

Assessing the Aesthetic Quality of Waterfront Spaces in Tourist-Oriented Villages Using Scenic Beauty Estimation

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Abstract: Scenic Beauty Estimation (SBE) is a widely applied psychophysical method for quantifying landscape aesthetic quality based on public visual preferences. Rural waterfront landscapes serve important ecological, social, and economic functions, and their visual quality plays a critical role in shaping visitor experience and community well-being. This study evaluates the aesthetic quality of waterfront spaces in Jiangxin Island, Zhenjiang, using a combination of field surveys and photographic documentation. Different respondent groups were invited to assess landscape scenes, and key influencing factors were identified through expert-based screening. Correlation and multiple regression analyses were conducted to develop a quantitative evaluation model. The results show that scenic beauty scores are significantly higher in well-developed areas, such as Orange Island, and lower in relatively undeveloped agricultural zones. Five factors were identified as having significant effects on scenic beauty: plant species diversity, waterfront morphology, rationality of vegetation configuration, landscape coordination, and types of spatial elements. The developed regression model provides a robust tool for evaluating and optimizing waterfront landscape quality, offering practical support for planning, management, and tourism-oriented development of rural waterfront environments.

Keywords: Rural Waterfront; Landscape Evaluation; SBE; Jiangxin Island, Zhenjiang City;

1. Introduction

Rural waterfront spaces are important components of rural landscapes, contributing significantly to daily life, agricultural production, and cultural identity in rural communities [9,25]. With rapid urbanization and increasing public expectations for living environments, aesthetic quality has become a key concern in environmental planning [24,17]. High-quality landscapes extend beyond visual appeal, providing economic, social, and ecological benefits. They support regional economic development, promote sustainable tourism, and improve residents' quality of life. These functions are particularly evident in rural landscapes, especially in suburban areas, where they deliver diverse ecosystem services and help alleviate the pressures associated with urbanization [24,29]. As Shen et al. demonstrated in Zhenjiang, plant species diversity provides measurable ecosystem services beyond aesthetic value [19].

In China, the implementation of the national Rural Revitalization Strategy has promoted substantial improvements in rural economic development, environmental conditions, and infrastructure [16]. However,

environmental governance capacity in many rural areas remains insufficient, and the aesthetic quality of rural landscapes has received relatively limited research attention[16,29]. This research gap highlights the need for systematic evaluation of rural waterfront spaces, which inherently involve multiple dimensions, including rural industry, economic development, ecological processes, and social well-being[9,8]. Recent studies on Jiangxin Island and riverside greenways have assessed landscape performance and user perception differences, yet neither quantified scenic beauty drivers in rural waterfronts using a predictive mode[13,14].

The Scenic Beauty Estimation (SBE) method, developed by Daniel and Boster (1976), is a widely recognized psychophysical approach for quantifying public preferences for scenic beauty[5,11]. It has been extensively applied in various contexts, including landscape assessment, public preference evaluation, and environmental planning[2]. In a typical SBE study, respondents evaluate visual representations of landscapes, enabling researchers to quantify perceived scenic beauty. The reliability and validity of the SBE method are grounded in its foundation on public perception, which has been consistently demonstrated to provide a robust and objective measure of aesthetic quality[6].

The SBE method has been widely applied to a variety of landscape types, with evaluation factors adapted to specific environmental contexts. For example, studies on forest landscapes have identified tree density, understory openness, and visibility as key determinants of scenic beauty[4,7,18]. In agricultural settings, factors such as architectural characteristics, water quality, and farmland texture have been shown to influence visual preferences [27,28]. In addition, the method has been successfully applied to agroforestry systems[10], roadside vegetation [1], and rural landscapes more broadly[26,23]. These studies indicate that while the SBE method provides a robust and flexible framework, the selection of evaluation factors should be tailored to the specific characteristics of different landscape types.

In waterfront contexts, SBE-based research has progressed along two main directions. Methodologically, studies have integrated SBE with techniques such as eye-tracking to explore observers' cognitive processes and aesthetic responses[13]. From an application perspective, researchers have developed conceptual frameworks incorporating ecological, structural, and visual indicators for waterfront landscape assessment[3]. In addition, studies have examined the relationship between visual quality and landscape character in waterfront linear parks [7], analyzed the influence of river scale on aesthetic quality[12], and investigated the coupling of spatial, psychological, and behavioral dimensions in landscape evaluation[15]. However, several critical gaps remain. First, existing studies often lack a systematic typological framework that captures the diversity of waterfront spaces (e.g., rivers, ponds, canals, and wetlands) in rural contexts, resulting in findings with limited specificity and applicability. Second, more targeted analyses are needed to isolate and quantify the influence of key natural and biophysical factors, moving beyond general aesthetic evaluations to identify specific attributes that drive scenic beauty.

Addressing these gaps is of considerable practical significance. Developing a tailored evaluation model for diverse rural waterfront spaces can provide a scientific basis for targeted planning and management interventions, thereby enhancing rural tourism attractiveness, supporting local economic development, and promoting environmental improvement. To achieve this, the present study aims to: (1) identify and characterize the key natural and biophysical factors influencing scenic beauty in rural waterfront environments; (2) evaluate the aesthetic quality of different types of rural waterfront spaces and develop a quantitative evaluation model; and (3) propose evidence-based optimization strategies to support landscape planning and management.

2. Materials and methods

2.1 Study area

The study area, Jiangxin Island, is a river island located in the Yangtze River within Dantu District, Zhenjiang, China (**Figure 1**). The island is situated approximately 1–3 km from the riverbanks and is characterized by

predominantly flat terrain with a dense network of waterways. A “Y”-shaped river system, together with numerous ponds and wetlands, forms diverse waterfront spaces that define the island’s rural landscape. These water resources play an important role in supporting local livelihoods, including agriculture, daily activities, and tourism. The area has developed agro-tourism based on its agricultural production, integrating activities such as fruit picking, sightseeing, and recreation. The combination of rural landscape features and accessible waterfront environments makes Jiangxin Island a representative case for studying rural waterfront spaces.

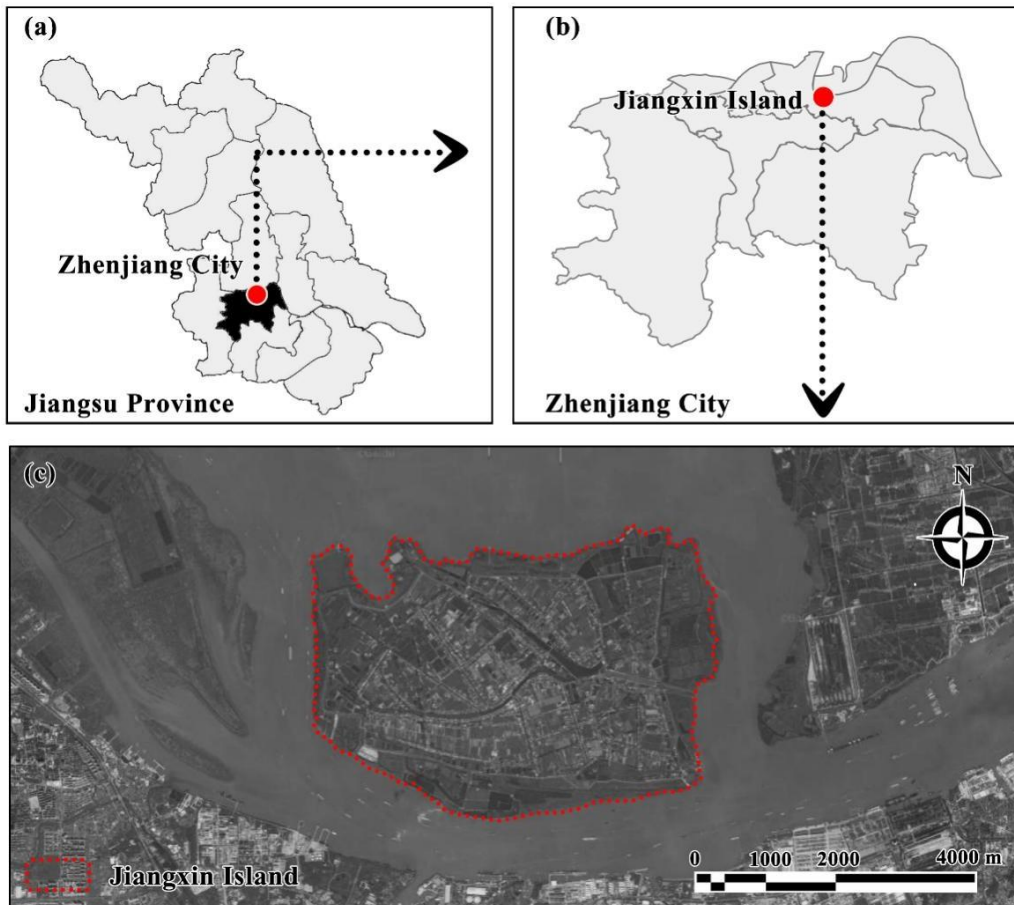


Figure 1. Study area of Jiangxin Island

2.2 Methodology

This study follows a structured framework consisting of four sequential phases: classification of waterfront space types, aesthetic evaluation using the SBE method, analysis of influencing factors based on the Semantic Differential (SD) method, and model development through statistical analysis. Specifically, waterfront spaces were first classified into distinct typologies according to their functional and morphological characteristics. The aesthetic quality of each type was then quantitatively evaluated using SBE based on public perception. Subsequently, the key influencing factors were analyzed using the SD method. Finally, correlation and multiple regression analyses were conducted to identify significant predictors and to develop an evaluation model for scenic beauty.

The overall research workflow is illustrated in **Figure 2**, and the detailed procedures for each phase are described in the following subsections.

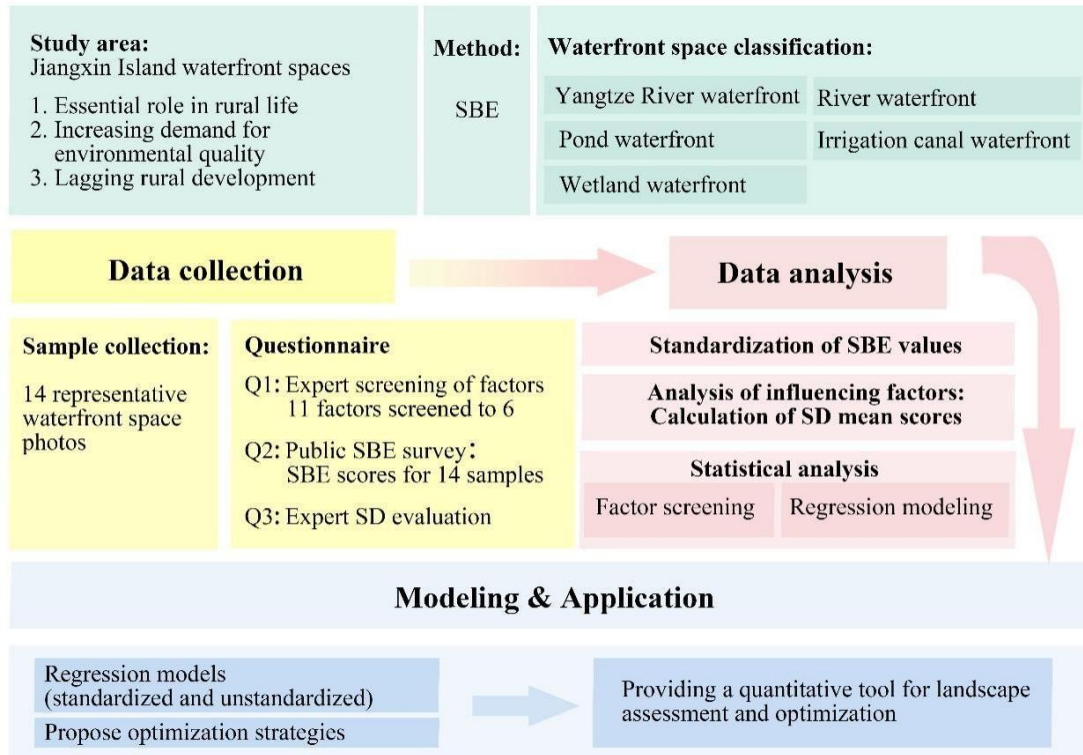


Figure 2. Research framework and methodological workflow of the study

2.2.1 Questionnaire design and distribution

This study employed three structured questionnaires to collect data from different respondent groups, incorporating both expert knowledge and public perception. This multi-group approach leverages the complementary strengths of each group: experts provide analytical evaluations of landscape attributes, while the public reflects holistic aesthetic preferences. The integration of these perspectives enables the development of a comprehensive and reliable evaluation system. Our distinction between resident and tourist perceptions follows Li et al., who reported significant evaluation gaps between these two user groups[13].

Questionnaire 1 (Expert screening of factors): This questionnaire was distributed to 50 experts in environmental design, landscape architecture, and urban planning. Its purpose was to identify and screen the key visual evaluation factors for waterfront spaces, ensuring a scientifically grounded selection of variables. Experts were asked to assess the relative importance of pre-defined factors.

Questionnaire 2 (Public Scenic Beauty Assessment using SBE): This questionnaire was designed to evaluate the scenic beauty of waterfront spaces on Jiangxin Island using the SBE method. It was distributed to 152 respondents, including both professionals and non-professionals, to capture diverse perceptions. Respondents were asked to rate the overall perceived scenic beauty of each landscape photograph. After removing 16 invalid responses, 136 valid questionnaires were retained, resulting in an effective response rate of 89%.

Questionnaire 3 (Expert SD evaluation of factors): This questionnaire was administered to another group of 50 experts. Using the SD method, respondents evaluated the presence and degree of the selected factors in each landscape sample. This provided quantitative assessments of landscape attributes (independent variables), which were later correlated with public scenic beauty scores.

2.2.2 Waterfront space classification

Waterfront spaces in Jiangxin Island were classified to facilitate a comprehensive understanding of the study area and to provide a basis for targeted landscape optimization. The classification was based on two key criteria: the socio-functional role of the water body and its physical spatial scale. Accordingly, five types were identified: the Yangtze River waterfront, river waterfront, pond waterfront, irrigation canal waterfront, and wetland waterfront

(Figure 3).

The first criterion, socio-functional role, refers to the primary functions of the water body within the rural community, including both domestic and productive uses. Domestic functions involve daily activities and leisure, such as washing, recreation, and visual enjoyment, while productive functions relate to agricultural and economic activities, including irrigation, aquaculture, and transportation. These functional differences influence patterns of human activity, infrastructure, and management practices, thereby shaping the visual characteristics of waterfront spaces.

The second criterion, physical spatial scale, considers the size and form of the water body, such as large rivers, linear canals, and small ponds. Spatial scale influences visual openness, ecological processes, and the ways in which people interact with the landscape.

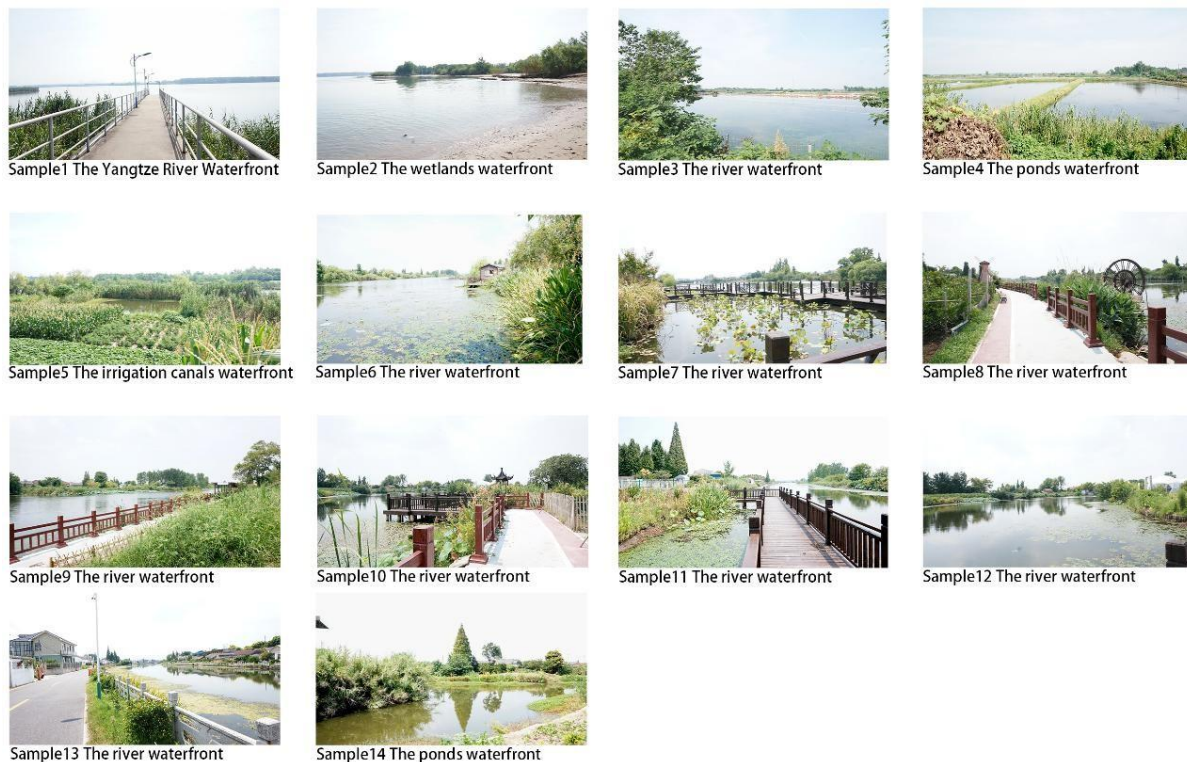


Figure 3. The 14 landscape samples of Jiangxin Island used for evaluation

Applying this dual-criteria framework to Jiangxin Island resulted in the identification of five distinct waterfront types. The Yangtze River waterfront represents a large-scale space characterized by composite ecological, transport, and scenic functions. River waterfronts (tributaries) are typically medium-scale corridors with mixed domestic and productive roles. Pond waterfronts are small-scale, intimate spaces that integrate daily activities with aquaculture. Irrigation canal waterfronts are characterized by their linear form and primary agricultural function. Wetland waterfronts vary in scale and are dominated by ecological and aesthetic functions.

This classification system establishes a structured framework for subsequent scenic beauty evaluation. By linking physical landscape characteristics with patterns of human use, it enables a more systematic analysis of aesthetic preferences and supports the development of differentiated optimization strategies for different waterfront types.

2.2.3 Image acquisition and factor quantification

To ensure that the photographs accurately represented on-site conditions and to minimize the influence of environmental variability (e.g., weather and lighting), a standardized image acquisition protocol was implemented. All landscape samples were photographed in August under consistent natural lighting conditions between 9:00 and

16:30, without the use of flash. Photographs were taken at a height of 1.5 m, corresponding to the average human eye level. A consistent horizontal shooting angle was maintained across all samples, and non-landscape elements (e.g., people, vehicles, and animals) were excluded from the frame. All images were captured using the same camera and by the same photographer (**Figure 3**).

Based on the aesthetic characteristics and natural attributes of rural waterfront spaces, an initial set of 11 potential factors influencing scenic beauty was identified for subsequent screening. These included vegetation-related factors (plant species diversity, color richness, and vertical layering), water-related attributes (water surface cleanliness and waterfront morphology), and spatial characteristics such as hydrophilicity, rationality of vegetation configuration, residential architecture, spatial rhythm, landscape coordination, and types of spatial elements.

Following the screening process, six key factors were retained for quantitative analysis. The SD method was employed to assess the presence and intensity of these factors within each landscape sample. A total of 50 undergraduate and graduate students from relevant disciplines participated as evaluators. They rated each factor for all 14 landscape samples using a Likert scale. The mean score for each factor across all evaluators was calculated for each sample. These values, referred to as SD scores, represent the quantified landscape attributes and were used as independent variables in subsequent correlation and regression analyses.

2.2.4 Expert-based factor screening

Following the identification of the preliminary evaluation factors, a questionnaire survey was conducted among 50 experts in environmental design and landscape architecture. The experts were asked to assess the influence of each factor based on their professional judgment. Ratings were collected using a 5-point Likert scale, where 1 indicated “very low impact” and 5 indicated “very high impact.”

The mean score of each factor (\bar{x}_j) was computed to evaluate the level of agreement among experts. Factors with higher mean scores and lower variance values were considered more important and consistent, and were therefore retained for further analysis:

$$\bar{x}_j = \frac{\sum_{i=1}^n x_{ij}}{n} \tag{1}$$

The variance reflects the degree of agreement among experts regarding each evaluation factor.

$$s_j^2 = \frac{\sum_{i=1}^n (x_{ij} - \bar{x}_j)^2}{n-1} \tag{2}$$

x_{ij} is the influence of the j th factor, s_j^2 is the variance of the j th factor score. x_{ij} is the rating of the j th factor by the i th expert, n is a number of experts.

Factors with a variance greater than 1 were considered indicative of substantial disagreement among experts and were excluded. Factors with a mean score greater than 3 (the midpoint of the 5-point scale) were regarded as having a significant influence on scenic beauty and were retained. This two-step screening ensured that the selected factors were both influential and consistent.

To mitigate variability in scoring caused by differences in rater stringency (i.e., some evaluators being more critical and others more lenient), the raw scenic beauty scores from Questionnaire 2 were standardized. This transformation converts subjective ratings into normalized values, enabling meaningful comparison and aggregation. The standardization was performed as follows:

$$z_j = \frac{x_j - \bar{x}_j}{s_j} \tag{3}$$

where x_{ij} is the standardized score given by the i -th respondent to the j -th landscape sample, x_{ij} is the original rating, \bar{x}_i is the mean rating of the i -th respondent across all samples, and s_i is the standard deviation of that respondent's ratings.

The standardized scores were then averaged across all respondents to obtain the scenic beauty score (SBE value, S) for each landscape sample:

$$S = \frac{\sum_{i=1}^n x_{ij}}{n} \tag{4}$$

where n denotes the total number of respondents. This transformation removes individual rating biases and produces comparable scenic beauty scores for subsequent statistical analysis.

3. Results

3.1 Selection of impact factors

The results of expert scoring for the influencing factors of scenic beauty are presented in **Table 1**. The variance of each factor reflects the level of consensus among experts. As shown in Table 1, the variance values range from 0.596 to 1.173.

Factors such as “plant color richness,” “water surface cleanliness,” “waterfront hydrophilicity,” “waterfront residential architecture,” and “spatial rhythm” exhibited variance values greater than 1, indicating substantial disagreement among experts regarding their influence. These factors were therefore excluded to improve the reliability and consistency of the selected variables. For the remaining factors, the relatively low variance values indicate a high level of agreement among experts, supporting their inclusion in subsequent analysis.

In addition, based on the 5-point Likert scale used in this study, factors with a mean score greater than 3 were considered to have a significant influence on scenic beauty. This threshold is commonly used to distinguish between factors with limited influence (≤ 3) and those with substantial influence (> 3).

Based on these two criteria—high consensus (low variance) and a mean score above 3—six key factors were identified: plant species diversity, plant layer richness, waterfront morphology, rationality of waterfront vegetation configuration, landscape coordination, and types of spatial elements.

Table 1. Expert scoring results for impact factor screening

No.	Aesthetics Evaluation Factor	degree of influence	Variance ²
1	Plant species diversity	3.970	0.734
2	Plant color richness	3.680	1.160
3	Plant layer richness	3.970	0.911
4	Water surface cleanliness	4.320	1.101
5	Waterfront morphology	3.740	0.665
6	Waterfront space hydrophilicity	3.940	1.173
7	Rationality of vegetation configuration	4.290	0.678
8	Waterfront residential architecture	3.150	1.243
9	Spatial rhythm	3.650	1.228
10	Landscape coordination	4.000	0.882
11	Types of spatial elements	3.850	0.596

3.2 Evaluation results of scenic beauty

A total of 152 questionnaires were distributed, of which 136 were considered valid after excluding 16 invalid responses, resulting in an effective response rate of 89%.

As presented in **Table 2**, the SBE values of the 14 waterfront landscape samples are evenly distributed, with seven samples having positive values and seven having negative values. The samples, ranked in descending order of SBE values, are as follows: Sample 7 > Sample 8 > Sample 10 > Sample 9 > Sample 11 > Sample 6 > Sample 3 > Sample 12 > Sample 1 > Sample 14 > Sample 13 > Sample 4 > Sample 2 > Sample 5.

A clear distinction can be observed between samples with positive and negative SBE values. Samples with higher SBE scores generally indicate a higher level of aesthetic preference, whereas samples with lower or negative values indicate relatively lower aesthetic evaluations.

Table 2. SBE values of the 14 waterfront landscape samples

No.	SBE value	Waterfront type	No.	SBE value	Waterfront type
1	-0.280	Yangtze River waterfront	8	0.620	River waterfront
2	-0.590	Wetland waterfront	9	0.400	River waterfront
3	0.120	Pond waterfront	10	0.450	River waterfront
4	-0.380	Pond waterfront	11	0.320	River waterfront
5	-0.660	Irrigation canal waterfront	12	-0.230	River waterfront
6	0.290	River waterfront	13	-0.350	River waterfront
7	0.630	River waterfront	14	-0.340	Pond waterfront

To explore potential perceptual differences among respondent groups, a preliminary analysis was conducted based on available demographic variables. Using the raw beauty scores (1–5 scale) from Questionnaire 2, ratings from local residents (living or studying in Zhenjiang, n = 61) and non-local visitors (n = 91) were compared. Residents rated the irrigation canal waterfront (Sample 5) slightly higher (mean = 2.07) than visitors (mean = 1.92), whereas visitors assigned higher scores to the developed Orange Island area (Sample 7) (mean = 3.21) compared to residents (mean = 3.02). Similar differences were observed across other landscape types. In contrast, comparisons between professionals (n = 51) and non-professionals (n = 101) showed no substantial differences (e.g., Sample 7: 3.18 vs. 3.12). Given the limited sample size for subgroup analysis, these findings should be considered preliminary.

Table 3. Mean raw scenic beauty scores of selected samples by respondent group

Sample type	Sample No.	Residents (n = 61)	Visitors (n = 91)
Irrigation canal waterfront	5	2.070	1.920
Wetland waterfront	2	2.300	2.180
River (developed, Orange Island)	7	3.020	3.210
River (typical)	10	2.980	3.110

3.3 Analysis of the Influence of Evaluation Factors

The SD scores of all factors for each sample are presented in **Table 4**. The influencing factors were coded as follows: X1: plant species diversity, X2: plant layer richness, X3: waterfront morphology, X4: rationality of vegetation configuration, X5: landscape coordination, and X6: types of spatial elements. To examine the relationship between SD scores and scenic beauty, the samples were grouped based on their SBE rankings (Section 3.2). Differences in SD scores were observed between high-ranking samples (e.g., Nos. 7, 8, and 10) and low-ranking samples (e.g., Nos. 2, 4, and 5).

Higher-ranked samples generally exhibited SD scores above the overall mean in key factors such as waterfront morphology (X3), rationality of vegetation configuration (X4), landscape coordination (X5), and types

of spatial elements (X6). In contrast, lower-ranked samples tended to show SD scores below the overall mean in factors including plant species diversity (X1), vegetation configuration (X4), landscape coordination (X5), and types of spatial elements (X6). These results indicate that variations in these factors are associated with differences in scenic beauty evaluations.

Table 4. Mean SD scores of evaluation factors for each sample

No.	X1	X2	X3	X4	X5	X6
1	2.660	2.660	2.940	2.710	2.890	2.860
2	2.830	2.970	3.260	2.800	2.660	2.540
3	3.140	3.200	2.940	3.000	3.260	3.000
4	3.230	2.970	3.140	3.110	2.830	3.030
5	3.400	3.600	3.030	2.970	3.030	2.770
6	3.800	3.740	3.430	3.510	3.600	3.490
7	3.690	3.430	3.600	3.430	3.340	3.510
8	3.630	3.510	3.290	3.310	3.600	3.400
9	3.630	3.510	3.090	3.510	3.260	3.260
10	3.600	3.630	3.430	3.710	3.690	3.800
11	3.740	3.660	3.340	3.600	3.630	3.490
12	3.490	3.230	3.260	3.260	3.290	3.280
13	2.860	2.890	2.970	2.970	3.110	3.090
14	3.910	3.690	3.310	3.460	3.600	3.200
average value	3.400	3.340	3.220	3.240	3.270	3.190

4. Discussion

4.1 Correlation between scenic beauty and landscape factors

Prior to developing the evaluation model, a correlation analysis was conducted between the SBE values and the six influencing factors to identify variables for subsequent regression analysis. The results are presented in **Table 5**. A factor was considered significantly correlated with scenic beauty when the p-value was less than 0.05.

As shown in Table 5, plant layer richness (X2) was the only factor with a p-value greater than 0.05, indicating that it was not significantly correlated with scenic beauty. In contrast, the remaining five factors—plant species diversity (X1), waterfront morphology (X3), rationality of vegetation configuration (X4), landscape coordination (X5), and types of spatial elements (X6)—all exhibited statistically significant positive correlations with SBE values, as indicated by p-values below 0.05 and positive Pearson correlation coefficients. The significance of plant diversity (X₁) and waterfront morphology (X₃) in our model aligns with the ecosystem service findings of Shen et al. and the spatial comfort study of Song et al., both conducted in Zhenjiang [19,20].

Table 5. Pearson correlation results SBE and evaluation factors

Impact factor	r	p-value (two-tailed)	Significance
X1 Plant species diversity	0.562	0.036	Significant
X2 Plant layer richness	0.492	0.074	Not significant
X3 Waterfront morphology	0.543	0.045	Significant
X4 Rationality of vegetation configuration	0.706	0.005	Significant
X5 Landscape coordination	0.707	0.005	Significant
X6 Types of spatial elements	0.816	0.000	Significant

4.2 Multiple Linear Regression Modeling of Scenic Beauty

This section aims to quantify the influence of evaluation factors on scenic beauty and to develop a predictive model using regression analysis. The modeling process was conducted in two steps. First, univariate linear regression analyses were performed to evaluate the relationship between each individual factor (X₁–X₆) and the

SBE values. Subsequently, the significant factors were incorporated into a multiple linear regression model to construct a comprehensive predictive framework. The results of the univariate regression analyses are presented in **Table 6**.

Table 6. Results of univariate linear regression analyses for SBE values

Independent Variable	B	Std. Error	Beta	t	p	R ²
X ₁	0.641	0.272	0.562	2.356	0.036*	0.316
X ₃	1.199	0.535	0.543	2.238	0.045*	0.295
X ₄	1.013	0.294	0.706	3.449	0.005**	0.498
X ₅	0.960	0.277	0.707	3.461	0.005**	0.499
X ₆	1.086	0.222	0.816	4.887	0.000**	0.666

Note: X₁ = plant species diversity; X₃ = waterfront morphology; X₄ = rationality of vegetation configuration; X₅ = landscape coordination; X₆ = types of spatial elements.

* $p < 0.05$, ** $p < 0.01$.

The analysis indicated that five factors (X₁, X₃, X₄, X₅, and X₆), excluding X₂ due to its non-significant correlation, were significantly associated with scenic beauty ($p < 0.05$). Among these, X₆ (types of spatial elements) exhibited the strongest explanatory power ($R^2 = 0.666$).

Scenic beauty is typically influenced by the combined effects of multiple factors. Therefore, a multiple linear regression analysis was conducted using the five significant variables (X₁, X₃, X₄, X₅, and X₆) as independent variables and the SBE value as the dependent variable, in order to develop a comprehensive predictive model and evaluate the relative contribution of each factor.

The results show that the overall regression model is highly significant ($F(5, 8) = 17.215$, $p < 0.001$). The adjusted R^2 value is 0.874, indicating that the model explains 87.4% of the variance in scenic beauty and demonstrates a high level of goodness of fit. The variance inflation factor (VIF) values for all variables are below 3, suggesting that multicollinearity is not a concern. The detailed regression coefficients are presented in **Table 7**.

Table 7. Results of multiple linear regression analysis for SBE values

Variable	B	Std. Error	Beta	t	p	VIF
Constant	-3.726	0.698		-5.338	0.001**	
X ₁	0.192	0.184	0.168	1.044	0.327	1.892
X ₃	0.450	0.321	0.204	1.403	0.199	1.543
X ₄	0.359	0.264	0.250	1.361	0.211	2.135
X ₅	0.273	0.237	0.201	1.152	0.283	1.985
X ₆	0.707	0.241	0.531	2.934	0.018*	1.732

**Note:* * $p < 0.05$, ** $p < 0.01$. *Dependent variable: SBE value. $R^2 = 0.915$, Adjusted $R^2 = 0.874$.*

When controlling for other variables, X₆ (types of spatial elements) emerged as the most influential factor, as it was the only variable that remained statistically significant ($p = 0.018$) in the multivariate model and exhibited the largest standardized coefficient (Beta = 0.531). This indicates that variation in spatial element diversity is strongly associated with differences in scenic beauty under multivariate conditions.

The p-values for the other four factors (X₁, X₃, X₄, and X₅) were greater than 0.05, suggesting that their independent effects were not statistically significant when controlling for other variables. This may reflect overlapping influences among predictors or potential interactions between variables. Despite their lack of statistical significance in the multivariate model, these factors were retained based on their theoretical relevance and their significance in univariate analyses, thereby contributing to a more comprehensive evaluation framework.

4.3 Model Establishment, Validation and Discussion

The scenic beauty evaluation model for waterfront spaces in Jiangxin Island was developed based on the results of the regression analysis. To reflect the data processing workflow and provide a quantitative reference for prediction, the model is presented in two equivalent forms.

4.3.1 The Multiple Regression Model

Based on the multiple regression results, the final predictive model for the scenic beauty of Jiangxin Island's waterfront spaces is established using the unstandardized coefficients. The model is expressed as:

$$B = -3.726 + 0.192X_1 + 0.450X_3 + 0.359X_4 + 0.273X_5 + 0.707X_6 \quad (9)$$

where B represents the predicted scenic beauty estimation value, and X_1 , X_3 , X_4 , X_5 , and X_6 denote the mean scores (on a 1–5 scale) of the corresponding evaluation factors.

This model provides a quantitative approach for estimating scenic beauty. By inputting the mean scores of the relevant factors for a given waterfront space, the corresponding SBE value can be calculated.

4.3.2 Model validation

To evaluate the generalizability of the model and reduce the risk of overfitting, a leave-one-out cross-validation (LOOCV) approach was applied. This method is particularly suitable for small sample sizes ($n = 14$), as it maximizes the use of available data by training the model on $n - 1$ samples and testing it on the remaining sample.

The procedure generated 14 models. In each iteration, one sample was excluded, the model was calibrated using the remaining 13 samples, and the excluded sample was predicted. This process resulted in 14 predicted SBE values, each obtained from a model that did not include the corresponding observation during training.

The predicted values showed a strong and statistically significant correlation with the observed SBE values ($r = 0.927$, $p < 0.001$). The root mean square error (RMSE) was 0.152, indicating a relatively high level of predictive accuracy given that SBE values are standardized scores.

These results suggest that the model has good predictive performance within the study context, although further validation with larger datasets is needed to confirm its broader applicability.

4.3.3 Implications for landscape design and cultural interpretation

The model results suggest that the scenic beauty of rural waterfront spaces is shaped by the combined influence of multiple landscape characteristics. Among these, types of spatial elements (X_6) appear to be the most influential factor, as indicated by its significance in the multivariate model. This finding implies that introducing diverse spatial elements—such as viewing platforms, walkways, and resting areas—may enhance the perceived attractiveness of waterfront spaces. In addition, waterfront morphology (X_3) and the rationality of vegetation configuration (X_4) show relatively strong associations with scenic beauty, indicating their potential importance in shaping overall landscape quality. Although plant species diversity (X_1) and landscape coordination (X_5) were not statistically significant in the multivariate model, they remain important components of landscape aesthetics and may contribute to scenic beauty through combined or context-dependent effects.

While this study quantitatively identifies key biophysical factors influencing scenic beauty, aesthetic perception is also shaped by cultural context. The higher SBE scores observed in developed areas, such as Orange Island, may reflect not only the quality of landscape design but also visitors' expectations of an accessible and curated rural environment. In contrast, lower scores in undeveloped agricultural areas may indicate a perceptual gap between functional landscapes and aesthetic expectations.

These findings suggest that the interpretation of landscape features may vary depending on users' cultural backgrounds and experiential contexts. Future research incorporating qualitative approaches could further explore how local traditions, visitor perceptions, and landscape use patterns interact with the biophysical factors identified in this study.

5. Conclusion

This study applied the SBE method to evaluate the aesthetic quality of rural waterfront spaces in Jiangxin Island. By integrating expert screening, SD-based factor assessment, and regression modeling, a quantitative framework was established to analyze the relationship between landscape characteristics and scenic beauty.

The results indicate that scenic beauty is associated with multiple landscape factors, including types of spatial elements (X_6), rationality of vegetation configuration (X_4), landscape coordination (X_5), waterfront morphology (X_3), and plant species diversity (X_1). Among these, types of spatial elements (X_6) showed the strongest and statistically significant effect in the multivariate model, suggesting its prominent role in shaping perceived aesthetic quality. Other factors, although not statistically significant in the multivariate context, may contribute to scenic beauty through combined or context-dependent effects.

The developed regression model demonstrates good predictive performance within the study context (Adjusted $R^2 = 0.874$; LOOCV $r = 0.927$), indicating its potential as a quantitative reference for evaluating and comparing the scenic quality of similar rural waterfront spaces.

In addition, the findings highlight that scenic beauty is not solely determined by biophysical characteristics but may also be influenced by cultural perceptions and user expectations. This suggests that the interpretation of landscape features can vary depending on experiential and socio-cultural contexts, which should be considered in future research and practice.

Overall, this study contributes a data-driven approach to understanding and evaluating rural waterfront aesthetics, providing a foundation for evidence-based landscape planning and management. By focusing on key influencing factors, the proposed framework may support more informed decision-making in the development and enhancement of rural waterfront environments.

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