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Landscape Assessment for Stream Regulation Works in a Watershed Using the Analytic Network Process (ANP)

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Abstract: There is varied natural landscape in Taiwan. Erosion and sediment control engineering used to be a major strategy for watershed management and planning but ecological conservation in natural environments and industrial development, as well as the development of a sustainable watershed, have become priorities. This study established the factors that are used for landscape assessment for stream regulation works and their weights using a questionnaire survey of experts with different professional backgrounds in order to determine a method to assess the landscape. The factors, "texture and form", "color", and "ecology" were used to assess scenic beauty. The analytic hierarchy process (AHP) and the analytic network process (ANP) were used initially and an expert questionnaire was used to determine the criteria and weights for landscape assessment for watershed stream regulation works. The questionnaire results showed that "integration with natural environment" was the most important factor for the assessment of landscape aesthetics for watershed stream regulation works, followed by "availability of greening and vegetation space". To preserve scenic beauty after watershed stream regulation works, an expert landscape assessment was undertaken beforehand. This study established a means to integrate the design of engineering structures with the natural landscape. Landscape assessments, strategies for architecture, and landscape design were combined to give an aesthetic solution for soil and water conservation engineering in Taiwan.

Keywords: landscape assessment; stream regulation works; analytic hierarchy process; analytic network process

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1. Introduction

With varied natural landscapes and mountain and forest resources, the management of middle and upstream watersheds in Taiwan generally focuses on the protection of forests and water sources. This increases ecological diversity and reduces psychological stress. However, weak geology and concentrated rainfall result in frequent sediment hazards. To protect the lives and property of residents in the middle and downstream regions and to ensure the safety of infrastructure, various engineering structures that protect soil and conserve water must be established in proper locations on slopes [1], thus ensuring good watershed management. The establishment of these structures often changes the natural landscape and affects the original ecological and psychological functions. The balance between engineering safety and natural landscape is one of the important topics of soil and water conservation projects.

Landscape is a term that describes all visual, physical, aesthetic and spatial characteristics in an environment [2]. It describes natural ecology, human culture, and aesthetics, which change depending on the observers and the time. Hydroscape describes the aesthetic design of a hydrological landscape based on a current texture analysis and an analysis of the physics and mechanics of structures.

The understanding of flow expression and the texture that is generated by the physical factors are analyzed [3]. Flow expression means various water landscapes that could reflect different textures of streaming water. For instance, in the upstream, the large stream slope is likely to result in spatters with falling water so that the more complex texture of the water surface is presented. In comparison with research on stream ecology and the visual assessment of a river [4,5], there is little research concerning the effect of artificial structures on landscape aesthetics. Most studies focus on the assessment of the visual aesthetics of natural torrents [6–8].

Using the classification method of previous studies [9,10], landscape assessment has four categories: Psychophysical, cognitive, empirical assessment and expert assessment. These pertain to the beauty of the landscape, and involve more specific descriptions and analyses of the physical features of the environment. This is the most common method that is used for environment planning or engineering design. Many studies [11–15] use multi-objective decision methods for scenic quality in various fields. Landscape aesthetics should be a topic of concern. However, aesthetic consideration is not given to these types of engineering structures, so there is often visual inconsistency within the landscape when planning soil and water conservation projects in Taiwan. As engineering technology has matured, the aesthetic considerations of stream engineering structures will be a new challenge for designers including engineers, ecologists, landscape architects, architects, etc.

The main objective of this study was to develop a method for the landscape assessment of stream regulation works in a watershed by means of the analytic network process (ANP). Using an expert questionnaire survey, the principles related to the aesthetics for the design of dams and stream channels by past studies [16–18] were applied to set up the visual preferences for natural and artificial landscapes. Using a visual scale as the analysis scale, independent factors such as "texture and form", "color", and "ecology" were used as the elements of the visual characteristics of a watershed. Dependent factors such as simplicity, rhythm, and harmony were used as the factors for the visual perception of engineering structures and of the environmental background in order to determine the design process and the principles that would allow the assessment of scenic beauty for watershed stream regulation works. The results were also compared with the scenic beauty estimation method (SBE) based on other psychological aspects of landscape assessment [19–21]. The validation of the proposed method by comparing with SBE was the secondary aim of this study.

2. Material and Methods

Because the beauty of a landscape is a concept of abstraction, only qualitative research is used in early stages. Daniel and Boster [19] developed the scenic beauty estimation method (SBE), which is the result of quality analysis of landscape beauty. The SBE method is a psychophysiological experimental method for assessing the beauty of forest landscapes. The concept is derived from the behavioral psychology of the stimulus and response model, and improved according to the signal detection method and the Thurston-scaling models. It took the evaluators' perceived scenic aesthetics allocations to represent the viewers' preference for a landscape or for beauty [20,21].

This study used the analytic hierarchy process (AHP) and the analytic network process (ANP) to determine the weights of the factors for landscape designs of watershed stream regulation works. The purpose was to establish an expert landscape assessment method and compare it with the results of traditional assessment methods such as the SBE. The entire research process is shown in Figure 1.

The ANP is an extension of the AHP and adds feedback to the AHP to predict the precise internal relationship between criteria, goals, and programs, using ratio scales. It is also used to optimize decision making [22]. Furthermore, the ANP is used to determine the correlation between landscape design criteria for watershed stream regulation works and to determine the important factors in these criteria and the sequencing of weights. The results of this analysis were used to establish a landscape assessment process for stream regulation works. The AHP and the ANP are explained in the following.

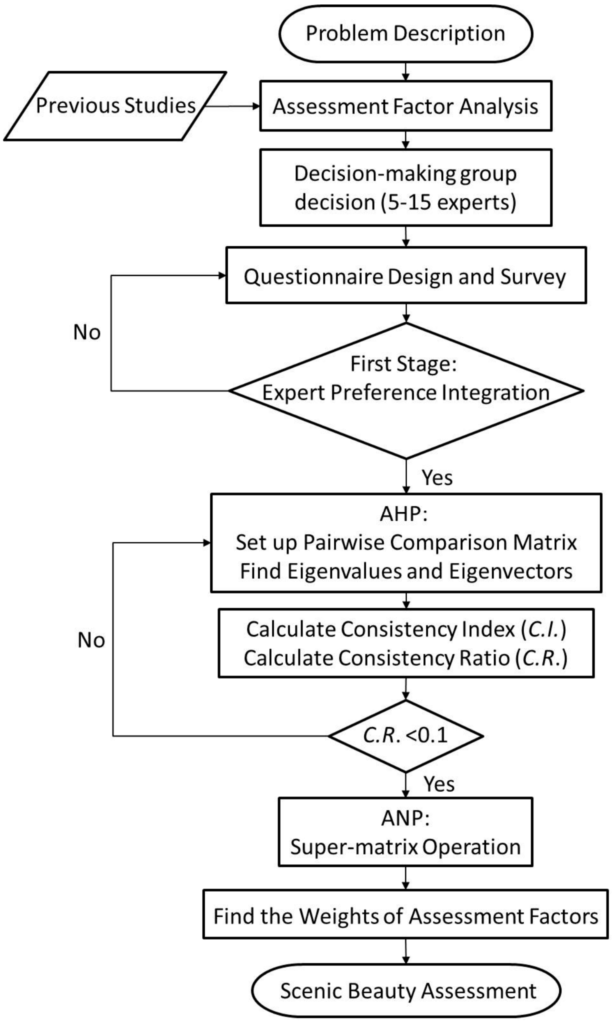

Figure 1. Research flow chart.

2.1. Design of the Expert Questionnaire

The expert questionnaire was designed by referencing the assessment factors from previous studies [16,17]. It was used to determine the criteria for the assessment of scenic beauty in watershed stream regulation works. The hierarchical structure of the assessment factors is shown in Table 1.

Table 1. Hierarchical structure of assessment factors for scenic beauty in watershed stream regulation works.

Hierarchy I: Goal	Hierarchy II: Assessment Item	Hierarchy III: Factor
Scenic beauty assessment of stream regulation works in watershed	A. Texture and form	A-1 Lamination A-2 Symmetry and balance A-3 Integration with natural environment A-4 Hydrophilic accessibility
	B. Color	B-1 Hue B-2 Value B-3 Chroma
	C. Ecology	C-1 Biodiversity C-2 Availability of greening and vegetation space C-3 Minimization of engineering structure C-4 Reducing volume vision with vegetation

For Hierarchy III, the factors are explained as follows:

A-1 Lamination: Texture characteristics of the engineering structure.

A-2 Symmetry and balance: Symmetry refers to the presence of the same visual forms on both sides of the axis, while balance involves the presence of different forms on both sides of the axis, but conforms to the harmony of the modeling force field. It pertains to complete symmetry, partial symmetry and partial balance, partial symmetry and partial randomness, partial balance and partial randomness, partial symmetry with partial balance and partial randomness, and complete asymmetry and imbalance (randomness).

A-3 Integration with the natural environment: When the contours of a structure compliment a skyline, the integration of the environment precludes a symmetrical structure. The similarity or balance between structural contours and the skyline is classified as extremely integrated, integrated, moderate, incongruous, or extremely incongruous.

A-4 Hydrophilic accessibility: The available hydrophilic space in the engineering design.

B-1 Hue: Blue, green, yellow, red, and purple represent forest hues: 5 G, 7.5 R, 10 G, and 7.5 B; grassland hues: 2.5 GY, 5 R, 7.5 G, and 5 B; and sand land hues: 2.5 GY, 10 G, 10 R, and 10 B.

B-2 Value: Ranging from 0 to 10 (black: 0, white: 10, standard gray: 5). Forest values, 7.5–8.5; grassland values, 7–8; and sand land values, 7.5–9.

B-3 Chroma: Ranging from 0 to 20 (the value is proportional to the vividness). Different levels appear in various hues: Forest chroma, 2–4; grassland chroma, 1–4; and sand land chroma, 1–4.

C-1 Biodiversity: Biodiversity (or biological diversity), also called the species diversity index, is the degree to which life is changed. It can refer to the genetic change, species change, or ecosystem change in a region, biome, or planet.

C-2 Availability of greening and vegetation space: "Greening" is interpreted as landscape that improves the patterns of cement or concrete in the environment to increase perceived comfort.

C-3 Minimization of the design of Engineering Structures: Following natural engineering, design and construction use minimal engineering structures in terms of size and the minimum amount of materials to achieve the maximum ecological function and effectiveness. Revetments, check dams, submerged dams, and groundsill works for stream disaster control effectively reduce the impact of construction on the environment and reduce damage to natural ecology.

C-4 Reducing volume vision with vegetation: The proportions of the vegetation and the structures.

2.2. Analytic Hierarchy Process

The AHP is a decision-making method that was developed by Saaty [23,24] and is mainly used to simplify complicated decision-making problems for uncertain situations using several assessment criteria. It is also used to determine priority, as a planning resource, for allocation, for prediction, and for investment portfolios. The AHP uses clear and simple theories and can accommodate several experts' and decision makers' opinions, so it is widely used in academia and in practical applications [12,25–28].

In terms of the operation of the AHP, firstly the problem is described to determine the factors and to establish the hierarchy. Using a paired comparison, the relative importance of decision-making attributes in various hierarchies is determined using ratio scales. In order to obtain the relative importance of factors, they are paired for comparison. A paired questionnaire as shown in Table 2 could be designed according to the assessment factors in Table 1. When there are n criteria, $n(n-1)/2$ times pair comparisons are required in Table 1.

Two factors are paired to compare their advantages and to establish a paired comparison matrix. The paired comparison matrix is then established and the eigenvalue and eigenvector are calculated to obtain the weights of the attributes. For the relative weight among factors, the eigenvalue solution in numerical analyses could be utilized for the maximum eigenvalue and the corresponding eigenvector.

This study used MATLAB for calculation, which is suitable for the vector matrix algorithm. The window interface programming codes were self-developed, the functions built in MATLAB were used for direct calculation of the eigenvalue and eigenvector, and the maximum eigenvalue and the corresponding eigenvector were regarded as the weight of the evaluated factor. By calculating the eigenvalue and eigenvector for the matrix, the weights of the attributes and programs were acquired. Finally, the program sequencing was obtained using a comprehensive evaluation.

Table 2. Questionnaire example of pair comparison in AHP.

	More Important on the Left					More Important on the Right				
	Absolutely important	Extremely important	Quite important	Slightly important	Equally important	Slightly important	Quite important	Extremely important	Absolutely important	
	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	
A. Texture and form										B. Color
A. Texture and form										C. Ecology
B. Color										C. Ecology

2.3. Analytic Network Process

The ANP is a decision-making method that is useful for a non-independent "hierarchical structure" and was proposed by Saaty [22] using the principles of the AHP. Saaty includes dependent relationships and the feedback effect (including the interaction and feedback effects within clusters and between clusters) in the ANP. Therefore, the ANP adds feedback to the AHP and uses a super matrix to calculate the effect of mutual dependency. The dependency relationship in the ANP is close to human thinking and changes an originally standardized hierarchical structure into an amoeba-like complex network that describes a problem's characteristics.

The ANP is a multi-goal decision-making method that is used in economics, sociology, and management science to give decision makers a deep understanding of issues in specific situations where there are several evaluation factors to complicate the decision-making process [29–32]. The ANP involves five steps: (a) Forming the structure of the problem; (b) questionnaire design; (c) an eigenvector W and consistency test; (d) a test of the hierarchy consistency ratio; and (e) the use of a supermatrix and estimation of the weights of indicators.

For the AHP, each hierarchy has clusters/components as nodes, which have various elements whose weights are calculated using a matrix operation. The ANP divides the system's elements into two parts. The first part is a control factor layer, including goals and decision-making criteria. All decision-making criteria are regarded as independent and as being dominated by goal elements. It is not necessary to consider decision-making criteria for control factors, but at least one goal is required. The weight of each criterion in the control layer is acquired using the AHP. The second part is a network layer, which is composed of all elements that are dominated by the control layer. The interior contains mutually affected network structures. It is composed of all elements that are dominated by the control layer. These elements are mutually dependent and dominated and there is internal independence between elements and layers. Each criterion in the hierarchical structure does not dominate only an internally independent element, but also a mutually dependent network structure with feedback.

The ANP involves a mutual function called a supermatrix which is used to obtain the mixed weight, where C_i ($i = 1 \ldots m$) is a cluster and n elements in cluster i are denoted as $e_{i1}, e_{i2}, \ldots, e_{in}$, W_{ij} is the vector matrix wherein j is affected by i, and the row vector of W_{ij} is the eigenvector of the matrix in which the factors in C_i have a factor in C_j as the sub-criterion for comparison. The initial super matrix is denoted as $\mathbf{W}'$ [33].

$$
\mathbf{W}' = \begin{array}{cc} & \\ & \\ C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \vdots \\ C_m & \begin{array}{c} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{array} \end{array}
\begin{array}{c}
\begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_{11}e_{12}\cdots e_{1n_1} & e_{21}e_{22}\cdots e_{2n_2} & \cdots & e_{m1}e_{m2}\cdots e_{mn_m} \end{array} \\
\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{bmatrix}
\end{array}, \quad (1)
$$

The entire ANP calculation process uses three supermatrices: An initial supermatrix, a weighted supermatrix, and a limiting global supermatrix. In the initial supermatrix, also named the un-weighted supermatrix, the row value might not conform to the row random principle, i.e., the row sum may not be 1. Using a row sum that is not 1 to evaluate the criteria matrix and the relative importance weight, the weighted supermatrix is acquired. The limiting global supermatrix involves multiplying the weighted supermatrix by itself to give a convergent dependency relationship until the relative weight between elements is obtained.

Super Decisions is powerful decision-making software mainly used to analyze related research of the ANP. Super Decisions has good compatibility with Microsoft operating systems. It not only has interactive dialog boxes and graphical presentation methods, but also can output the results to Excel for subsequent analysis. This study employed Super Decisions for the supermatrix calculation of the ANP.

3. Results and Discussions

3.1. Expert Questionnaire Survey Results

The questionnaire survey in this study had two stages: To determine the relationship between factors and to assess scenic beauty for watershed stream regulation works. The first stage confirmed the importance sequence for the assessment factors for "research on scenic beauty assessment for watershed stream regulation works." The evaluation used levels 0–10, where a higher score represented a greater degree of importance. The results could become the reference for expert evaluations in the second stage. In the second stage, the experts compared the relative importance of the paired factors for the comparison matrices in various hierarchies, see Tables 3–6. The second stage determined the relative importance of evaluation items in order to determine the hierarchical matrix for the AHP and the ANP. The purpose of the first stage was to provide the results in order to design the second stage of the questionnaire and to ensure the evaluations would more easily reach the demands of the consistency ratio.

A total of nine expert questionnaires were returned. The experts specialized in civil and hydraulic engineering, landscape, architecture, urban planning, community development, soil and water conservation, and environmental studies. All experts had more than 10 years of experience; three were serving in academic institutes, two in engineering consultancies, and one in the governmental sector. The remaining three were an architect, a soil and water conservation technician, and a hydraulic engineer. The results of the first stage of the expert questionnaire survey were used to design the second stage of the questionnaire. When evaluating the second stage, factors were paired in order to compare their relative importance for the comparison matrix in the hierarchy, see Tables 3–6.

To acquire the relative weight among the factors, the solution for a numerically analyzed eigenvalue could be applied, thus acquiring the maximum eigenvalue ($\lambda_{\max}$) of the comparison matrix and the corresponding eigenvector (Table 3). Saaty [23] considered the use of a consistency test on pairwise evaluation, which included the following steps:

(1) The Consistency Index (*C.I.*) is calculated

$$C.I. = \frac{\lambda_{\max} - n}{n-1}, \tag{2}$$

(2) The Consistency Ratio (*C.R.*) is calculated

$$C.R. = \frac{C.I.}{R.I.}, \tag{3}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the matrix, n is the matrix rank, and the random index (*R.I.*) is a randomly generated consistency index of a matrix and is related to the rank of the matrix. Saaty [23] regarded the comparison as randomly generated when *C.R.* approached 1 and the consistency as higher when *C.R.* approached 0. In general, $C.R. \leq 0.1$ was considered acceptable, while $C.R. > 0.1$ showed a level of inconsistency that meant they had to be re-compared.

The weights of the factors were calculated by multiplying the relative weights of the evaluation items in Hierarchy II, Table 3, with the relative weights of factors in Hierarchy III, Tables 4–6. The weights are shown in Table 7. Table 7 shows that "integration with natural environment" had the highest weight for "texture and form", "hue" had the highest weight for "color", and "biodiversity" had the highest weight for "ecology". The hierarchical analysis of the expert questionnaire was used to determine the major items for the assessment of scenic beauty for watershed stream regulation works, using the weights.

Table 3. Relative importance of evaluation items.

	A. Texture and form	**B. Color**	**C. Ecology**	**Weight** [1]
A. Texture and form	1	2.2998	0.3191	0.2456
B. Color	0.4348	1	0.2623	0.1320
C. Ecology	3.1339	3.8123	1	0.6224

[1] Maximum eigenvalue ($\lambda_{\max}$) = 3.0452; Consistency Index (*C.I.*) = 0.0226; Consistency Ratio (*C.R.*) = 0.039.

Table 4. Relative importance of factors in "A. Texture and form".

	A-1. Lamination	**A-2. Symmetry and Balance**	**A-3. Integration with Natural Environment**	**A-4. Hydrophilic Accessibility**	**Weight** [1]
A-1. Lamination	1	1.0909	0.3503	0.6984	0.1470
A-2. Symmetry and balance	0.9167	1	0.2130	0.8851	0.1293
A-3. Integration with natural environment	2.8549	4.6938	1	4.4410	0.5655
A-4. Hydrophilic accessibility	1.4319	1.1298	0.2252	1	0.1582

[1] Maximum eigenvalue ($\lambda_{\max}$) = 4.058; Consistency Index (*C.I.*) = 0.0193; Consistency Ratio (*C.R.*) = 0.0215.

Table 5. Relative importance of factors in "B. Color".

	B-1. Hue	**B-2. Value**	**B-3. Chroma**	**Weight** [1]
B-1. Hue	1	1.7395	1.6901	0.4478
B-2. Value	0.5749	1	2.7850	0.3657
B-3. Chroma	0.5917	0.3591	1	0.1865

[1] Maximum eigenvalue ($\lambda_{\max}$) = 3.1245; Consistency Index (*C.I.*) = 0.0622; Consistency Ratio (*C.R.*) = 0.1073.

Table 6. Relative importance of factors in "C. Ecology".

	C-1. Biodiversity	C-2. Availability of Greening and Vegetation Space	C-3. Engineering Structure Minimal Design	C-4. Reducing Volume Vision with Vegetation	Weight [1]
C-1. Biodiversity	1	4.9413	3.5870	4.4932	0.5826
C-2. Availability of greening and vegetation space	0.2024	1	0.7435	1.2915	0.1286
C-3. Engineering structure minimization design	0.2788	1.3450	1	2.1729	0.1851
C-4. Reducing volume vision with vegetation	0.2226	0.7743	0.4602	1	0.1038

[1] Maximum eigenvalue (λ_{max}) = 4.03; Consistency Index (*C.I.*) = 0.01; Consistency Ratio (*C.R.*) = 0.0111.

Table 7. Weights of factors evaluated using the AHP and the ANP.

Item	Assessment Factor	AHP Weight	ANP Weight
A. Texture and form	A-1 Lamination	3.61%	2.64%
	A-2 Symmetry and balance	3.17%	5.13%
	A-3 Integration with natural environment	13.89%	30.18%
	A-4 Hydrophilic accessibility	3.89%	2.20%
B. Color	B-1 Hue	5.91%	1.54%
	B-2 Value	4.83%	2.39%
	B-3 Chroma	2.46%	1.29%
C. Ecology	C-1 Biodiversity	36.26%	29.56%
	C-2 Availability of greening and vegetation space	8.00%	6.28%
	C-3 Minimization of engineering structure	11.52%	8.79%
	C-4 Reducing volume vision with vegetation	6.46%	10.01%

Super Decisions Software was used for the ANP calculation to produce an un-weighted supermatrix and a weighted supermatrix. These two matrices were multiplied to a convergent dependency relationship until the relative weight of each element was obtained. The correlation between the ANP assessment factors is shown in Figure 2 and the final results are listed in Table 7.

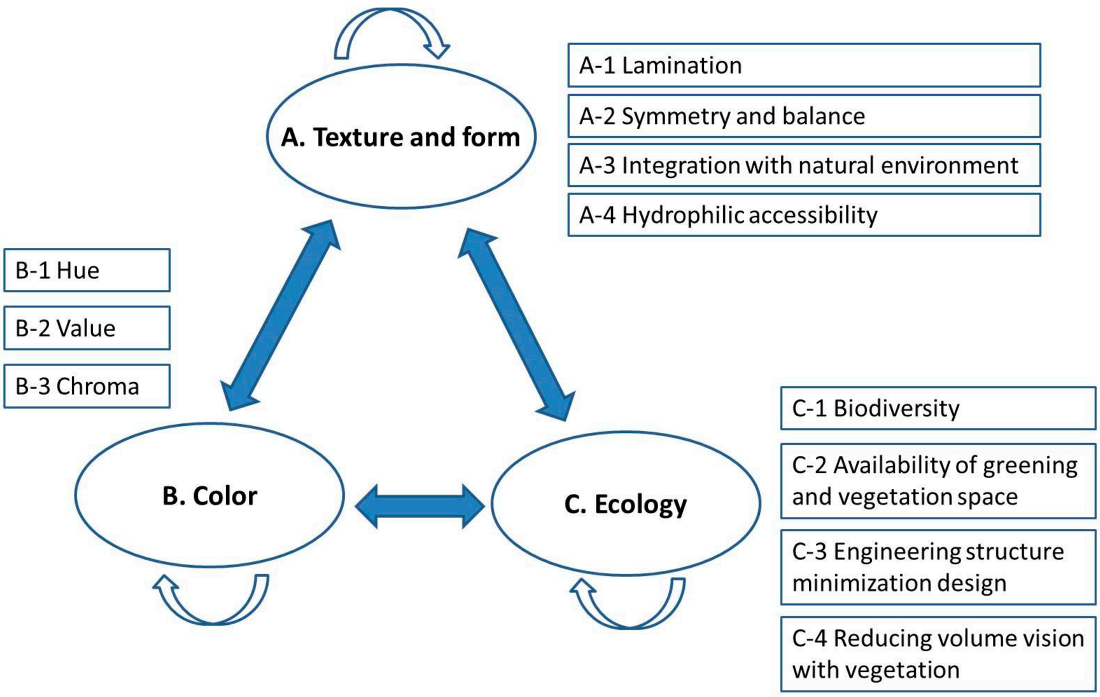

Figure 2. Mutual relationship between ANP factors.

3.2. Evaluation of Scenic Beauty for Watershed Stream Regulation Works

Eight scenarios (cases 1–8) related to soil and water conservation engineering in Taiwan were used for the evaluation. The evaluation used a scale of 1–3, where 1 represents low-quality scenic beauty and 3 represents high-quality scenic beauty. The evaluators were standardized using different evaluation criteria to identify possible differences due to distinct evaluation benchmarks. This was used to measure the experts' relative perceived preference for different landscapes.

The assessment table included an intangible resource value in the quantitative evaluation. This combined psychology and statistics and used experts' "perceived preference" for a distinct landscape to reflect viewers' perceived preference for a landscape and the listed landscape factors. The value was established using the ANP weights. The assessment results showed the positive and negative effects of factors on users, which were used to decide on strategies for future watershed stream control, as shown in Table 8. The evaluation standard in Table 8 was used to determine the proportion of structure material, color, and greening and vegetation. The eight soil and water conservation engineering-related pictures were then assessed and the results are shown in Table 9.

Peng and Han [21] used the preferred psychophysical landscape assessment model (SBE) that was proposed by Daniel and Boster [19]. The eight cases in Table 9 are compared with the results of the SBE. One hundred and fifty-six students from Chienkuo Technology University participated in the evaluation. Slides were rapidly browsed before a formal assessment was given to establish an evaluation standard. During the formal evaluation, each slide was shown for 16 s and the evaluation was scored from 0 (extremely dislike) to 9 (extremely like). The data for the evaluation were then converted into scenic beauty estimates (SBEs) using RMRATE software [34,35] from the United States Department of Agriculture (USDA). The SBEs for the eight cases in this study are listed in Table 9 and compared with previous results.

Since the two evaluation methods have distinct standards, the sequencing of the evaluation results was compared (Figure 3). The x-axis of Figure 3 shows the sequencing of weights acquired from the ANP expert questionnaire and based on the evaluation standards in Table 8. The y-axis shows the sequencing for the 156 college students' assessment results in terms of SBEs. The results for the two evaluation methods were close, except for cases 4 and 8. It is interesting that cases 4 and 8 involved regularly and repeatedly arranged artificial structures, which did not obtain better evaluations for ecology in the ANP expert evaluation. However, they did not receive bad assessments in terms of the simple visual assessment of beauty. In other words, ecology did not seem to be as important in the instant impression. Repeated, symmetrical, or regular arrangements were comparatively acceptable. This also conforms to the principle of design aesthetics.

If cases 4 and 8 are removed for re-sequencing (Figure 4), the two assessment methods give consistent results. In principle, the ecological detention pond in case 5, the ecological revetment in case 1, and the groundsill works in case 7 had a varied waterscape, a small volume structure that is harmonious with the environment and conformed to the aesthetic principle of the structure integrating with the environment. The integration of the structure with nature scored better in terms of an aesthetic evaluation. Although the structural form of the groundsill works in case 7 appeared ordinary, according to general aesthetic principles, and there was little planting, a sufficient water flow meant that water was the focal landscape and the rich flow expression largely enhanced the overall scenic beauty [3]. This demonstrates that the scenic beauty of a riverbank with a medium flow is greater than it is with a low flow [36]. An ANP expert evaluation considers ecology without a questionnaire survey and analysis, so it is a practicable landscape assessment method.

Table 8. Evaluation of an assessment of scenic beauty for watershed stream regulation works.

Sub-Item	Particular	Evaluation Criteria
A. Texture and form	A-1. Lamination: Texture characteristics on engineering structure	Natural materials close to local landscape are selected for structure (3 points) Textures similar to natural materials are used for structure (2 points) Material of artificial structure is inconsistent with environment (1 point)
	A-2. Symmetry and balance: Same forms on both sides of axis	Same visual shapes on both sides of axis (3 points) Different shapes on both sides of axis, but conforming to the harmony of modeling force field (2 points) Different shapes on both sides of axis (1 point)
	A-3. Integration with natural environment: Structure contour corresponding to the graceful skyline and the visual effect of high integration with environment being able to reduce the monotone of symmetric structure	Very similar outline for structure and skyline (3 points) Similar outline for structure and skyline (2 points) Little similarity between outlines of structure and skyline (1 point)
	A-4. Hydrophilic accessibility: Available hydrophilic space in the engineering design	Traffic flow reaches water and hydrophilic facilities are available or landscape is planned to provide space on both banks (3 points) Traffic flow does not reach water, but hydrophilic facilities are available or landscape is planned to provide space on both banks; or, traffic flow reaches water, but hydrophilic facilities are not available or landscape is not planned on both banks (2 points) Traffic flow does not reach water, and hydrophilic facilities are not available or landscape is not planned for the space on both banks (1 point)
B. Color	B-1. Hue: Blue, green, yellow, red, and purple as the representatives	Yellowish brown, green (3 points) Red and yellow (2 points) Other colors (1 point)
	B-2. Value: 0–10 (black is 0, white is 10, standard gray is 5)	Forest value 7.5–8.5 (3 points) Grassland value 7–8 (2 points) Sand land value 7.5–9 (1 point)
	B-3. Chroma: 0–20 (higher scores show more vividness)	Forest chroma 2–4 (3 points) Grassland chroma 1–4 (2 points) Sand land chroma 1–4 (1 point)

Table 8. *Cont.*

Sub-Item	Particular	Evaluation Criteria
C. Ecology	C-1. Biodiversity [1]: Also called species diversity index, the degree of life change	More than three plant species (3 points) Two plant species (2 points) Only one plant species or null (1 point)
	C-2. Availability of greening and vegetation space: To improve the patterns of cement or concrete in the environment to increase comfort	With broad space and using plants for environment greening (3 points) No broad space, but harmonious with original ecology (2 points) No broad space and over-artificial (1 point)
	C-3. Engineering structure minimization: Revetment, check dam, submerged dam, and groundsill works for stream disaster control could effectively reduce the impact of construction on environment and reduce damage to natural ecology	Green planting more than two-thirds of concrete area (3 points) Green planting more than one-third of concrete area but less than two-thirds (2 points) Mostly artificial and little natural ecology (1 point)
	C-4. Reducing volume vision with vegetation: Proportion of vegetation and structure	Flourishing planting to cover most structures (3 points) Planting to cover some structure (2 points) Little planting to cover structure (1 point)

[1] Biodiversity refers to species changes in a region or biome or ecological system changes. The pictures of the biome do not allow the type of plant in the picture to be identified.

Table 9. Scenic beauty assessment using expert questionnaire results.

Sub-Item	Particular	Weight	Case 1 	Case 2 	Case 3 	Case 4 	Case 5 	Case 6 	Case 7 	Case 8 
A. Texture and form	A-1	2.64%	3	1	2	1	3	2	2	2
	A-2	5.13%	2	1	2	2	2	1	2	3
	A-3	30.18%	2	1	1	2	3	1	1	1
	A-4	2.20%	3	1	2	2	3	1	2	2
B. Color	B-1	1.54%	3	3	3	1	3	1	3	1
	B-2	2.39%	1	1	3	1	2	1	3	1
	B-3	1.29%	1	1	3	1	2	1	3	1
C. Ecology	C-1	29.56%	3	1	3	3	3	2	3	1
	C-2	6.28%	3	2	2	3	3	2	2	1
	C-3	8.79%	3	3	3	3	3	2	2	2
	C-4	10.01%	1	3	1	1	1	1	2	1
Evaluation result [1]			76.14	46.75	65.15	73.89	87.31	47.87	65.56	39.94
Ranked by this study			2	7	5	3	1	6	4	8
SBE			127.36	−155.48	14.55	−73.81	164.71	−125.89	42.46	66
Ranked by SBE			2	8	5	6	1	7	4	3

[1] There are 11 evaluation items and the highest score for each item is 3 points. Each item is formalized and multiplied with the weight to convert to the full score of 100 points.

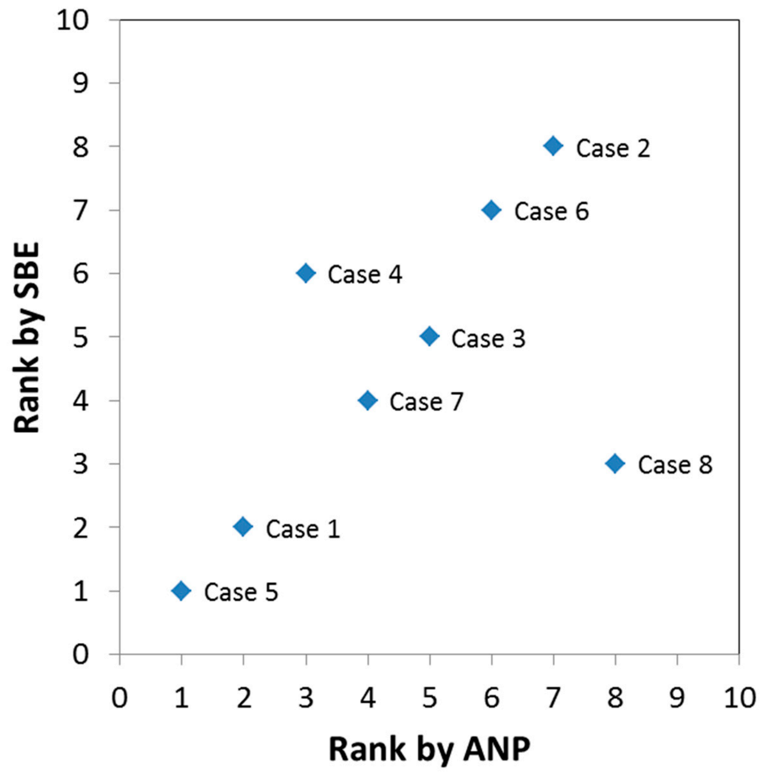

Figure 3. Comparison of the two evaluation methods.

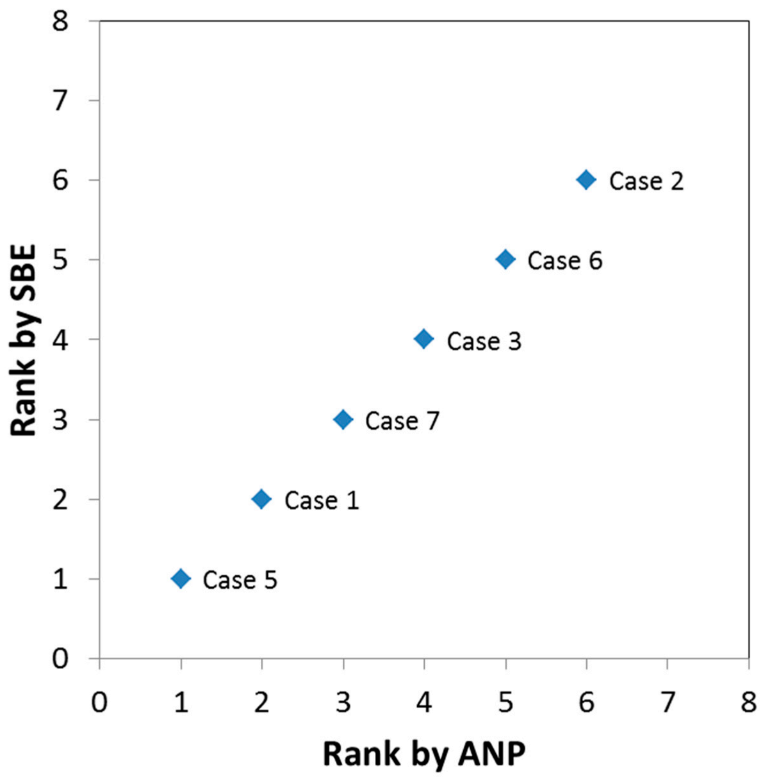

Figure 4. Comparison of the two evaluation methods when cases 4 and 8 are omitted.

4. Conclusions

This study used the design aesthetics principle of previous reports for an expert questionnaire survey. The scenic beauty of watershed stream regulation works was established using the results of a questionnaire. The questionnaire used the relationships between factors to assess the scenic beauty of watershed stream regulation works to establish a scientific and objective evaluation model that uses the weights of the assessment factors acquired from the expert questionnaire. Few studies had adopted this approach.

In this study, eight cases were used to assess the scenic beauty of watershed stream regulation works. The test results showed that the assessment method is reasonable and useful for planning and design recommendations. The method saves time spent on fieldwork because it uses pictures and a questionnaire evaluation so it is convenient and fast and requires few experts. However, the disadvantage of this method is that the photos cannot fully represent the actual landscape quality, and there is still doubt about whether the weights set by the experts are representative. If more experts from various fields set the weights for similar studies in the future, the judgment would be more objective.

In terms of future applications, this model uses multi-goal selection (AHP and ANP) to construct an assessment method that uses an expert model and is more applicable to planning and design than past landscape assessment methods such as the SBE method. Using 3D simulation or virtual reality with a questionnaire at the planning and design stage to assess the impact of various stream regulation works on the landscape could produce a more aesthetically pleasing solution without the need for trial and error.

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