of these loess sequences for building bricks should be forbidden. Unfortunately, 25 years later, the number of houses increased.

Due to massive exploitation, many existing formations within the loess layers are ruined, and it is too late to explore them. On the other hand, extraction of the sediments can reveal evidence of paleo relief, which might not be in consistent with current topography, and thus provide information on the fast-changing environment, appealing to scientific research. This was the case in the exploitation of Ruma brickyard (Serbia), where the exposed paleosols were formed in depressions not existing on the modern topographic surface [7]. This extraordinary formation was visited by 60 experts in loess research in a single excursion organized after the most important loess conference called "Loess fest '09," which was held that year in Serbia.

## 4 Methodology

Studies associated with the assessment of geoheritage are relatively recent and fast-growing [60]. The assessment of geoheritage is an important step in the process of geotourism development [61], and it is widely accepted as a tool for the effective protection, development, and management of geological heritage [62]. The evaluation methodology has been constantly developing in the past two decades. The methodology applied in this study is based on the M-GAM model developed by Tomić and Božić [63]. This method represents a synthesis of previous geosite assessment methods [64–73] and is based on the importance factor (Im) introduced by Tomić [74]. The method considers the opinion of both tourists and experts, and neither is favored in the assessment process. The M-GAM was successfully applied in numerous studies for the evaluation of geoheritage in Serbia, Hungary, Iran, India, Slovenia, Greece, and USA [75–85].

The M-GAM model consists of two key indicators: main values (MVs) and additional values (AVs), which are divided into 12 and 15 indicators, each of them individually marked in a discrete way from 0 to 1. The distribution is based on two general types of values: MVs (mostly generated on the basis of geosite's natural attributes) and AVs (related to mostly human-induced factors). The MVs comprise three groups of indicators: scientific/educational (VSE), scenic/aesthetical values (VSA), and protection (VPr). However, the AVs are divided into two groups of indicators: functional (VFn) and touristic values (VTr). The MVs and AVs are presented in detail in Table 1. In total, there are 12 sub-indicators of MV and 15 sub-indicators of AV, which are ranging from 0 to 1, thus defining the M-GAM as a simple equation:

$$\text{M-GAM} = \text{MV} + \text{AV}. \tag{1}$$

Since MV and AV consist of three and two groups of indicators, respectively, their two equations are defined as:

$$\text{MV} = \text{VSE} + \text{VSA} + \text{VPr}, \tag{2}$$

$$\text{AV} = \text{VFn} + \text{VTr}. \tag{3}$$

Each group of indicators consists of several sub-indicators, so equations (2) and (3) can be described as follows:

$$\text{MV} = \text{VSE} + \text{VSA} + \text{VPr} \equiv \sum_{i=1}^{12} \text{SIMV}_i, \quad \text{where } 0 \le \text{SIMV}_i \le 1, \tag{4}$$

$$\text{AV} = \text{VFn} + \text{VTr} \equiv \sum_{j=1}^{15} \text{SIAV}_j, \text{ where } 0 \le \text{SIAV}_j \le 1. \tag{5}$$

Values $\text{SIMV}_i$ and $\text{SIAV}_j$ represent 12 sub-indicators of MVs ($i = 1, \ldots, 12$) and 15 sub-indicators ($j = 1, \ldots, 15$) of AVs. The main characteristic of M-GAM is that its focus is on both experts' and visitors' evaluation regarding the importance of each indicator in the assessment process. Visitors' participation in the assessment process is assessed through a survey where each respondent rated the Im of all 27 sub-indicators (from 0.00 to 1.00) in the M-GAM model (Table 1). The Im permits visitors to express their judgment about each sub-indicator in the model and to show how significant it is for them when choosing and deciding between several geosites that they wish to visit. After each respondent rates the importance of every sub-indicator, the average value of each sub-indicator is calculated and the final value of that sub-indicator is the Im. Then, the value of the Im is multiplied with the value that was given by experts (also from 0.00 to 1.00) who assessed the current state and value of each sub-indicator (Table 2).

This is conducted for each sub-indicator in the M-GAM model after which the values are added up according to the M-GAM equation, however, in this instance with more objective and accurate final results due to the addition of the Im. This parameter is determined by visitors and tourists who rate it in the same way as experts rate the sub-indicators for MVs and AVs by awarding them one of the following numerical values: 0.00, 0.25, 0.50, 0.75, and 1.00, marked as points. According to this, the Im is defined as:

$$\text{Im} = \frac{\sum_{i=1}^{K} \text{Iv}_i}{K}, \tag{6}$$

where $\text{Iv}_k$ is the assessment/score of one visitor for each sub-indicator and $K$ is the total number of visitors. Note that the Im parameter can have any value in the range from 0.00 to 1.00. Finally, the M-GAM equation is defined and presented in the following form:

$$\text{M-GAM} = \text{MV} + \text{AV}, \tag{7}$$

$$\text{MV} = \sum_{i=1}^{12} \text{Im}_i \times \text{MV}_i, \tag{8}$$

$$\text{AV} = \sum_{j=1}^{15} \text{Im}_j \times \text{AV}_j. \tag{9}$$

The value of the Im, which is rated by visitors, for each sub-indicator separately, is multiplied by the value given by experts, separately for each sub-indicator. This is performed for each sub-indicator in the model.

The Im (Table 2) is calculated for each sub-indicator in the M-GAM model related to Serbian tourists according to Božić and Tomić [75]. For the purposes of this research, the values of the Im have been adopted from the mentioned article. Tomić and Božić [63] conducted a survey among the visitors of the Lazar Canyon area (East Serbia) in July and August of 2013. The questionnaire consisted of 27 sub-

Table 1: Structure of M-GAM model values

| Indicators/sub-indicators | Description |
|---|---|
| **MV** | |
| 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 articles 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 |
| 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 areas, etc. |
| 8. Environmental fitting of sites ($SIMV_8$) | Level of contrast to nature, contrast of colors, appearance of shapes, etc. |
| VPr | |
| 9. Current condition ($SIMV_9$) | Current state of geosite |
| 10. Protection level ($SIMV_{10}$) | Protection by local or regional groups, national government, international organizations, etc. |
| 11. Vulnerability ($SIMV_{11}$) | Vulnerability level of geosite |
| 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 geosite |
| **AV** | |
| VFn | |
| 13. Accessibility ($SIAV_1$) | Possibilities of approaching the site |
| 14. Additional natural values ($SIAV_2$) | Number of additional natural values in the radius of 5 km (geosites also included) |
| 15. Additional anthropogenic values ($SIAV_3$) | Number of additional anthropogenic values in the radius of 5 km |
| 16. Vicinity of emissive centers ($SIAV_4$) | Closeness of emissive centers |
| 17. Vicinity of important road network ($SIAV_5$) | Closeness of important road networks in the radius of 20 km |
| 18. Additional VFn ($SIAV_6$) | Parking lots, gas stations, mechanics, etc. |
| VTr | |
| 19. Promotion ($SIAV_7$) | Level and number of promotional resources |
| 20. Organized visits ($SIAV_8$) | Annual number of organized visits to the geosite |
| 21. Vicinity of visitors centers ($SIAV_9$) | Closeness of visitor center 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 tourists (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 geosite |
| 27. Restaurant service ($SIAV_{15}$) | Restaurant service close to geosite |

*(Continued)*

**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 | 2–3 | 4–6 | 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 | 0–10 | 10–20 | 20–50 | 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 | 2–3 | 4–6 | More than 6 |
| 15. | None | 1 | 2–3 | 4–6 | More than 6 |
| 16. | More than 100 km | 100–50 km | 50–25 km | 25–5 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 | 12–24 per year | 24–48 per year | More than 48 per year |
| 21. | More than 50 km | 50–20 km | 20–5 km | 5–1 km | Less than 1 km |

*(Continued)*

Table 1: *Continued*

| Indicators/sub-indicators | | Description | | | |
|---|---|---|---|---|---|
| 22. | None | Low quality | Medium quality | High quality | Utmost quality |
| 23. | None | Low (less than 5,000) | Medium (5,001–10,000) | High (10,001–100,000) | 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. [73].

indicators from M-GAM. Each of the visitors was asked to assess the Im of every sub-indicator on a five-point Likert-type scale by rating it from zero to one (where 0 = not at all important; 0.25 = not very important; 0.50 = neutral;

**Table 2:** Sub-indicator values given by authors for each analyzed loess geosite

| Indicators/sub-indicators | Values given by authors | | Im | Total values | |
|---|---|---|---|---|---|
| **VSE** | **$GS_1$** | **$GS_2$** | | **$GS_1$** | **$GS_2$** |
| Rarity (SIMV1) | 0.25 | 0.25 | **0.89** | 0.22 | 0.22 |
| Representativeness (SIMV2) | 0.25 | 0.50 | **0.79** | 0.19 | 0.39 |
| Knowledge on geoscientific issues (SIMV3) | 1.00 | 1.00 | **0.45** | 0.45 | 0.45 |
| Level of interpretation (SIMV4) | 0.50 | 0.50 | **0.85** | 0.00 | 0.00 |
| **VSA** | | | | | |
| Viewpoints (SIMV5) | 0.50 | 1.00 | **0.79** | 0.39 | 0.79 |
| Surface (SIMV6) | 0.00 | 0.50 | **0.54** | 0.00 | 0.27 |
| Surrounding landscape and nature (SIMV7) | 0.75 | 0.75 | **0.95** | 0.71 | 0.71 |
| Environmental fitting of sites (SIMV8) | 0.50 | 0.50 | **0.68** | 0.34 | 0.34 |
| **VPr** | | | | | |
| Current condition (SIMV9) | 0.00 | 0.00 | **0.83** | 0.00 | 0.00 |
| Protection level (SIMV10) | 0.00 | 0.00 | **0.76** | 0.00 | 0.00 |
| Vulnerability (SIMV11) | 0.75 | 0.75 | **0.58** | 0.43 | 0.43 |
| Suitable number of visitors (SIMV12) | 1.00 | 1.00 | **0.42** | 0.42 | 0.42 |
| **VFn** | | | | | |
| Accessibility (SIAV1) | 0.00 | 0.00 | **0.75** | 0.00 | 0.00 |
| Additional natural values (SIAV2) | 0.25 | 0.00 | **0.71** | 0.17 | 0.00 |
| Additional anthropogenic values (SIAV3) | 0.25 | 1.00 | **0.70** | 0.17 | 0.70 |
| Vicinity of emissive centers (SIAV4) | 0.75 | 1.00 | **0.48** | 0.36 | 0.48 |
| Vicinity of important road network (SIAV5) | 1.00 | 1.00 | **0.62** | 0.62 | 0.62 |
| Additional VFn (SIAV6) | 0.00 | 0.00 | **0.59** | 0.00 | 0.00 |
| **VTr** | | | | | |
| Promotion (SIAV7) | 0.00 | 0.00 | **0.85** | 0.00 | 0.00 |
| Organized visits (SIAV8) | 0.00 | 0.00 | **0.56** | 0.00 | 0.00 |
| Vicinity of visitors centers (SIAV9) | 0.00 | 0.00 | **0.87** | 0.00 | 0.00 |
| Interpretative panels (SIAV10) | 0.00 | 0.00 | **0.81** | 0.00 | 0.00 |
| Number of visitors (SIAV11) | 0.00 | 0.00 | **0.43** | 0.00 | 0.00 |
| Tourism infrastructure (SIAV12) | 0.00 | 0.00 | **0.73** | 0.00 | 0.00 |
| Tour guide service (SIAV13) | 0.00 | 0.00 | **0.87** | 0.00 | 0.00 |
| Hostelry service (SIAV14) | 1.00 | 1.00 | **0.73** | 0.73 | 0.73 |
| Restaurant service (SIAV15) | 1.00 | 1.00 | **0.78** | 0.78 | 0.78 |

GS1 –Kisiljevo; GS2 – Požarevac A and B.
Bold values represents Importance factor values used from the article Tomič and Božič [62].

0.75 = somewhat important; and 1.00 = very important). A total of 96 visitors filled out the questionnaire.

Based on the obtained results, a matrix of MVs (*X*-axes) and AVs (*Y* axes) is created (Figure 4). The matrix is divided into nine fields represented by $Z(i, j)$, $(i, j = 1,2,3)$. Depending on the final score, each geosite will fit into a certain field. For example, if a geosite's MVs are 9 and AVs are 8, the geosite will fit into the field $Z_{23}$.

# 5 Results

## 5.1 M-GAM analysis

### 5.1.1 MVs

Detailed evaluation of the investigated loess profiles for geotourism affirmation included consideration of VSE and VSA as well as VPr values. Additionally, VFn and VTr values were assessed in order to obtain a detailed information on the current state of tourist use of these geosites. When it comes to rarity, all sites received a score of 0.25, which indicates that these loess profiles are a regional phenomenon. Furthermore, the representativeness sub-indicator was assessed for each loess profile individually. The Kisiljevo site received low values (0.25) of representativeness due to lower configuration and general appearance, while the loess profiles in Požarevac received medium values of representativeness due to general geological attractiveness. All loess profiles have been studied by international experts, and these studies have been published in international scientific journals; thus, the sub-indicator for knowledge on given geological issues is rated with the highest values for all loess geosites. The level of interpretation was assessed with a score of 0.50, because it was determined that the given geological processes are very good for paleoclimate research. However, the interpretation of the given sites is not so favorable, because these processes are not so easy to explain to common visitors. Therefore, a certain geotourism management structure should invest more creative and innovative ideas for sustainable interpretation of the paleoclimate data.

Aesthetic values are generally assessed as favorable, since all loess profiles are located in a relatively appropriate natural environment. The only exceptions are the loess profiles in Požarevac, which are located in the immediate vicinity of a private brickyard company. However, this did not affect the aesthetic values because it is considered that the company's activities do not significantly influence the aesthetics of the loess profiles.

There are a number of challenges and problems in terms of protection. Primarily, the lack of institutional protection of this geoheritage is a crucial inconvenience, because the loess profiles are currently not recognized as geological sites that need to be protected. In addition, there is no awareness among the local population about the scientific values of the loess profile and about the necessary protection measures. Therefore, geotourism popularization and affirmation of paleoclimatic reconstructions could potentially affect the establishment of adequate protection and conservation measures. A significant advantage of loess profiles is that a large number of visitors can access the profiles, without negative anthropogenic impacts on the geosites themselves, which is not the case with all geotourism sites (e.g., caves). Therefore, all protection ratings are low, except for the sub-indicator for the appropriate number of visitors, which received the highest rating for both geosites.

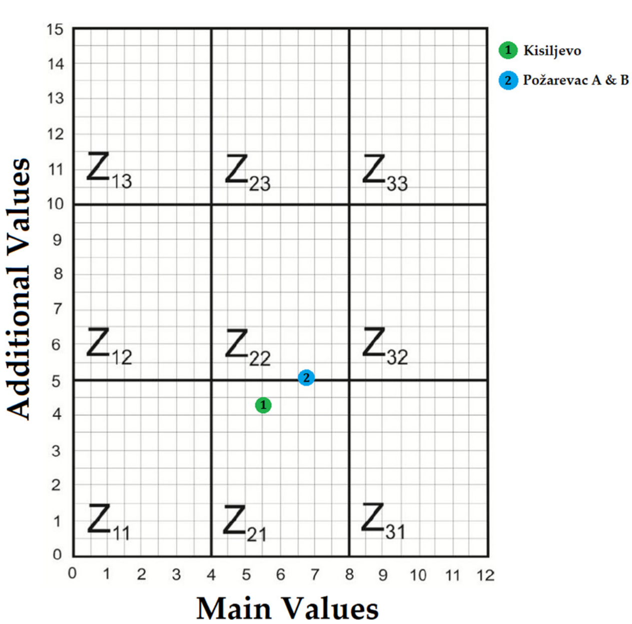


**Figure 4:** M-GAM matrix.

### 5.1.2 AVs

In terms of VFn and VTr values, the ratings differ significantly. VFn were generally rated higher. Since the loess profiles in Požarevac are located in the immediate vicinity of the city's cultural tourist attractions, the ratings for additional anthropogenic values are the highest. Also, the ratings are the highest for the sub-indicator of the proximity of the emissive centers and the proximity of important roads. Additional natural values and VFn in terms of communal and tourist infrastructure are missing, and these sub-indicators received the lowest ratings. Ratings for the

loess profile in Kisiljevo are somewhat lower, given that this geosite is not located in an urban area, but in a rural one. However, this geosite was awarded a higher rating for additional natural values, due to the close proximity of the popular tourist destination "Silver Lake."

Considering that the unique geoheritage objects that are not affirmed for tourist use were evaluated, almost all sub-indicators of tourist values received the lowest evaluations. The only exceptions are the existing hotel and restaurant services, which are available in the immediate vicinity of the investigated loess profiles. Therefore, only these indirect tourist indicators represent an advantage for the establishment of a geotourism destination with a focus on paleoclimatic interpretation. The lack of additional tourist values represents a great challenge, which needs to be solved in order to establish the foundations for the geotourism affirmation of the presented VSE values and potentials.

### 5.2 M-GAM matrix

The final results of the evaluation are shown in Table 3. Loess profiles in Požarevac have higher MVs and AVs, and it is concluded that their general geotourism potential is somewhat more significant compared to the loess profile in Kisiljevo.

More specifically, loess profiles in Požarevac have higher VSE and VSA values, while the VPr values are identical. Požarevac loess profiles have a higher final assessment of VFn values, while VTr values are identical for both geosites. Therefore, the given final grades position the loess profile of Kisiljevo in field $Z_{21}$, while the loess profiles in Požarevac are positioned in field $Z_{22}$ (Figure 4). This means that loess profiles have an advantage when it comes to general geotourism potential that can be affirmed and become significant socio-economic values at the local level. With the introduction of tourist infrastructure and monitoring of modern trends in geological interpretation, the management structure can implement the modernization of geotourism in the city of Požarevac. In this way, the position of the Požarevac loess profile in the M-GAM matrix could be found in the $Z_{32}$ field in the future. Moreover, with continuous scientific research, paleoclimatic parameters could provide additional data, and the general MVs would be further enhanced as well.

Based on the presented research results, it can be stated that suitable conditions exist at the site of the loess profile in Požarevac for the establishment of a visitor center or a paleoclimate museum that would unite all scientific paleoclimatic findings of the research area. In addition to the interpretation of local paleoclimatic events, this museum could also interpret the dynamics of global paleoclimatic events, and it could become a representative regional promoter of paleoclimatic research.

## 6 Discussion

Loess profiles of Požarevac certainly have potential for inclusion in the (geo)tourism offer of the city, even though they present very specific landscape elements. The evaluated loess profiles provide a possibility to disseminate scientific knowledge to a wider audience. This study presents a preliminary evaluation of loess geoheritage of Požarevac, which represents an initial step for loess geotourism development in this area. As the loess sections of Požarevac have suffered serious damage and ruination due to human activities and erosion, legal protection and conservation is an important step for geotourism development. Currently, evaluated geosites are not recognized as important geoheritage by Institute for Nature Conservation of Serbia, and they are not on the list of geoheritage of Serbia, so, first they need to be listed as valuable geoheritage and then need to be legally protected. However, some conservation measures have to be implemented in order to prevent further destruction of these scientifically valuable resources.

As loess landscape, formations, and processes are usually not recognizable to a wider public as a tourist attraction, interpretation is of a crucial significance for geotourism. Effective interpretation is important for animating and informing general public about the processes that are not easy to explain to common visitors. The interpretation can be implemented on the site (*in situ* interpretation) via information panels, guided tours, brochures, thematic

**Table 3:** Overall assessment for analyzed loess geosites

| Geosite | MVs VSE + VSA + VPr | ∑ | AVs VFn + VTr | ∑ | Zone |
|---|---|---|---|---|---|
| Kisiljevo – GS1 | 2.00 + 1.75 + 1.75 | 5.50 | 2.25 + 2.00 | 4.25 | $Z_{21}$ |
| Požarevac A and B – GS2 | 2.25 + 2.75 + 1.75 | 6.75 | 3.00 + 2.00 | 5.00 | $Z_{22}$ |

maps, or linking similar geosites in a thematic route. On the other hand, dissemination of Earth's science can be presented in related facilities through lecturing, audio and video presentation, or laboratory demonstration.

The most common way of geoheritage interpretation is via information panels, as they do not require high resource investment. The interpretation of loess geoheritage demands accurate scientific knowledge of loess and should be intellectually accessible to a wider public. Also, the interpretation through information panels should be effective, inclusive, storytelling, with strong visual display, and to be able to provoke active learning [86]. The interpretative panels have to include information about loess sections, loess formations, and chronostratigraphic units. The text needs to be bilingual (both Serbian and English), so foreign tourist can also be educated, illustrations have to be colored, and the construction material should be nature-friendly. Also, the position of the panels is very important. They should be placed in such a position that provides the best view on the geosite. Thus, high-quality interpretive panels are of a very high significance for self-guided tours.

Another popular way of geoheritage interpretation that does not demand huge investments is a guided tour. Effective verbal interpretation is very important for the overall tourist experience. High-quality and multi-lingual guide service is required to explain complex processes, as geotourists are usually visitors that seek knowledge about geological and geomorphological processes. One of the tasks of tour guides is to improve the visitor's knowledge and raise the public awareness on the importance of natural heritage and their protection and conservation. Investing in the education of tour guides about geology and geomorphology would most certainly result in a greater tourist experience.

On the other hand, modern technologies, such as mobile applications and geographical information system, provide the best experience for the visitors during self-guided tours. The promotion of geotourism and the interpretation of geoheritage through mobile applications are successfully applied in Sesia Val Grande UNESCO Global Geopark [87], Torino [88], Rome [89], and Lausanne [90].

The collaboration between the local community and tourism managers, planners, and tourist organizations is a vital part of tourism development. Community volunteerism, participation, and involvement would lead to idea exchange and a closer connection between locals, protected areas, and officials. Such connection would bring locals closer to the tourism practices and lead to economic development of local communities. A good example is the Luochuan Loess National Geopark in China, where thousands of locals were trained, educated, and involved in tourism practices within the area of the geopark [34].

## 6.1 Loess-based geotourism and georoute potentials

Loess-based geotourism includes a very specific form of geoheritage interpretation. Nevertheless, through the affirmation of paleoclimatic indicators, it is possible to reach a large number of interested geotourists, bearing in mind the popularity of the topic of climate change in the world.

Along the Danube River, there are several loess areas near Titel, Stari Slankamen, Surduk, Batajnica, and Zemun, significant for geoeducation and geotourism. Linking those areas in a unique thematic route would create a new tourism product and popularize such geoheritage, as well as raise public awareness of the need for their protection and conservation. Georoutes are one of the most widespread forms of modern geotourism interpretation methods [91]. They are an emerging trend that links geosites, natural, and cultural features in a unique tourism product [92]. Loess-based georoute would allow geotourists to gain insight into the sites that allowed scientists to reconstruct paleoclimates as well as to learn about the methods scientists used.

The geology of northern Serbia and Požarevac can be closely linked to the deposition of Quaternary sediments. Here, we propose a touristic route (Figure 5), including the most diverse, yet related sedimentary sequences. The route links evaluated site Požarevac A and B (due to high representativeness) from this article and other loess profiles. The trip lasts for 2 days, and there is a combination of transportations: one bus that drives and follows the group during the trip and two boats (one for Danube River and second for Tisza River). The target groups are students of geosciences and nature lovers. The route starts at one of the oldest sediments at Požarevac brickyard, and on the same day, geotourist can see the oldest LPS in Serbia, covering almost 1 Ma – Stari Slankamen [11]. The bus leaves the tourists in Zemun where the tourist boat takes them by the Danube next to the biggest cliffs on the northern side of the Srem Loess Plateau: Zemun [93,94], Batajnica [8], and Surduk [95] LPS. At Stari Slankamen, the tourists switch to another boat that takes them to the Titel Loess Plateau. Here, they witness 620 ka old loess deposits [96] and continue by bus to Zrenjanin, the biggest city near the profile. The group have overnight. On the next day, the Tamiš Loess Plateau with the Orolovat section is visited, and the tourist is getting into younger terrain, as this LPS is only 160 ka old [97]. After this, they are taken to the youngest part of Quaternary sediments, the Deliblato Sand area, where the cross-section of the sand dune is exposed. Close to this area are the Zagajica Hills (Zagajička brda in Serbian), very attractive grass-covered accumulations of sand

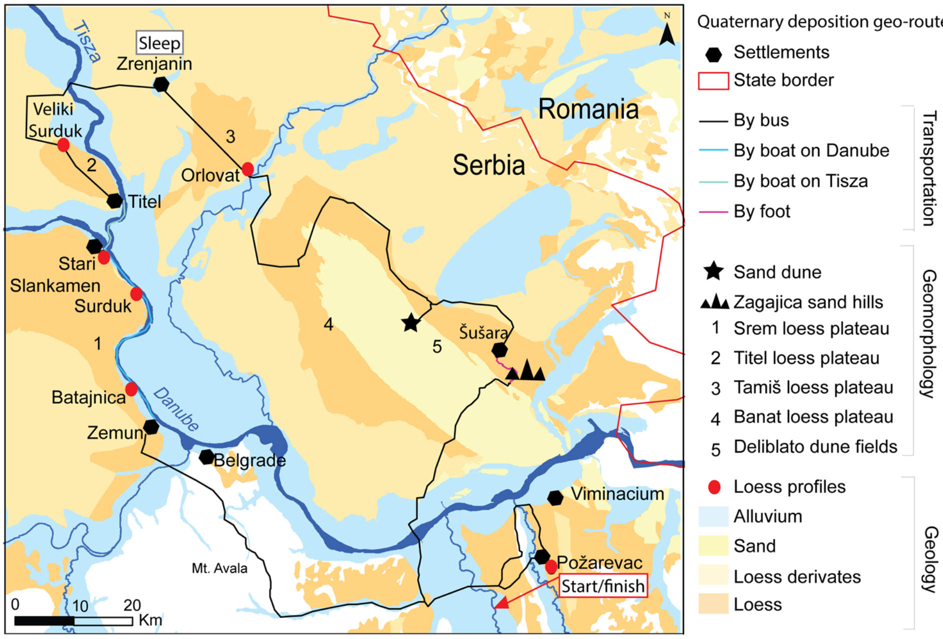


**Figure 5:** Loess-based georoute in Serbia.

and loess up to 250 m high, where the tourists go on foot. The bus waits for them on the other side of the hills and takes them through the Deliblato Sand area toward the Požarevac, where they can visit a mammoth park in Viminacium [97]. This route covers the 1 Ma of Quaternary deposits in Serbia.

## 6.2 Perspectives for paleoclimate visitor center

Innovations in the interpretation of geotourism are constantly advancing [98]. Geoparks are becoming more and more visited, while the richness of geodiversity is a growing indicator that attracts geotourists [99]. However, the climate is rarely the focus of storytelling when it comes to geotourism tours. As a result, a high-quality paleoclimatic interpretation in geotourism would provide a unique scientific and educational experience for visitors [26]. It is known that geotourists are mostly visitors with high interests in the field of geosciences [61,100], but also in other fields that concern the planet Earth and the environment. Paleoclimatic reconstruction is extremely important for scientists in all fields that concern the Earth [101]. Understanding the paleoenvironmental dynamics is a crucial indicator for understanding the migrations of hunter-gatherer communities [102], but also the way in which humans founded civilizations. Therefore, unique geotourism programs and storytelling of paleoclimatic reconstructions are a necessary complementary attractiveness to the global geotourism market.

The existing paleoclimatic research presented in this study was conducted on loess geosites in northeastern Serbia. This region is already globally recognized for tourism due to the archaeological–paleontological park Viminacium. Within this tourist complex are the remains of an ancient Roman city and a military camp that includes a wide range of cultural heritage of the Roman Empire [103]. In addition, the remains of a mammoth, which was found in a surface pit in the immediate vicinity of the Viminacium complex, are on display. Given that the mammoth was found in a loess profile and that the paleontological heritage is a symbol of the Ice Age, the paleoclimatic interpretation in this area already has a solid foundation and a sufficient amount of data [57]. Although there is already rich tourist content in Viminacium, it is necessary to use paleoclimate data through the establishment and affirmation of a special visitor center for the promotion of paleoclimate. Moreover, it is important to mention that within the archaeological–paleontological park Viminacium, archaeological research is continuously carried out, and relatively often new archaeological discoveries are made that enrich the tour in Viminacium. The most recent discoveries are three lead sarcophagi, with the remains of children, jewelry, and objects that reveal a specific way of funeral ritual among the population of Upper Moesia between the 2nd and 4th century, as well as a letter addressed to “God” engraved on a silver sheet, 1,800 years old [104]. However, in addition to new archaeological discoveries

enriching the tour, they also extend it. The current Viminacium tour lasts about 3 h. This is the main reason why the ideal location for the establishment of a paleoclimatic visitor center is in the city of Požarevac, which is located 18 km from Viminacium. Furthermore, the loess profiles in Požarevac still exist physically, while the Nosak (Viminacium) loess profile was completely destroyed due to surface mining. Therefore, specialized guides could more easily interpret the paleoclimate in Požarevac, showing tourists physical and landscape examples of loess. Given that the proposed visitor center would be located in an urban environment, numerous restaurants, the city museum, the Milena Pavlović Barili Gallery, the Ljubičevo Equestrian Club, the Čačalica Memorial Park, and other attractions would be accessible to tourists.

The goal of the paleoclimatic visitor center would be a scientific-educational experience through modernized animated tourist content. The visitor center itself must be equipped with modern information technology, such as VR technology, which would allow visitors to reconstruct the paleoenvironment, have a glimpse into the ice age, and experience mammoth encounters and the everyday life of hunter-gatherer communities. Geochronological climate graphics must be emphasized, while replicas of mammoths and prehistoric people can be found in the exhibition area of the visitor center.

## 7 Conclusion

Paleoclimatic geotourism interpretation includes a wide range of scientific and educational content. Most often, nature museums are the ones that institutionally promote the field of paleoclimate to the general public. Nevertheless, the creation of specific facilities for the promotion, affirmation, and interpretation of paleoclimatic knowledge and research is a significant and unique step that certainly has the potential to grow into a tourism product of exceptional value. In this study, for the first time, loess geosites in the Braničevo District are presented as indicators of the development of geotourism with an emphasis on paleoclimatic interpretation in Serbia. Although the human impact on the loess sediments in Serbia was linked to exploitation, this process made a degraded landscape, which can serve as a touristic destination with appropriate interpretation.

The research results were obtained using the reliable and reputable M-GAM method. The obtained data indicate evident geotourism potential that, with minimal investment, can become significant geotourism values with significant socio-economic advantages. The primary advantages of the researched loess geosites are reflected in their proximity to the urban environment and their reasonable accessibility. The proximity of hotels and restaurants, other cultural sites, and important roads was also recorded as an exceptional advantage, as it indicates the possibility of visitors to visit a greater number of attractive places in the area of Braničevo District. Of particular value are the already existing paleoclimatic research and the exploitation of the mammoth paleontological heritage in the Viminacium paleontological park, not far from the city of Požarevac. The main shortcomings are reflected in the current lack of appropriate infrastructure for the development of geotourism, as well as the complete lack of initiatives and marketing strategies that would affirm geotourism and paleoclimate interpretation.

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## References

[1] Heller F, Evans ME. Loess magnetism. Rev Geophys. 1995;33(2):211–40.
[2] Catt JA. The agricultural importance of loess. Earth-Sci Rev. 2001;54(1–3):213–29.
[3] Arsenović M, Stanković S, Pezo L, Mančić L, Radojević Z. Optimization of the production process through response surface method: Bricks made of loess. Ceram Int. 2013;39(3):3065–75.
[4] Arsenović M, Pezo L, Mančić L, Radojević Z. Thermal and mineralogical characterization of loess heavy clays for potential use in brick industry. Thermochim Acta. 2014;580:38–45.
[5] Yoon HK. Loess cave-dwellings in Shaanxi province, China. Geojournal. 1990;21(1):95–102.
[6] Liu J, Zhu X, Yang L, Hu R. Exemplary project of green cave dwellings in Loess Plateau. Front Energy Power Eng China. 2010;4(1):122–30.
[7] Marković SB, Oches E, Sümegi P, Jovanović M, Gaudenyi T. An introduction to the Middle and Upper Pleistocene loess–paleosol sequence at Ruma brickyard, Vojvodina, Serbia. Quat Int. 2006;149(1):80–6.
[8] Marković SB, Hambach U, Catto N, Jovanović M, Buggle B, Machalett B, et al. Middle and late Pleistocene loess sequences at Batajnica, Vojvodina, Serbia. Quat Int. 2009;198(1–2):255–66.
[9] Kukla GJ. Pleistocene land—sea correlations I. Europe. Earth-Sci Rev. 1977;13(4):307–74.
[10] Smalley IJ, Jefferson IF, Dijkstra TA, Derbyshire E. Some major events in the development of the scientific study of loess. Earth-Sci Rev. 2001;54(1–3):5–18.

[11] Marković SB, Hambach U, Stevens T, Kukla GJ, Heller F, McCoy WD, et al. The last million years recorded at the Stari Slankamen (Northern Serbia) loess-palaeosol sequence: revised chronostratigraphy and long-term environmental trends. Quat Sci Rev. 2011;30(9–10):1142–54.
[12] Marković SB, Korač M, Mrđič N, Buylaert JP, Thiel C, McLaren SJ, et al. Palaeoenvironment and geoconservation of mammoths from the Nosak loess–palaeosol sequence (Drmno, northeastern Serbia): initial results and perspectives. Quat Int. 2014;334:30–9.
[13] Obreht I, Lehmkuhl F, Stevens T. Aeolian dynamics in Southeastern Europe during the Late Pleistocene, based on detailed sedimentological and geochemical investigations on loess. Doctoral dissertation. Aachen: Universitätsbibliothek der RWTH Aachen; 2017.
[14] Marković SB, Bokhorst MP, Vandenberghe J, McCoy WD, Oches EA, Hambach U, et al. Late Pleistocene loess-palaeosol sequences in the Vojvodina region, north Serbia. J Quat Sci: Publ Quat Res Assoc. 2008;23(1):73–84.
[15] Marković SB, Hambach U, Stevens T, Basarin B, O'Hara-Dhand K, Gavrilov MM, et al. Relating the astronomical timescale to the loess–paleosol sequences in Vojvodina, Northern Serbia. In Climate change. Vienna: Springer; 2012. p. 65–78.
[16] Marković SB, Oches EA, Perić ZM, Gaudenyi T, Jovanović M, Sipos G, et al. The Požarevac loess–paleosol sequence: a record of increased aridity in the south-eastern margin of the Carpathian Basin during the last 350 ka. J Quat Sci. 2021;36(8):1436–47.
[17] Perić ZM, Marković SB, Sipos G, Gavrilov MB, Thiel C, Zeeden C, et al. A post-IR IRSL chronology and dust mass accumulation rates of the Nosak loess-palaeosol sequence in northeastern Serbia. Boreas. 2020;49(4):841–57.
[18] Perić ZM, Marković SB, Filyó D, Thiel C, Murray AS, Gavrilov MB, et al. Quartz OSL and polymineral post IR–IRSL dating of the Požarevac loess–palaeosol sequence in north–eastern Serbia. Quat Geochronol. 2021;66:101216.
[19] Perić ZM, Marković SB, Avram A, Timar-Gabor A, Zeeden C, Nett JJ, et al. Initial quartz OSL and dust mass accumulation rate investigation of the Kisiljevo loess sequence in north-eastern Serbia. Quat Int. 2022;620:13–23.
[20] Jovanović M, Marković SB, Gaudenyi T, Oches EA, Hambach U, Zöller L, et al. Warm glacial climate during loess deposition recorded at exposures of the Pozarevac brickyard, NE Serbia. In Geophysical Research Abstracts. Vienna: EGU General Assembly; 8, 2006. p. 10599.
[21] Warowna J, Zgłobicki W, Kołodyńska-Gawrysiak R, Gajek G, Gawrysiak L, Telecka M. Geotourist values of loess geoheritage within the planned Geopark Małopolska Vistula River Gap, E Poland. Quat Int. 2016;399:46–57.
[22] Solarska A, Hose TA, Vasiljević DA, Mroczek P, Jary Z, Marković SB, et al. Geodiversity of the loess regions in Poland: Inventory, geoconservation issues, and geotourism potential. Quat Int. 2013;296:68–81.
[23] Liu Q, Jin C, Hu P, Jiang Z, Ge K, Roberts AP. Magnetostratigraphy of Chinese loess–paleosol sequences. Earth-Sci Rev. 2015;150:139–67.
[24] Dar RA, Chandra R, Romshoo SA, Kowser N. Micromorphological investigations of the Late Quaternary loess–paleosol sequences of the Kashmir Valley, India. J Asian Earth Sci. 2015;111:328–38.
[25] Marković SB, Jovanović M, Mijović D, Bokhorst M, Vandenberghe J, Oches EA, et al. Titel Loess Plateau e Geopark. Proceedings of 2nd Conference on the Geoheritage of Serbia. Belgrade; 2005. p. 177–84.
[26] Višnić T, Spasojević B, Vujičić M. The potential for geotourism development on the Srem Loess Plateau based on a preliminary geosite assessment model (GAM). Geoheritage. 2016;8(2):173–80.
[27] Vasiljević Đ, Marković SB, Hose TA, Basarin B, Lazić L, Stojanović V, et al. The use of web-based dynamic maps in the promotion of the Titel loess plateau Vojvodina, Serbia, a potential geotourism destination. Geogr Pannonica. 2009;13(3):78–84.
[28] Vasiljević DA, Marković SB, Hose TA, Smalley I, Basarin B, Lazić L, et al. The Introduction to Geoconservation of loess-palaeosol sequences in the Vojvodina region: Significant geoheritage of Serbia. Quat Int. 2011a;240(1–2):108–16.
[29] Vasiljević DA, Marković SB, Hose TA, Smalley I, O'Hara-Dhand K, Basarin B, et al. Loess towards (geo) tourism–proposed application on loess in Vojvodina region (north Serbia). Acta Geogr Slovenica. 2011b;51(2):391–406.
[30] Vasiljević DA, Marković SB, Hose TA, Ding Z, Guo Z, Liu X, et al. Loess–palaeosol sequences in China and Europe: common values and geoconservation issues. Catena. 2014;117:108–18.
[31] Mulec I, Wise N. Strategic guidelines for the potential geotourism destination Titel Loess Plateau (Vojvodina region, Serbia). Geoheritage. 2012;4(3):213–20.
[32] Jary Z, Owczarek P, Ryzner K, Widawski K, Krawczyk M, Krzyszkowski D, et al. Loess documentary sites and their potential for geotourism in Lower Silesia (Poland). Open Geosci. 2018;10(1):647–60.
[33] Bollati IM, Zerboni A. The Po Plain Loess Basin (Northern Italy): Scientific values, threats, and promotion opportunities. Geoheritage. 2021;13(3):74. doi: 10.1007/s12371-021-00596-2.
[34] Dong H, Song Y, Chen T, Zhao J, Yu L. Geoconservation and geotourism in Luochuan loess national geopark, China. Quat Int. 2014;334:40–51.
[35] Wang G, Ye W, Lv Y. Loess geoheritage and geohazard protective measures at luochuan loess national geopark in NW China. Geoheritage. 2019;11(3):1089–100.
[36] Zhao T, Zhao X. Recent development of global geoparks and present status of geological heritage protection in Southeast Asia. Geol Bull China. 2008;27(3):414–25.
[37] Vasiljević DA, Marković SB, Tomić N. Geoheritage case study: The Danube Region in Serbia. In Geoheritage and geotourism: A European perspective. Woodbridge: The Boydell Press; 2016. p. 291–303.
[38] Maher BA. Palaeoclimatic records of the loess/palaeosol sequences of the Chinese Loess Plateau. Quat Sci Rev. 2016;154:23–84.
[39] Muhs D. Loess deposits: Origins and Properties. In: Elias SA, Mock CJ, editors. Encyclopaedia of Quaternary Science. 2nd edn. Oxford: Elsevier; 2013. p. 573–84.
[40] Targulian V. Elementary pedogenic processes. Eurasian Soil Sci. 2005;38:1255–64.
[41] Orbe R. Aeolian and pedogenic processes of loess in Southern England. Master thesis. Uppsala University, Disciplinary Domain of Science and Technology, Earth Sciences, Department of Earth Sciences; 2019. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-385756.
[42] Britannica, The Editors of Encyclopaedia. "loess". Encyclopedia Britannica, Invalid Date, https://www.britannica.com/science/loess. Accessed 2 October 2022.
[43] Muhi B, Bugarin D, Miloradić J. Resources and development perspectives of industrial and mining tourism in Serbia. Poslovna Ekonomija. 2018;12(2):141–56.

[44] Štetić S, Trišić I. Strengthening the tourism offer–case study Braničevo district. Modern management tools and economy of tourism sector in present era. Belgrade: Udruženje ekonomista i menadžera Balkana; 2018. p. 637–50.
[45] Nikolić E, Roter-Blagojević M. Cultural landscape of ancient Viminacium and modern Kostolac–creation of a new approach to the preservation and presentation of its archaeological and industrial heritage. In Conference Proceedings/5th international Academic Conference on Places and Technologies. Belgrade: University of Belgrade-Faculty of Architecture; 2018. p. 785–92.
[46] Mekić C, Ćosić M. Livestock and tourism development as a conservation concept of the specificity of rural area in the municipality of Petrovac on Mlava. Tourism International Scientific Conference Vrnjačka Banja-TISC. 2019;4(2):153–71.
[47] Jovic V. The development of Geology in Serbia. Publications of the Astronomical Observatory of Belgrade. 2008;85:113–27.
[48] Kowalke T, Harzhauser M. Early ontogeny and palaeoecology of the Mid-Miocene rissoid gastropods of the Central Paratethys. Acta Palaeontol Polonica. 2004;49(1):111–34.
[49] Malešević M, Kalenić M, Karajičić LJ. Tumač za list Požarevac L34-127 Savezni geološki zavod. Yugoslavia: Savezni geološki zavod; 1978. p. 1–46. (in Serbian).
[50] Rakić M. Tumač za list Bela Crkva L34-115. Yugoslavia: Savezni geološki zavod; 1978. p. 1–49. (On Serbian).
[51] Popović I. O dosadašnjem planiranju turizma u prostoru priobalja Srebrnog jezera. Bull de la Société Serbe de Géographie. 1991;71(1):87–90. (in Serbian).
[52] Lehmkuhl F, Bösken J, Hošek J, Sprafke T, Marković SB, Obreht I, et al. Loess distribution and related Quaternary sediments in the Carpathian Basin. J Maps. 2018;14(2):661–70.
[53] Ehlers J, Ehlers J, Gibbard PL, Hughes PD, editors. Quaternary glaciations-extent and chronology: A closer look. Vol. 15, Amsterdam, The Netherlands: Elsevier; 2011.
[54] https://www.eorc.jaxa.jp/ALOS/en/index_e.htm.
[55] Pavlović S. Improvement of tourist valorization: Case study of the Viminacium archaeological site. Zbornik Radova-Geografski Fakultet Univerziteta u Beogradu. 2017;65(1a):393–406.
[56] Dimitrijević V, Mrdjić N, Korać M, Chu S, Kostić D, Jovičić M, et al. The latest steppe mammoths (Mammuthus trogontherii (Pohlig)) and associated fauna on the Late Middle Pleistocene steppe at Nosak, Kostolac Basin, Northeastern Serbia. Quat Int. 2015;379:14–27.
[57] Tomić N, Marković SB, Korać M, Mrđić N, Hose TA, Vasiljević DA, et al. Exposing mammoths: From loess research discovery to public palaeontological park. Quat Int. 2015;372:142–50.
[58] Sümegi P. Upper Pleistocene evolution history of the Hajdusag (Hungary) region on the basis of stratigraphical investigations. Debrecen, Hungary: University of Debrecen; 1989.
[59] Marković SB, Kukla HJ, Tomić P, Kovačev N, Jovanović M. Predlog zaštite lesnog profila Čot u Starom Slankamenu. Zaštita Prirode. 1998;50:431–7.
[60] Burlando M, Firpo M, Queirolo C, Rovere A, Vacchi M. From geoheritage to sustainable development: strategies and perspectives in the Beigua Geopark (Italy). Geoheritage. 2011;3(2):63–72.
[61] Reynard E. Scientific research and tourist promotion of geomorphological heritage. Geogr Fis Din Quat. 2008;31:225–30.
[62] Suzuki DA, Takagi H. Evaluation of geosite for sustainable planning and management in geotourism. Geoheritage. 2018;10(1):123–35.
[63] Tomić N, Božić S. A modified geosite assessment model (M-GAM) and its application on the Lazar Canyon area (Serbia). Int J Environ Res. 2014;8(4):1041–52.
[64] Coratza P, Giusti C. Methodological proposal for the assessment of the scientific quality of geomorphosites. Alp Mediterr Quat. 2005;18(1):307–13.
[65] Bruschi VM, Cendrero A. Geosite evaluation; can we measure intangible values? Alp Mediterr Quat. 2005;18(1):293–306.
[66] Pralong JP. A method for assessing the tourist potential and use of geomorphological sites. Géomorphol Relief Process Environ. 2005;3:189–96.
[67] Serrano E, González-Trueba JJ. Assessment of geomorphosites in natural protected areas: the Picos de Europa National Park (Spain). Géomorphol Formes Process Environ. 2005;3:197–208.
[68] Pereira P, Pereira D, Caetano-Alves MI. Geomorphosite assessment in Montesinho Natural Park (Portugal). Geogr Helv. 2007;62(3):159–68.
[69] Zouros NC. Geomorphosite assessment and management in protected areas of Greece case study of the Lesvos Island - coastal geomorphosites. Geogr Helv. 2007;62(3):169–80.
[70] Reynard E, Fontana G, Kozlik L, Scapozza C. A method for assessing “scientific” and “additional values” of geomorphosites. Geogr Helv. 2007;62(3):148–58.
[71] Reynard E. Scientific research and tourist promotion of geomorphological heritage. Geogr Fis e Dinamica Quaternaria. 2008;31:225–30.
[72] Erhartič B. Vrednotenje geomorfološke dediščine. Acta Geogr Slov. 2010;50(2):295–319.
[73] Vujičić MD, Vasiljević DA, Marković SB, Hose TA, Lukić T, Hadžić O, et al. Preliminary geosite assessment model (GAM) and its application on Fruška Gora Mountain, potential geotourism destination of Serbia. Acta Geogr Slovenica. 2011;51(2):361–76.
[74] Tomić N. The potential of Lazar Canyon (Serbia) as a geotourism destination: inventory and evaluation. Geogr Pannonica. 2011;15:103–12.
[75] Božić S, Tomić N. Canyons and gorges as potential geotourism destinations in Serbia: comparative analysis from two perspectives–general geotourists’ and pure geotourists’. Open Geosci. 2015;7:531–46. doi: 10.1515/geo-2015-0040.
[76] Jonić V. Comparative analysis of Devil’s town and Bryce canyon geosites by applying the modified geosite assessment model (M-GAM). Researches review of the department of geography. Tour Hotel Manag. 2018;47(2):113–25.
[77] Tičar J, Tomić N, Breg Valjavec M, Zorn M, Marković SB, Gavrilov MB. Speleotourism in Slovenia: Balancing between mass tourism and geoheritage protection. Open Geosci. 2018;10(1):344–57. doi: 10.1515/geo-2018-0027.
[78] Miljković Đ, Božić S, Miljković L, Marković SB, Lukić T, Jovanović M, et al. Geosite assessment using three different methods; a comparative study of the Krupaja and the Žagubica Springs–Hydrological Heritage of Serbia. Open Geosci. 2018;10(1):192–208.
[79] Pal M, Albert G. Comparison of geotourism assessment models: And experiment in Bakony-Balaton UNSECO Global Geopark Hungary. Acta Geoturistica. 2018;9(2):1–13.
[80] Crane R, Fletcher L. The speleotourist experience: approaches to show caves operations in Australia and China. Helictite. 2016;42:1–11.
[81] Vukoičić D, Milosavljević S, Valjarević A, Nikolić M, Srećković-Batoćanin D. The evaluation of geosites in the territory of National park „Kopaonik“ (Serbia). Open Geosci. 2018;10(1):618–33.

[82] Tomić N, Antić A, Marković SB, Đorđević T, Zorn M, Breg Valjavec M. Exploring the potential for speleotourism development in eastern Serbia. Geoheritage. 2019;11(2):359–69.
[83] Marjanović M, Tomić N, Radivojević AR, Marković SB. Assessing the geotourism potential of the Niš City area (Southeast Serbia). Geoheritage. 2021;13(3):1–18. doi: 10.1007/s12371-021-00597-1.
[84] Mahato MK, Jana NC. Exploring the potential for development of Geotourism in Rarh Bengal, Eastern India using M-GAM. Int J Geoheritage Park. 2021;9(3):313–22. doi: 10.1016/j.ijgeop.2021.05.002.
[85] Zafeiropoulos G, Drinia H. Comparative analysis of two assessment methods for the geoeducational values of geosites: A case study from the volcanic island of Nisyros, SE Aegean Sea, Greece. Geosciences. 2022;12(2):82.
[86] Bruno BC, Wallace A. Interpretive panels for geoheritage sites: Guidelines for design and evaluation. Geoheritage. 2019;11:1315–23. doi: 10.1007/s12371-019-00375-0.
[87] Perotti L, Bollati IM, Viani C, Zanoletti E, Caironi V, Pelfini M, et al. Fieldtrip and virtual tours as geotourism resources: Example from the Sesia Val Grande UNESCO Global Geopark (NW Italy). Resources. 2020;9(6):63. doi: 10.3390/resources9060063.
[88] Gambino F, Borghi A, d'Atri A, Gallo LM, Ghiraldi L, Giardino M, et al. TOURinSTONES: A free mobile application for promoting geological heritage in the city of Torino (NW Italy). Geoheritage. 2019;11:3–17.
[89] Pica A, Grangier L, Reynard E, Kaiser C, Del Monte M. Geoguide Rome, urban geotourism offer powered by mobile application technology. In Geophysical Research Abstracts. Vol. 18, 2016. Viena: EGU General Assembly 2016.
[90] Reynard E, Kaiser C, Martin S, Regolini G. An application for geosciences communication by smartphones and tablets. In: Lollino G, Giordan D, Marunteanu C, Christaras B, Yoshinori I, Margottini C, editors. Engineering geology for society and territory. Vol 8, Cham: Springer; 2015. p. 265–8. doi: 10.1007/978-3-319-09408-3_46.
[91] Hose TA. Geotrails. In The geotourism industry in the 21st Century. New York, USA: Apple Academic Press; 2020. p. 247–75.
[92] Dowling RK, Newsome D. Chapter 17. Geoheritage and geotourism. In Geoheritage. Amsterdam, The Netherlands: Elsevier Inc; 2018. p. 305–21. doi: 10.1016/B978-0-12-809531-7.00017-4.
[93] Gavrilović B, Sümegi P, Ćirić M, Radaković MG, Gavrilov MB, Mlađan D, et al. The middle and late Pleniglacial (Weichselian) malacofauna of the Zemun loess–paleosol sequence, Serbia. PalZ. 2020;94(3):519–31.
[94] Laag C, Hambach U, Zeeden C, Lagroix F, Guyodo Y, Veres D, et al. A detailed paleoclimate proxy record for the Middle Danube Basin over the last 430 kyr: a rock magnetic and colorimetric study of the Zemun loess-paleosol sequence. Front Earth Sci. 2021;9:600086.
[95] Lukić T, Marković SB, Stevens T, Vasiljević DA, Machalett B, Milojković N, et al. The loess "cave" near the village of Surduk-an unusual pseudokarst landform in the loess of Vojvodina, Serbia. Acta Carsol. 2009;38:2–3.
[96] Song Y, Guo Z, Marković S, Hambach U, Deng C, Chang L, et al. Magnetic stratigraphy of the Danube loess: A composite Titel-Stari Slankamen loess section over the last one million years in Vojvodina, Serbia. J Asian Earth Sci. 2018;155:68–80.
[97] Lukić T, Basarin B, Buggle B, Marković SB, Tomović VM, Raljič JP, et al. A joined rock magnetic and colorimetric perspective on the Late Pleistocene climate of Orlovat loess site (Northern Serbia). Quat Int. 2014;334:179–88.
[98] Fassoulas C, Nikolakakis E, Staridas S. Digital Tools to Serve Geotourism and Sustainable Development at Psiloritis UNESCO Global Geopark in COVID Times and Beyond. Geosciences. 2022;12(2):78.
[99] Gray M. Geodiversity, geoheritage and geoconservation for society. Int J Geoheritage Park. 2019;7(4):226–36.
[100] Hose TA. Geotourism and interpretation. In Geotourism. Amsterdam, The Netherlands: Elsevier; 2006. p. 249–69.
[101] Bradley RS. Paleoclimatology: Reconstructing climates of the Quaternary. San Diego, USA: Elsevier; 1999.
[102] Thompson JC, Wright DK, Ivory SJ. The emergence and intensification of early hunter-gatherer niche construction. Evolut Anthropol: Issues News Rev. 2021;30(1):17–27.
[103] Nikolić EV. Creation of the Mammoth Park at Viminacium, Serbia. Geoheritage. 2019;11(3):935–47.
[104] Milovanović BD, Danković ID. Anthropomorphic amulets from Viminacium. Starinar. 2020;(70):127–43.