



Article

Sustainable Tourism Valorization of Lakes in Serbia Using the Fuzzy TOPSIS Method

Danijela Vukočić ^{1,*}, Dragan Petrović ², Ljiljana Mihajlović ², Dušan Kićović ³ and Dušan Ristić ¹

¹ Faculty of Sciences and Mathematics, University of Priština in Kosovska Mitrovica, 38220 Kosovska Mitrovica, Serbia; dusan.ristic@pr.ac.rs

² Faculty of Geography, University of Belgrade, 11000 Belgrade, Serbia; dragan.petrovic@gef.bg.ac.rs (D.P.); ljiljana.mihajlovic@gef.bg.ac.rs (L.M.)

³ Department of Economic Sciences, State University of Novi Pazar, 36300 Novi Pazar, Serbia; dkicovic@np.ac.rs

* Correspondence: danijela.vukoicic@pr.ac.rs

Abstract

Lakes represent valuable natural resources with significant potential for sustainable tourism development. Their tourism valorization requires a comprehensive assessment framework that integrates environmental, infrastructural, socio-economic, and governance dimensions. This study applies the Fuzzy TOPSIS method to evaluate the sustainable tourism potential of ten selected lakes in Serbia. A multi-criteria framework was developed based on ten indicators, including water quality, tourism pressure and carrying capacity, biodiversity, environmental conservation, tourism infrastructure, accessibility, economic effects, and community involvement. Expert evaluations, supported by available evidence, were transformed into triangular fuzzy numbers in order to account for uncertainty and subjectivity in the assessment process. The Fuzzy TOPSIS model was used to calculate the relative closeness of each lake to the ideal solution for sustainable tourism valorization. The results reveal significant differences among the analyzed lakes. Lake Đerdap achieved the highest ranking ($C_i = 0.818$), followed by Lake Zaovine ($C_i = 0.723$), Lake Perućac ($C_i = 0.644$), and Lake Vlasina ($C_i = 0.640$), reflecting their favorable overall performance across the selected environmental, infrastructural, accessibility, and tourism-related criteria. Lower-ranked lakes were characterized by infrastructural limitations and less favorable performance in selected tourism-related criteria. The study illustrates the applicability of the Fuzzy TOPSIS approach for sustainable tourism evaluation and provides a practical framework for tourism planning, destination management, and policy-making aimed at supporting sustainable lake tourism development in Serbia.

Keywords: sustainable tourism; lake tourism; tourism valorization; Fuzzy TOPSIS; MCDM; Serbia

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1. Introduction

Natural resources constitute a fundamental basis for tourism development and significantly influence the competitiveness of tourist destinations [1]. Among these resources, water bodies occupy a particularly important position because they support diverse recreational, ecological, aesthetic, and socio-economic functions within tourism systems. Lakes, in particular, strongly influence destination attractiveness [2]. Because of

their natural, scenic, recreational, and ecological value, lakes represent important resources for tourism development, especially in the context of increasing demand for sustainable and nature-based forms of tourism. Their multifunctional character makes them complex tourism resources that require integrated and multidisciplinary assessment. Their tourism value depends on morphometric characteristics, hydrological properties, water quality, infrastructure, accessibility, environmental condition, land management, and visitor perception [3]. According to Stanković S. M. [4–6], key features for lake tourism valuation include location, transport access, lake type, size, water properties, protection level, beach quality, tourism facilities, and other related factors.

Traditional approaches to evaluating tourism resources have most often relied on individual indicators and descriptive analyses, often resulting in incomplete or insufficiently comparable assessments of destinations' tourism potential. However, contemporary trends in tourism indicate the need for comprehensive methodological frameworks that enable the simultaneous consideration of multiple criteria. In this context, Multi-Criteria Decision Making (MCDM)—a set of methods for evaluating and ranking alternatives using various quantitative and qualitative factors—has become an important methodological approach in tourism evaluation, as it enables the integration of quantitative and qualitative indicators into a unified decision-making model [7,8].

Analytic Hierarchy Process (AHP) [9,10], TOPSIS [11–14], ELECTRE [15,16], and other MCDM methods are widely used to assess and rank tourism resources according to defined criteria and weighting systems [17–21]. These methods are particularly useful because they can be adapted to different spatial contexts and can incorporate both empirical indicators and expert judgement. Combining MCDM models with Geographic Information Systems (GIS) enables spatial tourism analysis and result visualization, which improves destination planning and management [22–24].

One of the key challenges in tourism evaluation is the presence of uncertainty and subjectivity in assessing certain criteria, particularly those related to the aesthetic value of a destination, visual perception, the quality of the tourism experience, and visitor satisfaction. To overcome these limitations, recent studies have increasingly applied fuzzy set theory, which enables the modeling of imprecise and linguistically expressed data, where elements can have varying degrees of membership rather than binary classification [25,26]. This approach allows subjective assessments to be quantified using fuzzy numbers, thereby increasing the analytical consistency and realism of evaluation results. In applied tourism evaluation, fuzzy approaches are particularly useful when expert judgement is combined with available empirical, documentary, and field-based evidence.

The Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is one of the most significant and widely applied methods in the framework of fuzzy multi-criteria decision-making. Fuzzy TOPSIS ranks alternatives by comparing their relative distance from the positive ideal solution and the negative ideal solution, while expressing evaluations in fuzzy terms in order to capture uncertainty. Its primary advantage lies in its ability to rank alternatives based on their distance from the ideal and anti-ideal solutions, while accounting for uncertainty and subjectivity in the data within a fuzzy environment [21,25,26]. In contemporary research, this method has been successfully applied to the evaluation of tourist destinations, as it enables structured decision-making under conditions of limited or imprecise information.

Although MCDM methods have been increasingly used in tourism research, integrated fuzzy multi-criteria assessments focused specifically on the sustainable tourism valorization of lake destinations remain relatively limited, particularly when environmental, infrastructural, socio-economic, and governance-related criteria are considered simultaneously. Previous studies have often relied on descriptive assessments or conventional decision-making methods, which may insufficiently capture the uncertainty,

subjectivity, and multidimensionality involved in evaluating lake tourism resources from a sustainability perspective. This is particularly important in lake tourism studies, where environmental quality, tourism infrastructure, carrying capacity, governance-related pressures, and local community involvement must be considered simultaneously.

Today, climate change, environmental degradation, and tourism growth underscore the need to evaluate lakes from an integrated sustainability perspective. Sustainable tourism requires balancing economic gains with resource protection and community well-being [27,28]. Key indicators include water quality, biodiversity, carrying capacity, ecosystem services, and environmental health [29]. Integrating these into multi-criteria models supports better planning and management.

This study assesses the sustainable tourism valorization potential of selected Serbian lakes using the Fuzzy TOPSIS method. Ten lakes are analyzed and ranked to provide a comparative assessment of their sustainability-related tourism potential. The selected lakes differ in terms of origin, size, altitude, environmental condition, tourism development, accessibility, and management context, which enables the evaluation of diverse lake tourism settings within Serbia [30].

We evaluated lakes using criteria that cover environmental, infrastructural, socio-economic, and governance-related aspects. Including all these elements allows for a more comprehensive assessment of sustainable tourism valorization and supports decision-making in destination planning and resource management. In summary, the Fuzzy TOPSIS method offers a robust, contemporary framework for the multi-criteria tourism evaluation of lakes. It integrates diverse data types, addresses assessment uncertainty and subjectivity, and supports a transparent and structured ranking of destinations in relation to selected sustainability criteria.

Accordingly, the main aim of this research is to evaluate and rank selected lakes in Serbia according to their sustainable tourism valorization potential using the Fuzzy TOPSIS method. The specific objectives are: (1) to define a multi-criteria framework for assessing sustainable lake tourism; (2) to rank the selected lakes according to environmental, infrastructural, socio-economic, and governance-related criteria; and (3) to identify the main strengths and limitations of the analyzed lakes from the perspective of sustainable tourism development. The main contribution of the study is primarily applied and lies in adapting a fuzzy multi-criteria framework to the assessment of lake tourism in Serbia, thereby providing a methodological basis for destination planning, tourism management, and future sustainability-oriented research.

Unlike studies primarily focused on developing new multi-criteria decision-making methodologies, the contribution of this research lies in the application of the Fuzzy TOPSIS method as a decision-support framework for evaluating the sustainable tourism potential of lake destinations in Serbia. By integrating environmental, tourism, socio-economic, and governance-related criteria, the proposed approach provides practical decision-support guidance for sustainable tourism planning, destination management, and regional development in similar lake tourism contexts.

2. Materials and Methods

2.1. Study Area

The study focuses on ten of Serbia's most relevant lakes, emphasizing their value as key natural and tourism resources with strong potential for sustainable tourism development (Table 1). Previous research provides a foundation for understanding the lakes' characteristics. Notable contributions include Cvijić's geomorphological studies, Siniša Stanković's limnological works, and significant tourism and limnology research by Stevan M. Stanković [31]. The selected lakes vary by location, origin, altitude, size [32], and

environmental preservation. These differences allow for a clear comparison of their tourism potential and sustainable management options.

This selection was not intended to include all lake destinations in Serbia, but to provide a diverse set of cases suitable for comparative fuzzy multi-criteria evaluation. The selection includes lakes with different levels of anthropogenic pressure, infrastructural development, and protection status, which enables a comparative assessment of sustainable tourism valorization under diverse geographical and management conditions.

Table 1. Basic characteristics of the analyzed lakes [32].

	Lake	Area km ²	Altitude (m a.s.l.)	Maximum Depth (m)	Water Volume (Million m ³)
A1	Lake Palić	5.6	101	3.5	11
A2	Lake Zlatar (on Uvac river)	7.2	880	75	273
A3	Lake Sjenica (on Uvac river)	5.0	985	35	212
A4	Lake Perućac (on Drina river)	12.4	290	70	340
A5	Lake Zaovine (on Beli Rzav river)	4.3	881.5	110	150
A6	Lake Đerdap (on Danube river)	253	70	92	5000
A7	Silver Lake (on Danube river)	4	70	8	32
A8	Lake Bor	0.79	438	52	12
A9	Lake Zavoj (on Visočica river)	5.5	612	60	170
A10	Lake Vlasina (on Vlasina river)	16.0	1213	22	176

The data presented in Table 1 accompany Figure 1 and provide its corresponding legend.

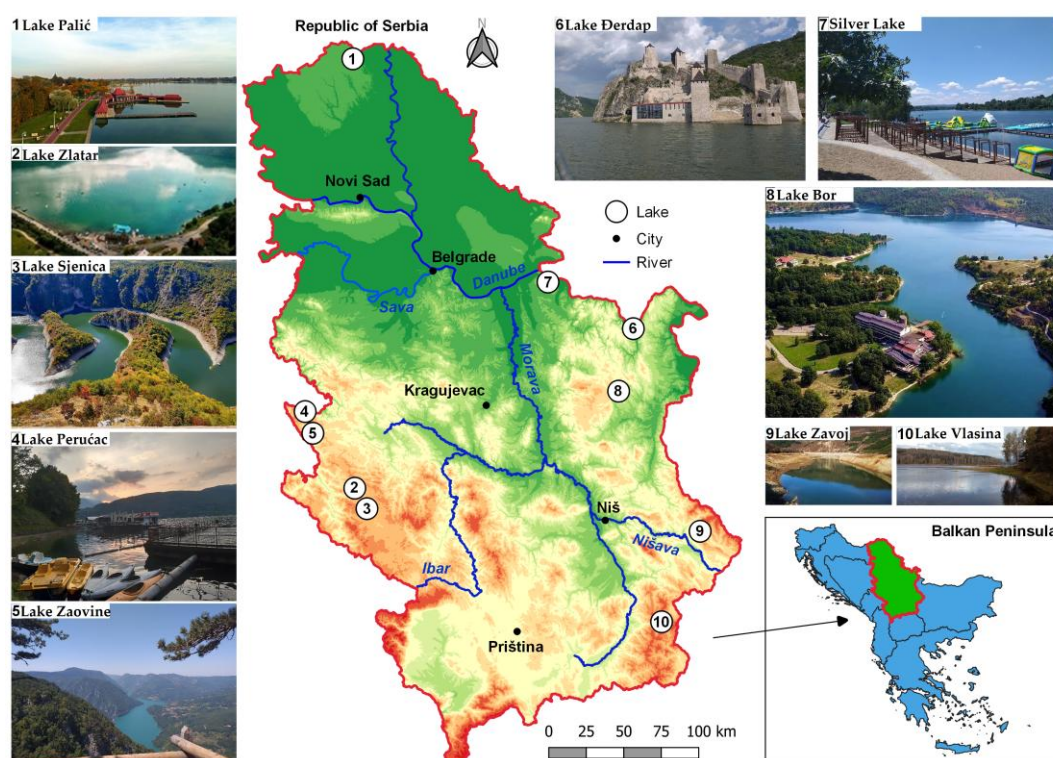


Figure 1. Location of Lakes in Serbia (Source: Created by the authors).

Lake Palić is located in the northern part of Serbia, approximately 8 km from Subotica, at an elevation of 101 m above sea level (Figure 1). The lake covers an area of 5.6 km², reaches a maximum depth of 3.5 m, and has a volume of approximately 11 million cubic meters [32]. During the summer, water temperatures reach up to 25 °C [33], water

transparency is up to 1.5 m, and the water color ranges from green to dark green. These characteristics contribute to the lake's role as a significant destination. It is one of the oldest tourist lakes in Serbia, featuring well-developed infrastructure, spa facilities, and recreational amenities. Long-term, intensive tourism development and urbanization have increased pressure on the lake ecosystem, particularly on water quality. Sustainable tourism valorization requires improvements in environmental protection systems, reductions in eutrophication, and the development of sustainable forms of recreational and health tourism [34].

Lake Zlatar is located in southwestern Serbia, between the mountains of Zlatar and Murtenica, on the Uvac River (Figure 1). It was formed by the construction of a dam in 1962 for hydroelectric power generation purposes. The lake is situated at an elevation of 880 m above sea level, covers an area of 7.2 km², reaches a maximum depth of 75 m, and has a volume of 273 million cubic meters [32]. During the summer, water temperatures reach up to 20.9 °C in July, water transparency is up to 4 m [35,36], and the water color ranges from dark green to blue-green. The lake is characterized by pronounced meanders, steep limestone slopes, numerous viewpoints, and a high degree of environmental preservation. Sustainable tourism development is based on promoting ecotourism, recreational fishing, and nature-based activities, while ensuring biodiversity conservation and mitigating tourism pressures.

Lake Sjenica is located on the Uvac River, near the town of Sjenica, at an elevation of 985 m above sea level (Figure 1). The lake covers an area of 5 km², has a maximum depth of 35 m, and a volume of 212 million cubic meters [32]. Summer water temperatures reach up to 16 °C in July and August, water transparency is up to 7 m, and the water color is blue-green [35–37]. The area is characterized by canyon valleys, scenic viewpoints, well-preserved natural landscapes, and significant biodiversity. The lake is located within the Special Nature Reserve “Uvac,” renowned for being the habitat of the Griffon Vulture (*Gyps fulvus*). The sustainable valorization of this area involves developing ecotourism and rural tourism while ensuring strict protection of natural values and limiting negative anthropogenic impacts.

Lake Perućac was formed on the Drina River in western Serbia through the construction of the Bajina Bašta Dam (Figure 1). It is located at an elevation of approximately 290 m above sea level and covers an area of 12.4 km². The lake reaches a maximum depth of 70 m and has a volume of 340 million cubic meters [32]. Summer water temperatures reach up to 22 °C in July and August, water transparency is up to 6 m, and the water color ranges from green to blue-green [38]. Surrounded by the forest complexes of Tara National Park, the lake possesses high landscape and ecological value. It has favorable natural and locational conditions for the development of sustainable nautical, recreational, and excursion tourism. Sustainable management involves protecting water quality, conserving forest ecosystems, and developing tourism infrastructure in a controlled manner.

Lake Zaovine is located on Mount Tara at an elevation of approximately 880 m above sea level (Figure 1). The lake covers 4.3 km² and reaches a maximum depth of 110 m, making it one of the deepest reservoirs in Serbia. It is known for its exceptionally clean water, with transparency reaching up to 10 m, and its well-preserved natural environment. During the summer months, water temperatures reach up to 22 °C, while the water color ranges from dark blue to blue-green. Sustainable tourism development is based on the growth of ecotourism, recreational fishing, mountain tourism, and outdoor recreation, alongside strict oversight of construction activities and the conservation of natural resources [38].

Lake Đerdap was created by damming the Danube River through the construction of the “Đerdap I” Hydroelectric Power Plant (Figure 1). It is situated at an elevation of 70 m above sea level. This is the largest reservoir in Serbia, covering 253 km² and reaching a

maximum depth of 92 m [32]. Summer water temperatures reach 26 °C, water transparency reaches 5 m, and water color varies from greenish-brown to blue-green. The Đerdap Gorge area is characterized by exceptional geomorphological, hydrological, and cultural-historical values [39,40]. Sustainable tourism valorization of this area involves developing cultural, nautical, and ecological tourism while preserving protected natural and cultural heritage assets.

Silver Lake (Srebrno Lake) is located in eastern Serbia, near Veliko Gradište on the right bank of the Danube River (Figure 1). It was formed by damming a Danube side arm and lies at approximately 70 m above sea level, covering around 4 km² with a maximum depth of 8 m and a volume of 32 million cubic meters [32]. Summer water temperatures reach up to 27 °C, transparency is up to 1.40 m [41], and the water color varies from light green to bluish. As a well-known lake tourism destination in Serbia, Silver Lake contributes to local tourism activity and related economic functions. Intensive tourism requires sustainable development principles, including improved waste management, protection of water quality, and rational spatial planning and use.

Lake Bor is located in eastern Serbia, at the foot of Mount Crni Vrh, at an elevation of approximately 438 m above sea level (Figure 1). The lake covers an area of up to 0.79 km² and reaches a maximum depth of about 52 m. During the summer months, water temperatures reach approximately 24 °C, water transparency reaches 7 m, and the water is dark green [42]. The lake was created in the mid-twentieth century as a reservoir for the mining industry, but over time it has become a significant destination for tourism and recreation. Sustainable tourism valorization of this area involves remediation of potential environmental issues, protection of water quality, and development of sustainable recreational facilities.

Lake Zavoj is located in southeastern Serbia, in the Stara Planina region, at an elevation of 612 m above sea level (Figure 1). It was formed following a major landslide in 1963 and the subsequent regulation of the Visočica River. The lake covers approximately 5.5 km² and reaches a maximum depth of 60 m [32]. During the summer months, water temperatures reach up to 23 °C, water transparency extends to 8 m, and the water appears blue-green [43]. The lake is characterized by its well-preserved natural environment, mountainous landscapes, and low level of urbanization. Sustainable valorization is based on the development of ecological, mountain, and recreational tourism while preserving the natural setting and environmental quality.

Lake Vlasina is located in southeastern Serbia, on the Vlasina Plateau, at an elevation of 1,213 m above sea level, making it the highest artificial reservoir in Serbia (Figure 1). The lake covers an area of 16 km² and has a maximum depth of approximately 22 m [32]. During the summer months, water temperatures reach up to 20 °C, water transparency extends to 7 m, and the water color ranges from dark blue to blue-green. The lake is renowned for its floating peat islands, distinctive microclimate, and rich biodiversity [44]. Sustainable tourism valorization of this area involves developing ecotourism, scientific-educational tourism, and recreational tourism, while ensuring strict protection of natural values and careful oversight of tourism-related construction activities.

The analyzed lakes represent different types of lake tourism resources in Serbia. Their natural characteristics, tourism potentials, and degree of environmental preservation enable an assessment of the possibilities for developing sustainable tourism while simultaneously conserving natural resources and enhancing the socio-economic development of local communities.

2.2. Methods

This study applies the Fuzzy TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution) to assess the sustainable tourism valorization potential of

lakes in Serbia. The selection of this method is justified by its ability to integrate quantitative indicators, qualitative information, and expert judgement, while accounting for uncertainty and subjectivity through fuzzy logic. The study includes ten lakes in Serbia, which represent alternatives within the multi-criteria evaluation model (see Table 1). The selected lakes differ in morphometric, hydrological, ecological, and tourism-related characteristics, enabling a comparative analysis of their tourism potential and sustainability. The diverse physical–geographical characteristics of the analyzed lakes contribute to the heterogeneity of the sample and enable comparison across different lake tourism settings in Serbia.

The evaluation criteria cover environmental quality and conservation, infrastructural development and accessibility, socio-economic effects, governance-related pressures, and stakeholder involvement in sustainable tourism valorization (Table 2). Criteria selection was based on previous research on lake tourism valorization and natural area tourism [1–6], sustainable tourism assessment [27–29], and the application of multi-criteria decision-making methods in tourism evaluation [7,8,17–21,30].

Table 2. Description of Criteria.

	Criterion	Description
C1	Water quality	Physicochemical and visual lake water characteristics, such as cleanliness and transparency.
C2	Balance between tourism use and carrying capacity	The extent to which tourism use is aligned with the environmental and spatial capacity of the lake area.
C3	Conservation of the natural environment	Preservation of the lake, shoreline, and surrounding natural elements, including the absence or presence of degradation processes.
C4	Biodiversity	Diversity and conservation status of species and their role in maintaining ecological balance.
C5	Management limitations, insufficient protection, and climate-related pressures	The extent to which the lake area is affected by management limitations, insufficient protection measures, environmental vulnerability, and climate-related pressures.
C6	Tourism infrastructure	Level and quality of tourism infrastructure and supporting facilities.
C7	Accessibility and transport connectivity	Geographic location and transport links to urban centres, tourist sites, and main transport routes.
C8	Diversity of tourism activities	Variety of tourism, recreational, educational, and nature-based activities.
C9	Economic effects	Indicative tourism-related economic effects, assessed through available municipal-level tourism indicators and expert interpretation of the lake's role in local tourism activity.
C10	Involvement of the local community	Participation of local residents and stakeholders in lake tourism development.

Given the subjectivity and uncertainty in the tourism evaluation process, a linguistic fuzzy scale with five levels of assessment was used in the study: very low, low, medium, high, and very high. The use of a predefined linguistic scale ensured that all alternatives were assessed according to the same interpretative framework. For each criterion, descriptive evaluation levels were defined to enable a more precise assessment of the condition of the analyzed lakes with respect to the observed dimensions of sustainable tourism valorization (Table 3). The linguistic scale was used in the expert evaluation

of alternatives, in which qualitative judgments were converted into fuzzy values suitable for further mathematical processing.

Table 3. Descriptive levels of lake evaluation.

Criterion	Very Low	Low	Medium	High	Very High
C1	Highly polluted water of very poor quality	Noticeably degraded water quality with visible pollution	Satisfactory water quality with occasional deviations	Good water quality with preserved physico-chemical properties	Very high water quality with exceptional clarity and transparency
C2	Severe exceedance of carrying capacity and pronounced degradation	Increased tourism pressure with visible negative impacts	Moderate pressure without significant long-term consequences	Good balance between tourism use and carrying capacity	Optimal balance between tourism use and environmental preservation
C3	Severely degraded natural environment and disrupted ecological balance	Partially degraded environment with visible damage	Moderately preserved natural environment	Well-preserved environment with minor anthropogenic impacts	Exceptionally preserved natural environment without significant degradation processes
C4	Very low biodiversity and pronounced species endangerment	Reduced diversity and weakened ecosystem stability	Moderate level of biodiversity	High level of species diversity and conservation	Exceptionally rich and well-preserved biodiversity
C5	Very low management, protection, and climate-related pressure	Limited management limitations and relatively low environmental vulnerability	Moderate management limitations, protection challenges, and climate-related pressure	High management limitations, insufficient protection measures, and increased environmental vulnerability	Very high management limitations, insufficient protection, and pronounced climate-related/environmental pressures
C6	Very underdeveloped or non-functional infrastructure	Poorly developed infrastructure	Satisfactory level of infrastructure development	Well-developed and functional infrastructure	Very-high-quality and fully functional infrastructure
C7	Extremely poor accessibility and weak connectivity	Limited accessibility and insufficient connectivity	Satisfactory accessibility with certain limitations	Good transport connectivity and accessibility	Excellent accessibility and favorable transport position
C8	Very limited tourism offer	Few available activities and facilities	Moderate diversity of tourism activities	Developed and diverse tourism offer	Very rich and attractive range of tourism offer

			ities		ism activities
C9	Very limited indicative tourism-related economic effects	Limited indicative tourism-related economic effects	Moderate indicative tourism-related economic effects	Significant indicative tourism-related economic effects within the local tourism context	Very significant indicative tourism-related economic effects within the local tourism context
C10	Very low participation of the local population	Limited involvement of the local community	Partial involvement of local stakeholders	Active participation of the local community in tourism development	Very high level of participation and cooperation of the local community

In order to improve the transparency of the evaluation procedure, expert assessments were based on a predefined linguistic scale and the same set of criteria for all analyzed lakes. Each alternative was evaluated according to the ten criteria, and the linguistic assessments were subsequently transformed into triangular fuzzy numbers. This procedure enabled the incorporation of expert judgement while limiting the drawbacks associated with the direct use of precise numerical scores in cases where data are partly qualitative or uncertain.

The evaluation was supported by both quantitative and qualitative sources of information. Quantitative data were obtained from the Statistical Office of the Republic of Serbia, including tourist arrivals, overnight stays, accommodation capacity, and other tourism development indicators for the municipalities in which the analyzed lakes are located. Since standardized lake-level tourism and economic statistics are not available for all analyzed destinations, municipal-level data were used as proxy indicators and interpreted together with lake-specific field observations, planning documents, and expert knowledge. Additional environmental information was collected from hydrological databases, reports of the Serbian Environmental Protection Agency, spatial planning documents, protected area management plans, and relevant scientific publications.

The empirical evidence was complemented by long-term field investigations conducted by the members of the expert panel, who have monitored the environmental conditions, tourism development, and management practices of the analyzed lakes over several years. These field observations enabled the verification of published information and the assessment of recent changes that were not fully reflected in official statistical sources.

Each expert based the evaluation on the available set of empirical, documentary, and field-based evidence, ensuring that the linguistic assessments represented an integrated synthesis of statistical data, scientific literature, institutional documentation, and field observations.

Because not all sustainability-related criteria can be expressed through standardized quantitative indicators, expert judgement was used to integrate heterogeneous environmental, tourism, socio-economic, and governance-related information into a unified fuzzy multi-criteria decision-making framework. This combination helped to limit the influence of purely subjective judgement and improved the transparency and consistency of the evaluation process.

2.2.1. Expert Panel and Evaluation Procedure

The expert evaluation was conducted by a multidisciplinary panel consisting of fifteen experts with complementary scientific and professional backgrounds relevant to sustainable lake tourism assessment. The panel included three hydrologists, one climatologist, five experts in environmental protection and sustainable development, five experts in tourism and sustainable development, and one specialist in spatial planning.

The experts were selected based on their academic qualifications, professional experience, and long-term involvement in research related to natural resource management, sustainable tourism, environmental protection, and spatial planning. Their multidisciplinary expertise enabled environmental, tourism, socio-economic, and planning aspects of sustainable lake tourism to be considered simultaneously during the evaluation process.

Each expert independently evaluated the ten selected lakes using the same set of evaluation criteria (Table 2) and the predefined five-level linguistic scale (Table 3). To ensure methodological consistency, all experts received identical evaluation instructions and assessed every lake according to the same criteria and evaluation framework. The linguistic assessments were subsequently transformed into triangular fuzzy numbers and incorporated into the Fuzzy TOPSIS model. The final fuzzy decision matrix represents the aggregated evaluations of all participating experts. The individual linguistic assessments were aggregated using the arithmetic mean of the corresponding triangular fuzzy numbers before constructing the final fuzzy decision matrix.

2.2.2. Operationalization of Criteria and Data Sources

The assessment of the selected lakes was based on the integration of multiple complementary sources of information. Expert evaluations were supported by published scientific literature, official statistical data, environmental and spatial planning documents, reports of relevant national institutions, and the experts' own long-term field observations of the analyzed lakes (Table 4) [31–44].

Table 4. Operationalization of the evaluation criteria and supporting data sources.

	Criterion	Operationalization	Main Empirical Indicators	Data Sources
C1	Water quality	Assessment of physicochemical and ecological status of lake water	Water transparency, ecological status, monitoring data	Serbian Environmental Protection Agency ¹ , scientific literature
C2	Balance between tourism use and carrying capacity	Evaluation of tourism pressure relative to environmental capacity	Visitor intensity, protection regime, land use, field observations	Spatial plans, management plans, field research
C3	Conservation of the natural environment	Degree of preservation of natural ecosystems	Landscape integrity, anthropogenic impacts, protected areas	Scientific literature, protected area documentation, field surveys
C4	Biodiversity	Diversity and conservation of habitats and species	Protected species, habitat diversity, conservation status	Nature protection reports, scientific publications
C5	Management limitations, insufficient protection, and climate-related	Assessment of management constraints, environmental vulnerability, and climate-related	Protection gaps, management constraints, climate-related risks, environmental vulnerability	Spatial plans, management documents, scientific literature, field observations

	pressures	mate-related pressures	nerability	
C6	Tourism infrastructure	Availability and quality of tourism facilities	Accommodation capacity, hotels, restaurants, visitor centres, recreational facilities	Statistical Office of the Republic of Serbia, Tourism Organization reports, field surveys
C7	Accessibility and transport connectivity	Accessibility of the destination	Road network, travel distance, proximity to urban centres	GIS analysis, road network data, field observations
C8	Diversity of tourism activities	Diversity of tourism products	Recreational activities, ecotourism, boating, fishing, hiking, educational tourism	Tourism organizations, destination management plans, field surveys
C9	Economic effects	Indicative assessment of tourism-related economic effects within the local tourism context	Municipal-level tourist arrivals, overnight stays, accommodation-related indicators, available destination information	Statistical Office of the Republic of Serbia, municipal/destination documents, expert assessment
C10	Local community involvement	Participation of local stakeholders	Participation in tourism projects, local initiatives, stakeholder cooperation	Local development strategies, municipal reports, field observations

¹ Source: Authors' elaboration based on official statistical data, environmental monitoring reports, spatial planning documents, protected area management plans, scientific literature, and field observations [31–44].

Environmental criteria, including water quality (C1), balance between tourism use and carrying capacity (C2), conservation of the natural environment (C3), biodiversity (C4), and management limitations, insufficient protection, and climate-related pressures (C5), were assessed using available hydrological and environmental monitoring data, scientific publications, reports of the Serbian Environmental Protection Agency, protected area management documents, and relevant spatial planning documentation. Long-term field observations conducted by the participating experts were additionally used to verify the current environmental conditions and identify recent changes that may not yet have been reflected in published datasets.

Tourism-related criteria were evaluated using both empirical information and expert knowledge. Tourism infrastructure (C6) was assessed according to the availability and quality of accommodation facilities, recreational infrastructure, visitor services, and tourism amenities. Accessibility and transport connectivity (C7) were evaluated considering the geographical position of each lake, road accessibility, proximity to major urban centres, and transport infrastructure. Diversity of tourism activities (C8) was assessed based on the range of recreational, educational, cultural, nautical, fishing, ecotourism, and nature-based tourism opportunities available at each destination.

Economic effects (C9) were evaluated as indicative tourism-related economic effects, using available municipal-level statistical indicators, including tourist arrivals, overnight stays, accommodation-related data, and published information on the lake's role in local tourism activity whenever such information was available. Local community involvement (C10) was assessed using planning documents, published reports, and evidence of stakeholder participation in tourism development and destination management.

Since several sustainability dimensions cannot be fully represented by standardized quantitative indicators alone, the final evaluation combined objective empirical evidence with expert judgement. This approach enabled the integration of heterogeneous environmental, tourism, socio-economic, and governance-related information into a unified fuzzy multi-criteria decision-making framework, while helping to limit the uncertainty associated with individual qualitative assessments.

Although some tourism-related criteria are conceptually interconnected, they were intentionally treated as separate evaluation dimensions because each captures a distinct aspect of sustainable tourism development. Tourism infrastructure (C6) evaluates the availability and quality of tourism facilities and services; accessibility and transport connectivity (C7) measure the ease with which visitors can reach the destination; diversity of tourism activities (C8) reflects the variety of tourism experiences and recreational opportunities offered at each lake; economic effects (C9) assess indicative tourism-related economic effects within the local tourism context, using available municipal-level indicators such as tourist arrivals, overnight stays, and accommodation-related data as supporting proxy evidence. The involvement of the local community (C10) represents a governance and socio-economic dimension, focusing on stakeholder participation in tourism planning and destination management. Although these dimensions are related, they address different components of destination sustainability and were therefore retained as independent criteria, consistent with previous applications of multi-criteria decision-making methods in tourism and sustainable tourism assessment [7,8,17,19,21,30].

The data presented in Table 5 were used only as supporting proxy indicators, since they refer to municipalities or broader destination areas rather than direct visitation to individual lakes. Accordingly, they were interpreted together with lake-specific documentary sources, field observations, and expert knowledge. Official statistical data were obtained from the Statistical Office of the Republic of Serbia [32], while lake-specific environmental, planning, and management information was derived from monitoring reports, protected area management plans, spatial planning documents, and relevant scientific studies [33–44].

Table 5. Tourist arrivals, overnight stays, and accommodation facilities for the analyzed lake destinations (2025–2026).

Lake	Municipality	Tourist Arrivals ¹	Overnight Stays ¹	Voucher-Listed Accommodation Facilities
				²
Lake Palić	Subotica	138,154	303,823	38
Lake Zlatar (on Uvac river)	Nova Varoš	12,805	39,777	2
Lake Sjenica (on Uvac river)	Sjenica	11,433	20,368	5
Lake Perućac (on Drina river)	Bajina Bašta	50,639	128,641	7 *
Lake Zaovine (on Beli Rzav river)	Bajina Bašta	50,639	182,863	7 **
Lake Đerdap (on Danube river)	Golubac, Majdanpek, Kladovo ***	56,819	182,863	75
Silver Lake (on Danube river)	Veliko Gradište	37,067	120,867	101
Lake Bor	Bor	14,513	42,669	3
Lake Zavoj (on Visočica river)	Pirot	33,658	78,781	23
Lake Vlasina (on Vlasina river)	Surdulica	6120	15,327	8

¹ Statistical Office of the Republic of Serbia. Tourist arrivals and overnight stays by municipalities—monthly data (January–December 2025). Available online: <https://data.stat.gov.rs/Home/Result/220205?languageCode=sr-Latn&displayMode=table&guid=ccac4e9d-4494-488e-9a12-77080ea82031> (accessed on 5 May 2026). ² List of accommodation providers

and accommodation facilities in Serbia for 2026. Available online: <https://www.vauceri.net/lista-svih-ugostitelja/> (accessed on 5 May 2026). * The number of voucher-listed accommodation facilities refers to Perućac. ** The number of voucher-listed accommodation facilities refers to Zaovine. *** The value represents the sum of municipal-level data for the municipalities covering the broader Đerdap area.

2.2.3. Procedure for Applying the Fuzzy TOPSIS Method

TOPSIS was originally proposed by Hwang and Yoon in 1981, while Fuzzy TOPSIS represents its extension for decision-making in a fuzzy environment [45]. The Fuzzy TOPSIS method as applied through several interconnected steps.

Step 1: Construction of the Decision Matrix

In this study, 10 criteria (Table 2) and 10 alternatives (Table 1) were evaluated and ranked using the Fuzzy TOPSIS method. Most criteria were treated as benefit criteria, meaning that higher values indicate more favorable conditions for sustainable tourism valorization. However, C5 was treated as a cost criterion because it refers to management limitations, insufficient protection, and climate-related pressures, where higher values indicate greater management constraints, protection deficiencies, environmental vulnerability, or climate-related pressure. Table 6 presents the weights assigned to each criterion.

Table 6. Characteristics of Criteria [46].

	Criterion	Type	Weight
C1	Water quality	+	(0.800, 1.000, 1.000)
C2	Balance between tourism use and carrying capacity	+	(0.600, 0.800, 1.000)
C3	Conservation of the natural environment	+	(0.800, 1.000, 1.000)
C4	Biodiversity	+	(0.600, 0.800, 1.000)
C5	Management limitations, insufficient protection, and climate-related pressures	−	(0.000, 0.800, 1.000)
C6	Tourism infrastructure	+	(0.600, 0.800, 1.000)
C7	Accessibility and transport connectivity	+	(0.200, 0.500, 0.800)
C8	Diversity of tourism activities	+	(0.600, 0.800, 1.000)
C9	Economic effects	+	(0.200, 0.500, 0.800)
C10	Involvement of the local community	+	(0.600, 0.800, 1.000)

The experts participating in the study determined the criterion weights shown in Table 6 by assessing the relative importance of each criterion for the sustainable tourism valorization of lakes. The fuzzy weights were obtained by aggregating expert assessments and expressing the final values as triangular fuzzy numbers. To implement the multi-criteria evaluation using Fuzzy TOPSIS, qualitative expert assessments were converted into triangular fuzzy numbers. Each triangular fuzzy number was defined by three values: the lower bound (l), the middle value (m), and the upper bound (u). This enabled uncertainty in expert judgement to be represented mathematically within the decision model. This approach enables more precise modeling of expert opinions than conventional numerical scales.

After the evaluation, the linguistic assessments were converted into fuzzy numbers and used to construct the decision matrix. This procedure allowed uncertainty and variability in expert judgments to be incorporated into the model. Applying the fuzzy scale is an essential step in the Fuzzy TOPSIS model, as it enables a more realistic representation of the relationships between sustainability criteria and tourism potential for the analyzed lakes.

In the decision matrix, higher fuzzy values generally indicate more favorable conditions for sustainable tourism valorization (Table 7). The exception is C5, which was treated as a cost criterion and therefore represents management limitations, insufficient protection, and climate-related or environmental pressures.

Table 7. Fuzzy decision matrix based on expert evaluation.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	(2.000, 4.000, 6.000)	(2.500, 4.500, 6.500)	(4.000, 6.000, 8.000)	(4.500, 6.500, 8.500)	(3.000, 5.000, 7.000)	(7.000, 9.000, 9.000)	(7.000, 9.000, 9.000)	(6.000, 8.000, 9.000)	(6.000, 8.000, 9.000)	(6.000, 8.000, 9.000)
A2	(6.000, 8.000, 9.000)	(5.500, 7.500, 8.500)	(6.500, 8.500, 9.000)	(7.000, 9.000, 9.000)	(5.000, 7.000, 9.000)	(2.500, 4.500, 6.500)	(4.500, 6.500, 8.500)	(2.500, 4.500, 6.500)	(2.500, 4.500, 6.500)	(3.500, 5.500, 7.500)
A3	(6.500, 8.500, 9.000)	(6.000, 8.000, 8.500)	(7.000, 9.000, 9.000)	(7.000, 9.000, 9.000)	(6.500, 8.500, 9.000)	(1.000, 3.000, 5.000)	(3.000, 5.000, 7.000)	(2.500, 4.500, 6.500)	(2.000, 4.000, 6.000)	(3.500, 5.500, 7.500)
A4	(4.000, 6.000, 8.000)	(5.500, 7.500, 8.500)	(6.500, 8.500, 9.000)	(6.500, 8.500, 9.000)	(3.000, 5.000, 7.000)	(4.500, 6.500, 8.500)	(5.000, 7.000, 9.000)	(6.500, 8.500, 9.000)	(6.000, 8.000, 9.000)	(4.500, 6.500, 8.500)
A5	(6.500, 8.500, 9.000)	(6.000, 8.000, 8.500)	(6.500, 8.500, 9.000)	(7.000, 9.000, 9.000)	(6.500, 8.500, 9.000)	(4.500, 6.500, 8.500)	(3.000, 5.000, 7.000)	(4.000, 6.000, 8.000)	(4.000, 6.000, 8.000)	(4.500, 6.500, 8.500)
A6	(4.000, 6.000, 8.000)	(6.000, 8.000, 8.500)	(7.000, 9.000, 9.000)	(7.000, 9.000, 9.000)	(7.000, 9.000, 9.000)	(5.000, 7.000, 9.000)	(6.500, 8.500, 9.000)	(7.000, 9.000, 9.000)	(5.000, 7.000, 9.000)	(4.500, 6.500, 8.500)
A7	(3.000, 5.000, 7.000)	(2.500, 4.500, 6.500)	(4.000, 6.000, 8.000)	(4.000, 6.000, 8.000)	(4.000, 6.000, 8.000)	(7.000, 9.000, 9.000)	(7.000, 9.000, 9.000)	(7.000, 9.000, 9.000)	(7.000, 9.000, 9.000)	(5.000, 7.000, 9.000)
A8	(4.000, 6.000, 8.000)	(4.000, 6.000, 8.000)	(4.500, 6.500, 8.500)	(4.500, 6.500, 8.500)	(3.000, 5.000, 7.000)	(5.000, 7.000, 9.000)	(5.000, 7.000, 9.000)	(4.000, 6.000, 8.000)	(4.500, 6.500, 8.500)	(4.500, 6.500, 8.500)
A9	(7.000, 9.000, 9.000)	(6.000, 8.000, 8.500)	(6.500, 8.500, 9.000)	(7.000, 9.000, 9.000)	(3.500, 5.500, 7.500)	(1.000, 3.000, 5.000)	(2.500, 4.500, 6.500)	(2.500, 4.500, 6.500)	(1.000, 3.000, 5.000)	(3.000, 5.000, 7.000)
A10	(7.000, 9.000, 9.000)	(6.000, 8.000, 8.500)	(7.000, 9.000, 9.000)	(7.000, 9.000, 9.000)	(6.500, 8.500, 9.000)	(1.500, 3.500, 5.500)	(2.500, 4.500, 6.500)	(5.500, 7.500, 8.500)	(3.000, 5.000, 7.000)	(3.500, 5.500, 7.500)

The input values in the fuzzy decision matrix were obtained from aggregated expert evaluations, while the subsequent normalization, weighting, distance calculation, and ranking procedures were performed using the OnlineOutput web-based Fuzzy TOPSIS software (accessed on 5 May 2026) [46]. e

The construction of the decision matrix represents the initial and one of the most important phases of the Fuzzy TOPSIS model, as it provides the basis for further mathematical procedures, including data normalization, weighting of criteria, determination of ideal solutions, and ultimately the ranking of alternatives.

Step 2: Construction of the Normalized Decision Matrix

The fuzzy decision matrix was normalized in order to make the values of different criteria comparable. Since the model includes both benefit and cost criteria, two normalization procedures were applied.

For benefit criteria, the normalized fuzzy decision matrix was calculated using Equation (1):

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right); c_j^* = \max_i c_{ij}; \text{Positive ideal solution} \quad (1)$$

For cost criteria, the normalized fuzzy decision matrix was calculated using Equation (2):

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right); a_j^- = \min_i a_{ij}; \text{Negative ideal solution} \quad (2)$$

where $\tilde{r}_{ij}$ represents the normalized fuzzy value of alternative (i) according to criterion (j), while a_{ij} , b_{ij} and c_{ij} are the lower, middle, and upper values of the triangular fuzzy number.

Step 3: Construction of the Weighted Normalized Decision Matrix

Considering the different weights assigned to each criterion, the weighted normalized decision matrix was obtained by multiplying the normalized fuzzy decision matrix by the fuzzy weight of each criterion, according to Equation (3):

$$\tilde{v}_{ij} = \tilde{r}_{ij} \cdot \tilde{w}_{ij} \quad (3)$$

where $\tilde{w}_{ij}$ represents the weight of criterion c_j .

Step 4: Determine the fuzzy positive ideal solution (FPIS, A^*) and the fuzzy negative ideal solution (FNIS, A^-)

The FPIS and FNIS of the alternatives can be defined as follows ((4) and (5)):

$$A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*\} = \left\{ \left(\max_j v_{ij} \mid i \in B \right), \left(\min_j v_{ij} \mid i \in C \right) \right\} \quad (4)$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-\} = \left\{ \left(\min_j v_{ij} \mid i \in B \right), \left(\max_j v_{ij} \mid i \in C \right) \right\} \quad (5)$$

where $\tilde{v}_i^*$ is the max value of i for all the alternatives and $\tilde{v}_i^-$ is the min value of i for all the alternatives, where B denotes the set of benefit criteria and C denotes the set of cost criteria. FPIS (A) represents the fuzzy positive ideal solution, whereas FNIS (A^-) represents the fuzzy negative ideal solution.

Step 5: Calculate the distance between each alternative and the fuzzy positive ideal solution A^* and the distance between each alternative and the fuzzy negative ideal solution A^-

The distance between each alternative and FPIS and the distance between each alternative and FNIS are respectively calculated as follows ((6) and (7)):

$$S_i^+ = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^*) \quad i = 1, 2, \dots, m \quad (6)$$

$$S_i^- = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad i = 1, 2, \dots, m \quad (7)$$

where d is the distance between two fuzzy numbers. Given two triangular fuzzy numbers, $\tilde{M}_1 = (a_1, b_1, c_1)$ and $\tilde{M}_2 = (a_2, b_2, c_2)$, the distance between them can be calculated as follows (8):

$$d_v(\tilde{M}_1, \tilde{M}_2) = \sqrt{\frac{1}{3} [(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \quad (8)$$

Note that $d(\tilde{v}_{ij}, \tilde{v}_j^*)$ and $d(\tilde{v}_{ij}, \tilde{v}_j^-)$ are crisp numbers.

Step 6: Calculate the closeness coefficient and rank the alternatives

The closeness coefficient of each alternative can be calculated as follows (9):

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (9)$$

The best alternative is the one closest to the FPIS and farthest from the FNIS. Accordingly, higher CC_i values indicate more favorable performance according to the selected sustainable tourism valorization criteria. The final ranking of the analyzed lakes was based on the calculated closeness coefficients.

3. Results

The application of the Fuzzy TOPSIS method enabled a multi-criteria evaluation of ten lakes in Serbia from the perspective of sustainable tourism valorization. After constructing the fuzzy decision matrix, the evaluation procedure included developing the weighted normalized decision matrix, determining the positive and negative ideal solutions, calculating the distances of the alternatives from the ideal solutions, and computing the closeness coefficient and the final ranking of the alternatives.

The normalized decision matrix presents the relative values of the alternatives with respect to the defined criteria of sustainable tourism valorization (Table 8). The normalization process reduced differences arising from different measurement scales and enabled the comparison of all alternatives within a unified fuzzy evaluation framework. Since C5 was treated as a cost criterion, its normalized values should be interpreted in relation to management limitations, insufficient protection, and climate-related pressures, where lower original levels of limitations and pressures correspond to more favorable normalized performance.

Table 8. Normalized Decision Matrix [46].

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	(0.222, 0.444, 0.667)	(0.294, 0.529, 0.765)	(0.444, 0.667, 0.889)	(0.500, 0.722, 0.944)	(0.429, 0.600, 1.000)	(0.778, 1.000, 1.000)	(0.778, 1.000, 1.000)	(0.667, 0.889, 1.000)	(0.667, 0.889, 1.000)	(0.667, 0.889, 1.000)
A2	(0.667, 0.889, 1.000)	(0.647, 0.882, 1.000)	(0.722, 0.944, 1.000)	(0.778, 1.000, 1.000)	(0.333, 0.429, 0.600)	(0.278, 0.500, 0.722)	(0.500, 0.722, 0.944)	(0.278, 0.500, 0.722)	(0.278, 0.500, 0.722)	(0.389, 0.611, 0.833)
A3	(0.722, 0.944, 1.000)	(0.706, 0.941, 1.000)	(0.778, 1.000, 1.000)	(0.778, 1.000, 1.000)	(0.333, 0.353, 0.462)	(0.111, 0.333, 0.556)	(0.333, 0.556, 0.778)	(0.278, 0.500, 0.722)	(0.222, 0.444, 0.667)	(0.389, 0.611, 0.833)
A4	(0.444, 0.667, 0.889)	(0.647, 0.882, 1.000)	(0.722, 0.944, 1.000)	(0.722, 0.944, 1.000)	(0.429, 0.600, 1.000)	(0.500, 0.722, 0.944)	(0.556, 0.778, 1.000)	(0.722, 0.944, 1.000)	(0.667, 0.889, 1.000)	(0.500, 0.722, 0.944)
A5	(0.722, 0.944, 1.000)	(0.706, 0.941, 1.000)	(0.722, 0.944, 1.000)	(0.778, 1.000, 1.000)	(0.333, 0.353, 0.462)	(0.500, 0.722, 0.944)	(0.333, 0.556, 0.778)	(0.444, 0.667, 0.889)	(0.444, 0.667, 0.889)	(0.500, 0.722, 0.944)
A6	(0.444, 0.667, 0.889)	(0.706, 0.941, 1.000)	(0.778, 1.000, 1.000)	(0.778, 1.000, 1.000)	(0.333, 0.333, 0.429)	(0.556, 0.778, 1.000)	(0.722, 0.944, 1.000)	(0.778, 1.000, 1.000)	(0.556, 0.778, 1.000)	(0.500, 0.722, 0.944)
A7	(0.333, 0.556, 0.778)	(0.294, 0.529, 0.765)	(0.444, 0.667, 0.889)	(0.444, 0.667, 0.889)	(0.375, 0.500, 0.750)	(0.778, 1.000, 1.000)	(0.778, 1.000, 1.000)	(0.778, 1.000, 1.000)	(0.778, 1.000, 1.000)	(0.556, 0.778, 1.000)
A8	(0.444, 0.667, 0.889)	(0.471, 0.706, 0.941)	(0.500, 0.722, 0.944)	(0.500, 0.722, 0.944)	(0.429, 0.600, 1.000)	(0.556, 0.778, 1.000)	(0.556, 0.778, 1.000)	(0.444, 0.667, 0.889)	(0.500, 0.722, 0.944)	(0.500, 0.722, 0.944)
A9	(0.778, 1.000, 1.000)	(0.706, 0.941, 1.000)	(0.722, 0.944, 1.000)	(0.778, 1.000, 1.000)	(0.400, 0.545, 0.857)	(0.111, 0.333, 0.556)	(0.278, 0.500, 0.722)	(0.278, 0.500, 0.722)	(0.111, 0.333, 0.556)	(0.333, 0.556, 0.778)

A10	(0.778, 1.000, 1.000)	(0.706, 0.941, 1.000)	(0.778, 1.000, 1.000)	(0.778, 1.000, 1.000)	(0.333, 0.353, 0.462)	(0.167, 0.389, 0.611)	(0.278, 0.500, 0.722)	(0.611, 0.833, 0.944)	(0.333, 0.556, 0.778)	(0.389, 0.611, 0.833)
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The normalized values indicate pronounced heterogeneity among the alternatives with respect to the observed criteria. Lake Zaovine (A5), Lake Perućac (A4), and Lake Vlasina (A10) show more favorable values in relation to natural preservation and environmental quality, whereas Lake Đerdap (A6), Silver Lake (A7), and Lake Palić (A1) show comparatively stronger performance in tourism infrastructure, accessibility, diversity of tourism activities, and indicative tourism-related economic effects. In contrast, Lake Zlatar (A2), Lake Sjenica (A3), and Lake Zavoj (A9) exhibit clearer limitations in infrastructural development and tourism-related functions within the applied evaluation framework. Together, these findings form the basis for the next phase of the Fuzzy TOPSIS analysis: the construction of the weighted normalized decision matrix.

The weighted normalized decision matrix was obtained by incorporating the fuzzy weights of the criteria into the evaluation process (Table 9). Consequently, this matrix reflects the relative importance of each criterion within the sustainable tourism valorization assessment of the analyzed lakes.

Table 9. Weighted Normalized Decision Matrix [46].

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	(0.178, 0.444, 0.667)	(0.176, 0.424, 0.765)	(0.356, 0.667, 0.889)	(0.300, 0.578, 0.944)	(0.000, 0.480, 1.000)	(0.467, 0.800, 1.000)	(0.156, 0.500, 0.800)	(0.400, 0.711, 1.000)	(0.133, 0.444, 0.800)	(0.400, 0.711, 1.000)
A2	(0.533, 0.889, 1.000)	(0.388, 0.706, 1.000)	(0.578, 0.944, 1.000)	(0.467, 0.800, 1.000)	(0.000, 0.343, 0.600)	(0.167, 0.400, 0.722)	(0.100, 0.361, 0.756)	(0.167, 0.400, 0.722)	(0.056, 0.250, 0.578)	(0.233, 0.489, 0.833)
A3	(0.578, 0.944, 1.000)	(0.424, 0.753, 1.000)	(0.622, 1.00 0, 1.000)	(0.467, 0.800, 1.000)	(0.000, 0.282, 0.462)	(0.067, 0.267, 0.556)	(0.067, 0.278, 0.622)	(0.167, 0.400, 0.722)	(0.044, 0.222, 0.533)	(0.233, 0.489, 0.833)
A4	(0.356, 0.667, 0.889)	(0.388, 0.706, 1.000)	(0.578, 0.944, 1.000)	(0.433, 0.756, 1.000)	(0.000, 0.480, 1.000)	(0.300, 0.578, 0.944)	(0.111, 0.389, 0.800)	(0.433, 0.756, 1.000)	(0.133, 0.444, 0.800)	(0.300, 0.578, 0.944)
A5	(0.578, 0.944, 1.000)	(0.424, 0.753, 1.000)	(0.578, 0.944, 1.000)	(0.467, 0.800, 1.000)	(0.000, 0.282, 0.462)	(0.300, 0.578, 0.944)	(0.067, 0.278, 0.622)	(0.267, 0.533, 0.889)	(0.089, 0.333, 0.711)	(0.300, 0.578, 0.944)
A6	(0.356, 0.667, 0.889)	(0.424, 0.753, 1.000)	(0.622, 1.000, 1.000)	(0.467, 0.800, 1.000)	(0.000, 0.267, 0.429)	(0.333, 0.622, 1.000)	(0.144, 0.472, 0.800)	(0.467, 0.800, 1.000)	(0.111, 0.389, 0.800)	(0.300, 0.578, 0.944)
A7	(0.267, 0.556, 0.778)	(0.176, 0.424, 0.765)	(0.356, 0.667, 0.889)	(0.267, 0.533, 0.889)	(0.000, 0.400, 0.750)	(0.467, 0.800, 1.000)	(0.156, 0.500, 0.800)	(0.467, 0.800, 1.000)	(0.156, 0.500, 0.800)	(0.333, 0.622, 1.000)
A8	(0.356, 0.667, 0.889)	(0.282, 0.565, 0.941)	(0.400, 0.722, 0.944)	(0.300, 0.578, 0.944)	(0.000, 0.480, 1.000)	(0.333, 0.622, 1.000)	(0.111, 0.389, 0.800)	(0.267, 0.533, 0.889)	(0.100, 0.361, 0.756)	(0.300, 0.578, 0.944)
A9	(0.622, 1.000, 1.000)	(0.424, 0.753, 1.000)	(0.578, 0.944, 1.000)	(0.467, 0.800, 1.000)	(0.000, 0.436, 0.857)	(0.067, 0.267, 0.556)	(0.056, 0.250, 0.578)	(0.167, 0.400, 0.722)	(0.022, 0.167, 0.444)	(0.200, 0.444, 0.778)
A10	(0.622, 1.000, 1.000)	(0.424, 0.753, 1.000)	(0.622, 1.000, 1.000)	(0.467, 0.800, 1.000)	(0.000, 0.282, 0.462)	(0.100, 0.311, 0.611)	(0.056, 0.250, 0.578)	(0.367, 0.667, 0.944)	(0.067, 0.278, 0.622)	(0.233, 0.489, 0.833)

Compared to the previous stage, weighting further emphasized differences among the alternatives. This effect was particularly evident for criteria with greater importance in the decision-making process. In this study, environmental indicators refer to water quality, biodiversity, and conservation of the natural environment; infrastructural indicators refer to tourism infrastructure, accessibility, and transport connectivity; socio-economic indicators refer to indicative tourism-related economic effects and local community involvement; while governance-related indicators refer to management limitations, insufficient protection, and climate-related pressures. The results show that the most favorable alternatives are those achieving comparatively high values across several groups of criteria, especially environmental, infrastructural, and tourism-related indicators. Lower values are observed for lakes with more pronounced limitations in tourism development, accessibility, infrastructure, or indicative tourism-related economic effects within the applied evaluation framework.

The weighted normalized matrix was used to determine the fuzzy positive ideal solution and the fuzzy negative ideal solution. In the Fuzzy TOPSIS method, these solutions serve as reference points for evaluating each alternative. The positive ideal solution represents the most favorable combination of weighted fuzzy values, whereas the negative ideal solution represents the least favorable combination of values (Table 10).

Table 10. The Positive and Negative Ideal Solutions [46].

	Positive Ideal	Negative Ideal
Water quality	(0.622, 1.000, 1.000)	(0.178, 0.444, 0.667)
Balance between tourism use and carrying capacity	(0.424, 0.753, 1.000)	(0.176, 0.424, 0.765)
Conservation of the natural environment	(0.622, 1.000, 1.000)	(0.356, 0.667, 0.889)
Biodiversity	(0.467, 0.800, 1.000)	(0.267, 0.533, 0.889)
Management limitations, insufficient protection, and climate-related pressures	(0.000, 0.267, 0.429)	(0.000, 0.480, 1.000)
Tourism infrastructure	(0.467, 0.800, 1.000)	(0.067, 0.267, 0.556)
Accessibility and transport connectivity	(0.156, 0.500, 0.800)	(0.056, 0.250, 0.578)
Diversity of tourism activities	(0.467, 0.800, 1.000)	(0.167, 0.400, 0.722)
Indicative tourism-related economic effects	(0.156, 0.500, 0.800)	(0.022, 0.167, 0.444)
Involvement of the local community	(0.400, 0.711, 1.000)	(0.200, 0.444, 0.778)

The ideal solutions define boundary conditions that enable the assessment of how the analyzed alternatives align with the applied model of sustainable tourism valorization. Constructing the ideal solutions is a key stage of the method because it enables the calculation of the distance of each alternative from both the positive and negative reference models. This step directly influences the final ranking of the analyzed lakes.

The distances of the alternatives from the positive and negative ideal solutions serve as a basis for assessing their relative performance within the applied Fuzzy TOPSIS model (Table 11). Alternatives that are closer to the positive ideal solution and farther from the negative ideal solution are considered more favorable according to the selected sustainable tourism valorization criteria.

Table 11. Distance from Positive and Negative Ideal Solutions [46].

	Distance from Positive Ideal	Distance from Negative Ideal
Lake Palić	1.596	1.485
Lake Zlatar	1.405	1.686
Lake Sjenica	1.446	1.617

Lake Perućac	1.115	2.020
Lake Zaovine	0.859	2.246
Lake Đerdap	0.571	2.557
Silver Lake	1.349	1.723
Lake Bor	1.710	1.456
Lake Zavoj	1.825	1.232
Lake Vlasina	1.101	1.962

Lake Đerdap achieves the most favorable distance ratio, indicating strong alignment with the defined sustainability-related criteria within the applied model. Lake Zaovine, Lake Perućac, and Lake Vlasina also show favorable results, primarily due to their comparatively strong performance in environmental and nature-based tourism-related criteria. Lake Bor and Lake Zavoj exhibit greater deviations from the positive ideal solution, indicating less favorable overall performance according to the selected sustainable tourism valorization criteria. These results highlight the need to balance natural, infrastructural, socio-economic, and governance-related dimensions in tourism valorization.

Table 12 presents the final results of the Fuzzy TOPSIS method, expressed as closeness coefficient (Ci) values for each analyzed alternative. The closeness coefficient represents the relative position of each alternative in relation to the positive and negative ideal solutions, with higher values indicating greater similarity to the ideal solution within the applied sustainable tourism valorization model.

Table 12. Closeness coefficient values and ranking [46].

Alternative	Ci	Rank
Lake Palić	0.482	8
Lake Zlatar	0.545	6
Lake Sjenica	0.528	7
Lake Perućac	0.644	3
Lake Zaovine	0.723	2
Lake Đerdap	0.818	1
Silver Lake	0.561	5
Lake Bor	0.460	9
Lake Zavoj	0.403	10
Lake Vlasina	0.640	4

Based on the closeness coefficient values, the final ranking of the analyzed lakes was determined according to their relative performance within the applied Fuzzy TOPSIS model (Table 12; Figure 2). Alternatives with higher closeness coefficient values show greater alignment with the defined environmental, infrastructural, socio-economic, and governance-related criteria for sustainable tourism valorization.

The results show that Lake Đerdap achieved the highest closeness coefficient value (Ci = 0.818), ranking first among the analyzed alternatives. This result reflects its favorable overall position in terms of tourism infrastructure, transport accessibility, diversity of tourism activities, natural and landscape values, and governance-related pressures within the applied evaluation model.

Following Lake Đerdap, Lake Zaovine ranked second, with a closeness coefficient value of 0.723. This result is associated with favorable environmental preservation, water quality, and biodiversity potential. According to the applied evaluation framework, Lake Zaovine shows favorable conditions for sustainable tourism valorization, particularly for ecotourism and recreation based on natural resources.

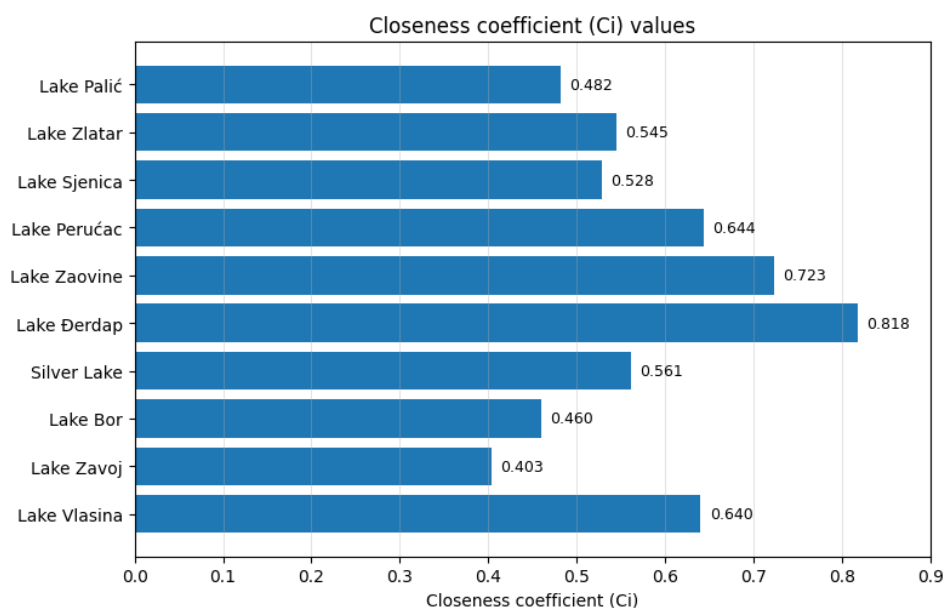


Figure 2. Closeness coefficient values [46].

Lake Perućac ($C_i = 0.644$) and Lake Vlasina ($C_i = 0.640$) also achieved high closeness coefficient values, indicating their favorable performance according to the selected sustainable tourism valorization criteria. These alternatives are characterized by well-preserved natural environments, high water quality, and opportunities for recreational and environmentally oriented tourism activities. The difference between Lake Perućac and Lake Vlasina is small, indicating that their positions within the ranking are relatively close.

Medium closeness coefficient values were recorded for Silver Lake ($C_i = 0.561$), Lake Zlatar ($C_i = 0.545$), and Lake Sjenica ($C_i = 0.528$). These alternatives possess certain positive tourism and natural potentials, but also limitations that affect their overall position within the applied evaluation model. These limitations are most commonly related to infrastructure, accessibility, tourism recognition, or the balance between tourism use and environmental protection.

Lake Palić recorded a lower closeness coefficient ($C_i = 0.482$), indicating certain challenges in sustainable tourism valorization. Although it has a well-developed tourism sector and a long tradition of tourism development, stronger anthropogenic pressures and water quality issues negatively affect its overall performance according to the selected criteria.

The lowest closeness coefficient values were recorded for Lake Bor ($C_i = 0.460$) and Lake Zavoj ($C_i = 0.403$), placing these alternatives at the bottom of the ranking list. These results indicate less favorable overall performance according to the selected sustainable tourism valorization criteria, primarily due to weaker tourism development, infrastructure limitations, or more restricted integration into broader tourism flows.

The analysis of the closeness coefficient confirms that the valorization of lakes for sustainable tourism depends on the alignment of natural, infrastructural, socio-economic, and governance-related factors. The results indicate that lakes with high environmental preservation, developed tourism infrastructure, stronger accessibility, and more balanced relationships between tourism use and management-related pressures achieve a more favorable position in the process of sustainable tourism valorization.

4. Discussion

The results of the Fuzzy TOPSIS method show pronounced differences among the analyzed lakes in terms of their relative performance according to the selected sustaina-

ble tourism valorization criteria. The obtained closeness coefficient values enabled the identification of alternatives with more favorable relative performance, as well as those facing infrastructural, environmental, socio-economic, and governance-related limitations within the applied evaluation framework. The ranking highlights the importance of an integrated assessment approach, since the tourism valorization of lake destinations depends not only on natural attractiveness, but also on infrastructure, accessibility, tourism functions, local community involvement, and management limitations, insufficient protection, and climate-related pressures.

Lake Đerdap was identified as the most favorable alternative for sustainable tourism valorization. Its leading position results from the combined influence of pronounced natural and landscape values, developed tourism infrastructure, good transport accessibility, and a diverse range of tourism activities. An additional advantage is the international tourism significance of the Danube River, together with the presence of protected natural areas and an established spatial-planning context. However, the further development of tourism in this area requires continuous monitoring of tourism pressure, careful management of shoreline use, and the preservation of natural and cultural heritage resources.

Lake Zaovine achieved a high ranking primarily due to its well-preserved natural environment, high water quality, and favorable biodiversity characteristics. Its landscape attractiveness and potential for ecotourism, recreational tourism, and excursion tourism further strengthen its position within the model. Nevertheless, its lower level of infrastructural development and more limited accessibility compared with leading destinations represent constraints that should be considered in future planning.

The results also confirm that Lake Perućac has a significant level of sustainable tourism valorization. Its advantages are reflected in its well-preserved natural environment, attractive landscape, and developed recreational functions. Its proximity to Tara National Park provides additional opportunities for active, nature-based, and environmentally responsible tourism. At the same time, the results indicate the need to further improve tourism infrastructure and strengthen the involvement of the local community in tourism development processes.

Lake Vlasina is characterized by a high level of environmental preservation, specific hydrological features, and significant biodiversity, which represent the main factors of its tourism attractiveness. Its potential for sustainable tourism development is particularly reflected in opportunities for ecotourism, health, sports, educational, and recreational tourism. However, weaker infrastructure development and lower tourism recognition compared with leading lake destinations in Serbia limit its overall valorization. The closeness coefficient values of Lake Perućac and Lake Vlasina are very similar, indicating that their positions in the ranking are relatively close and should not be interpreted as substantially different.

Silver Lake stands out among the analyzed lakes because of its developed tourism infrastructure, transport accessibility, and high level of tourist visitation. However, intensive tourism development and anthropogenic pressure may negatively affect long-term sustainability, particularly in relation to environmental quality and carrying capacity. This indicates the need to balance further tourism development with stricter control of spatial use, waste management, and water-quality protection.

Lake Zlatar and Lake Sjenica show relatively similar tourism outcomes, which can be partly explained by their geographical proximity and shared environmental characteristics. Their environmental preservation, water quality, and potential for selective forms of tourism, such as ecotourism, fishing, and recreation, place them ahead of some alternatives. Nevertheless, they remain less competitive than better-known destinations due to limitations in infrastructure, accessibility, and tourism recognition.

The results confirm that Lake Palić faces specific challenges within the framework of sustainable tourism valorization. Although it has a long tourism tradition, developed infrastructure, and a favorable geographical position, its overall sustainability performance is limited by water-quality problems and increased anthropogenic pressures. The long-term sustainability of tourism development at this lake therefore depends on ecosystem revitalization, improved environmental protection, and the reduction in pressures associated with intensive tourism and urbanization.

Lake Bor has natural and recreational potential, but the results indicate limitations related to tourism infrastructure, diversity of tourism activities, and destination recognition. Additional challenges are associated with the need to improve the organization of tourism spaces and strengthen local development initiatives that could support more sustainable tourism functions.

Lake Zavoj was ranked as the least favorable alternative in the model, primarily due to weaker infrastructure, limited accessibility, and lower tourism recognition. Although it possesses significant natural and landscape values, its current tourism function is not sufficiently developed to enable a higher level of sustainable tourism valorization. Future development should therefore prioritize basic tourism infrastructure, improved accessibility, spatial planning, and stronger involvement of the local community in tourism initiatives.

Overall, the results indicate that sustainable tourism valorization of lakes does not depend solely on natural characteristics, but rather on the alignment of environmental, infrastructural, socio-economic, and governance-related factors. The application of the Fuzzy TOPSIS method enabled the identification of key strengths and limitations of the analyzed alternatives according to the selected criteria, thereby providing a useful basis for decision-making in the planning and management of sustainable lake tourism development in Serbia.

4.1. Advantages and Limitations of the Methodology

The Fuzzy TOPSIS method integrates heterogeneous environmental, infrastructural, socio-economic, and governance-related criteria and accounts for uncertainty and subjectivity in evaluating tourist destinations. Its main advantage lies in the possibility of combining quantitative data and qualitative expert assessments within a single decision-making framework. By transforming linguistic evaluations into triangular fuzzy numbers, the method enables the ranking of alternatives according to their relative closeness to the positive ideal solution and their distance from the negative ideal solution.

Another advantage of the method is its applicability to tourism valorization contexts in which not all indicators are available in a fully standardized quantitative form. This is particularly relevant for lake destinations, where criteria such as tourism attractiveness, carrying capacity, local community involvement, and governance-related pressures often require expert interpretation. In this regard, Fuzzy TOPSIS provides a structured and transparent framework for comparing alternatives under conditions of incomplete information and assessment uncertainty.

Although the application of Fuzzy TOPSIS allows the integration of diverse criteria and the treatment of uncertainty, the study has several limitations. These include the dependence of the results on expert judgments, the selected set of criteria, and the assigned fuzzy weights. Different expert panels, alternative weighting procedures, or a broader set of indicators could produce partially different rankings of the analyzed lakes. In addition, some criteria are affected by seasonality, especially those related to tourism pressure, water quality, accessibility, and tourism activities. Climate variability and longer-term climate change may also influence the sustainability potential of lake desti-

nations, particularly through changes in hydrological regimes, ecosystem sensitivity, and tourism demand.

A further limitation concerns the availability and comparability of data for all analyzed lakes. While morphometric and basic hydrological characteristics are relatively well documented, indicators related to tourism flows, local economic effects, management pressures, and community involvement are not equally available for all destinations. For this reason, expert assessment was used to harmonize heterogeneous information and enable comparison within the Fuzzy TOPSIS model. Future research should therefore include more detailed field-based data, visitor statistics, water-quality monitoring results, and stakeholder surveys.

The results are generally consistent with findings from previous studies, which emphasize the important role of natural and environmental criteria in the sustainable tourism valorization of nature-based destinations [47]. Similar conclusions have been reported in studies on sustainable tourism in protected areas and lake destinations in other European countries, where environmental quality and ecosystem preservation represent important factors of tourism destination competitiveness [48–51]. The findings are also consistent with contemporary studies that demonstrate the applicability of Fuzzy TOPSIS and related fuzzy multi-criteria frameworks in tourism destination evaluation and tourism valorization, particularly where decision-making depends on multiple criteria and expert-based assessments [52–55].

An additional limitation of the present study concerns the validation of the obtained ranking. Although the expert evaluations were supported by official municipal-level tourism statistics used as proxy indicators, including tourist arrivals, overnight stays, accommodation-related data, environmental reports, scientific literature, spatial planning documents, and long-term field investigations, the final ranking was not independently validated using an alternative multi-criteria decision-making method. The primary objective of this research was to demonstrate the applicability of the Fuzzy TOPSIS method for assessing the sustainable tourism potential of Serbian lakes rather than to compare different MCDM techniques. Therefore, future research should validate the obtained rankings using alternative methods, such as VIKOR, PROMETHEE, or ELECTRE, and examine the consistency of the results using additional sustainability performance indicators.

4.2. Recommendations for Improving the Long-Term Sustainable Tourism Valorization of Lakes in Serbia

Based on the results of the conducted Fuzzy TOPSIS analysis, a set of general recommendations can be formulated to support the long-term sustainability of tourism development in the analyzed lakes. The proposed measures are oriented toward the preservation of natural resources, the improvement of tourism quality, the strengthening of institutional governance, and the increase in socio-economic benefits for local communities. Given the differences identified among the analyzed lakes, the recommendations should be understood as general strategic guidelines that need to be adapted to the specific environmental, infrastructural, and governance-related conditions of each destination.

Water quality is a key factor in the sustainable valorization of lakes; therefore, continuous monitoring of physicochemical and biological parameters is necessary. Particular attention should be given to lakes under pronounced anthropogenic pressure, such as Lake Palić and Silver Lake, where increased tourist visitation and urbanization may lead to ecosystem degradation. It is recommended to improve wastewater treatment systems, control illegal pollutant discharges, and implement revitalization measures in degraded parts of lake ecosystems.

The sustainable development of lake tourism requires balancing the intensity of tourism use with the ecological carrying capacity of lake areas. In this regard, it is necessary to define maximum visitor capacities, especially in sensitive natural areas such as Lake Vlasina, Lake Zaovine, and Lake Sjenica. The development of spatial planning documents is recommended to regulate land use, the construction of tourism facilities, and the utilization of shoreline areas in accordance with sustainability principles.

Lakes with high levels of environmental preservation and biodiversity represent important resources for the development of ecotourism and sustainable recreation. To preserve ecological balance, it is necessary to restrict unplanned construction, reduce shoreline degradation, and implement protection measures for sensitive habitats and endangered species. Educational programs and the promotion of environmentally responsible behavior among tourists and local residents are particularly important for destinations such as Lake Zaovine, Lake Vlasina, Lake Sjenica, and Lake Zavoj, where natural values represent the main basis of tourism potential.

Further development of lake tourism requires improvements to tourism infrastructure in line with sustainable development principles. This includes the construction and modernization of accommodation facilities, hiking and cycling trails, marinas, visitor centers, and recreational amenities with minimal environmental impact. Special attention should be given to the application of energy-efficient and environmentally friendly solutions in tourism infrastructure. Infrastructure development should be particularly carefully planned in less developed destinations, where tourism growth must not compromise environmental quality or shoreline stability.

Certain lakes, particularly Lake Zavoj, Lake Sjenica, and Lake Zaovine, are characterized by limited transport accessibility, which represents a significant constraint to tourism development. It is necessary to improve road infrastructure, signage, and connectivity with major tourism-generating centers, while simultaneously preserving the natural environment and minimizing the negative environmental impacts of transport.

The development of sustainable tourism also involves enhancing and diversifying tourism activities to reduce seasonality and increase destination competitiveness. In addition to bathing and recreational tourism, the development of ecotourism, sports, fishing, health, educational, and rural tourism is recommended. The organization of events, educational workshops, and nature-based activities can increase destination attractiveness and extend the tourist season, particularly in lakes whose tourism potential is still insufficiently recognized.

Effective governance is a key prerequisite for the sustainable tourism valorization of lakes. It is necessary to strengthen cooperation among local governments, tourism organizations, protected area managers, and scientific institutions to plan and manage tourism development. In addition, climate change adaptation strategies should be developed, including monitoring hydrological changes, protecting water resources, and reducing the risk of ecosystem degradation. Such measures are especially important for destinations exposed to stronger tourism pressure, as well as for lakes located within or near protected natural areas.

Active involvement of local communities in tourism planning and development processes may contribute to the long-term sustainability of destinations and a more equitable distribution of tourism-related benefits. It is recommended to encourage local entrepreneurship, develop family-run accommodation facilities, promote local products, and involve local residents in tourism activities and decision-making. This is particularly relevant for destinations where tourism development remains limited, since local participation can strengthen destination identity and improve the socio-economic effects of tourism.

Digital tools can support sustainable destination management through GIS-based monitoring, visitor-flow analysis, digital information systems, and improved communication with tourists and stakeholders. Such tools can contribute to better control of tourism pressure, more efficient promotion of destinations, and improved visitor experience, while also supporting evidence-based decision-making in lake tourism management.

Given the dynamic nature of tourism and environmental processes, it is necessary to establish a system of continuous monitoring of lake destination sustainability. Periodic application of multi-criteria methods, such as the Fuzzy TOPSIS model, would enable tracking changes in the tourism valorization of lakes and the timely definition of measures for improving sustainable development. Future monitoring should combine environmental data, tourism statistics, spatial planning indicators, and stakeholder feedback in order to provide a more comprehensive basis for adaptive management.

5. Conclusions

Lakes represent an important natural resource and a significant factor in contemporary tourism development, particularly amid the growing need for sustainable destination management. Their tourism potential is not based solely on natural and landscape characteristics, but also on the degree of environmental preservation, management limitations, insufficient protection, governance-related pressures, the level of tourism infrastructure development, accessibility, and the involvement of local communities in tourism development processes.

The application of the Fuzzy TOPSIS method in this study enabled a multi-criteria evaluation of ten lakes in Serbia, integrating quantitative and qualitative criteria for sustainable tourism assessment. The methodological advantage of this approach lies in its ability to incorporate expert judgment and address uncertainty through fuzzy logic, thereby providing a structured and flexible framework for comparative evaluation.

The study found clear differences among the analyzed lakes in their relative performance according to the selected sustainable tourism valorization criteria. The most favorable results were achieved by Lake Đerdap due to a combination of strong natural values, well-developed tourism infrastructure, good transport accessibility, and a diverse tourism offer. High rankings were also achieved by Lake Zaošćina, Lake Perućac, and Lake Vlasina, which are characterized by high environmental preservation, good water quality, and favorable potential for sustainable tourism valorization within the applied evaluation framework.

On the other hand, lower-ranked alternatives, such as Lake Bor and Lake Zavoj, reflect infrastructural constraints, limited visibility in the tourism sector, and weaker integration into broader sustainable tourism development flows. The results indicate that natural attributes alone are insufficient for high tourism valorization, and that sustainable development requires coordinated environmental, infrastructural, economic, and governance-related factors.

This study's main contribution is the identification of the main factors influencing the sustainable tourism valorization of lake destinations in Serbia through a fuzzy multi-criteria framework. Water quality, ecological preservation, biodiversity, and balanced pressure management emerge as important factors for long-term tourism development. At the same time, tourism infrastructure, accessibility, and diversity of activities strengthen destination attractiveness and overall performance within the applied evaluation framework.

Based on the results, the sustainable development of lake tourism in Serbia requires ongoing improvements in environmental protection, precise spatial planning, and increased local community participation in decision-making. Developing sustainable tourism that protects natural resources while supporting local economies is also essential.

The application of the Fuzzy TOPSIS method illustrates the usefulness of a multi-criteria framework for the sustainable tourism valorization of lakes, as it integrates diverse criteria and produces a transparent ranking of tourist destinations. The results provide a useful basis for future research and strategic decisions in planning, managing, and sustainably developing lake tourism in Serbia.

Future research may further integrate Fuzzy TOPSIS with more detailed GIS-based spatial analysis, incorporate the perspectives of tourists and residents into evaluations, and employ additional multi-criteria methods, such as AHP, DEMATEL, ANP, VIKOR, PROMETHEE, or ELECTRE. Another important research direction is assessing how climate change affects the sustainability of lake tourism destinations, particularly through changes in water quality, hydrological regimes, ecosystem sensitivity, and tourism demand.

The findings presented in this study are based on the integration of empirical data and expert evaluations within the Fuzzy TOPSIS framework. While the obtained rankings provide useful guidance for sustainable tourism planning and destination management, they should be interpreted as decision-support information rather than definitive measures of destination performance. Future research should further validate the proposed framework using alternative multi-criteria decision-making methods and additional sustainability indicators across a broader range of lake destinations.

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
DEMATEL	Decision-Making Trial and Evaluation Laboratory
ELECTRE	ELimination Et Choix Traduisant la REalité
FNIS	Fuzzy Negative Ideal Solution
FPIS	Fuzzy Positive Ideal Solution
GIS	Geographic Information Systems
MCDM	Multi-Criteria Decision Making

PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
VIKOR	Multicriteria Optimization and Compromise Solution

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