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Research on the Variable Fuzzy Evaluation Model of Ecotourism Resources in National Parks from a Big Data Perspective

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Abstract

The application of big data technology in ecological resource management in national parks has led to changes in its evaluation index system and evaluation methods. Due to the large volume of data involved in the evaluation process of national park ecotourism resources, which covers a wide range, data characteristics such as strong timeliness, rapid environmental changes, and incomplete data exhibit fuzziness and uncertainty, traditional evaluation methods are unable to effectively address these issues. The theory of variable fuzzy sets can more effectively depict and quantify the uncertain changes of ecotourism resources in national parks. Therefore, this study employs the Semantic Differential (SD) method to quantify qualitative textual data, integrates it into big data indicators, and applies game theory integrated with the G1 method and the CRITIC method to determine subjective and objective weights. Consequently, a variable fuzzy evaluation model for ecotourism resources in national parks is constructed. Additionally, using Qianjiangyuan National Park as an example, the effectiveness and reliability of this model method are verified through a case study. This model can provide a reference for research and application in this field and other domain.

Keywords: Big data, national park, ecotourism resources, the Semantic Differential (SD) method, variable fuzzy set theory.

1. Introduction

Sustainable development is the original intention behind the establishment of national parks and has always been the ultimate challenge for builders and managers of national parks [1]. Conducting evaluations of national park ecotourism resources and their practical application is a crucial prerequisite for promoting the rational use and protection of ecotourism resources. It is also an important measure to advance the sustainable development of national parks [2].

The evaluation of national park ecotourism resources not only needs to highlight the scientific, protective, educational, and recreational values of national park resources [2,3] but also needs to address and resolve issues caused by strong timeliness, rapid environmental changes, and incomplete data, which lead to fuzziness and uncertainty [4,5]. Additionally, with the continuous development of the internet, remote sensing technologies, and big data mining technologies and industries, constructing an evaluation indicator system from a big data perspective is becoming increasingly important. However, the field of ecotourism resource evaluation is mostly based on remote sensing data and official statistical data [6], and the application of massive online evaluation data is still lagging. The integration of big data mining technology is urgently needed [7]. Clearly, research on the evaluation of national park ecotourism resources should not be confined to a single discipline such as ecology or management. Instead, it should combine knowledge from multiple disciplines, including ecology, big data technology, and management, to establish unique classification and evaluation methods for objective and effective evaluation. This provides a scientific basis for the development and protection of national parks [8]. Evidently, the study of evaluation methods for national park ecotourism resources is a meaningful and fascinating topic.

To explore this interesting issue, the structure of this article is designed as follows: The first section is an introduction, mainly discussing the background, research value, and significance of this paper; the second section reviews the literature and innovation points, summarizing the forefront of domestic and international research on ecotourism resource methods and discussing the innovation points of this paper; the third section covers data and methods, mainly including the concepts and methods of game theory and variable fuzzy set models, construction of the evaluation indicator system from a big data perspective, and weight optimization based on game theory; the fourth section is case analysis and evaluation results, including an overview of the case, result analysis, and model comparison, mainly verifying the reliability and advancement of the model method. The fifth section concludes by summarizing the problems encountered in the evaluation model of national park ecotourism resources and its application value.

2. Literature Review and Article Structure

2.1 Progress in the study of national park ecotourism resource evaluation models

Research on national park ecotourism in foreign countries began earlier, with a more comprehensive system in place, particularly focusing on the exploration of issues such as regional stakeholder interests [9], community participation, and public involvement [10]. Domestic research mainly concentrates on the discussion of the conceptual understanding and the practical discussion of planning and development, while the evaluation research on national park ecotourism resources is still in its infancy. Moreover, the evaluation of ecotourism resources in protected areas has always been a focus of academic research, encompassing a variety of assessment methods and evaluation models, which can be mainly divided into three categories: The first category is qualitative evaluation, with notable representatives like Ross and Wall (1999) [11], Deng and King (2002) [12], and Aseres and Sira (2021) [13] employing qualitative analysis methods to evaluate the ecotourism resources of protected areas. The primary method used is the Delphi method and its improvements. The second category is quantitative evaluation, represented by Bunruamkaew and Murayam (2011) [14], Cetin et al (2018) [15], who utilized quantitative analysis methods to evaluate regional ecotourism resources. The main methods include the Analytic Hierarchy Process (AHP) and its improvements, such as the Fuzzy Analytic Hierarchy Process (FAHP) and the Rough Analytic Hierarchy Process (RAHP). The third category combines qualitative and quantitative methods, integrating expert experience and fully utilizing the information inherent in the data itself. This approach is currently mainstream, with key representatives like Budeanu et al (2016) [16], Del et al (2018) [17], and Zheng et al (2022) [18] employing quantitative analysis methods to evaluate the ecotourism resources of tourist destinations, nature reserves, national parks, etc. The primary method is based on the Analytic Hierarchy Process (AHP), combined with fuzzy sets, entropy method, logical framework approach, and sequential comparative rating method, among others.

2.2 Literature review

In recent years, with the emergence and application of various types of emerging big data, the standards and models for evaluating ecotourism resources have been further optimized and improved. However, at present, under the new context of the construction of the Chinese national park system, the indicator system for evaluating national park ecotourism resources is not yet perfect, and the methods for evaluating ecotourism resources still need further optimization: (1) Data sources are mostly based on remote sensing data, and there is insufficient emphasis on consumer behavior data, especially the vast amount of evaluation data; (2) Currently, weighting in evaluations often relies on a single method, which fails to consider both subjective and objective factors simultaneously, and combined weighting has certain instability, so a more stable method of weighting is required; (3) Existing evaluation methods often depend on fixed values, but the evaluation of ecotourism resources inherently involves dynamics and uncertainties. It is necessary to introduce new evaluation methods and technologies from a big data perspective to advance the progress and development of ecotourism resource evaluation technology. In view of this, this article constructs an indicator system for the evaluation of national park ecotourism resources from a big data perspective, and introduces game theory to optimize the weighting of the variable fuzzy set, thus constructing a new evaluation model for national park ecotourism resources: Game theory, through the mutual influence of multiple stakeholders, uses rational choices to determine decision-making methods, which can avoid human subjective factors and reflect the contribution of actual big data metrics to the final evaluation results. It can also more effectively allocate the weight results of different weighting methods, making the weight results more accurate and stable. The variable fuzzy set model can use fuzzy information for dynamic evaluation, effectively reducing human intervention to some extent, overcoming the limitations of existing static fuzzy evaluations, and comprehensively reflecting the fuzziness and randomness of the evaluation objects. This precisely addresses the uncertainties present in the evaluation process of national park ecotourism resources, making the evaluation results more objective and accurate.

2.3 Innovation

This paper aims to combine the advantages of improved game theory and variable fuzzy set model and propose a variable fuzzy evaluation model of ecotourism resources in National Parks from a big data perspective, based on game optimization weighting. Therefore, the innovations are mainly manifested in two aspects: (1) The introduction of massive online non-structured data about the evaluation of ecotourism resources, constructing an evaluation indicator system for ecotourism resources from a big data perspective; (2) The introduction of the variable fuzzy set model optimized by game theory combined weighting to address the fuzziness and randomness issues in the evaluation process of national park ecotourism resources, thereby making the evaluation results more objective and accurate.

3. Data and Methods

3.1 Data sources

The sources of big data acquisition are as follows: This paper requires the collection of individual user reviews on national parks for semantic analysis. Based on the text needed for semantic analysis and the accumulation of the number of reviews, the evaluation data from two websites, Ctrip (https://you.ctrip.com/sight/lishui441.html) and Qunar (http://travel.qunar.com/p-cs299813-lishui-jingdian), were ultimately selected. The landscape evaluation data were collected using Python 3.6; other data were mainly provided by the Qianjiangyuan National Park Administration Committee, specifically, including the latest remote sensing imagery, land change data, the third national land survey of 2019, the vectorized boundary lines of various types of nature reserves within the region, and the survey data of ecotourism resources; some data were obtained through expert consultation, with experts scoring the relevant indicators based on the data and information provided by the Qianjiangyuan National Park Administration Committee.

3.2 Research method

3.2.1 Construction of the evaluation indicator system from a big data perspective

To conduct evaluation research, it is first necessary to establish a scientific and effective evaluation indicator system. However, an authoritative ecotourism resource evaluation indicator system for national parks has not yet been formed for reference. Therefore, this paper takes scientificity and practicability as the basic principles for constructing the evaluation system. It refers to standards and norms such as the "Classification, Investigation, and Evaluation of Tourism Resources" (GB/T 18972-2017), hereinafter referred to as the "National Standard," and the "Specifications for the Investigation and Evaluation of National Park Resources" (LY/T 3189-2020), hereinafter referred to as the "Industry Standard." The paper selects resource entities with stable spatial forms and attributes of tangible cultural resources as the objects of evaluation. Based on references such as literature [2], [14,15], and [19,20], and on the basis of field surveys, from a big data perspective, the paper proposes the national park ecotourism resource evaluation indicator system as shown in Figure 1.

Based on Figure 1, the ecological resource evaluation indicator system for national parks includes four evaluation levels: the comprehensive evaluation objective layer A (Comprehensive Index of Ecotourism Resources); the constraining layer of impact factors on the protective use of ecotourism B_1~B_3 (Ecotourism Resource Conditions, Ecological Environment Conditions, and Location Development Conditions). On the basis of the constraining layer, these are further subdivided into the element layer C_1~C_3 and their corresponding indicator evaluation layers C_{11}~C_{53}. In the absence of corresponding standards, by referring to relevant literature [21-23], conducting field surveys, and combining expert experience, we have determined the evaluation indicators. The evaluation indicators are then graded and standardized, with the grading standards for the evaluation indicators shown in Table 1.

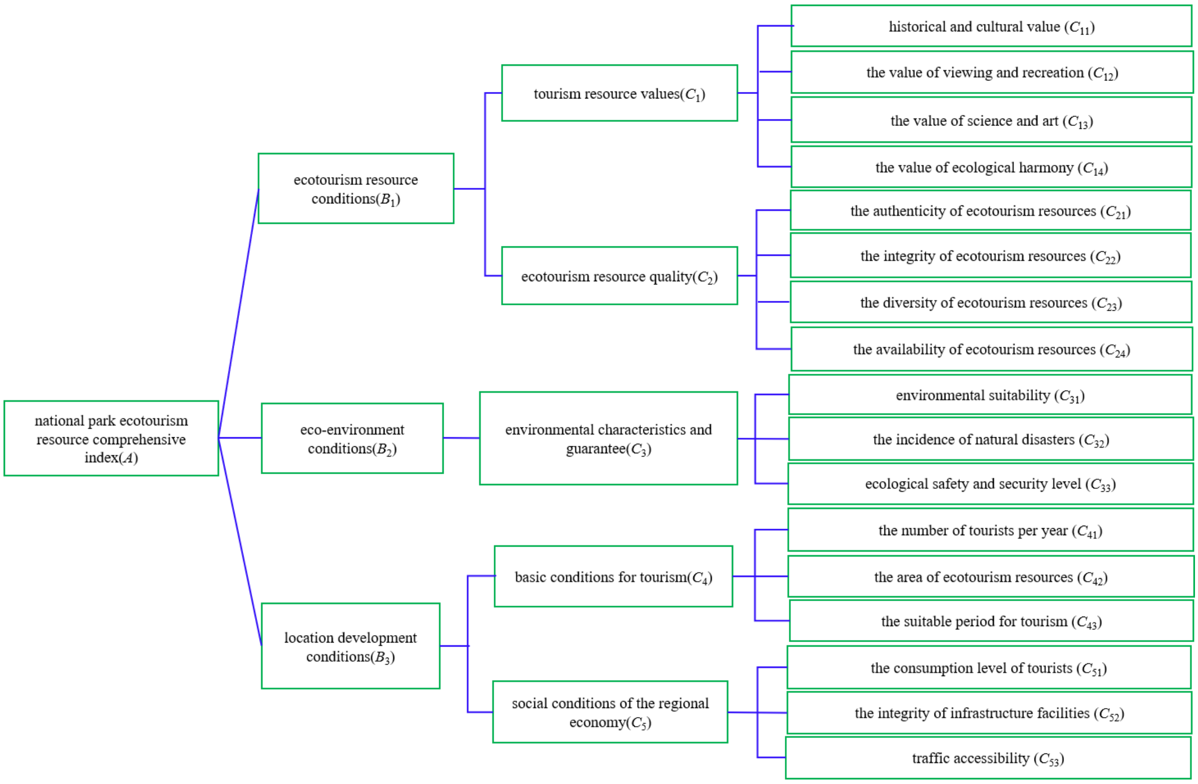

Figure 1 Evaluation indicator system for ecotourism resources in national parks from a big data perspective

The indicators in Table 1 integrate big data indicators, primarily reflected in C_{11}~C_{14}: By crawling evaluation data from the Ctrip and Qunar websites, a total of 24,508 reviews were accumulated. Referring to the processing and calculation methods described in references [24,25], the SD evaluation scores for C_{11}~C_{14} were obtained. Data for the other indicators mainly come from the park management committee or were obtained through expert scoring based on data provided by the park management committee.

3.2.2 Determination of evaluation indicator weights from a big data perspective

The rationality of weights directly impacts and determines the reasonableness and effectiveness of the comprehensive evaluation. Currently, methods for determining weights can be mainly divided into three categories: qualitative, quantitative, and subjective-objective weights (combined weights). Subjective weighting methods (such as the Delphi method, round-robin scoring, and AHP and objective weighting methods (such as principal component analysis, CRITIC method, entropy method, projection pursuit, and maximum deviation method) express the decision-maker's intentions regarding weights from different emphases when determining weights. Each method has its applicable conditions, advantages and disadvantages. Since combined weights utilize expert knowledge and experience from subjective weights and incorporate objective standards and data information from objective weights, they are widely used in comprehensive evaluations. Therefore, this paper will use combined weights to determine the indicator weights.

(1) Calculation of subjective weights

Subjective weights reference literature selection sequence relation analysis (G1 method) [26]. This method is an improvement on the traditional AHP, requiring only the comparison of the relative importance of indicators, with importance given in ratio form. This reduces the cognitive demands on subjective evaluators and effectively overcomes the disadvantages of the traditional AHP, where weight calculation can be unreasonable due to strong subjectivity. Additionally, this model does not require repeated adjustments to the judgment matrix to meet consistency test requirements, making the calculation process simpler and the weight calculation results more objective. G1 method requires meeting the criteria of strong consistency and weak consistency, addressing the issue of assigning values to evaluation indicators that may be disconnected from human thinking. By introducing the contribution rate of evaluation indicators, G1 method can discard strong consistency and focus on weak consistency, overcoming the phenomenon of disconnection between the assignment of values to evaluation indicators and human thinking. The steps for determining subjective weights are as follows:

Table 1 Grading Standards for ecotourism resource evaluation indicators in national parks from a big data perspective

Evaluation indicators	Evaluation contents	Resource levels					Evaluation methods or parameters
		I	II	III	IV	V	
C_{11}	Historical longevity	After Qing Dynasty(0~3 points)	Between Yuan and Qing Dynasties (3~5 points)	Between Song and Yuan Dynasties (5~7 points)	Between Tang and Song Dynasties (7~9 points)	Before Tang Dynasty (9~10 points)	SD Method Scoring
C_{12}	Value of viewing and recreation experience	Lower (0~3 points)	Average (3~5 points)	Medium (5~7 points)	Higher (7~9 points)	Very high (9~10 points)	SD Method Scoring
C_{13}	Value of science and art education	Lower (0~3 points)	Average (3~5 points)	Medium (5~7 points)	Higher (7~9 points)	Very high (9~10 points)	SD Method Scoring
C_{14}	Value of harmony between man and nature	Lower (0~3 points)	Average (3~5 points)	Medium (5~7 points)	Higher (7~9 points)	Very high (9~10 points)	SD Method Scoring
C_{21}	The authenticity of ecotourism resources	＜30% (0~3 points)	30%~50% (3~5 points)	50%~70% (5~7 points)	70%~90% (7~9 points)	>90% (9~10 points)	Provided by the park management committee
C_{22}	The integrity of ecotourism resources	Lower (0~3 points)	Average (3~5 points)	Medium (5~7 points)	Higher (7~9 points)	Very high (9~10 points)	Scored by experts
C_{23}	The diversity of ecotourism resources	＜4 species	4-6 species	6-8 species	8-10 species	More than 10 species	Provided by the park management committee
C_{24}	The availability of ecotourism resources	Lower (0~3 points)	Average (3~5 points)	Medium (5~7 points)	Higher (7~9 points)	Very high (9~10 points)	Scored by experts
C_{31}	Air/surface water/soil quality	Lower (0~3 points)	Average (3~5 points)	Medium (5~7 points)	Higher (7~9 points)	Very high (9~10 points)	Provided by the park management committee
C_{32}	Natural disaster occurrence/times a^{-1}	10<	8~10	5~8	3~5	<3	Provided by the park management committee
C_{33}	The timeliness of safeguard policies and measures	Lower (0~3 points)	Average (3~5 points)	Medium (5~7 points)	Higher (7~9 points)	Very high (9~10 points)	Questionnaire survey
C_{41}	Annual passenger flow/ten thousand person-times·a^{-1}	< 1	1~5	5~20	20~50	> 50	Provided by the park management committee
C_{42}	The area of ecotourism resources / /km^2	< 1	1~5	5~10	10~50	> 50	Provided by the park management committee
C_{43}	Annual tourist months/month·a^{-1}	< 1	1~2	2~6	6~8	> 8	Provided by the park management committee
C_{51}	Annual tourist consumption level/ten thousand yuan·a^{-1}	<0.5	0.5~1.5	1.5~2.5	2.5~5	> 5	Research report
C_{52}	Infrastructure distribution density	Lower (0~3 points)	Average (3~5 points)	Medium (5~7 points)	Higher (7~9 points)	Very high (9~10 points)	Provided by the park management committee
C_{53}	Distribution density of traffic network around the scenic spot/km·km^{-2}	< 0.5	0.5~1	3~3	3~5	>5	Scenic spot evaluation report

Step 1: Determine the order relation of evaluation indicators. Following the basic principles and procedures of assessment, form a panel consisting of experts, managers, and technical staff, referred to as the expert group set

$A=\{A_1,A_2,\cdots,A_m\}$, with m being the number of members in the expert group. Based on the experience of the expert group, select the most important indicator from the set $C=\{C_1,C_2,\cdots,C_n\}$ of n indicators, denoted as X_1, with its weight noted as w_1. Then, continue to select the most important indicator from the remaining $n-1$ indicators until all indicators have been selected, resulting in a collection $X=\{X_1,X_2,\cdots,X_n\}$ of indicators arranged according to their relative importance.

Step 2: Determine the relative importance ratios of evaluation indicators. Based on the indicator sequence set (X_1 , X_2,…, X_n), experts determine the relative importance ratios r_j, which reflect the degree of relative importance among indicators. Specific values can be seen in Table 2. The calculation formula for the relative importance ratio r_j is shown in equation (1):

$$r_j=\frac{w_j}{w_{j-1}}(j=2,3,\cdots,n) \tag{1}$$

In the formula, w_j and w_{j-1} respectively represent the weights of the j and $j-1$ indicators in the indicator set X .

Table 2 Relative importance ratio

r_j	Relative importance situation	r_j	Relative importance situation
1.0	equally important	1.2	It's a little important
1.4	Obviously important	1.6	It's very important
1.8	Extreme importance	1. 1 1.3 1.5 1.7 1.9	In between the above cases

Step 3: Introduce the evaluation indicator contribution rate c_j. The original evaluation data matrix provided by m experts is denoted as $B=\left(b_{ij}\right)_{m\times n}$. Using equation (2) to standardize the original data matrix B, the resulting matrix is $B'=\left(b'_{ij}\right)_{m\times n}$. After sorting according to the order relation, the corresponding data matrix is $X=\left(x_{ij}\right)_{m\times n}$. The evaluation indicator contribution rate c_j is shown in equation (3):

$$b'_{ij}=\begin{cases}\dfrac{b_{ij}-\min\left(b_j\right)}{\max\left(b_j\right)-\min\left(b_j\right)} & \text{Benefit indicators}\\[2ex] \dfrac{\max\left(b_j\right)-b_{ij}}{\max\left(b_j\right)-\min\left(b_j\right)} & \text{Cost indicators}\end{cases} \tag{2}$$

In equation (2): b_{ij} ; b'_{ij} respectively represent the values of the j indicator before and after standardization for the X_i indicator; $\max\left(b_j\right)$ and $\min\left(b_j\right)$ are the maximum and minimum values of the j indicator for the evaluation objects.

$$c_j=w_j\sum_{i=1}^{m}x_{ij}\Big/\sum_{j=1}^{n}\sum_{i=1}^{m}\left(w_jx_{ij}\right) \tag{3}$$

In equation (3), c_j represents the proportion of the sum of the j evaluation value in the indicator set X to the total evaluation values of n indicators; x_{ij} is the standardized variable value of the j indicator in the i evaluation object.

To obtain the optimal solution in equation (3), a mathematical programming model is established as shown in equation (4), and the optimal solution for the evaluation indicator contribution rate c_j is obtained using Matlab software:

$$\max\ f=\sum_{j=2}^{n}\left(c_{j-1}-c_j\right)=c_1-c_n$$
$$s.t.\begin{cases} c_{j-1}-r_jc_j\le 0,\ j=2,3,\cdots,n \\ c_{j-1}-c_j\le 0,\ j=2,3,\cdots,n \\ c_1-1.8c_n\le 0, \\ \sum_{j=1}^{n}c_j=1 \end{cases} \tag{4}$$

In equation (4), f represents the objective function in mathematical modeling.

Step 4: Calculate the subjective weights. Based on the order relation, we first calculate the weight of the n indicator in the indicator set x, and then convert it into the weight for the indicator set C, as shown in equation (5):

$$\begin{cases} w_n=\left(1+\frac{t_n}{c_n}\sum_{j=2}^{n}\frac{c_{j-1}}{t_{j-1}}\right)^{-1},t_j=\sum_{i=1}^{m}x_{ij} \\ w_{j-1}=w_j\frac{t_jc_{j-1}}{c_jt_{j-1}},\ j=n,n\text{-}1,\cdots,2 \end{cases} \tag{5}$$

In equation (5), t_j represents the summation of the j evaluation indicator across m evaluation objects.

(2) Calculation of objective weights

The calculation of objective weights refers to the use of the CRITIC method as cited in literature [26]. However, in practical applications, traditional CRITIC method does not consider the diversity of indicator dimensions, leading to unscientific and imprecise weight calculations. To eliminate the impact of diversification, a differentiation coefficient is introduced to improve the CRITIC method, enhancing the scientific accuracy of indicator weight calculations [27]. The steps for calculating the improved CRITIC method are as follows:

Step 1: Establish the original evaluation matrix. Assume there are m evaluation objects, and n indicators are selected to analyze and evaluate the objects to be evaluated. Based on the values of the indicators, construct the original evaluation indicator matrix X, as shown in equation (6):

$$X=\begin{bmatrix} x_1(k_1) & x_2(k_1) & \cdots & x_n(k_1) \\ x_1(k_2) & x_2(k_2) & \cdots & x_n(k_2) \\ \vdots & \vdots & \vdots & \vdots \\ x_1(k_m) & x_1(k_m) & \cdots & x_n(k_m) \end{bmatrix} \tag{6}$$

$\left(x_i\left(k_j\right)\right)_{n\times m},\ j=1,2,\cdots,n,i=1,2,\cdots,m.$

In equation (6), $x_i\left(k_j\right)$ represents the value of the j indicator for the i evaluation object.

Step 2: Normalize the original evaluation matrix. Normalize the original evaluation matrix x, where the normalization formula is seen in equation (7):

$$x_i^*\left(k_j\right)=\frac{x_i\left(k_j\right)-\overline{x}_j}{s_j} \tag{7}$$

In equation (7), $\overline{x}_j$ represents the mean of the indicator; s_j represents the standard deviation of the indicator.

Step 3: Calculate the difference coefficient of indicators. Introduce the difference coefficient to eliminate the dimensionality differences of indicators, where the calculation of the difference coefficient is seen in equation (8):

$$\upsilon_j = \frac{s_j}{\overline{x}_j} \tag{8}$$

In equation (8), υ_j represents the difference coefficient of the j indicator.

Step 4: Determine the independence coefficient. Convert the standard matrix $\boldsymbol{X}^*$ into a correlation coefficient matrix and calculate the independence coefficient, the formula for which is seen in equation (9):

$$\sum_{q=1}^{n}\left(1-\rho_{q1}\right),\sum_{q=1}^{n}\left(1-\rho_{q2}\right),\cdots,\sum_{q=1}^{n}\left(1-\rho_{qm}\right) \tag{9}$$

Step 5: Determine the objective weights of evaluation indicators. Assign objective weights to indicators by using the comprehensive coefficient h_j , where the comprehensive coefficient h_j is shown in equation (10):

$$h_j = \upsilon_j \sum_{q=1}^{n}\left(1-\rho_{qm}\right) \tag{10}$$

In equation (10), h_j represents the comprehensive coefficient of the j indicator. The formula for calculating the objective weights of evaluation indicators is seen in equation (11):

$$w_j = \frac{h_j}{\sum_{j=1}^{n} h_j} \tag{11}$$

In equation (11), w_j represents the weight of the j indicator.

(3) Calculation of combined weights based on game theory

The subjective-objective combined weighting methods based on additive and multiplicative synthesis lack a reliable interpretation. The comprehensive weight calculation method based on game theory seeks consensus or compromise among different weight determination methods, aiming to minimize the deviation between the possible weights and each basic weight, selecting the optimal weight vector from the possible set of weights. Considering the existence of negative values in the combination coefficients, constraints are introduced for optimization and improvement, with the specific process as follows:

Step 1: Establish a system of linear equations. Suppose the weights of the evaluation indicators are calculated using L methods. Establish the combined weight W as a linear combination of the L weights, as shown in equation (12):

$$\boldsymbol{W} = \sum_{l=1}^{L} a_l w_l^T \tag{12}$$

In the equation: a_l represents the linear combination coefficients, and $a_l > 0$; w_l^T is the transpose of the weight row vector calculated by the l method.

Step 2: Establish the objective function and optimize the model. With the goal of minimizing the deviation between the comprehensive weight $\boldsymbol{W}$ and all w_l , an optimization model for the best solution of $\boldsymbol{W}$ is established as shown in equation (13):

$$\min\left\|\sum_{l=1}^{L} a_l \boldsymbol{w}_l^{\mathrm{T}} - \boldsymbol{w}_p\right\|_2, p = 1, 2, \cdots, L \tag{13}$$

Based on the properties of matrix differentiation, the optimization condition for equation (13) is given by equation (14):

$$\min_{a_1,a_2,\cdots,a_L} f=\sum_{p=1}^{L}\left|\left(\sum_{l=1}^{L}a_l\boldsymbol{w}_p\boldsymbol{w}_l^{\mathrm{T}}\right)-\boldsymbol{w}_p\boldsymbol{w}_p^{\mathrm{T}}\right| \tag{14}$$

To ensure that the obtained combination coefficients are greater than 0, an optimization model is established with additional constraints as seen in equation (15):

$$\begin{cases}\min\limits_{a_1,a_2,\cdots,a_L} f=\sum_{p=1}^{L}\left|\left(\sum_{l=1}^{L}a_l\boldsymbol{w}_p\boldsymbol{w}_l^{\mathrm{T}}\right)-\boldsymbol{w}_p\boldsymbol{w}_p^{\mathrm{T}}\right| \\ s.t.\sum_{l=1}^{L}a_l^2=1, a_l>0\end{cases} \tag{15}$$

Step 3: Solve the model. Establish the Lagrange function to solve the optimization model, as seen in equation (16):

$$G(a_l,\lambda)=\sum_{p=1}^{L}\left|\left(\sum_{l=1}^{L}a_l\boldsymbol{w}_p\boldsymbol{w}_l^{\mathrm{T}}\right)-\boldsymbol{w}_p\boldsymbol{w}_p^{\mathrm{T}}\right|+\frac{\lambda}{2}\left(\sum_{l=1}^{L}a_l^2-1\right) \tag{16}$$

For equation (15), take the partial derivatives with respect to a_l and λ. Based on the conditions for the existence of an extremum, equation (17) is obtained:

$$\begin{cases}\dfrac{\partial G}{\partial a_l}=\sum_{p=1}^{L}\left|\boldsymbol{w}_p\boldsymbol{w}_l^{\mathrm{T}}\right|+\lambda a_l=0 \\ \dfrac{\partial G}{\partial \lambda}=\dfrac{\sum_{l=1}^{L}a_l^2-1}{2}=0\end{cases} \tag{17}$$

Solve equation (17) to obtain the optimal solution for the combination coefficients a_l, as shown in equation (18):

$$a_l=\sum_{p=1}^{L}\boldsymbol{w}_p\boldsymbol{w}_l^{\mathrm{T}}\Big/\sqrt{\sum_{l=1}^{L}\left(\sum_{l=1}^{L}\boldsymbol{w}_p\boldsymbol{w}_l^{\mathrm{T}}\right)^2} \tag{18}$$

Substitute the obtained solution into equation (12) and perform normalization to obtain the final combined weights, as shown in the equation (19):

$$\boldsymbol{W}^*=\boldsymbol{W}_i\Big/\sum_{i=1}^{n}\boldsymbol{W}_i \tag{19}$$

Based on the above calculation process, the implementation process of combined weight calculation based on game theory is shown in Figure 2.

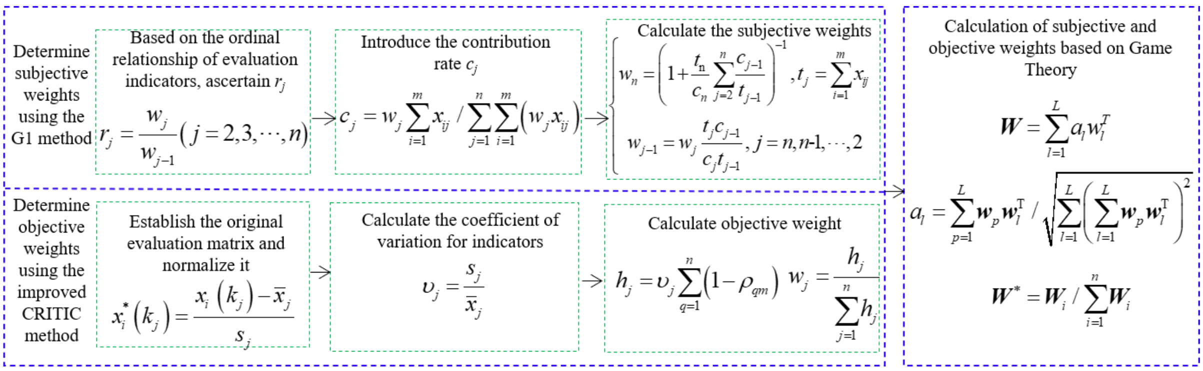

Figure 2 Main and objective combination weight calculation process of evaluation indicators

3.2.3 Grading of evaluation results based on variable fuzzy sets

Considering that the evaluation of ecological tourism resources in national parks has stochastic and fuzzy characteristics, it is a typical fuzzy problem. The variable fuzzy set theory is chosen to solve this issue. The fundamental principle of variable fuzzy set theory is to determine the state and grade of a subject by establishing a relative membership function and calculating the relative membership degree of single indicators and the comprehensive membership degree [28].

Suppose that $X = [a,b]$ represents the attraction domain of the variable fuzzy set V on the real axis, $X_1 = [c,d]$ represents the range domain of the variable set, and M is the midpoint, as shown in Figure 3. The relative difference degree is determined by utilizing the relative positional relationship of x on the real axis with respect to X and X_1, which further determines the state and grade of the evaluation indicators.

The specific calculation steps of the national park ecological resource evaluation model based on variable fuzzy set theory are as follows:

Figure 3 Schematic diagram of relative position

Step 1: Determine the index standard interval matrix $\boldsymbol{I}_{ab}$ and the range domain matrix $\boldsymbol{I}_{cd}$. If the evaluation criteria at the criterion level and target level of the evaluation object are p and q respectively, then the feature vector constructed from these indicators is as shown in Equation (20):

$$\boldsymbol{X} = \left(x_{ij}\right),\ i = 1,2,\cdots,p\ ;\ j = 1,2,\cdots,q \tag{20}$$

In the formula, x_{ij} represents the feature value of the i indicator under the j criterion.

Based on the classification of standard values for evaluation indicators in Table 1, we construct the index standard interval matrix $\boldsymbol{I}_{ab}$ and the range domain matrix $\boldsymbol{I}_{cd}$, as shown in Equations (21) and (22):

$$\boldsymbol{I}_{ab} = \left([a,b]_{ih}\right)_{mc} \tag{21}$$

$$\boldsymbol{I}_{cd} = \left([c,d]_{ih}\right)_{mc} = \begin{cases} [a_{i1}, b_{ih+1}], h = 1 \\ [a_{jh-1}, b_{ih+1}], 1 < h < c \\ [a_{ih-1}, b_{ic}], h = c \end{cases} \tag{22}$$

In the formula, h represents the number of grades, $h = 1,2,3\cdots,c$, a_{ih} and b_{ih} denote the upper and lower bounds of $\boldsymbol{I}_{ab}$, respectively; similarly, c_{ih} and d_{ih} represent the upper and lower bounds of $\boldsymbol{I}_{cd}$.

Step 2: Calculate the comprehensive relative membership degree. Determine the point value matrix $\boldsymbol{I}_M$ according to Equation (22), as shown in Equation (23).

$$\boldsymbol{I}_M = (M_{ih})_{mc} \tag{23}$$

In the formula, M_{ih} represents the point value of each indicator.

The membership function $\mu_{\tilde{A}}\left(x_{ij}\right)_h$ has the following two scenarios:

When x is located in the left interval of M :

$$\begin{cases} \mu_{\tilde{A}}\left(x_{ij}\right)_{h1} = 0.5 + 0.5 \times \left(\dfrac{x_{ij} - a_{ih}}{M_{ih} - a_{ih}} \right), x_{ij} \in \left[a_{ih}, M_{ih}\right] \\ \mu_{\tilde{A}}\left(x_{ij}\right)_{h2} = 0.5 - 0.5 \left(\dfrac{x_{ij} - a_{ih}}{c_{ih} - a_{ih}} \right), x_{ij} \in \left[c_{ih}, a_{ih}\right] \end{cases} \tag{24}$$

When x is located in the right interval of M :

$$\begin{cases} \mu_{\tilde{A}}\left(x_{ij}\right)_{h1} = 0.5 + 0.5 \times \left(\dfrac{x_{ij} - b_{ih}}{M_{ih} - b_{ih}} \right), x_{ij} \in \left[M_{ih}, b_{ih}\right] \\ \mu_{\tilde{A}}\left(x_{ij}\right)_{h2} = 0.5 - 0.5 \left(\dfrac{x_{ij} - b_{ih}}{b_{ih} - d_{ih}} \right), x_{ij} \in \left[b_{ih}, d_{ih}\right] \end{cases} \tag{25}$$

Determine the relative membership degree matrix $\boldsymbol{\mu}_{\tilde{A}}(\boldsymbol{u})$ for each evaluation grade according to Equations (24) and (25), as shown in Equation (26).

$$\boldsymbol{\mu}_{\tilde{A}}(\boldsymbol{u}) = \left(\mu_{\tilde{A}}\left(x_{ij}\right)_h \right) \tag{26}$$

Calculate the comprehensive relative membership degree μ_h , as presented in Equation (27).

$$\mu_h = \left\{ 1 + \left[\frac{\sum_{i=1}^{m} \left(w(i) \left(1 - \mu_{\tilde{A}}\left(x_{ij}\right)_h \right) \right)^t}{\sum_{i=1}^{m} \left(w(i) \mu_{\tilde{A}}\left(x_{ij}\right)_h \right)^s} \right]^{\frac{s}{t}} \right\}^{-1} \tag{27}$$

In the formula, $w(i)$ represents the combined weight of indicators, which is determined based on Game Theory; s and t are both optimization parameters, where s is the distance parameter, $s=1$ represents the Hamming distance, and $s=2$ denotes the Euclidean distance; t stands for the optimization criterion parameter, with $t=1$ representing the least absolute deviation criterion and $t=2$ indicating the least squares criterion.

Step 3: Comprehensive Evaluation of Ecological Tourism Resources Levels in National Parks

According to Equation (27), the level characteristic vector $\boldsymbol{H}$ can be determined, as shown in Equation (28):

$$\boldsymbol{H} = (1, 2, \cdots, c)\, \mu_h \tag{28}$$

The weighted average of $\boldsymbol{H}$ under the four combination methods results in the comprehensive characteristic value $\bar{\boldsymbol{H}}$ for the level, as demonstrated in Equation (29).

$$\bar{\boldsymbol{H}} = \frac{1}{4} \sum_{z=1}^{4} \boldsymbol{H} \,;\ z = 1, 2, 3, 4 \tag{29}$$

In the formula: z represents four combination methods of parameters s and t .

Step 4: Determination of the level of ecological tourism resources in national parks. The criteria for determination [28] are as follows: when $1 \le \bar{\boldsymbol{H}} \le 1.5$, it belongs to Level 1, indicating that the level of ecological tourism resources is very poor; when $n - 0.5 < \bar{\boldsymbol{H}} \le n$, it belongs to Level n , with a bias towards Level $n-1$; when $n < \bar{\boldsymbol{H}} \le n + 0.5$, it belongs to Level n , with a bias towards Level $n+1$; when $4.5 < \bar{\boldsymbol{H}} \le 5$, it belongs to Level 5, indicating that the level of ecological tourism resources is excellent.

4. Evaluation Results and Analysis

4.1 Overview of Qianjiangyuan national park

Qianjiangyuan National Park, located in Kaihua County, Zhejiang Province, is adjacent to Wuyuan County and Dexing City in Jiangxi Province, and Xiuning County in Anhui Province. It covers an area of approximately 252 square kilometers, encompassing three protected areas: Gutianshan National Nature Reserve, Qianjiangyuan National Forest Park, and Qianjiangyuan Provincial Scenic Area, as well as ecological areas connecting these natural reserves. The park includes four townships, 21 administrative villages, and 72 natural villages. It is one of China's first ten national park system pilot zones [29]. In accordance with international national park practices, the Qianjiangyuan National Park pilot area is divided into four functional zones as shown in Table 3: core protection zone, ecological conservation zone, recreation and exhibition zone, and traditional utilization zone. As specifically shown in Table 3.

Table 3 Management requirements of functional areas in the pilot areas

domain	number	proportion (%)	Protection and utilization requirements
Core reserve	FS1	28.49	Implement the strictest protection, maintain the natural process of the ecosystem, and prohibit the construction of any production facilities
Ecological conservation area	FS2	48.84	Strict protection shall be implemented to promote the restoration and renewal of natural ecosystems, and to prohibit commercial activities
Recreation exhibition area	FS3	6.27	Under the premise of protection, ecological tourism and environmental education activities should be carried out appropriately
Traditional utilization area	FS4	16.40	Under the premise of protection to guide the existing communities to achieve the sustainable development of traditional industries

According to the requirements of the functional zoning, ecotourism activities are mainly carried out in parts of the ecological conservation area (FS2), the recreation and exhibition area (FS3), and the traditional utilization area (FS4). Therefore, the evaluation of ecotourism resources in Qianjiangyuan National Park is conducted within these three functional zones. The evaluation area covers 180.21 km².

4.2 Results and analysis

4.2.1 Calculation of combined weights

(1) Calculation of subjective weights based on the G1 method

Table 1 includes both qualitative and quantitative indicators. The values for quantitative indicators are based on actual data from national parks, while the grading and assignment of qualitative indicators are determined according to the specific conditions of the national parks. The data obtained from expert scoring and survey data are shown in Table 4:

Table 4 Values of the evaluation indicators are taken

name	The evaluation index takes the value																
	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{51}	C_{52}	C_{53}
FS 2	1.2	4.2	2.5	9.5	97%	9.5	75	1.5	9.5	6.5	8.5	0.5	0.3	6.5	0.35	1.6	0.8
FS 3	3.5	9.6	8.4	8.2	58%	5.1	7.6	7.2	7.5	2	5.2	7.5	9.3	12	1.25	8.7	5.5
FS 4	2.5	7.8	5.7	7.8	45%	4.5	3.3	8.8	7.2	1.5	4.5	5.2	5.8	9.5	0.85	4.5	3.1

①Determine the order relation. The order relation of the indicators is determined by several experts in national park management, tourism management, and technical personnel as: $C_{14} \geq C_{21} \geq C_{13} \geq C_{23} \geq C_{11} \geq C_{12} \geq C_{22} \geq C_{24} \geq C_{31} \geq C_{33} \geq C_{52} \geq C_{53} \geq C_{42} \geq C_{43} \geq C_{32} \geq C_{41} \geq C_{51}$. Except for C32, which is a cost-type indicator, the rest are benefit-type indicators. Using equation (2) to normalize the values from Table 4 and reordering according to the order relation, the matrix composed of evaluation indicator data is shown in Table 5.

Table 5 Data standardization after order relation

name	The evaluation index takes the value																
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}
FS 2	1.0	1.0	0.0	1.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FS 3	0.2	0.3	1.0	0.1	1.0	1.0	0.1	0.8	0.1	0.2	1.0	1.0	1.0	1.0	0.9	1.0	1.0
FS 4	0.0	0.0	0.5	0.0	0.6	0.7	0.0	1.0	0.0	0.0	0.4	0.5	0.6	0.5	1.0	0.7	0.6
r_j	…	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}	r_{17}
	…	1.2	1.6	1.2	1.2	1.2	1.4	1.2	1.4	1.4	1.8	1.2	1.2	1.2	1.4	1.4	1.2
t_j	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}
	1.2	1.3	1.5	1.1	1.6	1.7	1.1	1.8	1.1	1.2	1.4	1.5	1.6	1.5	1.9	1.7	1.6

②To calculate the contribution rate c_j and determine the subjective weights, a mathematical programming model for the evaluation indicator contribution rate c_j is established according to r_j and equation (4). Using Lingo, the optimal solution for c_j is found to be $c_j =$ (0.080, 0.067, 0.061, 0.058, 0.056, 0.056, 0.056, 0.056, 0.056, 0.056, 0.056, 0.056, 0.056, 0.056, 0.056, 0.056, 0.056). Based on Table 4's t_j and equation (5), the calculation yields $w =$ (0.089, 0.073, 0.055, 0.075, 0.051, 0.048, 0.069, 0.045, 0.069, 0.066, 0.056, 0.053, 0.049, 0.051, 0.042, 0.048, 0.051). Converting x into the corresponding weights for the set of evaluation indicators w results in the subjective weights of the indicators $w' =$ (0.051, 0.048, 0.055, 0.089, 0.073, 0.069, 0.075, 0.045, 0.069, 0.042, 0.066, 0.048, 0.049, 0.051, 0.051, 0.056, 0.053). This process involves rigorous mathematical modeling and optimization techniques to ensure the evaluation results are as accurate and representative as possible, reflecting the core aspects and values of the indicators being assessed.

(2) Calculation of objective weights based on the improved CRITIC method

Using the data obtained from the normalization process shown in Table 2 and constructing the evaluation matrix in the original order, as indicated in equation (30). Using Matlab to calculate the following matrices, the standard deviations of the evaluation indicators are computed as $s =$ (0.501, 0.509, 0.501, 0.523, 0.520, 0.546, 0.561, 0.526, 0.544, 0.551, 0.534, 0.510, 0.504, 0.501, 0.501, 0.503, 0.500). Equation (11) is then used to normalize the indicator weights, resulting in the objective weights of the indicators $w'' =$ (0.046, 0.032, 0.051, 0.087, 0.090, 0.070, 0.064, 0.058, 0.071, 0.034, 0.077, 0.031, 0.039, 0.050, 0.048, 0.089, 0.063).

$$\boldsymbol{X} = \begin{bmatrix} 0.0 & 0.0 & 0.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.0 & 1.0 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 1.0 & 1.0 & 1.0 & 0.2 & 0.3 & 0.1 & 0.1 & 0.8 & 0.1 & 0.9 & 0.2 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 0.6 & 0.7 & 0.5 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 0.0 & 1.0 & 0.0 & 0.7 & 0.6 & 0.5 & 0.6 & 0.4 & 0.5 \end{bmatrix} \tag{30}$$

(3) Calculation of combined weights based on game theory

Following Figure 1, subjective and objective weights of evaluation indicators were obtained using the improved G1 method and the improved CRITIC method. Then, by applying the game theory model to solve for the optimal combined weights and utilizing equations (11) to (18) according to Figure 1, the combined weights can be determined as $W^* =$ (0.047, 0.035, 0.052, 0.088, 0.086, 0.070, 0.067, 0.055, 0.071, 0.036, 0.075, 0.035, 0.041, 0.050, 0.049, 0.082, 0.061). The composite weights at the element level are shown in Table 6.

The conservation value and ecological function of national parks hold a principal position within the national system of natural protected areas. According to Table 5, the weights of Criterion layers C_1 and C_2 lead other indicators, and at the evaluation layer, the weights of ecological harmony value, the authenticity, integrity, and diversity of ecotourism resources are relatively high. This indicates that the indicator system can effectively reflect the core content and essential requirements of ecotourism resources in national parks. Moreover, it also demonstrates the excellence of the model method, which can effectively identify key indicators and reflect them accordingly.

Table 6 Combined weights based on game theory optimization

Elements layer	Weight	Standard layer	Weight	Evaluation layer	Weight	Elements layer	Weight	Standard layer	Weight	Evaluation layer	Weight
B_1	0.500	C_1	0.222	C_{11}	0.047	B_2	0.182	C_3	0.182	C_{31}	0.071
				C_{12}	0.035					C_{32}	0.036
				C_{13}	0.052					C_{33}	0.075
				C_{14}	0.088	B_3	0.318	C_4	0.126	C_{41}	0.035
		C_2	0.278	C_{21}	0.086					C_{42}	0.041
				C_{22}	0.070					C_{43}	0.050
				C_{23}	0.067			C_5	0.192	C_{51}	0.049
				C_{24}	0.055					C_{52}	0.082
										C_{53}	0.061

4.2.2 Model evaluation and comparative analysis

(1) Analysis of evaluation results of the variable fuzzy set model

Referring to the grading standards in Table 1, the variable fuzzy attraction domain matrix $\boldsymbol{I}_{ab}$, range domain matrix $\boldsymbol{I}_{cd}$, and point value matrix $\boldsymbol{I}_M$ for the level evaluation of national park ecotourism resources are determined, respectively, as shown in Equation (31)~(33)

$$\boldsymbol{I}_{ab}=\begin{bmatrix} (0,3) & [3,5) & [5,7) & [7,9) & [9,10) \\ (0,3) & [3,5) & [5,7) & [7,9) & [9,10) \\ (0,3) & [3,5) & [5,7) & [7,9) & [9,10) \\ (0,3) & [3,5) & [5,7) & [7,9) & [9,10) \\ (0,30\%) & [30\%,50\%) & [50\%,70\%) & [70\%,90\%) & [90\%,100\%) \\ (0,3) & [3,5) & [5,7) & [7,9) & [9,10) \\ (0,4) & [4,6) & [6,8) & [8,10) & [10,40) \\ (0,3) & [3,5) & [5,7) & [7,9) & [9,10) \\ (0,3) & [3,5) & [5,7) & [7,9) & [9,10) \\ [10,50) & [8,10) & [5,8) & [3,5) & [0,3) \\ (0,3) & [3,5) & [5,7) & [7,9) & [9,10) \\ (0,1) & (1,5) & (5,20) & (20,30) & (30,50) \\ (0,1) & (1,6) & (6,10) & (10,17) & (17,50) \\ (0,1) & (1,2) & (2,6) & (6,8) & (8,12) \\ (0,0.5) & (0.5,1.5) & (1.5,2.5) & (2.5,5) & (5,10) \\ (0,3) & (3,5) & (5,7) & (7,9) & (9,10) \\ (0,0.5) & (0.5,1) & (1,3) & (3,5) & (5,10) \end{bmatrix} \tag{31}$$

$$\boldsymbol{I}_{cd}=\begin{bmatrix} (0,5) & [0,7) & [3,9) & [5,10) & [7,10) \\ (0,5) & [0,7) & [3,9) & [5,10) & [7,10) \\ (0,5) & [0,7) & [3,9) & [5,10) & [7,10) \\ (0,5) & [0,7) & [3,9) & [5,10) & [7,10) \\ (0,50\%) & [0,70\%) & [30\%,90\%) & [50\%,100\%) & [70\%,100\%) \\ (0,5) & [0,7) & [3,9) & [5,10) & [7,10) \\ (0,6) & [0,8) & [4,10) & [6,40) & [8,40) \\ (0,5) & [0,7) & [3,9) & [5,10) & [7,10) \\ (0,5) & [0,7) & [3,9) & [5,10) & [7,10) \\ [10,10) & [10,8) & [8,5) & [5,3) & [3,3) \\ (0,5) & [0,7) & [3,9) & [5,10) & [7,10) \\ (0,5) & (0,20) & (1,30) & (5,50) & (20,50) \\ (0,6) & (0,10) & (1,17) & (6,50) & (10,50) \\ (0,2) & (0,6) & (1,8) & (2,12) & (6,12) \\ (0,1.5) & (0,2.5) & (0.5,5) & (1.5,10) & (2.5,10) \\ (0,5) & (0,7) & (3,9) & (5,10) & (7,10) \\ (0,1) & (0,3) & (0.5,5) & (1,10) & (3,10) \end{bmatrix} \tag{32}$$

$$I_M = \begin{bmatrix} 0 & 3 & 0 & 9 & 10 \\ 0 & 3 & 0 & 9 & 10 \\ 0 & 3 & 0 & 9 & 10 \\ 0 & 3 & 0 & 9 & 10 \\ 0 & 30\% & 0 & 90\% & 100\% \\ 0 & 3 & 0 & 9 & 10 \\ 0 & 4 & 0 & 10 & 40 \\ 0 & 3 & 0 & 9 & 10 \\ 0 & 3 & 0 & 9 & 10 \\ 10 & 8 & 0 & 5 & 3 \\ 0 & 3 & 0 & 9 & 10 \\ 0 & 1 & 0 & 30 & 50 \\ 0 & 1 & 0 & 17 & 50 \\ 0 & 1 & 0 & 8 & 12 \\ 0 & 0.5 & 0 & 5 & 10 \\ 0 & 3 & 0 & 9 & 10 \\ 0 & 0.5 & 0 & 5 & 10 \end{bmatrix} \quad (33)$$

After determining I_{ab}, I_{cd}, and I_M, the standardized relative membership degrees can be calculated based on the data in Table 3 and equations (24) to (27). By combining the combined weights and using equations (28) to (29), the levels of national park ecotourism resources under different model parameters ($s=1$, $t=1$; $s=1$, $t=2$; $s=2$, $t=1$; $s=2$, $t=2$) can be calculated. The final results are shown in Table 7.

Table 7 Evaluation results of ecotourism resources in each region of national parks in the case

model parameter	FS 2	FS 3	FS 4
$s=1$, $t=1$	3.040	3.378	2.903
$s=1$, $t=2$	3.082	3.169	2.842
$s=2$, $t=1$	3.030	3.368	2.887
$s=2$, $t=2$	3.125	3.226	2.767
To evaluate the mean	3.069	3.280	2.850
order of evaluation	III, erroneous tendency IV	III, erroneous tendency IV	III, erroneous tendency II

(2) Comparative analysis of multiple evaluation models

To verify the reliability and credibility of the variable fuzzy set evaluation model based on combined weights, the fuzzy comprehensive evaluation method was used to evaluate the ecotourism resources in national parks. The specific evaluation process can refer to literature [29,30], and the evaluation results are shown in Table 8.

Table 8 Fuzzy comprehensive evaluation results of the ecotourism resources of national parks in the case

method		FS2	FS3	FS4
Variable fuzzy set	Evaluation of eigenvalues	3.069	3.280	2.850
	grade	III, erroneous tendency IV	III, erroneous tendency IV	III, erroneous tendency II
Fuzzy comprehensive evaluation method	Evaluation of eigenvalues	3.788	3.657	2.232
	grade	IV	IV	II

According to the evaluation results shown in Table 8, the results obtained by the two evaluation methods are basically consistent. However, the evaluation results of the variable fuzzy set are more flexible and dynamic, aligning more closely with the actual situation than the results of the fuzzy comprehensive evaluation. This demonstrates the effectiveness and scientific nature of the fuzzy comprehensive evaluation method.

4.2.3 Evaluation results discussion

The evaluation system for ecotourism resources in national parks differs significantly from the traditional tourism resource evaluation system: (1) In terms of evaluation indicator content. Traditional recreational resource evaluation mainly considers scientific research value, historical and cultural value, and aesthetic appreciation value, while the evaluation of ecotourism resources in national parks primarily focuses on scientific and conservation values, educational value, and recreational value, which is directly reflected in the subjective ranking results; (2) From the perspective of evaluation objectives, the fundamental purpose of evaluating ecotourism resources in national parks is to use and protect ecotourism resources rationally, rather than primarily evaluating based on the economic attributes of the resources, placing greater emphasis on the value orientation of harmonious coexistence between humans and nature; (3) In terms of evaluation methods, the improved variable fuzzy set model effectively addresses the fuzziness and dynamic issues of ecotourism resource evaluation in national parks, and introduces game theory to solve the weight integration problem, effectively utilizing expert knowledge and the objective information of data, making the evaluation results closer to reality.

5. Conclusion

At present, big data technology has been widely used in ecotourism resource management, making ecotourism resource data richer, and the corresponding evaluation system and methods should be innovated accordingly. The construction of traditional ecotourism resource evaluation indicator systems has predominantly relied on remote sensing data and official statistical yearbook data, which tend to be outdated and lack emphasis on the dynamic and fuzzy nature of the indicators themselves. Therefore, in response to the current development of internet data, this paper proposes the use of online review data, calculated using the SD method, thereby extending the data sources from structured to non-structured data and expanding the model method from deterministic to fuzzy values. This enhances the timeliness and effectiveness of the evaluation of ecotourism resources in national parks. The main conclusions of the research are as follows:

(1) From the perspective of evaluation indicator design, the integration of online non-structured data and traditional structured data indicators has constructed an evaluation indicator system for ecotourism resources in national parks from a big data perspective. This system reflects the primary functions of national parks, focusing on authenticity and integrity (with higher indicator weights), which aligns with the critical requirements for national park resource development. The indicator system proposed in this paper can provide important references for the evaluation of ecotourism resources in other national parks.

(2) Regarding the evaluation method, the application of the Game Theory Enhanced Order Relation Analysis Method (G1 method) and CRITIC method to determine subjective and objective weights, and the construction of a variable fuzzy evaluation model optimized by game theory, enrich the evaluation models and methods for ecotourism resources in national parks. Moreover, case study results show that this model can effectively solve the fuzziness and dynamism problems in the evaluation of ecotourism resources in national parks. Compared to traditional fuzzy comprehensive evaluation methods, the evaluation results have dynamic characteristics, aligning more closely with the actual situation.

(3) From the perspective of evaluation content and pathways, the indicator system and method proposed in this paper from a big data perspective are not only applicable to the evaluation of recreational resources in national parks but also suitable for the evaluation of ecotourism resources in land space areas prohibited from development. The spatial scope of these prohibited development areas is broader than that of national parks, but both share the basic spatial function of ecological protection, with the goal of enhancing the carrying capacity of natural ecological space. In terms of the concept, method, and implementation pathway of ecotourism resource evaluation, there is essential consistency.

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