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Fuzzy AHP Assessment of Urban Parks Quality and Importance in Novi Sad City, Serbia

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Abstract: This paper proposes an AHP approach that utilizes the fuzzy extent model to prioritize five city parks based on their present quality and projected importance for Novi Sad City, the capital of Vojvodina Province, in Serbia. The study involved an expert evaluation of a set of eight criteria to identify the most relevant subset of criteria for a detailed park assessment. The park evaluation took into account uncertainties (fuzziness), the expert's risk tolerance, and different levels of optimism and pessimism. The obtained results could serve when defining upcoming city plans and management agendas related to green areas in the city. The proposed fuzzy-based methodology can be extended to group decision-making scenarios by involving more experts and stakeholder representatives. The park weights obtained through the fuzzy AHP methodology described in this paper can aid city planners and politicians in the strategic allocation of financial, organizational, and human resources for parks.

Keywords: park evaluation; multi-criteria analysis; decision making; fuzziness; criteria

1. Introduction

Urban park management can be supported by numerous multi-criteria analysis methods, e.g., AHP, BWM, PROMETHEE, TOPSIS, and SMART. Each of them can be applied independently or combined with others [1,2], and there are many reports on their application in practical tasks and problems [3–6]. Ref. [7] proposes the combined use of the AHP [8] and a consensus convergence model [9] in landscape management, and it is suited for a group decision-making context. Many papers propose a combined application of the AHP and PROMETHEE (see, for example, [10]) because the PROMETHEE method requires a cardinal value—the weight of criteria [11] that can be obtained from the AHP method. The BWM method [12,13] is a newly developed multi-criteria analysis method (the first version was released in 2015), but there are already a few papers demonstrating its suitability in landscape management [14,15]. The main strength of BWM is a more condensed evaluation scheme (in comparison to the AHP) and, therefore, it can be a good alternative when working with a large number of decision-making elements (criteria, indicators, alternatives, etc.). In many cases, decision making should involve the question of risk and uncertainty, and there are methods supporting the process in these terms. The OWA method and OWA operators are a good starting point because they include decision makers' risk attitudes (degree of optimism/pessimism), and their application is also documented in environmental tasks [16,17]. The next level of including the uncertainty component is by applying fuzzy sets and fuzzy versions of the AHP and other multi-criteria methods, and their application in the domain of landscape and ecological tasks has been widely reported in the literature [18–20]. As stated by Lakicevic et al. [15], worldwide research in urban forestry is published in thousands of research papers, studies, and reports. Our research group is mostly oriented towards challenges related to the planning and management of urban parks, in particular five parks in Novi Sad, in Serbia. Research methods rely

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on the use of sophisticated software and tools, GIS technology, and close relation with academic and other professional experts and stakeholders' representatives from different sectors concerned about city parks' maintenance and development. Research methodologies include various MCDM methods and techniques for deriving individual and group decisions. In a later case, reaching consensus and external aggregation techniques are, when required, combined with social choice theory (SCT) and its voting methods to derive group solutions. Regarding SCT, the most used are the preferential Borda count method and different versions of the no preferential method approval voting. In addition to being applied solely, the SCT methods can be applied simultaneously, taking into account stakeholders' backgrounds, preferences, and competencies [21].

The AHP [8] is a widely applied method that supports multi-criteria analysis for decision problems defined in a form of hierarchy. The standard AHP hierarchy contains levels of goal, criteria, and alternatives (with the goal element being on the top). The AHP determines the weights of the criteria with respect to the goal, then the weights of the alternatives with respect to the criteria, and the final synthesis of all of the weights produces global weights of the alternatives with respect to the goal. Comparisons of the criteria and alternatives are performed in pairs using the given ratio scale. The judgment process performed by the decision maker (or decision makers if the AHP application includes more than one individual) is usually a tedious, time-consuming, and more or less inconsistent process for various reasons, such as limitations of the scale, subjective imprecisions while comparing the decision element (criteria and alternatives), difficulties in following the transition rules, etc. Aside from the standard AHP, there is also its extended version known as fuzzy AHP (FAHP). As Liu et al. (2020) [22] stated in their review paper (covering a period since 2008), there are many versions of FAHP applications in industry, economics, natural resources planning, and management.

FAHP techniques can be categorized in many different ways. If the developing aspect of the FAHP model is considered, fuzzy extent analysis is an efficient way to aggregate fuzzy sets with weights of decision elements at every hierarchy level and synthesize fuzzified priorities accordingly, following standard AHP principles. Defuzzification of fuzzy weights to a crisp value at the end can be performed in several ways too, including options for modeling decision makers' preferences and tolerance to the risks. Some of these aspects will be elaborated on in this study. A reader interested in the fuzzy extent model and various fuzzy versions of AHP should consult the pertinent literature given by [22], and many other papers referenced throughout this paper and listed at its end.

Imprecision in the AHP is successfully handled in [23] for evaluating water management plans in Brazil, and in [24] for ranking by importance groundwater ponds serving as the main freshwater suppliers of the city of Novi Sad, in Serbia. Worth mentioning is that a group of authors [25] used the FAHP method for the water management problem in Malaysia. The analysis included various parameters related to water quality, land use, and the economy, with 4 criteria and 20 subcriteria. As the result of the analysis, six state river systems were ranked and recommended (by priorities) for future investment and management.

One noteworthy study in the realm of FAHP methodologies, which focuses on recent publications, is [26]. This study developed a weighted groundwater quality index using FAHP, related to spatiotemporal alternations of the quality of groundwater during the period from 2009 to 2018 in An Gang Province, a region within the Vietnamese Mekong Delta. Another notable FAHP application is the group model proposed by [27], demonstrated on the area of the Gorganrood basin in Iran. This model categorized different land uses, and evaluated 21 alternative policies using 7 criteria. To fuzzify Saaty's ratio scale with triangular fuzzy numbers ranging from 1 to 9, a distance of 1 was adopted, and defuzzification was carried out using the center of gravity method. Other representative examples of FAHP application in the area of environmental management can be found in [28–31].

Our study aims to address the significant challenge of validating the quality and importance of city parks in general, while assessing the relevance of utilizing advanced decision-making methodologies and tools to support park planning and management. We specifically focused on the city of Novi Sad, in Serbia, and examined its five major parks. To advance the development of green spaces in the city, we considered it crucial to establish criteria for evaluating parks and to identify experts who could initially select relevant criteria and subsequently evaluate the parks based on those criteria.

To test the feasibility of our approach, we engaged an experienced and proven expert in the field to act as a decision maker and evaluate the parks in Novi Sad. To account for uncertainties inherent in the decision-making process, we employed fuzzy sets theory and fuzzy extent analysis, demonstrating that the expert's uncertainties can be satisfactorily modeled to achieve a favorable outcome.

The evaluation of the decision elements (criteria and parks) was carried out by a university professor with a strong academic and professional background in various aspects of greenery studies. The expert analyzed the decision problem with insight and objectivity. The criteria used in our study were carefully selected by the expert from a larger set of well-supported criteria, taking into consideration aesthetic, ecological, and social perspectives.

The evaluations conducted by the expert were guided by relevant research paper [1]. The outcome of the evaluation process, which involved using the fuzzy analytic hierarchy process (AHP) methodology to determine the weights of the parks, can provide valuable insights for city planners and politicians. This information can aid them in formulating strategies for allocating financial, organizational, and human resources effectively.

This paper is structured with four separate sections. Section 2 has two subsections. The first one discusses preliminaries on fuzzy theory and fuzzy norms. A brief presentation of fuzzy extent analysis and its principles is given along with two alternative normalization procedures applicable to fuzzified comparison matrices within a framework of fuzzified AHP. This subsection is concluded with a description of defuzzification methods and gives a detailed insight into how fuzzy versions of AHP and FAHP were used in our study (with the purpose of obtaining crisp values that can be directly used in the evaluation of the importance of city parks). The second subsection focuses on the selected example—city parks in Novi Sad and an explanation of the decision-hierarchy elements. Section 3 presents the results along with all of the important milestones of our case study. Section 4 sums up the conclusions and is supported by the selected references that can be useful in future studies.

2. Materials and Methods

2.1. Fuzzy Sets

A brief introduction necessary for the elaboration of the fuzzy AHP approach is given here, referring to recently published research [24] and an earlier study [23].

2.1.1. Fuzzy Sets—Basic Concept

The basic concepts of fuzzy sets and the norms used have been described in many literature sources, following the fundamental introduction given by [32]. A core definition in the theory of fuzzy sets, that fuzzy set A represents the degree of membership $\mu_A(x)$ over a universe of discourse X, is:

$$\mu_A : \mathrm{X} \to [0,1], \tag{1}$$

2.1.2. Fuzzy Operations

The triangular fuzzy numbers used here belong to a special class of the L–R fuzzy sets [33]. They are often expressed as $\widetilde{A} = (l, m, u)$, where l, m, and u are real numbers satisfying $l > 0$ and $l \leq m \leq u$. Any real number in the interval $[l, u]$ is characterized by a grade of membership between 0 and 1, and its membership function $\mu_A(x)$ is piecewise continuous, and linear. For a positive triangular fuzzy number x, the following conditions are satisfied:

$$\begin{gathered} 1.\ \mu_A(x) = 0,\ \forall x \in (-\infty, l] \cup [u, \infty) \\ 2.\ \mu_A(x) = 1,\ x = m \\ 3.\ \mu_A(x) = (x-l)/(m-l),\ \ \forall x \in [l, u] \\ 4.\ \mu_A(x) = (u-x)/(u-m),\ \forall x \in [m, u] \end{gathered} \tag{2}$$

The most probable value of the fuzzy number A is its modal value m. The lower and upper bounds, l and u, define the degree of fuzziness of m. The greater $u - l$ is, the fuzzier the degree is. For $u - l = 0$, the value m is a crisp number). The fuzzy number $\widetilde{A} = (l, m, u)$ is symmetrical if $u - m = m - l$.

For defining fuzzy arithmetic operations let $\widetilde{A} = (a_1, a_2, a_3)$ and $\widetilde{B} = (b_1, b_2, b_3)$ be two positive triangular fuzzy numbers. The basic operations on these fuzzy numbers are:

(a) Addition	$\widetilde{A} + \widetilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$
(b) Subtraction	$\widetilde{A} - \widetilde{B} = (a_1 - b_1, a_2 - b_2, a_3 - b_3)$
(c) Multiplication	$\widetilde{A} \cdot \widetilde{B} = (a_1 b_1, a_2 b_2, a_3 b_3)$
(d) Division	$\widetilde{A} / \widetilde{B} = (a_1/b_3, a_2/b_2, a_3/b_1)$
(e) Inversion	$\widetilde{A}^{-1} = (1/a_3, 1/a_2, 1/a_1)$
(f) Scalar multiplication	$k\widetilde{A} = (ka_1, ka_2,\ ka_3),\ \ \forall k > 0,\ k \in R$ $k\widetilde{A} = (ka_3, ka_2,\ ka_1),\ \ \forall k < 0,\ k \in R$

Fuzzy set operations are based on the utilization of triangular norms T and S, which represent the intersection and union operators in set theory, respectively. The *min* and *max* norms, as defined in [32], are widely used in these operations. Furthermore, composition operators such as *sup* (supremum) and *inf* (infinium) are commonly employed to connect fuzzy sets. By combining different norms and composition operators, various fuzzy set operations can be performed.

2.1.3. Extension Principle and Fuzzy Arithmetic

Fuzzy arithmetic is enabled by Zadeh's extension principle, which states that if $f : X \to Y$ is a function and A is a fuzzy set in X, then the extension of f to fuzzy sets, denoted as $f(A)$, is defined as:

$f : X \to Y$

$$\mu_{f(A)}(y) = \sup_{x \in X, f(x) = y} \mu_A(x), \tag{3}$$

where: $f : X \to Y, y \in Y$. The extension principle enables performing the basic fuzzy arithmetic operations listed in Section 2.1.2, but also logarithmization and exponentiation, which are not used in this study.

2.1.4. The Value of Fuzzy Synthetic Extent

In the fuzzy extent model [34], the process begins by defining an object set $X = \{x_1, x_2, \ldots, x_n\}$ and a goal set $G = \{g_1, g_2, \ldots, g_k\}$. Fuzzy extent analysis can then be conducted for each object with respect to each goal, resulting in m analysis values for each object. These values are given as:

$$\mu_i^1, \mu_i^2, \ldots,\ \mu_i^k,\ i = 1, \ldots, n \tag{4}$$

All $\mu_i^j (i = 1, \ldots, n; j = 1, \ldots, k)$ are triangular fuzzy numbers representing the performance of the object x_i concerning each goal g_j.

The value of the fuzzy synthetic extent S_i concerning the object i is defined as:

$$\begin{gathered} S_i = \sum_{j=1}^{k} \mu_i^j \cdot [\sum_{p=1}^{n} \sum_{l=1}^{k} \mu_p^l]^{-1} \\ i = 1, \ldots, n \end{gathered} \tag{5}$$

It is worth highlighting that Equation (5) corresponds to the fundamental equation of the additive normalization method (ANM), a prioritization technique used in the widely recognized multi-criteria decision-making method called the analytic hierarchy process (AHP). The AHP was established in 1980 [8]. Numerous studies, including [35], have demonstrated the usefulness of ANM as a matrix-based prioritization method for determining the weights of decision elements, criteria, and alternatives through pairwise comparison matrices. The values obtained from the fuzzy extension Equation (5) correspond functionally and mathematically to the crisp weights generated by ANM.

Remark 1. *Wang et al. (2008) [36] criticized the above fuzzy extent model proposed by Chang (1996) [34] for calculating a priority vector of a given triangular fuzzy comparison matrix. Arguments are presented that the normalization of rows' sum is wrong as proposed by [34], which may have consequences in the synthesis process within the complete AHP method.*

By using slightly different notation, [36] starts a discussion with a representation of a triangular fuzzy comparison matrix

$$\widetilde{A} = (\widetilde{a}_{ij})_{nxn} = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}), \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & & \\ \vdots & \vdots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & (1,1,1) \end{bmatrix}$$

where the fuzzy entries are $\widetilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and $\widetilde{a}_{ji} = (1/u_{ji}, 1/m_{ji}, 1/l_{ji})$ for $i, j = 1, 2, \ldots, n$ and $i \neq j$.

The first step is to sum all elements in each row ($i = 1, \ldots, n$) of the fuzzy comparison matrix, and then to normalize the rows' sums by applying standard fuzzy arithmetic operations, using Equation (6) and Equation (7), respectively:

$$RS_i = \sum_{j=1}^{n} \widetilde{a}_{ij} = (\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij} \sum_{j=1}^{n} u_{ij}), \quad i = 1, \ldots, n. \tag{6}$$

$$\widetilde{S}_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} l_{kj}} \right), i = 1, \ldots, n. \tag{7}$$

The degree of possibility of $\widetilde{S}_i \geq \widetilde{S}_j$ is defined as shown in Figure 1.

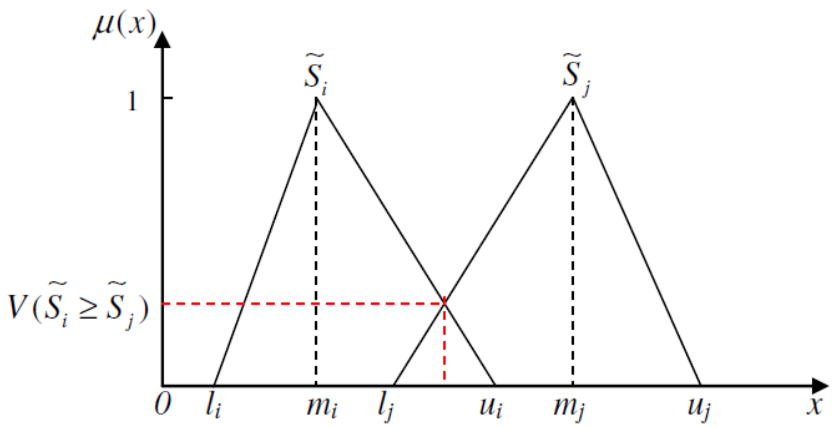

Figure 1. Definition of the degree of possibility of $V\left(\widetilde{S}_i \geq \widetilde{S}_j\right)$ [37].

The degree of possibility of $\widetilde{S}_i \geq \widetilde{S}_j$ can be computed by Equation (8).

$$\begin{aligned} \left(\widetilde{S}_i \geq \widetilde{S}_j\right) &= 1, \text{ if } \quad m_i \geq m_j \\ &= \left\{ \frac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)}, \qquad \text{if } l_j \leq u_i, \quad i, j = 1, \ldots, n; j \neq i \right. \\ &= \text{otherwise} \end{aligned} \tag{8}$$

In the above equation, $\widetilde{S}_i = (l_i, m_i, u_i)$ and $\widetilde{S}_j = \left(l_j, m_j, u_j\right)$.

The degree of possibility of $\widetilde{S}_i$ over all of the other $(n-1)$ fuzzy numbers can be calculated by Equation (9).

$$V\left(\widetilde{S}_i \geq \widetilde{S}_j \mid j = 1, \ldots, n; j \neq i\right) = min\ V(\widetilde{S}_i \geq \widetilde{S}_j),\ i = 1, \ldots, n. \tag{9}$$

Finally, the priority vector $W = (w_1, w_2, \ldots, w_n)^T$ of the fuzzy comparison matrix is calculated as:

$$w_i = \frac{V\left(\widetilde{S}_i \geq \widetilde{S}_j \mid j = 1, \ldots, n; j \neq i\right)}{\sum_{k=1}^{n} V\left(\widetilde{S}_k \geq \widetilde{S}_j \mid j = 1, \ldots, n; j \neq k\right)}, \quad i = 1, \ldots, n \tag{10}$$

Instead of using the normalization proposed by [34] and given by Equation (7), Wang (2008) [37] proposes using the correct Equation (11) developed by Wang and Elhag (2006) [36].

$$\widetilde{S}_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,\, k\neq i}^{n} \sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1, k\neq i}^{n} \sum_{j=1}^{n} l_{kj}}\right), i = 1, \ldots, n \tag{11}$$

Wang et al. (2008) [37] provided a few simple numerical examples to justify this alternative normalization, claiming that Chang's normalization method (Equation (7)) does not represent the relative importance of the decision elements compared within the fuzzy matrix A and that, as a consequence, the priority vector derived cannot be used for synthesis within the AHP.

Our tests with large fuzzy matrices showed only small differences in the final results obtained by the complete (fuzzified) AHP model with either normalization performed by Equation (7) or Equation (11). The case study application presented in Section 4 completely relies on Chang's fuzzy extent model, represented by Equation (7), in all local prioritizations, the AHP synthesis, and the defuzzification process.

2.1.5. Defuzzification Methods

The defuzzification methods that are often discussed in the literature are: MoM (the mean of maximum method) [38], CoS (the center of sums), the dominance measure method [39], the α-cut [39], etc.

After applying fuzzy rules to fuzzy variables, the defuzzification process can be summarized as follows. Assuming that the result of applying the fuzzy rules is represented as depicted in Figure 2 (left), the corresponding membership function displays a graph composed of combined triangles. When a straight horizontal line intersects this function at any point between the top and bottom of each composite triangle, the top portions are eliminated, leaving behind trapezoidal shapes, as illustrated in Figure 2a. All of these trapezoids are then overlaid on top of each other to create a single geometric shape, as shown in Figure 2b.

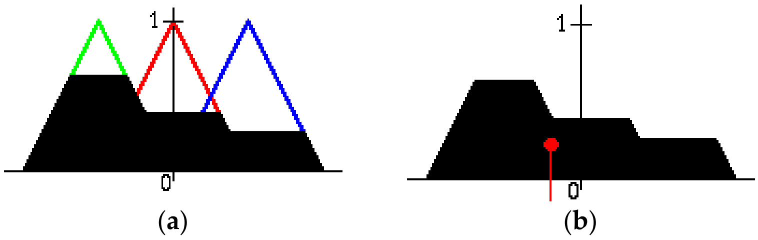

Figure 2. Defuzzification. (**a**) Triangular numbers and superimposed trapezoids; (**b**) x coordinate is a crisp value.

For a triangular fuzzy number $\widetilde{A} = (l, m, u)$, there are various methods to obtain its crisp value. The most commonly used method is the center of gravity approach:

$$defuzzy\ \widetilde{A} = [(u - l) + (m - l)]/3 + l \tag{12}$$

Another well-known method for defuzzification is the integral defuzzification approach. This method determines the range of the index $\lambda \in [0, 1]$ between pessimism and optimism as follows:

$$defuzzy\ \widetilde{A} = (1/2)[\lambda u + m + (1 - \lambda)l] \tag{13}$$

with $\lambda \in [0, 1]$ being an optimism index; 0—pessimism and 1—optimism.

2.2. Fuzzy AHP

In this paper we apply the following methodology steps (flowchart given at Figure 3):

1. In this approach, the decision maker uses the traditional (crisp) AHP and Saaty's 9-point scale to perform pairwise comparisons of criteria and alternatives. The cosine maximization method (CMM) [40] is applied for calculation purposes.
2. Fuzzification of the crisp values of the evaluations is a crucial step in the FDM approach. The decision maker's assessments of the criteria and alternatives are typically represented by crisp values on Saaty's scale. To fuzzify these crisp values, symmetrical and asymmetrical positive triangular fuzzy numbers with distances of 1 or 2 are used. For symmetrical triangular fuzzy numbers, the membership function takes the form of a triangular function centered at the crisp value. The membership degree of the crisp value is equal to 1, and the membership degrees decrease linearly to 0 at the distances of 1 or 2 from the center, depending on the choice of the distance parameter. Asymmetrical triangular fuzzy numbers are used when the decision maker indicates a preference for one of the alternatives or criteria over the others. In this case, the membership function is not symmetrical, and the parameters of the triangular function are adjusted accordingly to reflect the preference. To handle these boundary values (1,9) and avoid misinterpretations, the fuzzy numbers are truncated at the boundaries, and the resulting fuzzy sets are adjusted to maintain the same area as the original fuzzy sets.
3. The fuzzy extent analysis is used as an analogous method to the standard AHP prioritization method ANM and synthesis process. This is because the fuzzy extent analysis and ANM share the same core equation.
4. The center of gravity method is then used for defuzzification of the fuzzy weights of the alternatives, which determines the center of the area of the fuzzy set and returns the corresponding crisp value.
5. The total integral value method is also used for defuzzification to shape the decision maker's inclination towards a pessimistic or optimistic attitude. This method integrates the area under the membership function.

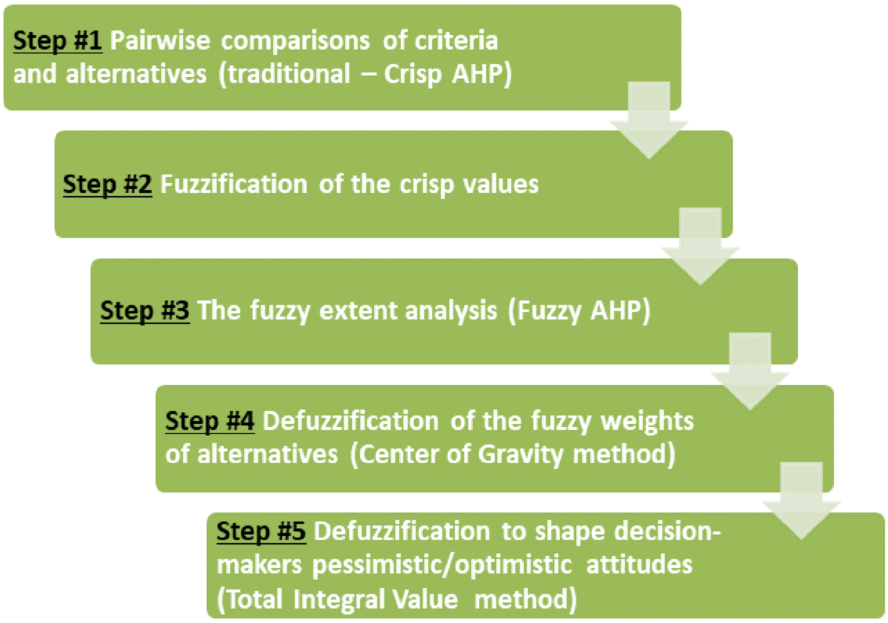

Figure 3. Flowchart of the methodology applied.

Using only odd integers for the Saaty's scale is a common practice in fuzzy decision making, as it allows for a more symmetrical and intuitive representation of the decision maker's judgments. In this approach, odd integers from 1 to 9 are mapped to triangular fuzzy numbers with a peak at the corresponding integer value and with the left and right slopes extending to the nearest odd integer values. For example, the value 5 would be mapped to a triangular fuzzy number with a peak at 5 and slopes extending to 3 and 7. This mapping allows for a smooth and gradual transition between the adjacent values, which is more appropriate for fuzzy reasoning [34,41]. In fuzzification by triangular fuzzy numbers, the distance of 2 is commonly used, as shown in Table 1 (right side). On boundaries, for crisp value 1, fuzzy value (1,1,1) or (1,1,3) is used. For crisp value 9, fuzzy equivalent (7,9,9) or (7,9,11) is used depending on distance 2; it should be noted that in a later case, the upper value 11 falls outside of Saaty's scale, rendering it unjustified due to the lack of a semantic equivalent. Two fuzzifications of Saaty's original (crisp) 9-point scale were executed in the presented case study.

- In the case of fuzzy distance $\delta = 1$, all whole numbers within Saaty's scale ranging from 2 to 8 are represented as symmetrical positive triangular fuzzy numbers. The fuzzy numbers at the edges are (1,1,2) and (8,9,9), as shown in Table 1 (left).
- When considering fuzzy distance $\delta = 2$, whole numbers ranging from 3 to 7 are represented as symmetrical positive triangular fuzzy numbers. The boundary values are represented by asymmetrical fuzzy numbers: (1,1,3), (1,2,4), (6,8,9), and (7,9,9), as shown in Table 1 (right).

Table 1. Original and fuzzified Saaty's scale for pairwise comparisons.

Saaty's Crisp Values	Judgment Definition	Fuzzified Values	
		Distance δ = 1	Distance δ = 2
1	Equal	(1,1,2)	(1,1,3)
3	Moderate	(2,3,4)	(1,3,5)
5	Strong	(4,5,6)	(3,5,7)
7	Very strong	(6,7,8)	(5,7,9)

Table 1. *Cont.*

Saaty's Crisp Values	Judgment Definition	Fuzzified Values	
		Distance δ = 1	**Distance δ = 2**
9	Extremely strong	(8,9,9)	(7,9,9)
2	Intermediate values	(1,2,4)	(1,2,4)
4	Intermediate values	(2,4,6)	(2,4,6)
6	Intermediate values	(4,6,8)	(4,6,8)
8	Intermediate values	(6,8,9)	(6,8,9)

Remark 2. *Once a fuzzified judgment matrix has been built by using fuzzy distance δ = 1 or δ = 2, ref. [34] proposed an option to defuzzify entries in the upper and lower triangle of a matrix by using Equations (14) and (15).*

$$\left(\widetilde{a}_{ij}^{\propto}\right)^{\gamma} = \left[\gamma \cdot L_{ij}^{\alpha} + (1-\gamma) \cdot U_{ij}^{\alpha}\right] \quad 0 \leq \propto \leq 1,\ \ 0 \leq \gamma \leq 1, \tag{14}$$

where $L_{ij}^{\alpha} = \left(u_{ij} - l_{ij}\right) \cdot \alpha$, and $U_{ij}^{\alpha} = u_{ij} - \left(u_{ij} - m_{ij}\right) \cdot \alpha$.

$$\left(\widetilde{a}_{ij}^{\propto}\right)^{\gamma} = \frac{1}{\left(\widetilde{a}_{ij}^{\propto}\right)^{\gamma}},\ 0 \leq \propto \leq 1,\ \ 0 \leq \gamma \leq 1,\ \ i > j \tag{15}$$

The underlying idea is that the above defuzzification procedure should display the decision maker's preference (α) and risk tolerance (γ). For a normal preference and risk tolerance, values α and γ should be set to 0.5. For α = 1, the uncertainty range is lowest and for γ = 1 the decision maker is pessimistic.

The proposed defuzzification of the fuzzy comparison matrix aims to include the regulating coefficients α and γ at an early stage of the decision-making process and then to continue with a crisp version of the AHP method. Note that the tolerance parameter γ is different from the parameter λ used as an optimism–pessimism index in Equation (13) within the context of fuzzy AHP.

Once the multi-criteria problem is formulated using the triangular fuzzy numbers and membership functions defined in Table 1 for distances 1 or 2, the fuzzy extent analysis and synthesis of results can commence. The ranking process begins by assessing the importance of the criteria relative to the goal. A fuzzy reciprocal judgment matrix is employed to assign triangular fuzzy weights to the criteria through fuzzy extent analysis, as depicted in Equation (5). This process is repeated for all alternatives and criteria. Ultimately, the overall fuzzy weights are synthesized using the basic logic of crisp AHP.

In summary, the main distinction between crisp and fuzzy decision-making approaches lies in the fuzzification of Saaty's scale and the utilization of triangular fuzzy numbers for all operations in the fuzzy approach. The ranking of alternatives takes place after defuzzification, which can be accomplished in various ways (e.g., Deng 1999), potentially leading to different final results. However, our case study demonstrates that the differences may not be significant, suggesting that the fuzzy version of AHP replicates the outcomes of the crisp version to a considerable extent. Thus, our case study provides evidence supporting this assertion.

2.3. Urban Parks in Novi Sad

There are five major parks in Novi Sad [42,43], and they were used as a case study for our research. The locations of the parks are given in Figure 4.

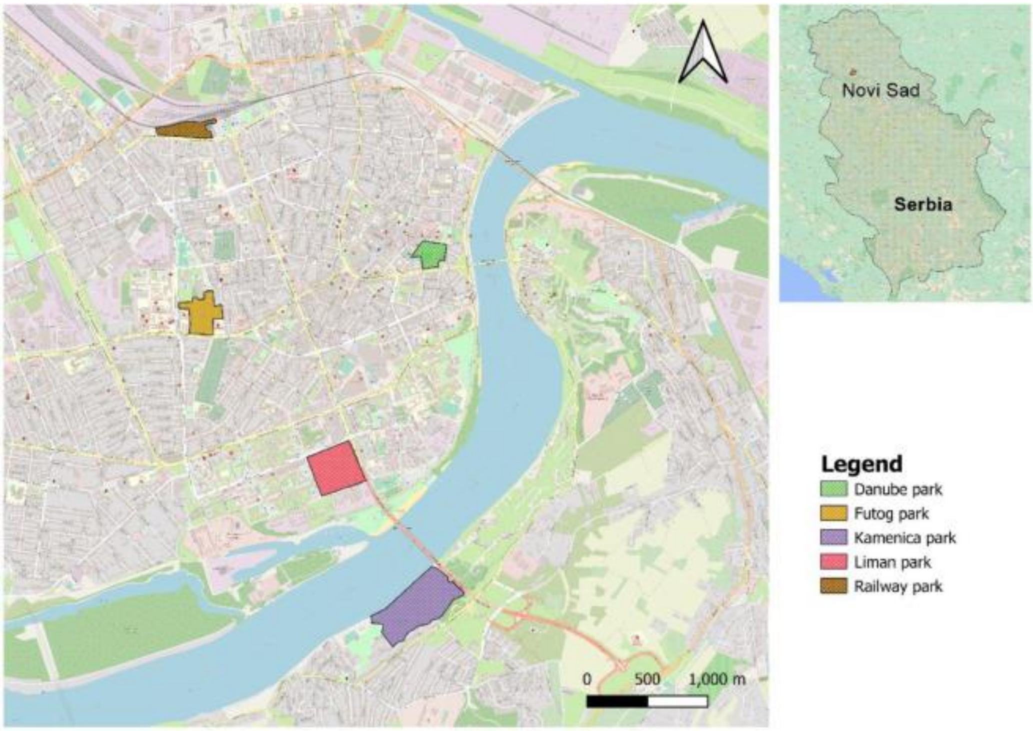

Figure 4. City parks in Novi Sad [43].

Table 2 provides the basic information related to the major parks in Novi Sad (area, year of establishment, and distance from the city center).

Table 2. Parks in Novi Sad—basic information.

Park	Area (ha)	Establishment (year)	Distance [1] (km)
Danube	3.9	1895	0.7
Liman	12.9	1950s	2.6
Futog	12.0	1910	1.8
Railway park	4.2	1970s	2.3
Kamenica	42.0	1834	3.6

[1] Distance refers to distance from the city center.

Decision Elements

The decision elements (criteria and alternatives—urban parks) were assessed and evaluated by an experienced university professor who has performed many diverse landscape analyses. The task of this expert was to analyze the decision problem insightfully and objectively. The decision problem is based on a former study [42], where three groups of criteria are evidenced regarding aesthetic, ecological, and social perspectives. Their descriptions are provided in Table 3. The decision maker based her evaluation following the ideas from recent papers [1,44].

Table 3 has been modified from [15], and the modifications are related to condensing the description. Full information regarding each criterion can be found in [15].

Table 3. Assessment criteria [15].

Label	Criterion	Description
C_1	Accessibility	Accessibility involves two main components, the outside accessibility (possibility to reach the park by all means of transportation, including path ways and bicycle paths) and inside accessibility of the park (existence of an appropriate path—communication system).
C_2	Location	Location refers to the proximity to city settlements and city landmarks that are frequently visited in Novi Sad.
C_3	Biodiversity preservation	This refers to the potential of the park for maintaining plant and animal species individuals, as well as their communities, within the city.
C_4	Equipment	This involves the equipment for providing both active (sport) and passive (rest) activities in parks.
C_5	Water elements	This criterion evaluates the existence of water elements (lakes, fountains, etc.) that influence the microclimate and enhance the visual qualities of parks.
C_6	Terrain	This refers to the configuration of the terrain, and an analysis of its "flatness" or "hilliness".
C_7	Cultural value	This takes into account all the cultural values of park elements, especially the ones which are important from a historical point of view.
C_8	Architectural objects	This involves the presence of small elements such as pavilions, terraces, and all other park equipment primarily designed for social gatherings.

3. Results and Discussion

The evaluation process started off by comaparing criteria in a pairwise manner using the standard Saaty's scale [8]. After that, the eigenvector method was used to obtain the criteria weights. Comparisons of the criteria obtained from the expert are presented in Table 4.

Table 4. Matrix of comparison of criteria to the goals and computed weights.

Criteria	C_1 Accessibility	C_2 Location	C_3 Biodiversity	C_4 Equipment	C_5 Water Elements	C_6 Terrain	C_7 Cultural Value	C_8 Architectural Objects	Weights
C_1	1	5	1/3	1	7	7	1/3	8	0.170
C_2	1/5	1	1/5	1/2	4	2	1/5	6	0.072
C_3	3	5	1	3	8	8	2	8	0.313
C_4	1	2	1/3	1	3	9	1/2	9	0.136
C_5	1/7	1/4	1/8	1/3	1	3	1/2	3	0.047
C_6	1/7	1/2	1/8	1/9	1/3	1	1/7	1	0.023
C_7	3	5	1/2	2	2	7	1	7	0.218
C_8	1/8	1/6	1/8	1/9	1/3	1	1/7	1	0.020

Once prioritization of the criteria had been performed and the criteria weights were obtained, as given in the last column in Table 4, the expert's posterior evaluation of the derived weights resulted in his decision to reduce the initial set of eight criteria by two. His final decision was to assess the quality of the five city parks using four criteria: (C_1) accessibility, (C_3) biodiversity preservation, (C_4) park equipment, and (C_7) cultural value (Table 4).

The analysis provided information regarding the cardinal values (weight) of the criteria, and the next step was to further process the obtained values. Table 4 shows that location (C_3) had an importance (weight) of 7.2%; the importance of the criterion water elements (C_5) was 4.7%, while the importance of terrain configuration (C_6) and the presence of small architectural objects were 2.3% and 2%, respectively. In further interpretation, this means that these criteria would have a minor effect on the final assessment of the parks (the importance of each of the criteria is below 10% or even below 5%) and, therefore, as they had a low influence, they could be discarded from further consideration. This means that the decision problem could be scaled down to a hierarchy with four criteria, as presented in Figure 5.

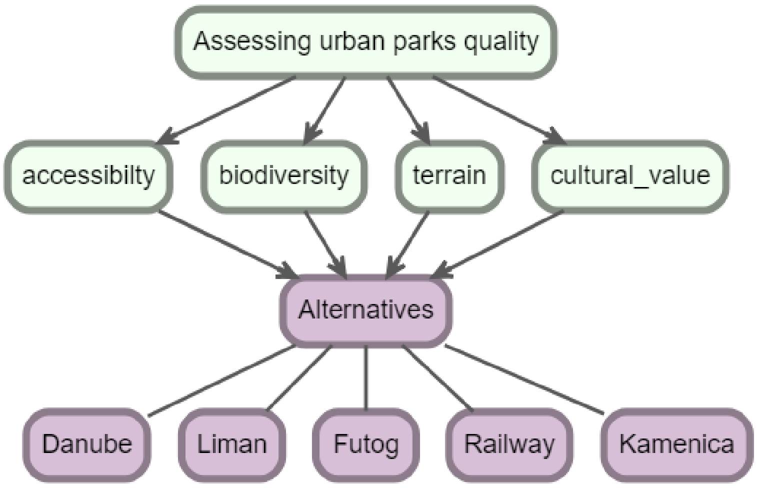

Figure 5. Final decision-making hierarchy (four selected criteria).

The AHP procedure was repeated after scaling down the decision hierarchy and Table 5 presents the comparison matrices used for evaluating the city parks respecting only a reduced set of criteria.

Table 5. Matrix of comparison for reduced set of criteria [1].

Criteria	C_1 Accessibility	C_3 Biodiversity	C_4 Equipment	C_7 Cultural Value
C_1 Accessibility	1	1/3	1	1/3
C_3 Biodiversity	3	1	3	2
C_4 Equipment	1	1/3	1	1/2
C_7 Cultural value	3	1/2	2	1

[1] The tables in the study present fuzzy triangular numbers with a distance δ (1 or 2) for each entry.

After fuzzifying the expert's judgments in the upper triangle of the mentioned matrix and applying fuzzy rules to generate reciprocals in the lower triangle (shaded region of the matrix), the fuzzy synthetic extent (11) yields a fuzzy priority vector w for M = 4 criteria as follows:

$$\widetilde{w}_i = \sum_{j=1}^{4} \widetilde{a}_{ij} \cdot [\sum_{k=1}^{4} \sum_{l=1}^{4} \widetilde{a}_{kl}]^{-1},\ i = 1, \ldots, 4 \tag{16}$$

For instance, each element in this vector is obtained by adding up the fuzzy values within the corresponding row of the comparison matrix shown in Table 5, and then dividing the sum by the total sum of all fuzzy values in that row:

$$\widetilde{w}_1 = \frac{\widetilde{1} + \widetilde{\tfrac{1}{3}} + \widetilde{1} + \widetilde{\tfrac{1}{3}}}{\widetilde{1} + \widetilde{\widetilde{\tfrac{1}{3}}} + \widetilde{1} + \widetilde{\tfrac{1}{3}} + \widetilde{3} + \widetilde{1} + \widetilde{3} + \widetilde{2} + \widetilde{1} + \widetilde{\tfrac{1}{3}} + \widetilde{1} + \widetilde{7} + \widetilde{3} + \widetilde{\tfrac{1}{2}} + \widetilde{\tfrac{1}{7}} + \widetilde{1}} = (0.068,\ 0.104,\ 0.254) \tag{17}$$

$$\widetilde{w}_C = \begin{bmatrix} \widetilde{w}_1 \\ \widetilde{w}_2 \\ \widetilde{w}_3 \\ \widetilde{w}_4 \end{bmatrix} = \begin{bmatrix} (0.068,\ 0.104,\ 0.254) \\ (0.164,\ 0.351,\ 0.660) \\ (0.211,\ 0.364,\ 0.584) \\ (0.094,\ 0.181,\ 0.364) \end{bmatrix} \tag{18}$$

and the vector is:

Following the same procedure, the expert compared parks in pairs for each criterion. After 4 × ((5 × 4)/2) = 40 judgments (as shown in Table 6), matrices were filled in the same manner as previously performed for the criteria. Two variants of distances δ = 1 and δ = 2) were again used in fuzzification. Please note that in the matrices, the rows and columns correspond to different parks.

Table 6. Final ranking of parks for different indices λ of decision maker's optimism.

City Parks	Fuzzy AHP (Distance δ = 1)			Fuzzy AHP (Distance δ = 2)		
	λ = 1 (Optimistic)	λ = 0.5 (Moderate)	λ = 0.0 (Pessimistic)	λ = 1 (Optimistic)	λ = 0.5 (Moderate)	λ = 0.0 (Pessimistic)
A1—Danube	0.4133	0.4216	0.4462	0.3869	0.3938	0.4451
A2—Liman	0.1494	0.1512	0.1563	0.1545	0.1548	0.1565
A3—Futog	0.2218	0.2191	0.2108	0.2251	0.2233	0.2105
A4—Railway	0.0711	0.0672	0.0558	0.0858	0.0824	0.0572
A5—Kamenica	0.1444	0.1410	0.1308	0.1477	0.1457	0.1307

Using the same method, the expert compared the parks pairwise for each criterion, resulting in a total of 4 × ((5 × 4)/2) = 40 comparisons, as shown in Table 6. The resulting matrices were filled using the same fuzzification process as for the criteria. Two variations of the distance parameter were used again in the fuzzification process, namely, δ = 1 and δ = 2. It is important to note that the rows and columns in the matrices correspond to the parks being compared.

For each matrix shown in Figure 6, a priority vector was obtained using the same prioritization method as for the criteria. The resulting vectors represent the columns of a new matrix (19). It is important to note that the elements of the *j*th vector are partial ratings of the alternatives with respect to the *j*th criterion, and they add up to 1.

$$\widetilde{X} = \begin{array}{c} \begin{matrix} \widetilde{w}_1 & \ldots & \widetilde{w}_4 \end{matrix} \\ \begin{bmatrix} \widetilde{x}_{11} & \ldots & \widetilde{x}_{14} \\ \ldots & \ldots & \ldots \\ \widetilde{x}_{51} & \ldots & \widetilde{x}_{54} \end{bmatrix} \end{array} \tag{19}$$

C1 Accessibility	A1	A2	A3	A4	A5
A1	1	4	6	7	8
A2		1	3	7	6
A3			1	3	3
A4				1	2
A5					1

C3 Biodiversity	A1	A2	A3	A4	A5
A1	1	7	2	9	3
A2		1	1/5	1	1/3
A3			1	5	2
A4				1	1/4
A5					1

C4 Equipment	A1	A2	A3	A4	A5
A1	1	7	8	9	3
A2		1	3	9	2
A3			1	5	1
A4				1	1/5
A5					1

C7 Cultural value	A1	A2	A3	A4	A5
A1	1	7	1	7	2
A2		1	1/7	1	1/6
A3			1	7	1/2
A4				1	1/6
A5					1

Figure 6. The fuzzy comparison matrices for parks versus criteria consist of entries that are fuzzy triangular numbers, each with a specific distance δ (1 or 2).

Lastly, the priority vectors (which correspond to the columns in the fuzzy matrix described above) were multiplied by their corresponding criteria weights $\widetilde{w}_1, \quad \widetilde{w}_2, \ldots, \widetilde{w}_4$ (using fuzzy interval arithmetic) to derive a fuzzy performance matrix (20). This matrix aggregates the performance ratings of all alternatives for all criteria, taking into account their relative importance.

$$\widetilde{Z} = \begin{bmatrix} \widetilde{x}_{11}\widetilde{w}_1 & \ldots \widetilde{x}_{14}\widetilde{w}_4 \\ \ldots & \ldots \quad \ldots \\ \widetilde{x}_{51}\widetilde{w}_1 & \ldots \widetilde{x}_{54}\widetilde{w}_4 \end{bmatrix} \tag{20}$$

In this method, additive synthesis was utilized as an approach that can be directly compared to the standard AHP synthesis. The final weights of the parks, concerning the overall goal, were calculated using fuzzy summation (21), which aggregates the elements in the rows of the performance matrix.

$$\widetilde{F}_i = \sum_{j=1}^{4} \widetilde{x}_{ij} \cdot \widetilde{w}_j \,, \quad i = 1, 2 \ldots, 5. \tag{21}$$

The weights assigned to the parks based on the overall goal, as determined by the calculation using Equation (21), are the final fuzzy weights (22):

$$\widetilde{w}_A = \begin{bmatrix} \widetilde{w}_{A1} \\ \widetilde{w}_{A2} \\ \widetilde{w}_{A3} \\ \widetilde{w}_{A4} \\ \widetilde{w}_{A5} \end{bmatrix} = \begin{bmatrix} (0.156, 0.442, 1.196) \\ (0.057, 0.153, 0.439) \\ (0.069, 0.214, 0.665) \\ (0.018, 0.057, 0.225) \\ (0.042, 0.134, 0.439) \end{bmatrix}. \tag{22}$$

To finally rank the parks, prioritization of the aggregated assessments was required. The center of gravity method (Equation (12)) produced the final result (crisp values):

$$F = \begin{bmatrix} w_{A1} \\ w_{A2} \\ w_{A3} \\ w_{A4} \\ w_{A5} \end{bmatrix} = \begin{bmatrix} 0.4168 \\ 0.1508 \\ 0.2202 \\ 0.0696 \\ 0.1427 \end{bmatrix} \tag{23}$$

By utilizing the integral defuzzification method (as shown in Equation (13)) with typical α values that represent the decision maker's level of optimism or pessimism, the final ranking of the parks could be determined. Based on the normalized values, it can be concluded that Danube park (A1) is the top-ranked park in terms of quality, followed by Futog park (A3) and Liman park (A2). On the other hand, Kamenica park (A5) and Railway park (A4) are ranked as the lowest quality parks. It is worth noting that these rankings remain the same regardless of the decision maker's level of optimism or the fuzzification distance used.

After applying the center of gravity method to defuzzify the F values given above (assuming a distance of 1 and a level of optimism of 1.0), the resulting weights for the parks were normalized to obtain the final weights: Danube park (0.41168), Liman park (0.1508), Futog park (0.2202), Railway park (0.0696), and Kamenica park (0.1427). The notable remark is that the final ranking of the parks remains unchanged and is the same as the previous ranking.

The fact that the final ranking of the quality of the urban parks remains consistent regardless of the level of optimism and fuzzification distance indicates the robustness of the results. This is not always the case in a fuzzy procedure, and if there are discrepancies in the results, they can reveal the impact of different levels of optimism attitude and/or fuzzification distance on the final ranking. In such cases, the results can be viewed as a sensitivity analysis, providing valuable information on the reasons for the alteration in the final ranking of urban park quality. The proposed methodology can be applied beyond the assessment of urban park quality and can be useful in evaluating climate change scenarios (as shown in [45]) and other environmental tasks.

4. Conclusions

Natural resources planning and management, whether in rural or urban areas, face a multitude of challenges such as climate change, limited data availability, insufficient funding, and a lack of legislative instruments. The urban greenery sector, in particular, has a significant amount of literature available and much of it, related to decision making, is cited in this manuscript and provided in the reference list. Fuzzy theory and sets, which have been used for over fifty years, are instruments for solving many environmental and urban management problems in uncertain environments. According to some earlier studies, the primary reason for using a fuzzy approach instead of a crisp one is that decision makers may not be certain about their judgments (the reason can be, for example, insufficient or limited information and available data).

This research focuses on the application of the FAHP multi-criteria tool for ranking the importance and quality of urban parks in Novi Sad (Serbia). Fuzzified AHP is used to demonstrate how modeling uncertainties can be made with fuzzy (triangular) numbers instead of standard (crisp) numbers from common ratio scales. In parallel, the standard version of the AHP is also used to enable the comparison of solutions in two decision-making environments, uncertain and certain. Both applications, fuzzified and crisp AHP, used weights of parks generated by an experienced expert which may be used in future considerations of improvements of the parks, for instance, by allocating funds along with human and institutional efforts, all aimed at multifunctional development and maintenance of parks in Novi Sad. The expert in the presented case study was highly satisfied with the overall decision-making process and methods employed. One of her conclusions was that the results, which involved weighting parks by importance and quality, were clearly expressed, and that the proposed fuzzy AHP approach (which was controlled by crisp AHP) can be applied to other problems that involve uncertainty. An important conclusion is also that the proposed fuzzy-based methodology can be extended to group decision-making scenarios by involving more experts and stakeholder representatives.

The potential for further research using fuzzy AHP is particularly high for the area of landscape architecture and urban park management. This methodology has practical applications and can be implemented by public enterprises such as city planning and urban greenery offices, as well as environmental and tourism agencies. Future research could expand on the current set of criteria, including economic indicators, and involve a wider range of stakeholder groups. The proposed procedure is flexible enough to accommodate different decision-making environments and can be tailored to suit specific problems, e.g., new touristic (ski or beach) resorts, industrial plants, housing/commercial land use, etc.

Further research could also explore and address potential limitations related to the fuzzy methodology used in our study. These limitations may include sample size issues, such as the number of parks, criteria, and experts involved. It would be important to examine how the results of the methodology are affected by variations in these factors.

Additionally, the selection of decision elements, including the criteria and parks, could be investigated for potential biases or limitations. It would be valuable to assess the sensitivity of the results to changes in criteria weights and determine the extent to which they impact the overall evaluation.

Furthermore, the generalizability of the results should be critically evaluated. It is essential to consider the specific application environment and determine if the findings can be applied to other contexts or if they are specific to the studied city and its parks.

The potential influence of consistent or inconsistent expert judgments should also be taken into account. Examining how different expert opinions or interpretations could affect the evaluation process would provide a more comprehensive understanding of the methodology's validity.

Addressing these directions and concerns would contribute to a critical assessment of the proposed method, ensuring its robustness and reliability in evaluating parks and similar contexts with consideration for biases and uncertainties in the evaluation process.

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