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Study on Highway Landscape Environment Assessment and Grading Method

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Abstract: The assessment and grading of a highway landscape environment is the basic work of highway route layout and landscape planning, and it is also a key link to whether the highway can be integrated into the surrounding environment. This article analyzes the connotation and value standard system of highway landscape assessment and proposes a highway landscape environment assessment method that combines a quantitative assessment and a humanistic assessment. Consequently, a highway landscape environment assessment indicator system with landscape features, environmental harmony, visual environment and environmental carrying capacity as assessment contents is constructed. Finally, using the set-pair analysis method, an evaluation model for grading the quality of the highway landscape environment is proposed. The model divides the highway landscape environment into four grades and proposes highway landscape planning and design strategies under the conditions of different grades. The theory is applied in the landscape planning of the Xi'an-Baoji highway in China. The results show that the overall assessment of the total indicator is "Grade 2", the environmental carrying capacity of the subsystem is "weak", and the landscape quality is "good". This theoretical approach combines discursive cognition with quantitative analysis to achieve a systematic and refined assessment of the highway construction environment.

Keywords: highway; landscape environment; landscape grading; landscape assessment

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1. Introduction

A highway is a combination of the natural environment and artificial structures and is an essential carrier for realizing landscape design and environmental reconstruction. A good highway landscape environment assessment system can comprehensively evaluate the current situation of the regional landscape environment along the highway. Thus, it provides a reliable theoretical system for landscape planning and design and brings many positive effects to road users in terms of aesthetics and driving experience [1]. It has been proved that if a highway landscape environment assessment is not fully considered, it will not only cause damage to the ecological environment but also cause great traffic safety hazards. For example, there should be at least 15 m long ecological corridors between highway routes and both agricultural and residential areas. However, if this is not adequately considered during the environmental assessment of the highway landscape, the accumulation of heavy metals on the highway route may pose a risk to agricultural and residential areas [2]. Similarly, if the impact of vegetation on traffic safety is not fully considered in the assessment of a highway landscape environment, overly colorful shrubs could be chosen as the main body of anti-glare. Moreover, this will distract the driver's attention, affect driving safety and cause fatal traffic accidents.

From the practice of countries around the world, common methods for environmental assessment of highway landscapes are divided into three types.

- The objective environmental assessment method: taking the experience of experts as a base point while referring to relevant standards. The landscape object is used as the assessment object, such as the Scenic Resource Management System of the U.S. Bureau of Land Management and the Visual Pollution Assessment System of the Federal Highway Administration [3].
- The subjective psychological assessment method: value judgments are made by analyzing the psychology and behaviour of landscape subjects, such as the landscape aesthetic model of Shelley, an American environmental psychologist [4].
- The economic value assessment method: taking economic value as the benchmark, the landscape environment is quantitatively accounted for as economic value [5].

The landscape environment design of contemporary highways is gaining more and more attention. The ecological wetland compensation mechanism proposed in highway construction in the United States, the greening and comprehensive slope management measures of highways in Japan, and the landscape eco-environmental design of German highways, etc., all reflect the new concept of highway landscape design [6,7]. Theano analyzed the relationship between highway landscape construction and cultural factors along the highway, making culture a highlight of the highway [8]. Lars analyzed the problems between the natural environment and highway construction by taking New Zealand highway construction as an example and proposed the idea of using GIS to solve this contradiction [9]. Viles proposed a theoretical system of how to create green roads according to environmental characteristics by analyzing numerous highway landscape cases [5]. Way analyzed the aesthetics of vegetated landscapes on highways in northern England using questionnaires and interviews. The results showed that most people considered the most aesthetic vegetation combination to be the planting of flowers and grass on the side of the road with tall trees as a background in the distance [10]. Xiong proposed the concept of road aesthetics and used the principle of kinetic vision to study the highway green theory [11].

After a comprehensive analysis of domestic and foreign research, this article concludes that the existing research focuses on the protection of the highway landscape environment, plant greening and other aspects. However, there is a lack of research on systematic highway landscape environment assessment. Due to a lack of environmental assessment of the highway corridor zone, in engineering practice, it often occurs that simple greening is used instead of landscape design, or the design is based on the experience and subjective consciousness of designers. It can be seen that the absence of scientific and rigorous design procedures and quantitative standards can lead to incomplete design considerations, and the design appears hollow and difficult to achieve. This paper takes highway landscape environment assessments and landscape environment grading as research objects and proposes highway landscape environment assessment methods, index systems and landscape grading standards. This aims to provide a perfect and reliable theoretical system for highway landscape environment assessments.

2. Highway Landscape Environment Assessment

A highway landscape environment assessment is based on investigation and analysis, using scientific and systematic methods to obtain assessment information on the current situation of the regional landscape environment. At the same time, based on the sustainable development of the ecosystem, formal beauty and the value orientation of road users, the current status of the regional landscape environment along the highway is comprehensively assessed. This can get the suitability level of the landscape environment for highway construction and provide the most basic information for landscape planning and design [12].

2.1. Assessment Content

Through the investigation of the landscape resources and visual environment of the area along the highway, the characteristics, sensitivity, carrying capacity, and integrity

of the landscape environment and the quality of the visual environment are assessed with the purpose of establishing basic information about the landscape environment. The assessment of the highway baseline and the surrounding landscape is shown in Figure 1.

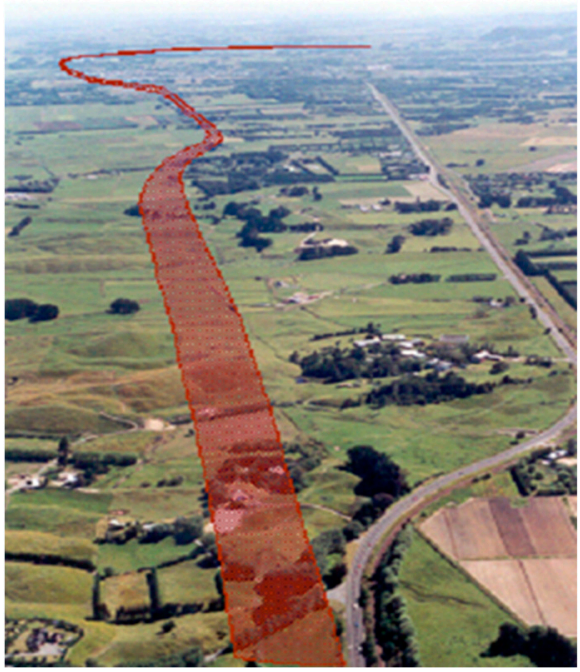

Figure 1. Assessment of the highway baseline and surrounding landscape.

The best corresponding area is sought for highway landscape elements within the scope of planning permission, and finally, the best ecological suitability is achieved for land use and management along the highway area [13]. Therefore, the content and scope of a highway landscape environment assessment should include the following aspects [14].

- Identification of landscape characteristics: identify the significant structure, characteristics and value of the existing landscape, and determine the landscape sensitivity;
- An environmental coherence assessment: assess the potential impact of the road on its ability to integrate with the surrounding landscape;
- A visual environmental assessment: assess the visual effects of road users and identify factors of traffic safety and visual attraction;
- An environmental carrying capacity assessment: assess the nature, extent and significance of various landscapes and analyze the impact of road development on environmental carrying capacity

2.2. Assessment Criteria

The assessment criteria for the highway landscape environment is a systematic and multi-level system. It needs both subjective assessment standards and quantitative objective assessment standards.

The subjective standard comes from the assessment subject and is expressed as an implicit psychological standard. It has the following three characteristics [15]:

- Embodying periodicity, regionality and nationality;
- Establishing assessment standards from the quality of environmental ontology;
- Popularization.

Objective criteria are mainly derived from the following aspects:

1. Relevant regulatory benchmarks

The relevant regulatory benchmarks in landscape environment assessment are international and national regulatory benchmarks, administrative regulations issued by administrative departments at all levels, local plans, development strategies and policies, etc.

2. Functional benchmarks

From the perspective of the visual needs of drivers and passengers and the basic functions of highways, the functional benchmarks of the highway landscape environment are mainly the following four aspects:

- Diverse visual space;
- Safe and comfortable spatial scale;
- Easy identification and visibility;
- Socio-economic.

3. Landscape ecological benchmark

The landscape ecological benchmark coordinates the harmonious relationship between landscape environmental aesthetics and ecological sustainability, which is essentially a deeper beauty. The landscape ecological benchmark can be analyzed from two aspects of landscape carrying capacity and suitability: the landscape environmental carrying capacity is the ability of the landscape environment to bear a certain type of impact or the ability of the land in a certain area to provide resources, services and allow the use of resources. Suitability is the degree of suitability of a certain area for its use.

4. Humanistic benchmark

The humanistic benchmark is mainly a value judgment of the cultural attributes of the landscape. It is generally measured from three aspects: the time of landscape formation, the quantity and quality of humanistic information of the landscape [16], see Figure 2.

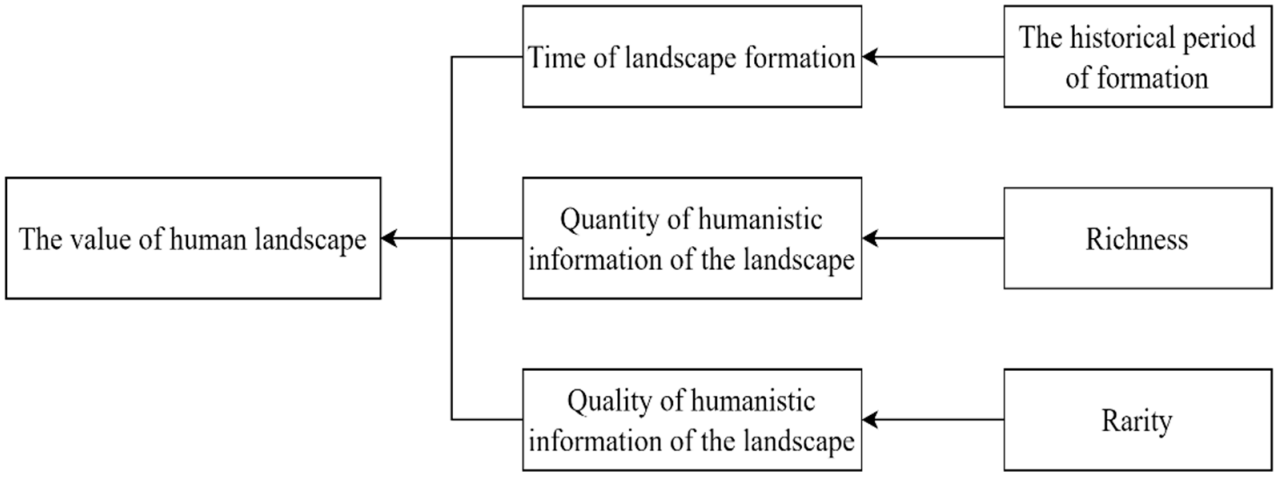

Figure 2. Humanistic benchmark of the landscape.

5. Formal beauty benchmark

The formal beauty benchmark can be reflected by three evaluation scales: diversity, coordination and peculiarity of the landscape environment. Diversity is to describe the differences in the types of elements contained in the highway landscape system. Coordination describes the coordination relationship between the highway and its surrounding environment, the coordination relationship between landscape elements or the coordination relationship between the size, proportion and scale of the internal indicators of the landscape elements. Peculiarity refers to an element or relationship between elements that is particularly rare or occupies a special advantage in the overall environment.

2.3. Assessment Methods

The highway landscape environment contains various elements of the physical landscape, usage psychology, social behavior and their related relationships. In terms of its assessment connotation and standard value system, the highway landscape environment assessment method develops along two main lines: scientific and humanistic. It is a comprehensive assessment that combines the scientific quantitative assessment method and the humanistic assessment method.

The basic idea of the scientific quantitative assessment method (see Figure 3) is to construct a model of assessment factors with systematic thinking. The mathematical model is used to analyze the intrinsic relationship of the landscape environment, study the influence of objective environmental factors on planning behavior, and use objective quantitative methods to ensure the evaluation results are scientific and reliable. Its disadvantage is that the mathematical model is abstract and rigid, the data collection does not take into account psycho-emotional factors, and the credibility is affected. The humanistic assessment method examines the influence of socio-economic and cultural factors on the assessment through behavioral observation, graphical surveys, and consultation interviews to study the intrinsic psychological emotions of individual road users under high-speed conditions. The advantage of this method is that it can accurately reflect the essence of the problem by studying subjective assessment attitudes while making the complex landscape environment assessment easy. The above shows that each of the two methods has corresponding conditions of application and has strong differences and complementarities. The scientific quantitative assessment method and the humanistic assessment method should be integrated to build a comprehensive assessment system combining quantitative and qualitative assessment. In the practice of landscape assessment, the same problem is studied and solved together in a complementary and composite manner.

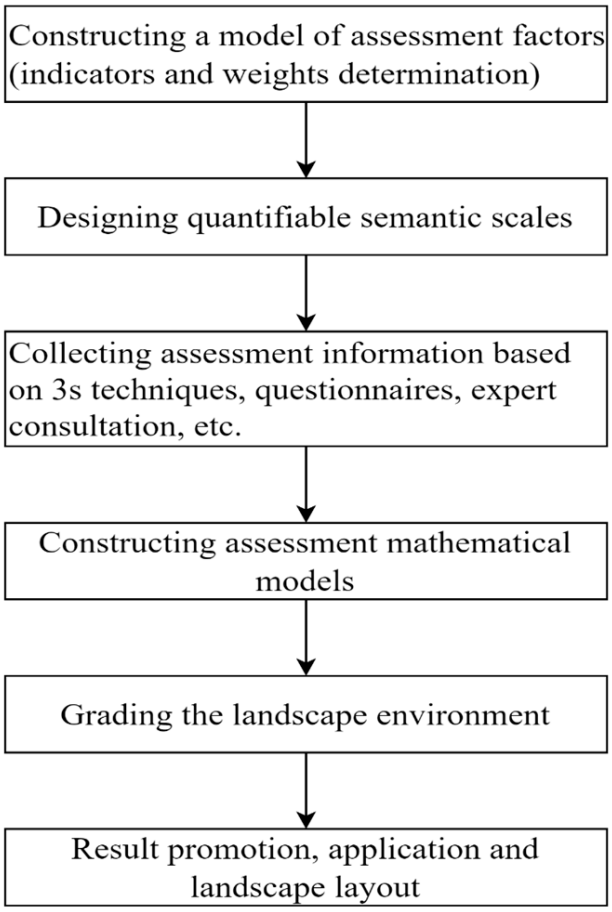

Figure 3. Scientific quantitative assessment method.

2.4. Assessment Steps

The highway landscape environment assessment is divided into four stages: preparation—investigation—assessment—application (see Figure 4). Each assessment stage has a detailed division of work, which can be referred to in specific practical operations.

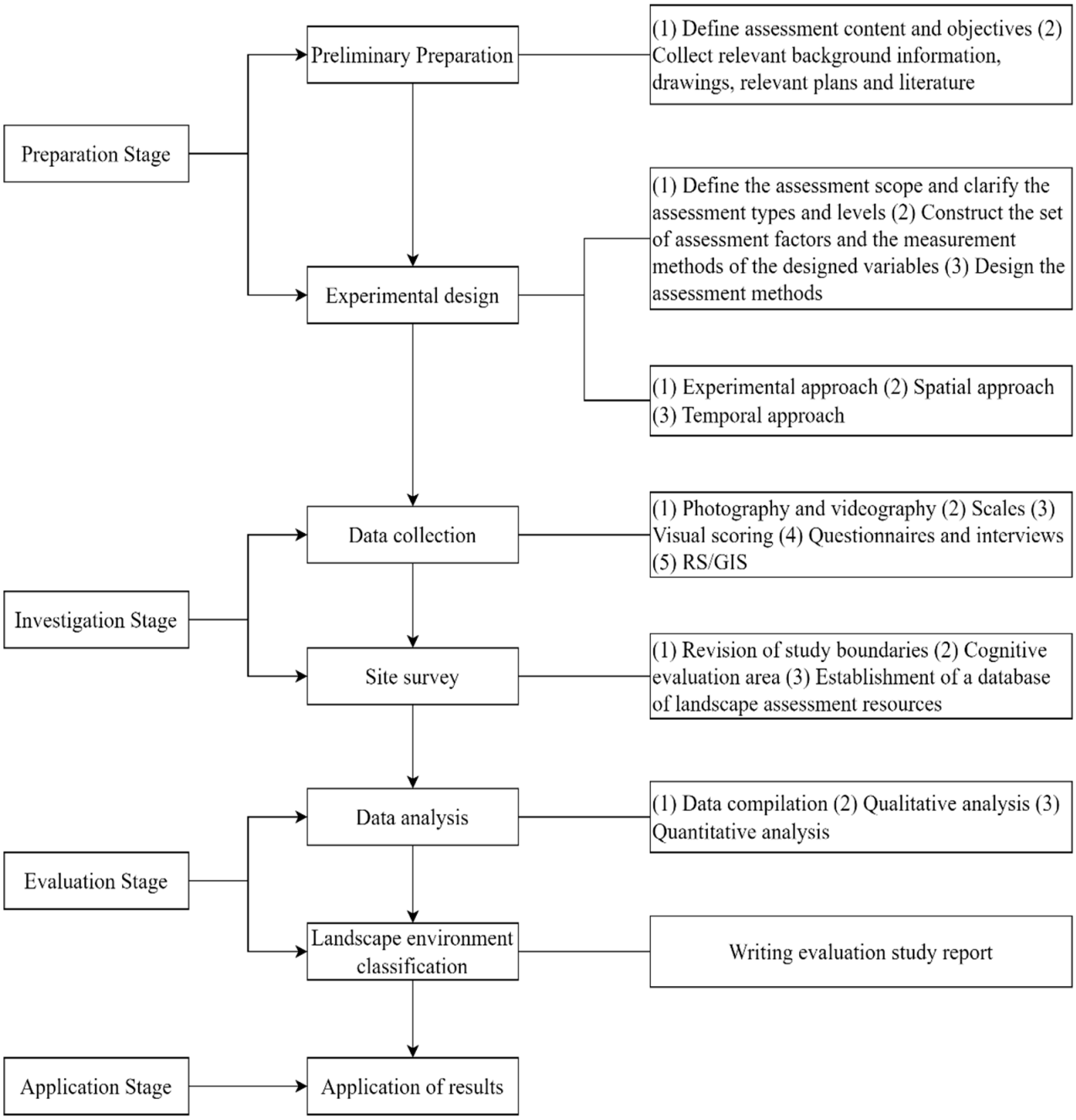

Figure 4. Steps of highway landscape environment assessment.

1. Preparation stage

Before the assessment, it is necessary to organize the environmental elements and nature of the highway baseline and collect the background information on the surrounding environment of the highway corridor zone so as to prepare for the landscape environmental assessment. Background information collection mainly includes the following aspects of work.

- Relevant drawings of highway planning and design.
- Landscape or other studies of the relevant area, including highway area strategy studies and environmental impact assessments.
- Maps containing information on roads, land use planning, geology, soils, landmarks, distribution of plant and animal populations, distribution of natural disaster levels, ecological quality status, infrastructure, topography, etc.
- Remote sensing and satellite image information of the relevant areas.
- Local regional planning; relevant regulations, standards and norms.
- Design of field survey analysis and assessment forms.

2. Survey Stage

The main purpose of the field survey is to familiarize with the site conditions in the areas along the corridor belt and to verify, supplement and refine the basic information collected in the preliminary preparation stage. The surveyors completed the assessment through visual, photographic, video and walking methods. The main tasks of the field survey are shown below.

- Checking maps and remote sensing satellite data and correcting relevant information. Adding information on land forms, surface forms, and land use.
- Identifying landscape control points through GPS positioning. Surveying the surrounding area in detail and recording relevant landscape features.
- Capturing the characteristics of the assessment area through photography and videography for internal analysis. Determining information on landscape features in the sightline area through visual assessment of sensitive areas and filling out various types of analysis and assessment forms.

3. Evaluation Stage

Highway landscape environment evaluation is a very critical part of highway landscape layout planning and design. The highway landscape environment is evaluated through the analysis of the information obtained in the survey phase. This is of great significance for the selection of route corridor zones, ecological environmental protection, the basic pattern of highway landscape environment and its structure.

After establishing the basic connotation of the landscape environment assessment, the value orientation of the assessment and the standard system, the basic methods and basic procedures of the assessment are further clarified. Based on the theory of set-pair analysis, the basic methods and grading standards of highway landscape environment quality grading are established to provide basic information for writing assessment research reports.

4. Application stage

After the evaluation model and grading criteria based on set-pair analysis are established, they are applied to the example analysis of highway landscape evaluation so as to verify the proposed evaluation theory system.

3. Indicator System of Highway Landscape Environment Assessment

3.1. Indicator Hierarchy

According to different objectives and uses, the highway landscape environment assessment system is divided into four layers, namely, the target layer, project layer, criterion layer, and indicator layer [17]. Among them, the highway landscape assessment is the target layer, the assessment content is the project layer, the attributes of the assessment content are the criterion layer, and the specific indicators of each attribute are the indicator layer, see Figure 5. The project layers are landscape characteristics, environmental coherence assessment, visual environmental assessment and environmental carrying capacity assessment.

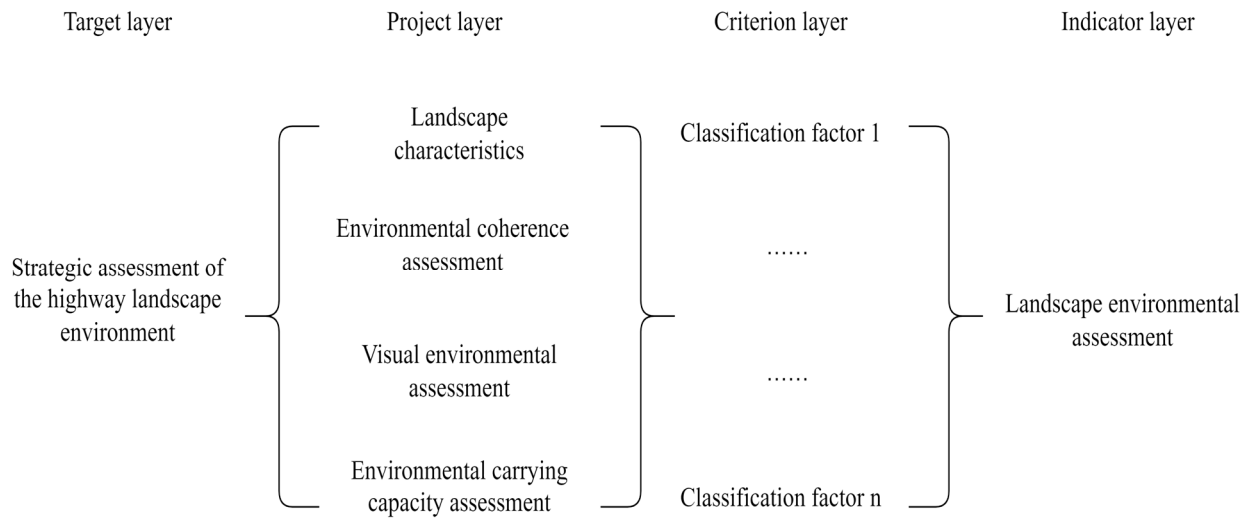

Figure 5. Indicator hierarchy.

3.2. Assessment Indicators

1. Landscape characteristics

Landscape characteristics refer to the attributes, quality, and characteristics of the landscape, which is the visual and cultural expression of the regional landscape attributes. Landscape characteristics consist of a combination of physical, ecological, and cultural attributes, i.e., it is composed of regional topography, water bodies, vegetation, land use, and other surface covers. Landscape features are the expression of the overall type or feeling of the landscape, which should be reflected at two levels: "physical elements" and "aesthetic elements", respectively [18], see Table 1.

Table 1. Assessment indicators and attributes of landscape environment.

Project Layer	Criterion Layer	Indicator Layer	Attributes
Landscape characteristics	Landscape ecological criteria	Topography	Mountainous areas, plains, hills, etc.
		Water bodies	Form of water bodies, bank type and area between land and water
		Vegetation	Richness, combination, texture, colour, and species of vegetation
		Land development pattern	Primitive villages, countryside, towns
		Integrity	Integrity of the landscape and its absence
	Formal aesthetic criteria	Colour	Hue, brightness, purity, matching, harmonization, contrast, etc.
		Peculiarities	Rarity
		Coherence	Orderliness, balance and stability of the landscape and its coordination with the surrounding environment
		Spatial pattern	Spatial sequence, quantitative structure, shape structure, degree of fragmentation and separation, etc.
		Visibility	Unity and diversity, rhythm and rhyme, proportional scale, primary and subordinate, etc.

2. Environmental coherence assessment

Environmental coherence assessment evaluates the intrinsic beauty of the landscape environment and the sensitivity of being noticed by the public. It is divided into five aspects: ecological integrity, social-humanistic, rarity, aesthetic value, and landscape sensitivity [19], as shown in Table 2.

Table 2. Indicators and attributes of environmental coherence assessment.

Project Layer	Criterion Layer	Indicator Layer	Attributes
Environmental coherence assessment	Ecological integrity	Degree of connectivity	Degree of connection of patches of similar landscape elements
		Degree of spatial proximity	Inter-dispersed nature of landscape elements
		Degree of landscape aggregation	The degree of contiguity between different patches
	Social humanity	Land use pattern, cultural characteristics	Impression and meaning formation of historical and extant visual element sites
	Rarity	Preciousness	Rarity, high landscape value
		Uniqueness	Peculiar
	Aesthetic value	Degree of influence on the surrounding environment	Relationship with the surrounding environment
		Iconic landscape	Dominant landscape
		Diversity or evenness	Landscape organization content and form
		External characteristics of the landscape	Topography, vegetation, water bodies, and specific attributes, including variety, pattern, colour, scale, etc.
		Visual attractiveness	The degree of visual attraction of the landscape
	Landscape sensitivity	Biological richness and diversity	Reflect the diversity of the landscape
		Topography and slope	Reflect the visibility of the landscape
		Eye-catching degree	Reflect the importance of the landscape and the degree of human attention
		Soil stability	Potential erosion
		Sight distance	Reflect the clarity of the view within the sight distance

3. Visual environmental assessment

The visual environment is used to measure the degree of change in the attribute characteristics of natural and artificial landscapes [20]. The visual environment determines landscape environmental characteristics, quality, visual interest, and visual sensitivity. It is a reflection of the degree of impact of highway landscape projects on the valuable environment. The visual environment is measured by the scale, intensity, and pattern of change in the attributes of landscape characteristics. Therefore, there is a need to classify the positive attributes of extant landscape characteristics. Usually, the criteria for public assessment of the visual environment can provide a perfect judgment basis for landscape planning, see Table 3.

Table 3. Indicators and attributes of visual environmental assessment.

Project Layer	Criterion Layer	Indicators and Attributes
Visual environmental assessment	Land use pattern	Land use development and history
	Landscape environmental quality	Attribute beauty, visibility, landscape sensitivity, landscape importance, etc.

4. Environmental carrying capacity assessment

The environmental carrying capacity assessment is a comprehensive assessment of the sensitivity of the integrated regional environment, the ability of the environment to resist the influence of external disturbances, and the ability to self-heal after being disturbed [21], as shown in Table 4. It also refers to the assessment of the relationship between the road and stakeholders, including communities and groups, through the social function of the landscape environment. This aims to capture the values and connections of stakeholders to the surrounding area landscape. The landscape carrying capacity of sensitive areas is measured through the ecological functional requirements of the landscape.

Table 4. Indicators and attributes of l environmental carrying capacity assessment.

Project Layer	Criterion Layer	Indicator Layer	Attributes
Environmental carrying capacity assessment	Social environmental carrying capacity	Economic	Economic development planning, conditions of exploitation and utilization of resources, industrial structure
		Compatibility with other facilities	Land use, impact on farmland, water drainage and irrigation facilities
		Support of the residents along the route	Attitude of the residents along the route towards the construction of the highway, the impact of the highway on the residents
	Ecological environmental carrying capacity	Impact on animal environment	Animal species and numbers, distribution, habits, activity patterns, habitat characteristics and protection level
		Impact on the plant environment	Vegetation population structure, distribution status, coverage rate and protection level
		Soil and water conservation	Slope and slope direction, soil erosion, geological stability, farmland protection and zoning, soil quality
		Water environment impact	Water system along the route, water environment function division, hydrological and water quality restrictions
	Air environmental carrying capacity	Air quality of sensitive points	Meteorological characteristics, air quality, air pollution sources, air sensitivity
	Acoustic environmental Carrying Capacity	Environmental noise	Current status of sound environment quality, distribution and type of existing noise sources, distribution and type of noise sensitive points

3.3. Indicator Assignment

The indicator values of the highway landscape environment assessment are derived from the analysis of background information and field survey information [22]. A field survey was conducted in the form of filming and collecting questionnaires to obtain

information on the current state of the highway landscape environment. At the same time, background information such as planning maps, topographic maps, and distribution maps of flora and fauna resources related to the landscape environment is consulted and analyzed. Finally, the information collected was put together by treating the assessment object as a systematic whole. The assignment of relevant indicators is confirmed through map overlay and expert correction. The technical route of indicator assignment is shown in Figure 6.

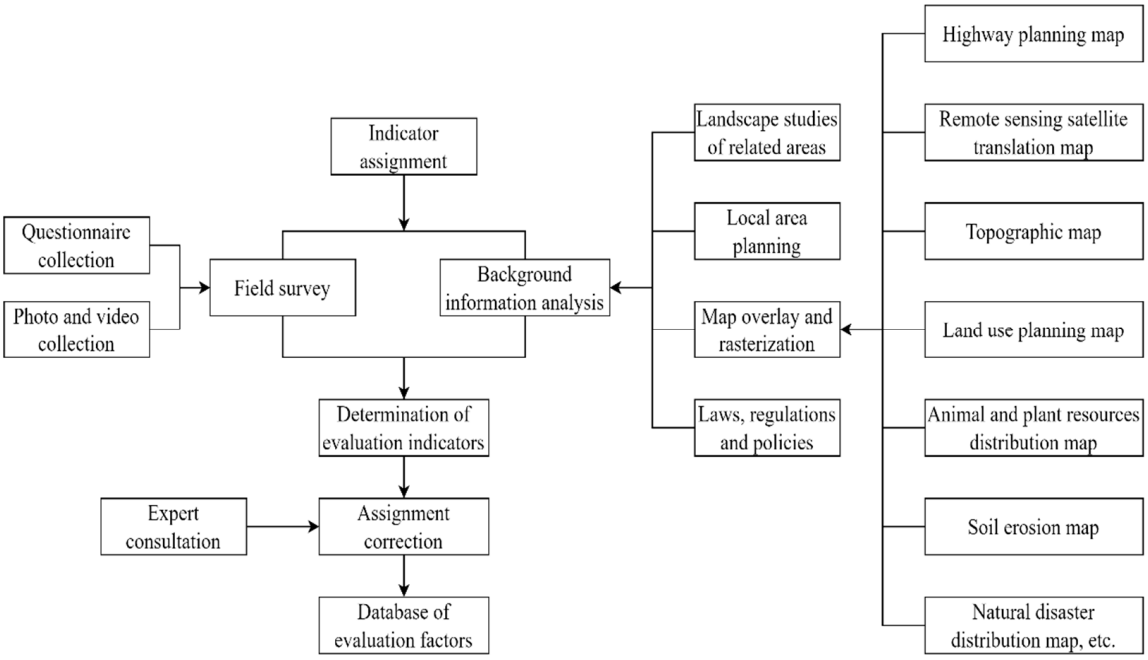

Figure 6. Technical route of data acquisition and processing.

3.4. Weight Coefficient Assignment

According to the characteristics of highway landscape environment assessment, the subjective weighting method is a more secure method in landscape assessment in order to better reflect the background conditions in which the assessment object is located and the intention of the assessor. In this paper, the hierarchical analysis method and expert consultation method are integrated to determine the weight coefficients. The specific steps are shown below.

- Analyzing the relationships among the basic elements in the assessment system and establishing a recursive hierarchy of the system.
- Comparing the importance of each element in different levels to a criterion and constructing a judgment matrix.
- Calculating the relative weights of the compared elements to the criterion from the judgment matrix.

The synthetic weights of the elements are calculated at each level for the purpose of the system.

4. Quality Grading of Highway Landscape Environment

A highway landscape environment assessment is the foundation work and basis of landscape grading, and landscape grading is the specific application of landscape assessment [23]. According to the indicator system and method of highway landscape environment assessment, the research framework of highway landscape environment quality grading is constructed (see Figure 7). This provides direction and guidance for landscape grading.

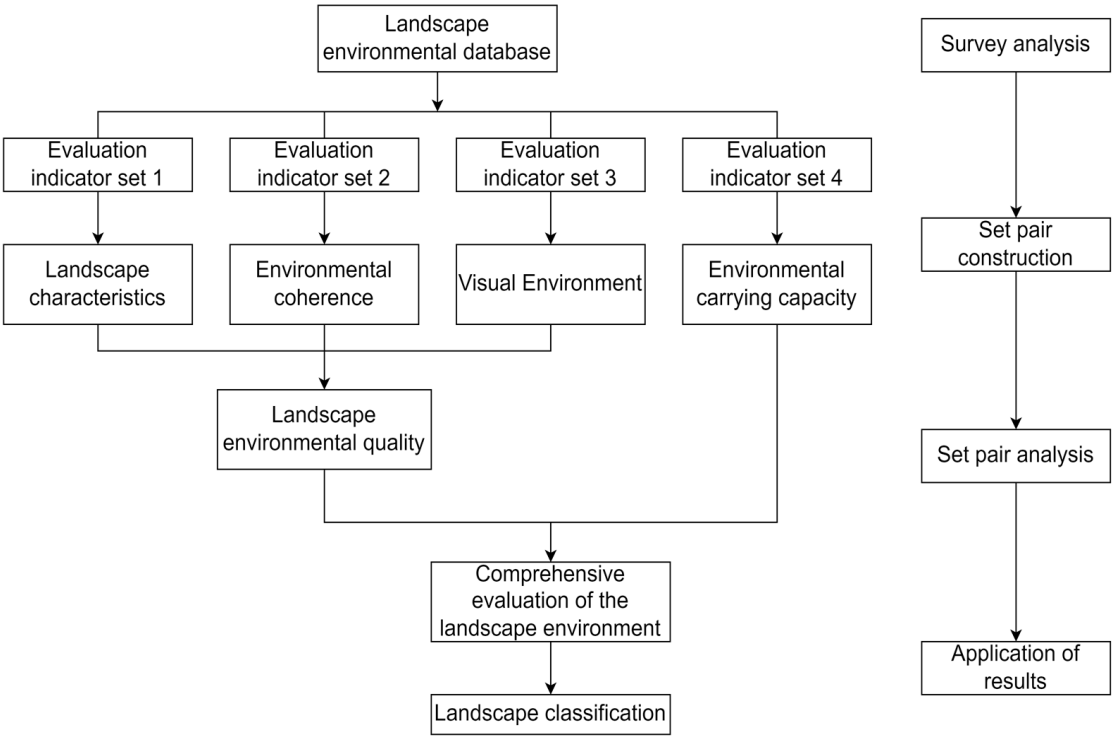

Figure 7. Model of highway landscape classification assessment process.

The highway landscape environment grading is for the landscape environment quality and the environmental carrying capacity of highway projects [24]. Therefore, its grading criteria should combine landscape environmental quality and landscape environmental carrying capacity. Based on the assignment of assessment indicators, the hierarchical assessment of set-pair analysis is used to assess the landscape characteristics, environmental coherence and visual environment within the road area separately. Then, a comprehensive analysis is carried out for landscape characteristics, environmental coherence and visual environment to obtain the overall quality level of the regional landscape environment. Finally, the quality grade of the landscape environment is determined comprehensively by combining the environmental carrying capacity of the project construction.

4.1. Set Pair Analysis

If we set the assessment object space A = {highway landscape assessment index} and the attribute space C = {landscape quality}, I_j is the weight of the highway landscape assessment indicator and the assessment set is $C = \{C_1, C_2, C_3, C_4\}$. C_1, C_2, C_3, C_4 form an ordered partition class of the attribute space C, and $C_1 > C_2 > C_3 > C_4$. The classification criteria of each indicator are known and written as a matrix of classification criteria, as shown below [25].

$$\begin{matrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{matrix} \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \quad (1)$$

In the matrix, I_j is the highway landscape assessment indicator and a_{mn} is the ratio of the importance of the assessment indicator I_m to I_n.

Then, after establishing the primary and secondary subsystems, the total indicator of the highway landscape environment grading assessment of the four elements of the linkage degree is μ. Moreover, the principle of the mean score is used to delineate the highway landscape grade; the specific steps are shown in Figure 8.

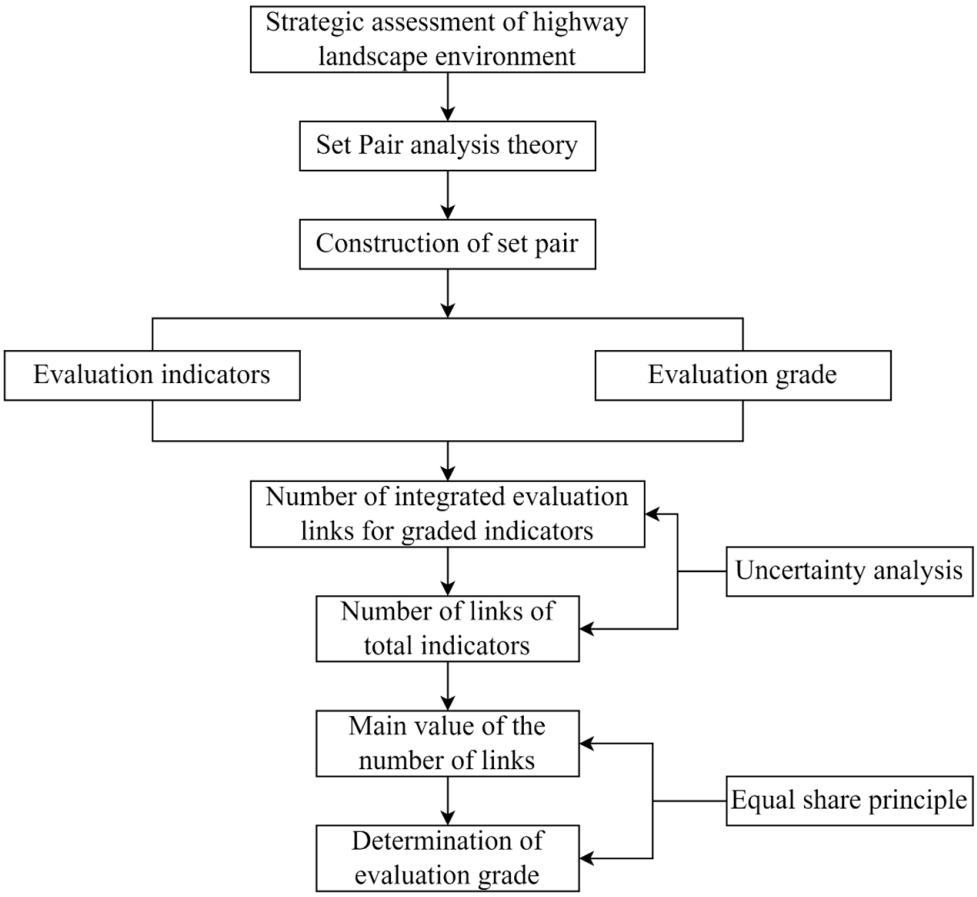

Figure 8. Flow chart of set pair analysis for landscape grading.

Set $\mu = r_1 + r_2 i_1 + r_3 i_2 + r_4 j$ as a quadratic associative number. Since $\mu \in [-1, 1]$, the interval $[-1, 1]$ is divided into three equal parts according to the 'principle of equipartition'. The main value of the quadratic associative number is obtained when i_1 and i_2 take three points value from left to right and $j = -1$. As shown below.

$$\hat{\mu} = r_1 + \frac{1}{3} \cdot r_2 - \frac{1}{3} \cdot r_3 + r_4 \cdot (-1) \tag{2}$$

In the formula, the linkage component of the total indicator of highway landscape environment grading evaluation is $r_n = \sum_{n=1}^{4} w_m r_{mn}$. w_m is the weight of the indicator I_m. r_{mn} represents the correlation coefficient of each level of evaluation level.

- For a comprehensive assessment of highway landscape environment grading according to Equation (2), the main value of the associative number $\hat{\mu}$ must be calculated.
- According to the main value of the associative number $\hat{\mu}$, the highway landscape planning and design solutions are ranked for merit. The higher the value of $\hat{\mu}$, the better the grade of the highway landscape environment.
- The comprehensive evaluation grade of the highway landscape is determined according to the main value of the associative number $\hat{\mu}$. According to the 'principle of equipartition', the interval $[-1, 1]$ is divided into four equal parts [26], then each interval from right to left corresponds to the four grades of C_1, C_2, C_3, C_4 in turn. Moreover, grade 1 landscape environment standard: $C_1 \in (0.5, 1]$; grade 2 landscape environment standard: $C_2 \in (0, 0.5]$; grade 3 landscape environment standard: $C_3 \in (-0.5, 0]$; gradel 4 landscape environment standard: $C_4 \in (-0.5, -1]$. If $\hat{\mu} \in [\frac{4-2l}{4}, \frac{4-2(l-1)}{4}]$, then the highway landscape environment grade is C_l level $(1 \leq l \leq 4)$.

4.2. Grading Criteria

According to the principle of set-pair analysis and highway landscape environment grading indicator system to obtain the highway landscape environment grading model: $\mu = a + b_1 i_1 + b_2 i_2 + cj$. The grade value of each assessment item is calculated by Equation $\hat{\mu} = a + \frac{1}{3} \cdot b_1 - \frac{1}{3} \cdot b_2 + c \cdot (-1)$. Among them, the value of grade 1 is $\hat{\mu} \in (0.5, 1]$, the value of grade 2 is $\hat{\mu} \in (0, 0.5]$, the value of grade 3 is $\hat{\mu} \in (-0.5, 0]$, and the value of grade 4 is $\hat{\mu} \in (-0.5, -1]$. In turn, it can be a comprehensive judgment of the landscape environment level of each section of the highway. The specific meaning under each environmental level is shown in Table 5.

Table 5. Highway landscape quality level standards.

Evaluation Object / Quality Level	Landscape Environment Quality	Landscape Suitability
Grade 1 landscape environment	Elegant	Very weak carrying capacity and high sensitivity
Grade 2 landscape environment	Good	Weak carrying capacity, some sensitivity
Grade 3 landscape environment	Normal	Good carrying capacity
Grade 4 landscape environment	Poor	Resource-poor, high-carrying capacity

4.3. Highway Landscape Design Strategies under Different Landscape Levels

1. Grade 1 landscape environment

In the grade 1 landscape environment, the environment along the highway is pleasant, the landscape resources are rich and diverse, and the ecological environment is good but sensitive and fragile. The visual quality of the landscape is high, and the spatial visual recognition is strong, but the suitability of the landscape environment and carrying capacity is low. The grade 1 landscape environment has the highest ecological requirements for the landscape, with "avoidance and protection" as the basic guiding principle. Optimizing the route plan, carrying out ecological design, and environmental compensation design with ecological benefits are the main focus and economic benefits as a supplement.

2. Grade 2 landscape environment

The grade 2 landscape environment is characterized by high ecological requirements, weak environmental carrying capacity, beautiful natural scenery, and strong landscape attractiveness. The visual sensitivity is high, the landscape integrity and continuity are good, and pedestrians are sensitive and excited about the scenery along the road [27]. In highway landscape design, attention should be paid to the fundamental role of highway alignment design in the overall architecture of the landscape. The focus should be on using the surrounding environment and carefully organizing and designing the background space of the highway. Through different spatial background processing techniques (such as borrowed scenery, pair of scenery, frame scenery, etc.), the beautiful scenery along the road is incorporated into the driving vision, reflecting the natural ecological beauty along the road. At the same time, the surrounding environment of the highway should be coordinated to improve its visual quality.

3. Grade 3 landscape environment

The grade 3 landscape environment is the most widely distributed in the construction of highways, and the structure and function of the ecological environment are more stable. There are significant differences in land use patterns along the route and large differences in regional humanities, architecture and customs. However, the environmental carrying capacity is high, the environmental sensitivity is weak, and the landscape integrity is poor. In the highway landscape design, regional differences should be used to give the highway regional characteristics and emphasize regional history and humanity. To improve the quality of the road's two-dimensional and three-dimensional line shapes, dynamic visual and psychological laws need to be combined. Full attention should be paid to planting,

strengthening the design of color, and weakening the influence of bad environmental sections to ensure good visual space and driving comfort for drivers and passengers.

4. Grade 4 landscape environment

In the grade 4 landscape environment, the ecological environment along the route is stable, and the environmental carrying capacity is high. However, the landscape resources along the route are poor, the visual environment is poor, the landscape attractiveness is low, and the spatial visual recognition is weak. It is suitable for high-intensity human development activities that meet the existing landscape features. In the highway landscape design, basic greening planting is carried out, and artificial landscaping is appropriately carried out, while the use of colour is strengthened to enhance the spatial recognition and the visibility of the landscape elements of the highway project itself.

5. Engineering Case Study

The Xi'an-Baoji highway in China is 151.97 km long, with a roadbed width of 24.5 m and a design speed of 120 km per hour. The highway is mostly farmland along the way, and the terrain is relatively flat. Its geological structure along the way is complex, with mountains, rivers and plains. Along the way, there are abundant plant resources, animal resources and mineral resources. The highway is in the continental warm temperate zone, and the climate conditions are semi-arid and semi-humid monsoon climate. The landscape design of the Xi'an-Baoji highway pays attention to the integration of regional characteristics and is coordinated with the surrounding environment.

The determination of indicator weights for highway landscape environment assessment is a multi-objective, multi-criterion, multi-level and complex problem. It requires a combination of qualitative analysis and quantitative analysis for comprehensive evaluation. A judgment matrix is established according to equation (1). Then the judgment matrix is solved to get the relative weights among the elements. The opinions of relevant experts are integrated to give a degree of importance to landscape characteristics, environmental coherence, visual environment and environmental carrying capacity, details are shown in Table 6.

Table 6. Judgment matrix and weight values of the indicator layer.

	Landscape Characteristics	Environmental Coherence	Visual Environment	Environmental Carrying Capacity	Weight
Landscape characteristics	1	2	7/2	2/3	0.3132
Environmental coherence	1/2	1	4/3	1/3	0.1460
Visual Environment	2/7	3/4	1	1/4	0.1027
Environmental carrying capacity	3/2	3	4	1	0.4380

Note: The maximum eigenvalue $\lambda_{max} = 4.0093 > 0$ and the consistency ratio CR = 0.0035 < 0.1, so it passes the consistency test.

Based on the weights of each indicator, the comprehensive evaluation contact main value of the total indicator is calculated using Equation (2). The resulting equation is shown below.

$$\hat{\mu} = 0.25 + 0.22i_1 + 0.26i_2 + 0.07j \quad (3)$$

In the formula, i_1, i_2 represent the uncertainty variance coefficients; the opposing coefficients to $j = -1$.

According to the principle of equalization, the comprehensive evaluation contact main value of the total indicator is calculated as $\hat{\mu} = 0.1667$. According to the evaluation standard, the landscape of the Xi'an-Baoji highway is in a Grade 2 landscape environment, the environmental carrying capacity of the subsystem is "weak" and the landscape quality is "good".

6. Conclusions

1. On the basis of the regional environmental survey along the highway, landscape and environmental information is obtained, and a systematic analysis is conducted. Based on the sustainable development of the ecosystem, formal beauty and the value orientation of road users, a highway landscape environment assessment method combining quantitative assessment and humanistic assessment is used to comprehensively assess the current situation of the highway landscape environment. This provides technical support and a decision basis for highway construction and landscape resource utilization.

2. A systematic and multi-layered highway landscape environment assessment system is constructed with the highway landscape assessment as the target layer, the assessment contents (landscape characteristic identification, environmental coherence assessment, visual environmental assessment and environmental carrying capacity) as the project layer, the attributes of the assessment contents as the criterion layer and each attribute indicator as the indicator layer. The indicator layer can be assigned with the help of high-precision maps, field surveys and expert corrections.

3. This article constructs a new method for grading highway landscape quality with the help of the set-pair analysis theory. This method not only establishes the grade of each subsystem but also represents multiple indicator systems into a total indicator. Then the quality grade is quantitatively determined by calculating the main value of the linkage number to determine the comprehensive evaluation grade. This method can better deal with the problem of uncertainty in the highway landscape environment, combining the dialectical cognition of the research problem with quantitative analysis. This method integrates the information of the highway environment system at different levels, thus deepening the research problem.

4. Grading the quality of the highway landscape environment not only makes the highway project appropriate for local conditions and integrates it into the surrounding environment but also has important significance for ecological and environmental protection, landscape resource utilization and landscape planning. It is the key foundation and prerequisite in highway landscape engineering.

5. In the assignment of indicators and weight coefficients, it is easy to be influenced by subjective differences. Therefore, it is appropriate to use high-precision maps, field surveys, and expert corrections to assign objective and accurate values to the research objects.

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