

Fuzzy AHP Method for Comprehensive Valuation of Sustainable Urban River Landscapes in Baxi Bay

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Abstract

The evaluation of urban river landscapes faces the challenge of minimizing subjective bias while integrating ecological, social, and visual factors. This study developed an evaluation model combining the Analytic Hierarchy Process (AHP) and the Fuzzy Comprehensive Evaluation method, and applied it to the Baxi Bay River in Yong'an City, Fujian Province. An evaluation system comprising 12 indicators across ecological, aesthetic, and social dimensions was established. The weights of each indicator were determined using AHP, and the membership scores for the Baxiwan River landscape were calculated using FCE. The results indicate that ecological factors dominate (63.34%), surpassing landscape aesthetics (26.05%) and social factors (10.61%). Among the indicator layers, river flow had the highest individual weight (0.38). Overall, the Baxiwan River received a landscape score of 70.6, corresponding to Grade 3 (moderate). Specifically, aesthetic factors averaged 67.34 points (Grade 2), ecological factors scored 70.5 points (Grade 3), and social factors scored 72.23 points (Grade 3). The recreational function received the highest score (85.9), while historical and cultural characteristics received the lowest score (58.5). The AHP-FCE model provides a systematic quantitative method for evaluating urban river landscapes, offering a theoretical basis and decision support for enhancing ecological functions and cultural integration.

Keywords

AHP, fuzzy comprehensive evaluation, urban landscape evaluation, sustainable urban river management

1. Introduction

Urban river landscapes serve as critical ecological corridors, shaping the city's image and environment through visual, ecological, and social functions [1, 2]. They mitigate green space fragmentation, regulate microclimates, and reduce surface runoff and soil erosion [3, 4]. Existing evaluation methods—AHP, aesthetic scoring, fuzzy logic, entropy methods, and backpropagation neural networks—often struggle to objectively integrate multidimensional factors and to address cultural indicators [5, 6]. There remains a significant research gap in balancing quantitative ecological data with qualitative social and aesthetic judgments.

To address these shortcomings, this study combines AHP with FCE. This hybrid method systematically evaluates urban river landscapes from ecological, landscape, and social dimensions, accounting for uncertainty while reducing subjective bias. The objectives of this study are: (1) To construct a comprehensive evaluation model based on AHP and FCE; (2) To apply this model to the Baxiwan River in

Yong'an City; (3) And to provide theoretical and decision-making support for sustainable urban river management and design optimization.

2. Research Hypotheses

The Baxi wan River is located in Yong'an City, Fujian Province (25°58' N, 117°22' E) and serves as a hub for local commercial, recreational, and residential activities. The region has a subtropical monsoon climate with an average annual precipitation of approximately 1,700 mm. Seasonal rainfall significantly influences river flow.

The Baxiwan River is 47 kilometers long, flows through Jiulong Creek, and empties into the Shaxi River. It has a watershed area of 505 square kilometers, a width of 30–60 meters, and an average gradient of 1/500. According to the Strahler River Classification System, this river is classified as a third-order river. Concrete revetments and submerged weirs line the riverbanks, and mixed-use developments—including residential, educational, and commercial areas—are distributed on the adjacent land. Recreational walkways have been installed along certain sections of the river, facilitating pedestrian access and scenic viewing.

This site was selected for its typical combination of urban pressures and ecological functions, serving as a representative case study for evaluating sustainable river landscape management in developing cities.

Figure 1: Location of the Baxi Bay River in Yong'an City (Source: Author, 2025)

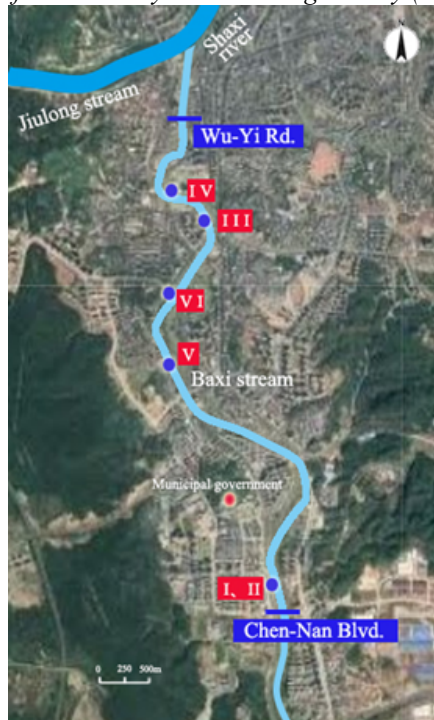


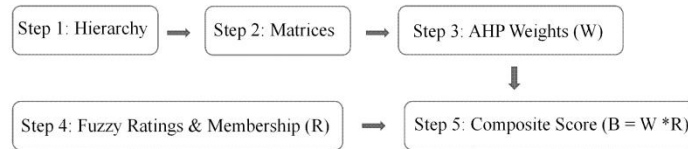
Figure 2: Current view of Baxi Bay, showing the urban-river interface, bank protection structures, and vegetation conditions (Source: Author, 2025)



3. Research Design

This study employs the AHP-FCE integrated method to evaluate urban river landscapes, combining structured weighting with fuzzy logic to address qualitative and uncertain indicators [7]. This method was chosen because it integrates expert judgment with quantitative data, thereby avoiding the need for the large training datasets required by machine learning models [8].

Figure 3: AHP-FCE evaluation flowchart (Source: Author, 2025)



3.1 Development of the Evaluation Indicator System

The evaluation system consists of three layers: objectives, criteria, and indicators. Based on prior research [9], 12 indicators were selected across ecological, landscape, and social dimensions. These indicators reflect key aspects of sustainability: ecological resilience, aesthetic harmony, and sociocultural functions [10].

Table 1: Evaluation Indicator System for Urban River Landscapes

Target Layer	Criteria Layer	Indicator Layer	Evaluation Factors
River Landscape Evaluation System	Landscape Factor B1	Harmony of Water Color B ₁₁	The color of the water body is natural and harmonizes with the surrounding environment.
		Species Richness B ₁₂	Species richness, the ecological complexity of all species, and their composition of animals and microorganisms.
		Types and Materials of River Dams B ₁₃	The form and color of artificial structures spanning the river Overall River.
		Greenery Coverage B ₁₄	Green plant coverage along the river channel and riparian areas.
		Riverbank Protection Forms and Materials B ₁₅	Bank protection should be gentle and harmonious, with colors that blend with the overall environment.
	Ecological Factors B2	Watercourse B ₂₁	Smooth riverbed, material exchange and energy flow among species.
		Water Quality B ₂₂	High water quality standards that support biodiversity.
		Community Stability B ₂₃	The distribution of species and individuals within the context of stable, coordinated interspecies development.
	Social Factors B3	Safety Factors B ₃₁	Comprehensive, safe, and reliable facilities to ensure the safety of river users.
		Management and Maintenance B ₃₂	River channel management and maintenance, including public facilities and natural vegetation.
		Recreational and Leisure Functions B ₃₃	Provides recreational and entertainment functions, increasing space for activities.
		History and Culture B ₃₄	Presenting the cultural significance and philosophical concepts of the river through landscape design.

3.2 Expert Survey and Weight Calculation (AHP)

Ten experts with over ten years of experience in landscape design, ecological management, or urban planning were selected. They completed pairwise comparisons via an online questionnaire. To ensure the reliability of the judgments, the consistency ratio (CR) was calculated [11]; all CR values were below 0.1. The data was processed using SPSSPRO software to derive the weights for the criteria and indicator levels. The results are summarized in Table 2.

Table 2: Weights and Consistency Ratios for the Criteria and Indicator Levels Derived from AHP

Hierarchy	Code/Item	Weight (%)	CR
Criteria Level	Aesthetic Factors (B ₁)	26.05	0.037
	Ecological Factors (B ₂)	63.34	
	Social factors (B ₃)	10.61	
Indicator Level	Water Color Harmony (B ₁₁)	4.24	0.075
	Species Richness (B ₁₂)	5.25	
	Dam Shape and Materials (B ₁₃)	1.94	
	Green View Ratio (B ₁₄)	11.31	
	Bank Protection Models and Materials (B ₁₅)	3.31	
	River Channel Freeness (B ₂₁)	38.00	0.00
	Water Quality (B ₂₂)	12.67	
	Community Stability (B ₂₃)	12.67	
	Safety Factor (B ₃₁)	5.36	0.086
	Management and Maintenance (B ₃₂)	1.79	
	Leisure and Recreation (B ₃₃)	2.92	
	History and Humanities (B ₃₄)	0.55	

Ecological factors were assigned the highest weight (63.34%), followed by landscape factors (26.05%) and social factors (10.61%). Among the various indicators, river channel accessibility had the highest weight (38.00%), highlighting its fundamental role. Green space coverage (11.31%), water quality (12.67%), and community stability (12.67%) also received high scores, reflecting the experts' emphasis on habitat and visual environment. The lower weights assigned to cultural and management indicators suggest that these are considered secondary factors in the current expert assessment.

3.3 Fuzzy Comprehensive Evaluation Process

3.3.1 Construction of the Fuzzy Evaluation Matrix

This study focuses on river landscapes and employs the Analytic Hierarchy Process (AHP) to analyze and evaluate urban river landscapes. First, the AHP is used to calculate the composite weights of each indicator. Then, based on the scores of each indicator, the fuzzy evaluation method is used to determine the membership degree (M) of the river landscape. M is calculated as the sum of the average scores of each indicator multiplied by the composite weight of each indicator level. Fuzzy logic is used to process qualitative and uncertain indicators, converting expert ratings into membership degrees. Four quality grades are defined:

- Grade I (81–100): Excellent
- Grade II (71–80): Good
- Grade III (60–70): Average
- Grade IV (≤ 60): Poor

Indicators are grouped according to their measurability (direct, indirect, or difficult to quantify). Membership degrees are assigned based on expert ratings, thereby forming the fuzzy evaluation matrix R.

3.3.2 Comprehensive Evaluation Calculation

This study focuses on river landscapes and employs the Analytic Hierarchy Process (AHP) to analyze and evaluate urban river landscapes. First, the AHP is used to calculate the composite weights of each indicator. By multiplying matrix R by the AHP weight vector W, a fuzzy evaluation vector is derived. The composite score is obtained using the weighted average method. Then, based on the scores of each indicator, the fuzzy evaluation method is used to determine the membership degree (M) of the river landscape.

The calculation of M involves multiplying the average score of each indicator by the sum of the composite weights of each indicator's level, and then converting the score into a quality grade based on preset levels. The final grade reflects the overall condition of the river and identifies areas requiring improvement.

4. Results

A total of 17 valid questionnaires were analyzed (response rate: 85%). The overall fuzzy score was 70.6, corresponding to Grade III (Moderate). The ecological factor scored 70.5 (Grade III), the aesthetic factor scored 67.3 (Grade II), and the social factor scored 72.2 (Grade III). The recreational factor scored the highest (85.9), while the historical and cultural characteristics scored the lowest (58.5).

The results indicate that the river landscape is of moderate quality, with strengths in recreation and ecology but deficiencies in cultural expression and visual harmony. The dominance of ecological weighting aligns with the global trend of prioritizing ecological health in river assessments. However, the low scores and low weighting of cultural indicators suggest gaps in the integration of heritage and identity—a common issue in urban river management [12]. Visual and ornamental qualities also received moderate scores, indicating that there is still room for design improvements to enhance public engagement and aesthetic value.

The findings highlight the necessity of balancing ecological, visual, and cultural dimensions. Management strategies should integrate cultural elements into ecological design to foster a sense of community belonging and responsibility. An overemphasis on ecological or recreational functions without cultural integration risks reducing rivers to mere recreational facilities rather than meaningful socio-ecological spaces [13].

5. Conclusion

Based on the AHP-based fuzzy comprehensive evaluation of urban river landscapes, the Ba Xi Wan river landscape achieved an average score of 67.34 for aesthetic factors, with an affiliation grade of II and a score of 17.11; an average score of 70.5 for ecological factors, with an affiliation grade of III and a score of 45.48; the social factors had an average score of 72.23 points, with a membership grade of III and a score of 7.91 points. The ecological factors had an average score of 70.5 points, with a membership grade of III and a score of 45.48 points; the social factors had an average score of 72.23 points, with a membership grade of III and a score of 7.91 points. This study applied the AHP-fuzzy comprehensive evaluation model to assess the landscape of the Baxiwan River in Yong'an City, yielding a composite score of 70.6 points (Grade III, moderate). These results indicate that the Baxiwan River largely meets expert requirements in terms of ecological and aesthetic factors, but its performance regarding social factors still needs improvement. The evaluation at the criterion level shows that ecological factors received the highest score (70.5 points, Level III) and had the greatest weight (63.34%); the evaluation results confirm the experts' high regard for ecological functions (criterion-level weight of 63.34%, with the highest indicator-level weight of 0.38 for river flow). At the same time, specific strengths and weaknesses were revealed: recreational and entertainment functions performed best (B33, 85.9 points), while historical and cultural characteristics (B34, 58.5 points) and water color harmony (B11, 68.5 points) were the main shortcomings. Aesthetic factors scored 67.34 points (Grade II); social factors scored 72.23 points (Grade III), but had the lowest weight (10.61%).

This study applied the AHP-FCE model to evaluate the landscape of the Bazhu Bay River, with results indicating an overall quality rating of moderate (70.6). Ecological factors dominated the assessment, while cultural indicators received the lowest scores. This model provides a structured, quantitative tool for the comprehensive evaluation of river landscapes, supporting sustainable urban river management that integrates ecological resilience, visual quality, and cultural identity.

6. Limitations and Future Research

The limitations of this study include its focus on a single case, a small sample size of experts, and reliance on subjective judgments. Future research should incorporate public perception surveys, field validation, and applications to diverse river systems to enhance the study's generalizability and robustness.

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Conflicts of Interest

The authors declare no conflict of interest.

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