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Quantitative Evaluation of the View of the Landscape Using a Visibility Analysis Optimization Algorithm

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Abstract: Visual evaluation of the landscape is an important way to judge landscape quality. In this study, by optimizing the vertical angle and relative slope parameters of a visibility analysis algorithm, we intuitively and quantitatively display visibility grid data on the landscape based on tourists' viewpoints and realize the transformation from making calculations only for the visible area to quantitatively evaluating the quality of visually experiencing the landscape considering parallax. We consider a variety of landscape visual influence factors (visible area, landscape water system distribution, number of landscape resources) to construct an index system for evaluating landscape visual effects. Finally, a set of improved landscape visual evaluation methods is proposed by integrating the analytic hierarchy process (AHP) and an optimization algorithm into the visibility analysis. Validation of the case study of the ancient town Fenghuang shows that these methods can effectively distinguish good and bad landscape viewpoints in a scenic area and support planning and design decisions on the related spatial layout and viewing platform. This study provides a new perspective for developing a quantitative, intelligent digital landscape analysis system.

Keywords: landscape visual evaluation; visibility analysis; analytic hierarchy process; landscape visual experience; site planning of viewing platform

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1. Introduction

With the rapid growth of tourism in China, the visual experiences of visitors at tourist sites significantly impact the overall quality of these sites [1]. We can thus utilize approaches to landscape visual assessment, using comprehensive analysis of the visible area, landscape water system distribution and number of landscape resources, to evaluate aesthetic qualities and provide scientific grounds for planning and the protection of landscapes. In the domain of analytical systems for landscape visibility, abundant research has been conducted by scholars in China and abroad. For instance, Qiao et al. [2] applied the analytic hierarchy process (AHP) to assessing the quality of the landscape in five housing quarters in Yangling, China, considering functionality, eco-friendliness and attractiveness. Meanwhile, Zhao et al. [3] devised questionnaires using the Semantic Differential (SD) method, evaluated the visual qualities of historical building blocks and constructed an assessment structure using the Factor Analysis (FA) method. Śleszyński Przemysław [4] presents a methodology for assessing the visual aesthetic value of landscapes, which is analyzed with respect to a highly environmentally diverse fragment of the Małopolska Upland (central Poland). This methodology provides a versatile platform for evaluating nature and landscapes, as well as for practical applications such as nature preservation, tourism development and spatial planning. However, by relying primarily on expert surveys, these methods lack objectivity and rigor. The imperative task of transforming subjective visual perceptions into computable data is essential to enabling quantitative evaluation of the landscape visibility and enhancing enjoyment for tourists.

Visibility is a prerequisite for judging whether a view of the landscape exists or not [5], which can be calculated using visibility analysis algorithms. Traditional algorithms like R3, R2 and XDraw have their respective strengths and weaknesses—R3 features high precision yet a lengthy computation time, while R2 and XDraw are more efficient but less accurate [6]. In recent years, visibility analysis has been widely applied across various domains, including travel route planning [7,8], scenic resource allocation and conservation [9–12] and site selection for fire lookout towers [13,14]. Different contexts require tailored optimization strategies. The existing improvements have centralized around speed and precision, as exemplified by Dou et al. [15], who combined parallel computing with visibility algorithms for geographic data processing, and Wu et al. [6]. who proposed the PDERL (Proximity-Direction-Elevation Reference Line) algorithm by establishing visibility algorithms in partial differential equation spaces, achieving precision close to R3 and efficiency comparable to XDraw. However, from tourists' perspective, the current algorithms can only determine whether landscape features are visible, without quantitatively assessing their viewing experiences. Prior studies like that undertaken by Wheatley and Gillings [16] defined distance zones to indicate decaying clarity, and Fisher [17] adopted fuzzy set theories to model atmospheric impacts across distances. Yet, vertical influences on viewing experiences remain insufficiently addressed.

This study aims to quantify tourists' landscape viewing experiences and construct an objective assessment framework for scenic visibility. To achieve this goal, the parameters in the visibility analysis are optimized from horizontal and vertical perspectives, incorporated with influential factors like aqueous distributions and the available resources. An enhanced approach is thereby established, integrating optimized visibility algorithms and the analytic hierarchy process (AHP) for the quantitative evaluation of landscape visibility. Its validity and accuracy will be evidenced using the case study of Fenghuang Town, Shaanxi Province, China, whereby sightseeing tower sites are selected based on the proposed method.

2. Methodology

This study, by optimizing the vertical angle and relative slope parameters of the visibility analysis algorithm, intuitively and quantitatively displays visibility grid data on the landscape based on tourists' viewpoints and realizes the transformation from making calculations only for the visible area to quantitatively evaluating the quality of visually experiencing the landscape considering parallax. It considers a variety of landscape visual influence factors (visible area, landscape water system distribution, number of landscape resources) to construct an index system for evaluating landscape visual effects. Finally, a set of improved landscape visual evaluation methods is proposed by integrating the analytic hierarchy process (AHP) and an optimization algorithm into the visibility analysis.

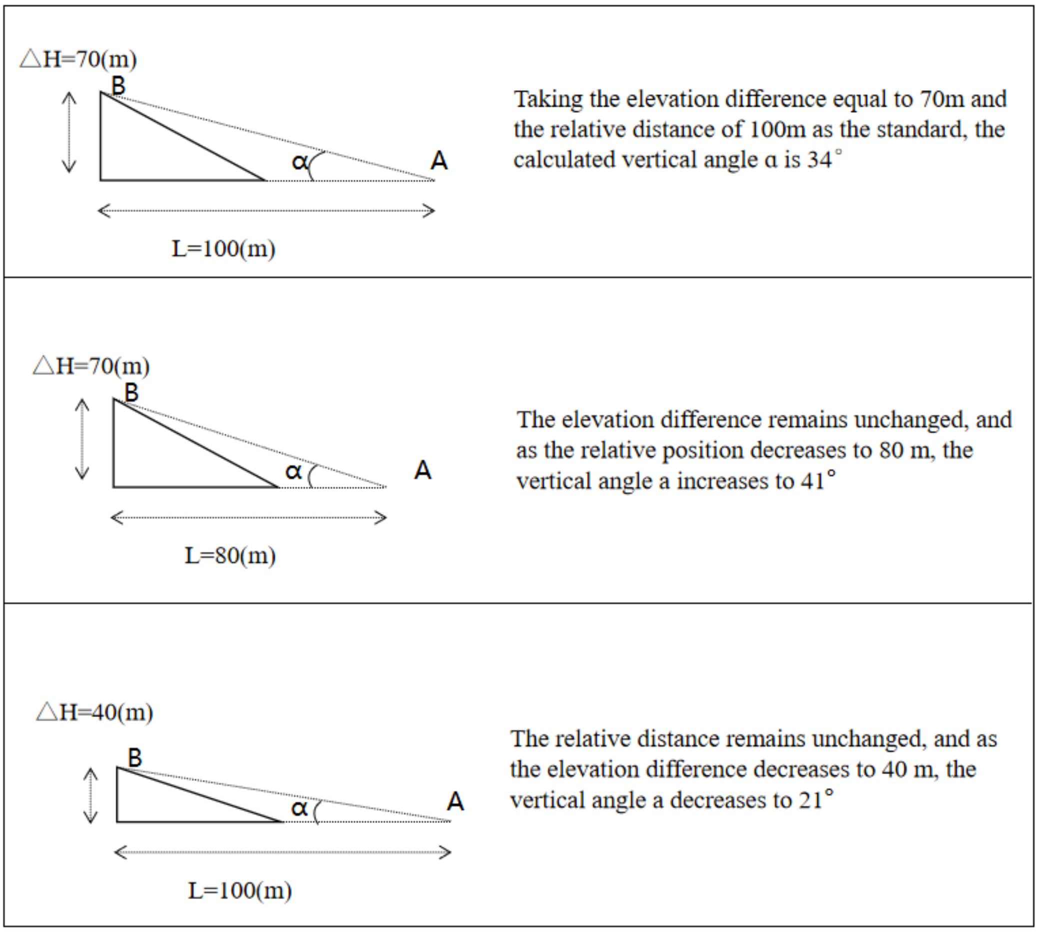
2.1. Visibility Analysis

The visibility analysis algorithm generates a binary raster of visible (coded as "1") and invisible areas (coded as "0") based on an input observation point [16]. Such outputs can merely determine the landscape visibility, without quantitatively depicting tourists' viewing experiences. This section optimizes the parameters in the visibility algorithm, specifically the vertical angle and relative slope, to quantify how topographic attributes like gradient, distance and elevation influence sightseeing and visual perception.

2.1.1. Parameter Optimization

The vertical angle takes into account the relative distance and relative height between tourists and the landscape. Without considering the terrain where tourists are located, the impacts of the relative distance and relative height on the vertical angle are shown in Figure 1. By simplifying and amplifying the slope and height of the terrain where the landscape is located within a two-dimensional triangular plane, as the vertical height decreases and the distance between the landscape and the tourists increases, the vertical angle becomes smaller, visibility weakens and the visual experience of sightseeing becomes worse. In contrast, the larger the vertical angle, the better the visibility and the sightseeing experience. The calculation formula for the vertical angle is:

$$\alpha = \arctan\left(\frac{\Delta \mathrm{H}}{L}\right) \tag{1}$$



Taking the elevation difference equal to 70m and the relative distance of 100m as the standard, the calculated vertical angle α is 34°

The elevation difference remains unchanged, and as the relative position decreases to 80 m, the vertical angle a increases to 41°

The relative distance remains unchanged, and as the elevation difference decreases to 40 m, the vertical angle a decreases to 21°

Figure 1. The effects of relative distance and elevation difference on vertical angle without considering the terrain where tourists are located.

In Figure 1, point A represents the tourist, and point B represents the landscape. Using the elevation of point A where the tourist is located as the reference line, α represents the vertical angle of point A, L represents the actual distance between the two points and ΔH represents the elevation difference between the two points.

However, the above ideal model does not exist because the slope and height of the terrain where the tourists are located also affect the accuracy of the vertical angle calculation. Therefore, we enlarge and simplify both the slope and height of the terrain where the tourists A and the landscape B are located within a two-dimensional triangular plane, respectively (Figure 2).

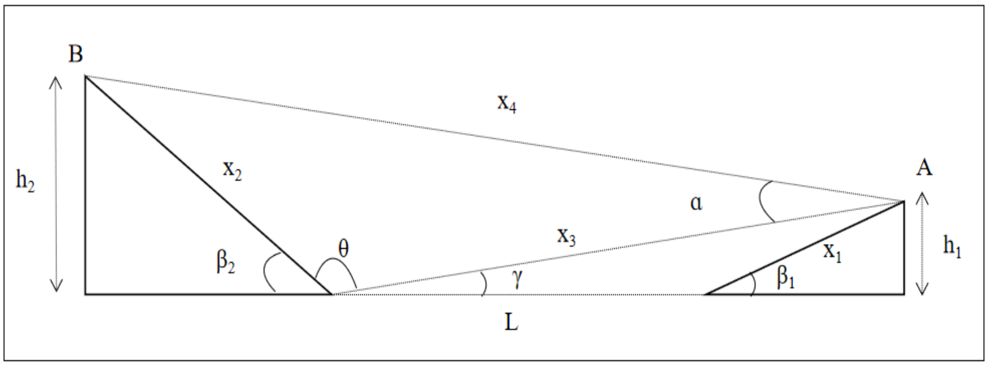


Figure 2. Vertical angle calculation schematic diagram after considering the terrain where tourists are located.

Where point A represents the tourist, point B represents the landscape, h_1 and h_2 represent the elevation where the tourists and the landscape are located, respectively, L represents the relative distance between the two and β_1 and β_2 represent the terrain slope where they are located, respectively. Therefore, after considering the terrain where the tourists are located, the calculation formula for the vertical angle is:

$$\alpha = \arccos(\frac{x_4^2 + x_3^2 - x_2^2}{2x_4 x_3}) \tag{2}$$

Because:

$$x_1 = \frac{\mathrm{h}_1}{\sin\beta_1} \tag{3}$$

$$x_2 = \frac{\mathrm{h}_2}{\sin\beta_2} \tag{4}$$

$$x_3 = \sqrt{(x_1^2 + L^2 - 2x_1 L\cos(180^\circ - \beta_1))} \tag{5}$$

$$x_4 = \sqrt{(x_2^2 + x_3^2 - 2x_2 x_3 \cos\theta)} \tag{6}$$

$$\gamma = \mathrm{arc}\ \cos(\frac{L^2 + x_3^2 - x_1^2}{2Lx_3}) \tag{7}$$

$$\theta = 180^\circ - \gamma - \beta_2 \tag{8}$$

We derive Equation (9) from Equations (3) and (5):

$$x_3 = \sqrt{((\frac{\mathrm{h}_1}{\sin\beta_1})^2) + L^2 + 2\cot\beta_1 h_1} \tag{9}$$

Then, Equation (10) can be derived from Equations (7)–(9):

$$\theta = 180^\circ - \arccos(\frac{L + \cot\beta_1}{\sqrt{(\frac{h_1}{\sin\beta_1})^2 + L^2 + 2h_1 L\cot\beta_1}}) - \beta_2 \tag{10}$$

Equation (11) is derived from Equations (4), (6), (9) and (10):

$$x_4 = \sqrt{((\frac{h_2}{\sin\beta_2})^2 + ((\frac{h_1}{\sin\beta_1})^2 + L^2 + 2h_1\cot\beta_1) - 2\frac{h_2}{\sin\beta_2}\sqrt{(\frac{h_1}{\sin\beta_1})^2 + L^2 + 2h_1\cot\beta_1}\cos\theta} \tag{11}$$

Finally, the vertical angle α is calculated by combining Equations (2), (4), (9) and (11). The larger the vertical angle, the better the visual experience for the tourists.

Evidently, the larger the slope of the landscape surface relative to the tourists' perspective, the larger the visible area and the likelihood of the landscape being noticed, and the more comfortable the visual sightseeing experience. Therefore, the projected area of the landscape surface along the line of sight can be used to describe the impact of the relative slope on the tourists' visual experience (denoted by sensitivity S), as shown in Figure 3 (level sight as an example). For level or upward sight, the relative slope is the actual terrain slope. For downward sight, the relative slope is the terrain slope minus 90°. If the landscape area is 1 and the terrain slope is β, then the sensitivity is:

$$S_1 = \sin\beta(0^\circ \leq \beta \leq 90^\circ) \tag{12}$$

$$S_2 = \sin(90 - \beta) \tag{13}$$

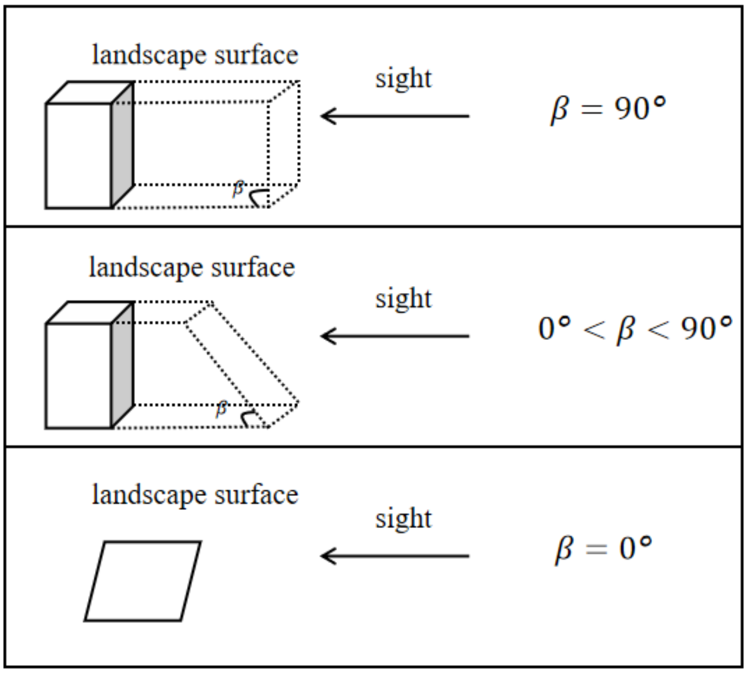


Figure 3. Sensitivity diagram considering the front horizontal view as an example.

In Figure 3, β represents the slope angle of the landscape surface. When the line of sight is perpendicular to the landscape surface, the projection area is maximized, and the sensitivity is equal to 1. When the line of sight is parallel to the landscape surface, the projection area is minimized, and the sensitivity is equal to 0. Other angles yield values between 0 and 1.

2.1.2. Algorithmic Implementation

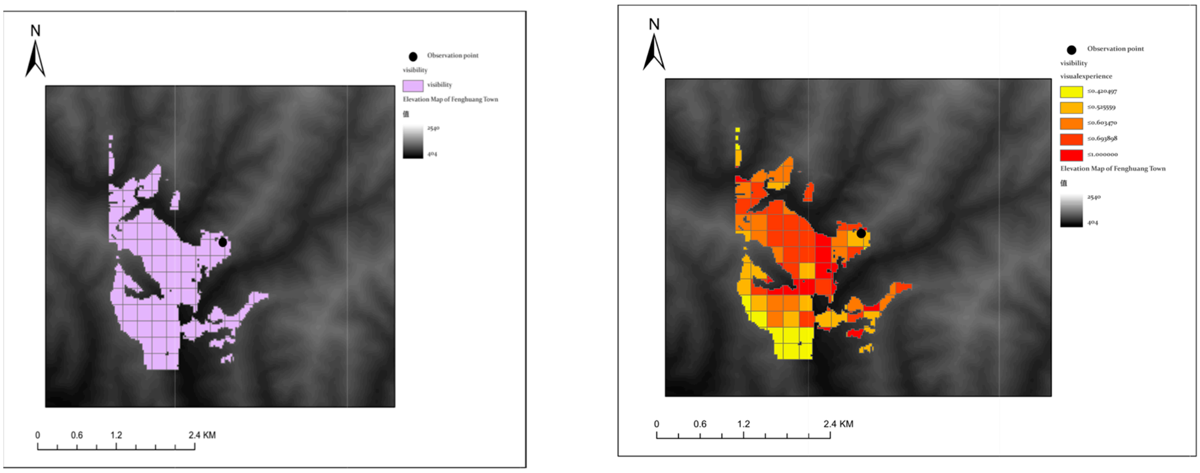
The implementation process for the visibility analysis optimization algorithm is as follows:

(1) Employ the visibility analysis algorithm to calculate the visible area of the observation points.
(2) Take the center points of each grid in the visible area as the target points.
(3) Implement the visibility analysis optimization algorithm to compute the optimization parameter values corresponding to each target point.
(4) The visible area obtained by weighting the optimization parameters and their corresponding weights (calculated using the AHP) can quantitatively evaluate tourists' visual experience of sightseeing. Utilize the GIS view function to display the visibility at graded levels from low to high based on the visual experience scores.

2.1.3. Algorithmic Validation

To validate the effectiveness of the visibility analysis optimization algorithm, Fenghuang Town was selected as the study area. We performed a comparison experiment before and after the optimization of the visibility analysis algorithm, keeping the tourists' coordinates, observation radius and landscape coordinates unchanged.

Figure 4a shows that the visibility analysis results before optimization can only display the visible area. As shown in Figure 4b, we can see that after optimization, not only can the visible area be obtained but the visual experience can also be quantitatively assessed, and the results can be displayed in graded colors. The darker the color, the better the visual experience.



(**a**) (**b**)

Figure 4. (**a**) denotes the visible region before optimization by the visibility analysis algorithm and (**b**) denotes the visible region after optimization by the visibility analysis algorithm.

To validate the accuracy of the proposed visibility analysis optimization algorithm, this study adopts the statistical correlation analysis method, comparing the correlation between on-site questionnaire survey results on the "landscape visual experience" and the landscape visual experience chromatic map predicted using the optimization algorithm. A higher correlation coefficient indicates that the chromatic map more accurately reflects the actual visual effect distribution for the landscape, thus proving the accuracy of the visibility analysis optimization algorithm. The specific verification procedures are as follows:

(1) A total of 100 test points were systematically randomly sampled within the research area for conducting questionnaire surveys using the landscape visual experience scale.
(2) The questionnaire scores for each test point were statistically normalized as the actual landscape visual experience values.
(3) The landscape visual experience chromatic map (as shown in Figure 5) was produced based on the visibility analysis optimization algorithm.
(4) The predicted landscape visual experience values corresponding to the 100 test points were extracted from the chromatic map.
(5) Pearson's correlation analysis was performed between the actual and predicted landscape visual experience values.

Our survey targeted ordinary tourists engaged in activities within the designated test points of the study area. We conducted on-site questionnaire surveys utilizing a Likert five-point scale, which included an item on the "landscape visual experience". Normalization was applied to the survey scores, mapping satisfaction values onto a 0–1 range (with 0 indicating complete dissatisfaction and 1 representing utmost satisfaction). The normalized scores were then used to calculate the average scores for each test point, representing the actual values.

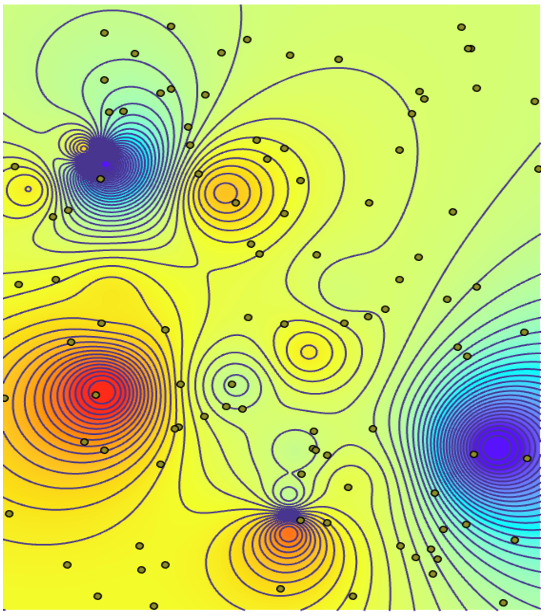


Figure 5. Chromatic map of the visual experience of the landscape.

Figure 6 presents the landscape visual experience value (RASTERVALU) along the horizontal axis, derived using the visibility analysis optimization algorithm. The vertical axis depicts scores representing the "landscape visual experience" (SCOER), obtained using an on-site questionnaire survey. This survey evaluates multiple facets of the visual experience by incorporating questions on sensory fulfillment, aesthetic appreciation and other relevant dimensions. Statistical summarization and analysis of the collected survey data produce finalized landscape visual experience scores for the test points. There is a positive correlation coefficient of 0.82 between the two, reaching a significance level of 0.01. The few test points in Figure 6 that show a large discrepancy between the questionnaire results and the predicted chromatic map results may be due to certain subjective randomness in different tourists' aesthetic needs and the landscape satisfaction criteria, causing deviations in the evaluation of the same landscape. Overall, there is a strong correlation between the actual and predicted values, which verifies that the chromatic map can accurately reflect the actual distribution of the landscape visual experience, thus proving the accuracy of the visibility analysis optimization algorithm.

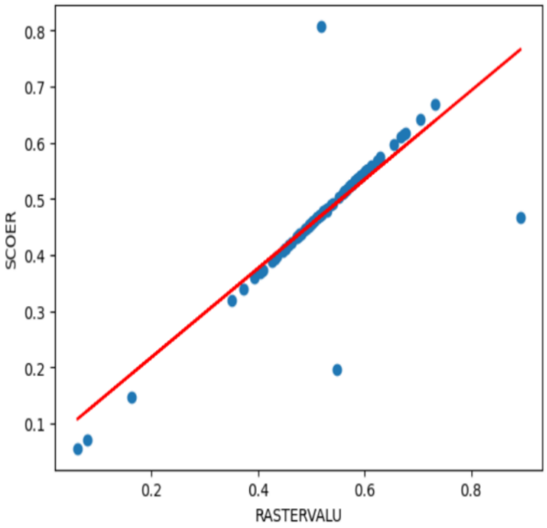


Figure 6. Pearson's correlation analysis.

2.2. Establishment of the Landscape Visual Evaluation Method

By optimizing the visibility analysis algorithm, this study achieves a transformation from merely making calculations for the visible area to the quantitative evaluation of the quality of visually experiencing the landscape considering parallax. However, comprehensively evaluating the landscape visual effects requires integrating influencing factors. This study selects quantitative indicators (e.g., visible area) and qualitative indicators (e.g., landscape water system distribution, number of landscape resources) closely related to landscape visual satisfaction. Then, by employing the analytic hierarchy process (AHP) to assign weights to these indicators, an integrated landscape visual evaluation method possessing both quantitative computation and qualitative assessment is finally established. This method not only considers the quantified effect but also comprehensively evaluates the qualitative factors affecting the landscape quality, and its scientificity and functionality have been validated in subsequent case studies.

The landscape visual evaluation method proposed in this study includes: (1) determination of the influence indicators; (2) calculation of the indicator weights; (3) calculation of landscape visual assessment total scores. Firstly, by comprehensively summarizing previous studies and the existing expert experience, the primary indicators within landscape visual evaluation are determined. Then, according to the AHP, the indicator weights are calculated. Finally, the total scores of the landscape visual evaluation are obtained using weighted calculation using both indicator values and weights.

(1) Determination of influence indicators

The Landscape Visual Management System (VMS) developed by the United States Forest Service (USFS) suggests that the spatial relationship between observers and landscapes can affect their visual experience. In 1995, the USFS updated the VMS to the Landscape Management System (SMS), adding terrain features, river systems and cultural features as important indicators affecting the visual quality of the landscape [18]. We select the indicators that affect the landscape visual assessment method based on the SMS in this paper. We can quantitatively analyze the impact of the terrain features on the visual experience within the visible area, which is affected by the vertical angle and relative slope. The landscape water system is divided into river system I, river system II and III river system, according to their river flow and size. The more landscape river systems tourists see and the higher the level, the more comfortable their visual experience will be [19,20]. The number of landscape resources can reflect the cultural characteristics of different regions, including natural and cultural landscapes. Tourists in areas with rich landscape resources are more likely to resonate with the scenery and history, enhancing their visual experience [21,22] (Alimardonova 2020; Iranmanesh 2010).

Overall, we propose a hierarchical landscape evaluation system, shown in Figure 7. The primary indicators include the visible area, landscape resources and landscape water systems, and the secondary indicators are composed of the vertical angle, relative slope, natural landscape, cultural landscape, river system I, river system II and river system III.

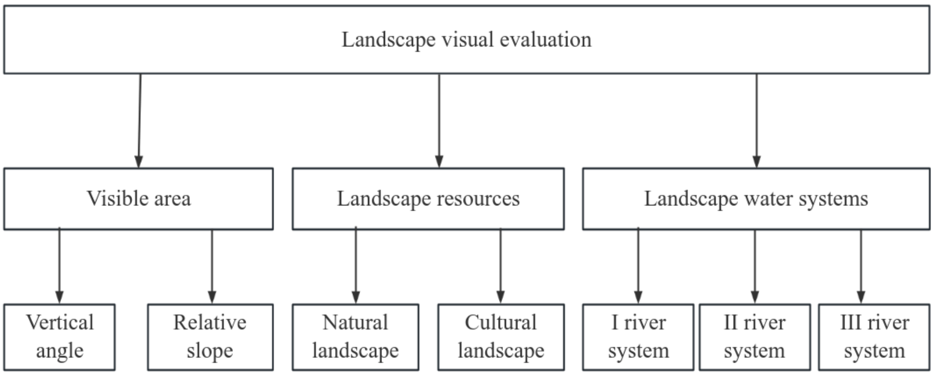


Figure 7. The landscape visual evaluation system.

(2) Calculation of the indicator weights

When determining the weight of each indicator, evaluation using the traditional methods is limited by subjective wishes or qualitative conditions, so the result is not ideal. To solve this problem, Santy et al. [23] proposed consistent matrix discrimination, which compares two factors with each other as much as possible to reduce the difficulty of comparing factors with different properties and improve accuracy. Therefore, in the evaluation process, it is necessary to compare each indicator with each other, and then determine the importance levels based on the importance of each indicator. In this process, a_{ij} denotes the results of the comparison of the importance of element *i* and element *j*. Table 1 lists nine importance levels and their assigned values. The matrix formed according to the results of pairwise comparison is called the judgment matrix. The judgment matrix has the following properties:

$$a_{ij} = \frac{1}{a_{ji}} \tag{14}$$

Table 1. Important levels from 1 to 9.

Scale	Meaning
1	Element *i* is as important as element *j*
3	Element *i* is slightly more important than element *j*
5	Element *i* is stronger and more important than element *j*
7	Element *i* is more important than element *j*
9	Element *i* is more important than element *j*
2,4,6,8	Element *i* and element *j* are intermediate in importance

For each obtained weight, a consistency test is required. We use the CR (consistency ratio) to verify the consistency of the weight. If the CR < 1, the consistency test is considered acceptable; otherwise, the matrix elements must be changed and rescaled according to Table 1 until the CR satisfies the consistency condition. The calculation of the CR is shown in Equation (15), where the RI (random consistency index) needs to be looked up in Table 2.

$$CR = \left(\frac{\lambda - \mathrm{n}}{n-1}\right) \times \left(\frac{1}{RI}\right) \tag{15}$$

where n represents the order of the matrix and λ represents the maximum eigenvalue of a matrix of order n.

Table 2. Average random consistency indicator RI values.

n	RI
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45

By selecting, modeling and calculating the weights of the landscape visual evaluation indicators, the weights of each indicator were finally obtained as shown in Tables 3–6.

Table 3. Weighting of primary indicators.

	Visible Area	Landscape Resources	Landscape Water Systems	Weight
Visible area	1	3	3	0.43
Landscape resources	1/3	1	1/2	0.33
Landscape water systems	1/3	2	1	0.24

Where λ = 3.1 and the CR = 0.08 < 1, which proves that the consistency of this judgement matrix is ideal.

Table 4. Secondary indicators: weighting of visibility.

	Vertical Angle	Relative Slope	Weight
Vertical angle	1	2	0.53
Relative slope	1/2	1	0.47

Where λ = 2 and the CR = 0 < 1, which proves that the consistency of this judgement matrix is ideal.

Table 5. Secondary indicators: weighting of landscape.

	Natural Landscape	Cultural Landscape	Weight
Natural landscape	1	2	0.53
Cultural landscape	1/2	1	0.47

Where λ = 2 and the CR = 0 < 1, which proves that the consistency of this judgement matrix is ideal.

Table 6. Secondary indicators: weighting of river systems.

	River System III	River System II	River System I	Weight
River system III	1	2	3	0.41
River system II	1/2	1	1/2	0.35
River system I	1/3	2	1	0.24

Where λ = 3.3 and the CR = 0.0025 < 1, which proves that the consistency of this judgement matrix is ideal.

(3) Calculation of the landscape visual assessment total scores

After calculating the weighted sum of the indicator values and the weights of each target point, the landscape visual evaluation score (LVES) of each target point is obtained (as shown in Equation (16)). We then obtain the total score for the landscape visual evaluation by summing up the scores of all the target points corresponding to the observation point (as shown in Equation (17)).

$$LVES_{\mathrm{k}} = \sum_{\mathrm{k}=1}^{\mathrm{k}} IV_{\mathrm{k}} \times W_k \tag{16}$$

$$LVES = \sum_{n=1}^{\mathrm{n}} LVES_k \tag{17}$$

where *LVES* represents the total score for the landscape visual evaluation of the observer point, $LVES_k$ represents the landscape visual evaluation score for the target point, k represents the number of indicators, IV_k represents the value of each indicator, W_k represents the weight value corresponding to each indicator and n represents the number of target points corresponding to the observer point.

3. Method Validation

To validate the effectiveness of the proposed landscape visual assessment method, we regard Fenghuang Town as the study object, which is located between 109.3123079° E to 109.4373592° E and 33.5706358° N to 33.4810015° N. Fenghuang Town is in the southeast of Zhashui County, Shangluo City, Shaanxi Province, China. The terrain of Fenghuang Town is mainly mountainous, with a high topography to the west and low topography to the east, and an average elevation of 709 m (Figure 8). Fenghuang Town is surrounded by abundant river systems, with a pleasant environment and rich natural and cultural landscape resources. The data source used in the experiment is shown in Table 7.

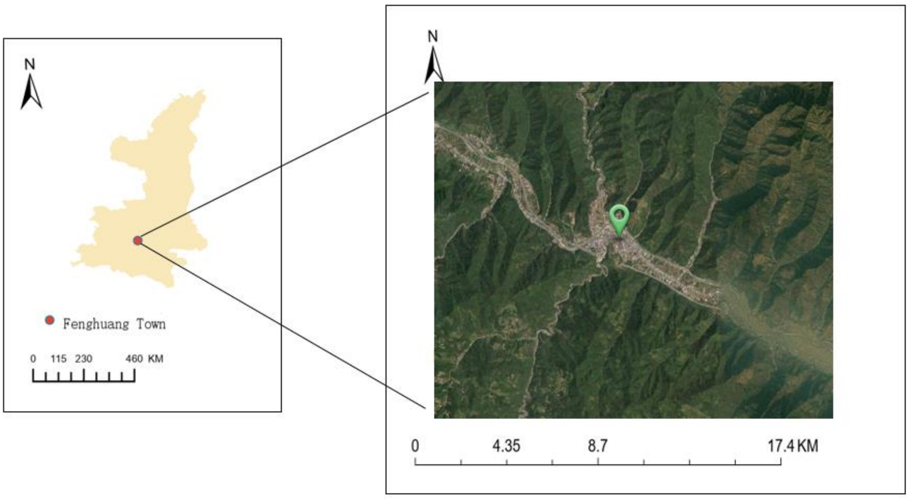


Figure 8. Overview of Fenghuang Town area.

Table 7. Experimental data source.

Database	Source
River system	Baidu Maps API
Landscape	Baidu Maps API
Elevation map of Fenghuang Town	Resource and Environmental Science and Technology Center, Chinese Academy of Sciences
Image of Fenghuang Town	Resource and Environmental Science and Technology Center, Chinese Academy of Sciences

3.1. Data Preprocessing

We adopt the GIS spatial analysis function for data extraction and preprocessing, as follows:

(1) Selecting observation points

We divide the research area into a grid of 5000 m × 5000 m, and the center point of each grid is regarded an observation point.

(2) Selecting the observation radius

To prevent overlaps in the visible areas between adjacent observation points from affecting the experiment results, we select the half distance between adjacent observation points as the observation radius.

(3) Selecting target points

We use visibility analysis to calculate the visible area corresponding to each observation point and regard the center point of the visible area the target point.

(4) Calculate the visual experience score of the landscape in the visible area

Based on using the visibility analysis optimization algorithm to calculate the landscape visual experience score within the visibility area of each observation point, a hierarchical display of the landscape visual experience score of Fenghuang Town is shown in Figure 9.

(5) Extracting river systems in the research area

We apply the Baidu Map API to extract the river system vector data surrounding Fenghuang Town and count the number of river systems covered within the observation radius centered on each observation point. The distribution of the river systems in Fenghuang Town is shown in Figure 10.

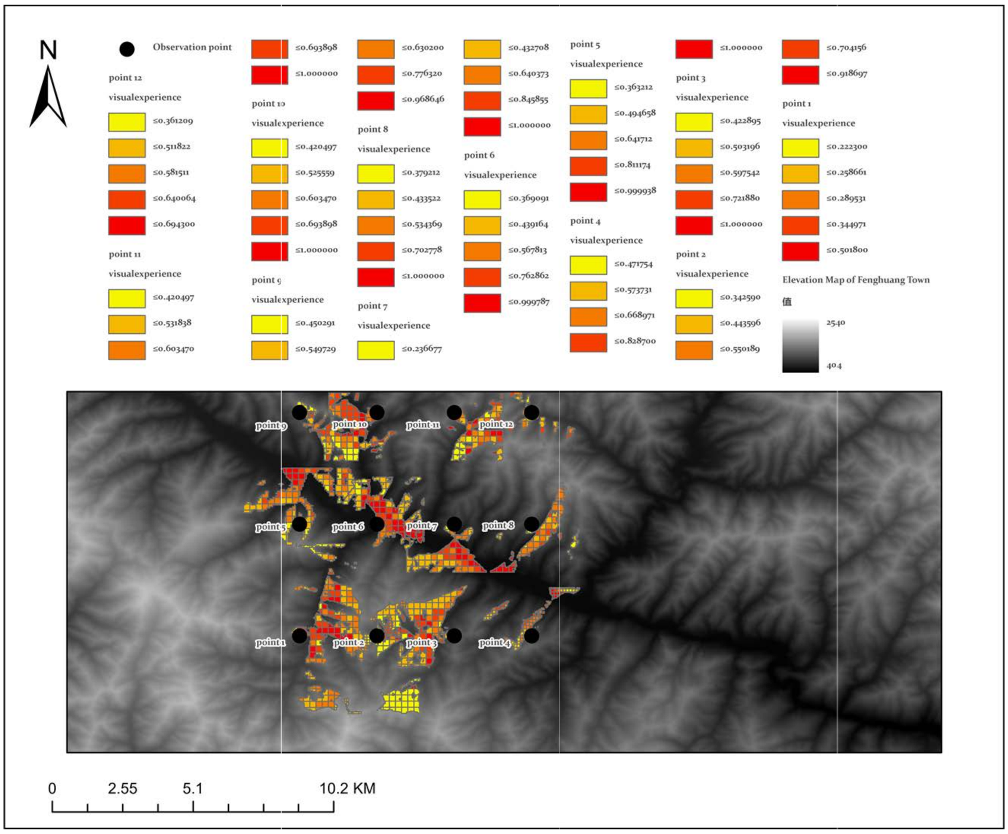


Figure 9. Visual effects of the visible area.

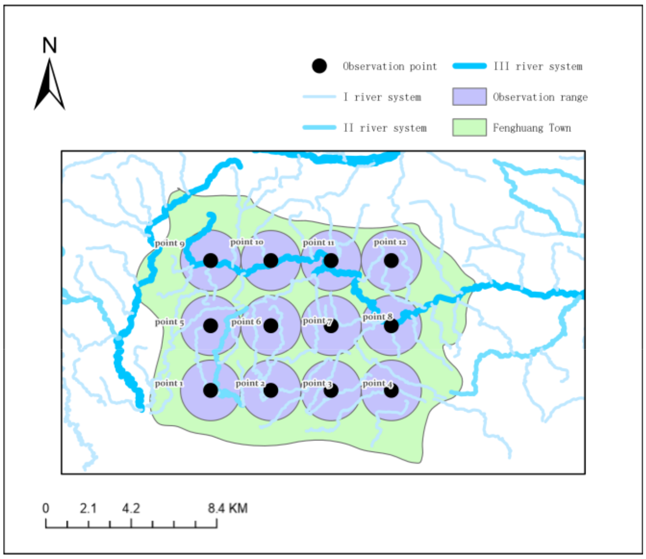


Figure 10. Distribution of river systems in Fenghuang Town.

(6) Extracting landscapes in the research area

We use the Baidu Map API to extract the landscape vector data surrounding Fenghuang Town and count the number of landscapes covered within the observation radius centered on each observation point. The distribution of the landscape in Fenghuang Town is shown in Figure 11.

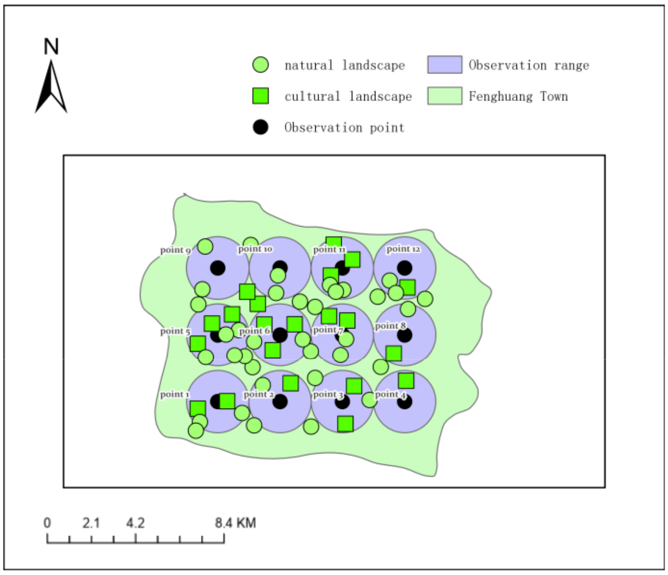
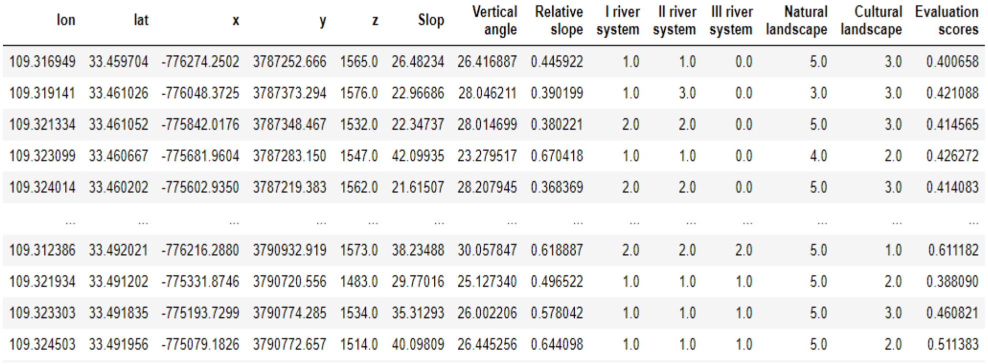


Figure 11. Distribution of landscape in Fenghuang Town.

3.2. Calculating the Total Scores for the Landscape Visual Evaluation

The landscape visual experience scores for the visible areas and the covered numbers of water systems and landscapes are extracted for each observation point using the spatial analysis function in the GIS. The obtained experimental data are shown in Figure 12. Based on the landscape visual evaluation system established in the previous section, the landscape visual assessment scores for 12 observation points in Fenghuang Town are calculated as shown in Figure 13.



lon	lat	x	y	z	Slop	Vertical angle	Relative slope	I river system	II river system	III river system	Natural landscape	Cultural landscape	Evaluation scores
109.316949	33.459704	-776274.2502	3787252.666	1565.0	26.48234	26.416887	0.445922	1.0	1.0	0.0	5.0	3.0	0.400658
109.319141	33.461026	-776048.3725	3787373.294	1576.0	22.96686	28.046211	0.390199	1.0	3.0	0.0	3.0	3.0	0.421088
109.321334	33.461052	-775842.0176	3787348.467	1532.0	22.34737	28.014699	0.380221	2.0	2.0	0.0	5.0	3.0	0.414565
109.323099	33.460667	-775681.9604	3787283.150	1547.0	42.09935	23.279517	0.670418	1.0	1.0	0.0	4.0	2.0	0.426272
109.324014	33.460202	-775602.9350	3787219.383	1562.0	21.61507	28.207945	0.368369	2.0	2.0	0.0	5.0	3.0	0.414083
...	...	...	...	...	...	...	...	...	...	...	...	...	...
109.312386	33.492021	-776216.2880	3790932.919	1573.0	38.23488	30.057847	0.618887	2.0	2.0	2.0	5.0	1.0	0.611182
109.321934	33.491202	-775331.8746	3790720.556	1483.0	29.77016	25.127340	0.496522	1.0	1.0	1.0	5.0	2.0	0.388090
109.323303	33.491835	-775193.7299	3790774.285	1534.0	35.31293	26.002206	0.578042	1.0	1.0	1.0	5.0	3.0	0.460821
109.324503	33.491956	-775079.1826	3790772.657	1514.0	40.09809	26.445256	0.644098	1.0	1.0	1.0	5.0	2.0	0.511383

Figure 12. Experimental data.

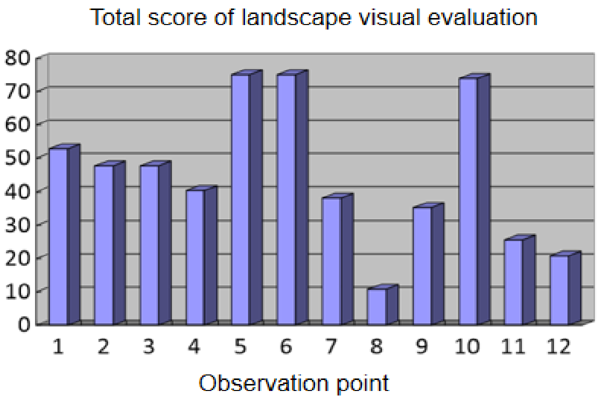


Figure 13. The total landscape visual assessment scores for each observation point.

3.3. Results Analysis

As shown in Figure 9, the results obtained using the visibility analysis optimization algorithm not only display the visible area but also quantitatively analyze the visual experience for tourists using the optimization parameters. The colors displayed in Figure 9 are arranged from low to high according to the scores, with darker colors indicating a better visual experience. Figure 13 shows that the total landscape visual assessment scores of observation points 5, 6, and 10 are between 70 and 100. Then, we select these three points as the predicted viewing platforms. We verify whether the landscape visual quality is consistent with the actual situation using error analysis.

3.4. Error Analysis

We select the existing viewing platforms in Fenghuang Town as the observation points and calculate the average value of the landscape visual evaluation scores for each observation point. We use the average value as the actual value in the root mean square error calculation. With the observation point as the center, as the radius increases by 500 m, we calculate the landscape visual evaluation scores for four target points corresponding to central angles of 90°, 180°, 270° and 360° and use them as the predicted values in the root mean square error calculation. Finally, the root mean square error (*RMSE*) of the landscape visual evaluation scores for different error radii is calculated as shown in Figure 14. The formula for the root mean square error is:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n=4} X_i - x}{n}} \tag{18}$$

where n represents the number of target points, X_i represents the predicted values and x represents the actual values.

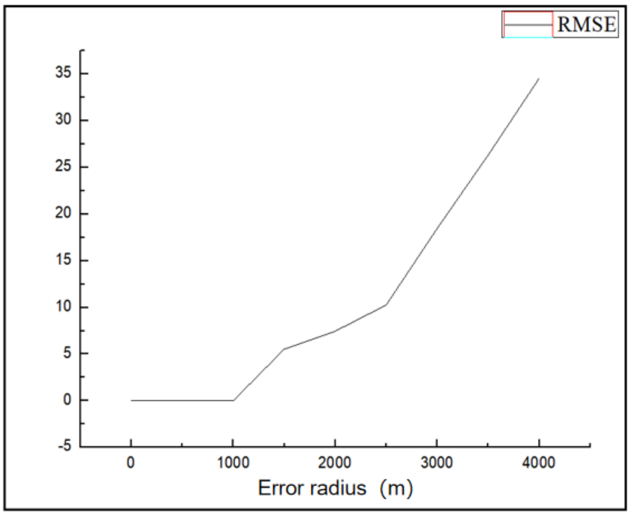


Figure 14. Root mean square error of landscape visual evaluation scores with different error radii.

As shown in Figure 14, we can see that the root mean square error of the landscape visual evaluation scores increases significantly when the error radius exceeds 1000 m, indicating that the landscape visual effect is basically consistent within a range of 1000 m. Therefore, the error range is defined as a circle with a radius of 1000 m centered on the original observation platform. Using error analysis (Figure 15), we see that observation points 5, 6 and 10 are all within the error range, indicating that their landscape visual effects are consistent with the actual situation, further verifying the effectiveness of the proposed viewshed analysis optimization algorithm and landscape visual evaluation method.

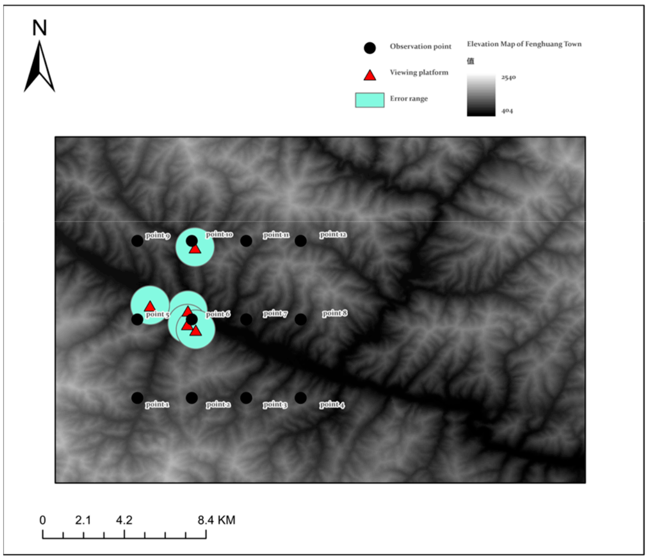


Figure 15. Results of the observation platform position error analysis.

4. Conclusions and Discussion

This study constructs a visibility analysis optimization algorithm to transform the abstract assessment of tourists' visual experience into quantitative data and graded visualization layers based on the landscape visibility. By utilizing influencing factors like the visible area, landscape water system distribution and the number of landscape resources, a landscape visual evaluation indicator system is established. Finally, by integrating the analytic hierarchy process with the visibility analysis optimization algorithm, an improved landscape visual evaluation method is proposed. In the case study conducted in Fenghuang Town, a graded display map (Figure 4) and chromatic map (Figure 5) of the landscape visual experience for the observation points show that the visibility analysis optimization algorithm not only can calculate the visible area but can also quantitatively analyze tourists' visual experience. The error analysis graph (Figure 15) indicates that compared to traditional evaluation methods based on tourists' subjective perception or expert scoring, the proposed method that quantitatively evaluates the landscape visual experience from an objective perspective can directly reflect tourists' actual visual experience effects, with evaluation results featuring higher accuracy, reliability, objectivity and scientificity.

This method has great potential to develop into a relatively mature, more automated and scalable software tool in the future. It can not only assist in site selection and planning for sightseeing platforms but also support landscape planning and conservation in scenic areas. Regions with high landscape visual evaluation scores are considered to have a higher visual quality and should be included in protected area list. For regions with lower scores, planners can scientifically transform the landscape structure without damaging the environment to increase diversity, improve visual quality and attract more tourists.

Of course, there are still some deficiencies in the research that need to be improved: many factors affect the landscape visual evaluation results, such as the landscape quality, weather factors and specific tourist-related factors. Therefore, the next plan is to establish a more comprehensive indicator system to quantitatively evaluate landscape visuals.

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