Study on the Evaluation Method of Subgrade Slope Green Protection Effect in Dry-Hot Valley of Sichuan-Tibet Railway

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In view of the harsh environment in the dry-hot valley of Sichuan-Tibet railway and the important role of the green protection of the subgrade slope in railway construction and ecological restoration, this paper evaluates the effect of the green protection of the subgrade slope in dry-hot valleys of the Sichuan-Tibet railway. First, an evaluation index system for the green protection effect of railway subgrade slopes is established in terms of the soil matrix quality, vegetation community quality, and protection performance of the slopes. Second, game theory is adopted to combine the improved-group-analytic-hierarchy-process method and the vector-angle-cosine method and thus determine the weight of each evaluation index. Moreover, the membership-cloud-gravity-center method is used to evaluate the green protection level of the railway subgrade slope, and an evaluation cloud map is drawn with the help of MATLAB software to further analyze the evaluation. Finally, a section subgrade slope of the DHV area of the Sichuan-Tibet railway is selected as the evaluation object, and the green protection effect is evaluated to verify the applicability and effectiveness of the model. The study provides a theoretical basis for the protection of subgrade slopes and ecological restoration in the DHV area.

1. Introduction

With the rapid development of social economy, the large number of exposed slopes caused by the increasing railway construction not only destroyed the vegetation along the railway but also caused a series of ecological problems and geological disasters [1], such as the sudden loss of slope plant species, slope structure damage, landslides, and debris flow [2]. The subgrade slope, as the foundation to maintain the stability of the railway subgrade, is exposed to the air for a long time, so it is strongly influenced by the natural factors, resulting in the strength attenuation; meanwhile, the rock and soil on the slope surface are ruptured, which can easily aggravate the collapse of the slope and cause the subgrade instability [3]. Geological disasters, such as subgrade collapse, landslides, and spalling of the slope surface, may seriously damage the railway and surrounding environment if the subgrade slope is not properly protected. The green protection (plant protection) of a slope not only prevents these disasters but also plays a role in consolidating the slope, growing vegetation along the subgrade slope, and protecting the ecological environment. The green protection of subgrade slopes has therefore become an indispensable part of railway construction. The implementation of ecological protection measures that take into account the engineering effect and landscape function on the subgrade slope, restore the vegetation on the slope surface, prevent the subgrade from destabilizing, and maintain the health of the slope ecosystem has become a hot issue shared by the majority of soil and water conservation and ecological engineering researchers [4].

In recent years, many experts have analyzed the causes of slope instability [5] and destruction [6] through extensive research and found that the main causes of slope damage are mostly rainfall [7], floods [8], and wind action [9] that eroded the soil of the slope, cracked the subgrade slope, reduced the resistance of the subgrade slope to external forces, and eventually caused the slope to collapse and lose
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2.1. Reasons for the Formation of DHV Areas.

The origins of DHV areas and secondary DHV areas. The original DHV areas and the secondary DHV areas. The original DHV areas already existed, and a special climate was formed due to the combination of special landforms and local microclimates. The area has a tropical and subtropical monsoon climate with a distinct dry and wet season. Moreover, the area has a unique gully system [18], where the foehn effect [19] and local circulation effect of valley wind often occur, causing warming and water loss. Forest vegetation in DHV areas is very difficult to recover. The main reason is that the lack of water makes large areas become barren, especially the loss of surface soil on the slopes of river valleys, which exposes large areas of bare soil and makes the afforestation survival rate low. Secondary DHV areas are formed by the continuous negative disturbance of deforestation. Some studies believe that most of the original vegetation along the banks of the Jinsha River between 3,000 and 5,000 years ago was green broad-leaved oak forests. The above factors have combined to create the extremely fragile ecological environment of the DHV areas. The geomorphological characteristics of DHV areas are shown in Figure 1.

2.2. Distribution and Characteristics of DHV Areas.

The DHV areas in China are mainly distributed [17] on the slopes of the valleys of the Minjiang River, Dadu River, Yalong River, Jinsha River, Nujiang River, Lancang River, and other rivers in the southwest of China. The areas are mainly located in the arid and semi-arid river-valley areas with latitude of 23° 00′–28° 10′ north, longitude of 98° 50′–103° 50′ east, and altitude below 1500 m [20].

The DHV areas [21] are located in a high-temperature valley area, which is rich in solar and thermal energy sources. It has a hot climate with little rain, severe soil erosion, and fragile ecology. Cold, drought, high wind, fire, and other natural disasters are particularly prominent. The dry season in the DHV areas lasts for more than 8 months each year. The average annual rainfall is about 800 mm (rainfall is 550–650 mm, and the dry season rainfall is 50–160 mm). However, the evaporation is more than 3 times the rainfall, the relative humidity is small, and the drought index is about 1.5 to 2.5. The highest surface temperature of bare land reaches 75°C, and the water content of the topsoil within 40 cm is close to zero, in April and May. Most of the sites in the DHV areas have thick soil, but the vegetation cover is less than 5%. The vegetation in the DHV areas is seminatural savanna, which has simple structure, low species richness, obvious dominance of herb layer, suboptimal shrub layer, and few trees [17].

3. Evaluation Index System

3.1. Analysis of Evaluation Factors. Slope protection engineering involves multidisciplinary and comprehensive system engineering. Therefore, the types and indexes of evaluations of engineering effects must have different properties and characteristics, and problems should be explained at different levels. Meanwhile, such indexes should be interconnected to reflect multiple aspects of the purpose of protection engineering effects comprehensively. From the perspective of system engineering, subgrade slope protection engineering can be regarded as a slope-matrix-vegetation system [22, 23]. This system and the environment form a unified entity having a certain structure and performance through interaction, intertwining, and infiltration. The construction of a scientifically feasible evaluation
index system of the engineering effect must therefore be based
on the structural integrity and stability and thus the durability of
the engineering system. There are two basic units, namely, the
matrix and vegetation, of the structure of the slope protection
engineering system. The matrix refers to the basic material (i.e.,
the soil in the present case) provided by the subgrade slope to
meet the normal growth of vegetation, which not only provides
a reasonable physical structure for vegetation growth but also
serves as a platform and carrier [24] for the transformation and
utilization of vegetation moisture and nutrients. Meanwhile, the
vegetation refers to the plant community on the slope, which is
the main biological factor for systematic development and
change. The performance of a slope protection engineering
system mainly refers to the protection performance of the
subgrade slope, which reflects the ability of the slope to resist
external environmental interference. According to the structure
and performance of the slope-matrix-vegetation system, the soil
matrix quality, vegetation community quality, and protection
performance are taken as first-level indexes, and second-level
evaluation indexes are further analyzed and screened.

The soil in the DHV area is dominated by torrid red soil
[25]. This type of soil has a low moisture content, high
nutrient loss, and a barren soil layer. Meanwhile, the soil
guarantees vegetation survival on the slope in the green
protection of the slope. The quality of the soil matrix is
therefore a factor that cannot be ignored. The soil matrix
quality can be measured by the volumetric weight of soil
[26], total soil porosity, soil infiltration rate, soil organic
matter and mineral nutrient content, soil expansion and
contraction, duration of the soil permanent wilting point
(PWP), and the ability of the soil to preserve moisture and
fertility [27]. Specifically, the volume weight of soil reflects
the comprehensive state of soil organic matter, texture, and
compactness; therefore, the volume weight of soil is an
important physical characteristic that reflects the quality of
the soil matrix. Total soil porosity [25] includes capillary
porosity and noncapillary porosity. Capillary porosity refers
to the main pore size for soil water retention, and it provides
water for plant growth. Noncapillary porosity refers to the
main breathable pore size of the soil, and it provides oxygen
and nutrients to plant roots in the soil. Moreover, the po-
orosity of the soil affects the infiltration rate [28] of the soil.
The infiltration rate affects the circulation, maintenance, and
storage of water in the soil. The water infiltrated into the soil
is the main source of water for the plant root system. Torrid
red soil is compact and the infiltration rate decreases with
increasing depth of the soil layer. The infiltration rate is
therefore an important factor in evaluating the quality of the
soil matrix. Carbonaceous compounds in soil are the main
components of soil organic matter [29] and are one of the
main sources of nutrients needed for the growth of slope
protection vegetation. The other source is mainly mineral
nutrients [30] containing trace elements such as total N, total
P, available P, and available K [31] in the soil. The content of
organic matter and mineral nutrients in the soil is therefore
an indispensable factor in measuring the quality of the soil
matrix. There are distinct dry and wet seasons in the DHV
area, resulting in the large expansion and contraction of soil
[32] due to temperature changes. The soil expansion and
contraction creates cracks in the slope. In the long run, such
cracks cause the slope to collapse, and expansion and
contraction damages plant root systems and causes plants to
die. Therefore, the root systems of slope plants must have a
certain tensile strength. Moreover, the alternation of a dry
and wet environment affects the mineralization rate of or-
ganic carbon in soil and thus the nutrient content of the soil.
The soil PWP [33] in the DHV area lasts for a long time,
usually 7-8 months, and this is the main cause for the sparse
vegetation. Slope protection must therefore improve the
quality of the soil matrix and thus shorten the duration of the
soil PWP to increase the survival rate of plants. Owing to
severe soil coarsening in the DHV area, the soil’s ability to
retain water and fertilizer is reduced, and soil fertility is
reduced. This is a major cause of soil infertility, and the soil
coarsening resistance and water and fertilizer retention
should thus be improved in slope protection.

The quality of a vegetation community is mainly measured
by the vegetation coverage, the vegetation survival rate, in-
cidence of vegetation diseases and insect pests, vegetation
species richness index, rationality of vegetation spatial collo-
cation, ability of vegetation to resist drought and heat, and
tolerance of vegetation to barrenness. Owing to the hot climate
in the DHV area, the soil is relatively infertile and lacks
nutrients, resulting in extremely scarce vegetation [34] in this
area. However, the construction of the railway greatly affected the environment of the area, and plants are therefore planted in the subgrade slope protection project not only to stabilize the subgrade but also to improve the local ecological environment. The numbers and types of slope protection vegetation must meet the requirements of slope protection and environmental improvement in the area, and vegetation coverage can be used as a measure of the number of plants and the area covered by vegetation. Owing to the harsh environment, there are many plant diseases and insect pests in the DHV area, which is a major reason for the low rate of plant survival. The survival rate of plants must therefore be improved by improving the soil and selecting suitable plant species. For slope protection vegetation, shrubs and herbaceous plants that are rich in variety and suitable for DHV growth should be selected. This vegetation has developed roots and strong root meristem, which can further improve the protection ability of slope by improving the soil shear strength. Moreover, vegetation with a strong meristematic ability can improve the coverage of slope vegetation in the short term and enhance the ability of slope stabilization, and vegetation suitable for the area can improve the soil and enhance soil fertility. When planting vegetation, it is also necessary to consider the rationality of the spatial arrangement and distribution. A reasonable structural arrangement can further improve the survival rate of plants and play a positive role in reinforcing the slope. Moreover, the climate of the DHV area is arid and hot; therefore, the selected vegetation should flourish in such a climate.

The protective performance of a slope mainly refers to the slope’s resistance to leaching erosion, antiscouring ability, ability to protect against wind and sand, ability to prevent water and soil loss, and ability to prevent natural disasters. Rainfall is concentrated in the DHV area, but evaporation is generally 3–6 times the rainfall. The amount of water infiltrating the soil is too large in the season of concentrated rainfall, and the infiltration water dissolves and leaches nutrients in the soil, such that the slope resistance to leaching erosion is important. Moreover, a large amount of rainwater will scour the slope surface and base, resulting in water and soil loss. Therefore, the slope must also have a strong ability to prevent water and soil loss and scouring. The land is gradually desertified in the DHV area owing to the coarsening of the soil. In addition, there is often windy weather, which causes severe weather such as sandstorms. Therefore, the ability of a slope to resist wind and sand is also important. Moreover, earthquakes, mudslides, landslides, and floods often occur in the area. Subgrade slope protection projects must therefore be able to resist sudden natural disasters and prevent slope collapse from causing serious damage to the environment and railways.

From the above analysis, the more important factors in evaluating the green protection effect of a slope in the DHV area are summarized in Table 1.

3.2. Construction of an Evaluation Index System. Through the above analysis of the soil, vegetation, hydrology, climate, topography, landform, and other geographical features of the DHV area in southwest China and referring to Interim Provisions on Green Protection Techniques for Railway Subgrade Slopes (2003) and relevant research results, the three first-level indexes of the soil matrix quality, vegetation community quality, and protective performance of the slope are determined, and an evaluation index system is established through the further refinement and screening of 20 evaluation indexes as second-level indexes, as shown in Figure 2.

A five-level index standard, as described in Table 2, is established on the basis of the evaluation index system, the grading data of organic matter content of a soil survey conducted in China, relevant research results, and consultation with experts.

4. Combination Weighting Model

Methods of determining weights can be divided into subjective weighting methods and objective weighting methods. The disadvantage of a subjective weighting method is the excessive reliance on the opinions of experts while the disadvantage of an objective weighting method is the excessive reliance on quantitative data, but these two methods are complementary. Therefore, to ensure that the weight distribution reflects both the subjective information and objective information, this paper uses GT to combine the weights obtained from both the subjective weighting method (i.e., the IGAHP method) and the objective weighting method (i.e., the vector-angle-cosine method), which make the weighting more reasonable and scientific.

4.1. IGAHP Method. The IGAHP method is based on the traditional analytic hierarchy process (AHP) method and considers the difference between different expert evaluations and assigns a weighting coefficient to each expert using the Euclidean distance to minimize the expert’s evaluation bias so that the weight of the index is more reasonable.

The weights of m indexes calculated by the tth expert using the AHP method are denoted as

$$Y^{(t)} = (y^{(t)}_1, y^{(t)}_2, \ldots, y^{(t)}_m),$$  \hspace{1cm} \text{(1)}$$

where $y^{(t)}_i$ is the AHP weight of the ith index given by the tth expert.

The difference between the evaluations of the gth and hth experts is then expressed by the Euclidean distance $d_{gh}$, where $g, h = 1, 2, 3, \ldots, T$:

$$d_{gh} = d(Y^{(g)}, Y^{(h)}) = \left[ \sum_{i=1}^{m} (y^{(g)}_i - y^{(h)}_i)^2 \right]^{1/2},$$ \hspace{1cm} \text{(2)}$$

where $y^{(g)}_i$ and $y^{(h)}_i$ are, respectively, the weights of the ith index given by the gth and hth experts, satisfying $d_{hh} = 0$ and $d_{gh} = d_{hg} \geq 0$.

Equation (2) shows that closer values of $Y^{(g)}$ and $Y^{(h)}$ (i.e., smaller differences between the evaluations of the two experts) result in smaller $d_{gh}$ if $d_{gh} = 0$ and $g \neq h$, then the evaluations of the two experts are exactly the same.
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#### Table 1: Evaluation indexes and description.

| First-level indexes | Second-level indexes | Index description |
|---------------------|----------------------|-------------------|
| Soil matrix quality, \( C_1 \) | Volumetric weight of soil, \( C_{11} \) (g cm\(^{-3}\)) | Refers to the mass of the soil per unit volume, reflecting the compactness of the soil. |
|                     | Total soil porosity, \( C_{12} \) (%) | Includes capillary porosity and noncapillary porosity, reflecting the soil’s ability to breathe and permeate. |
|                     | Organic matter content, \( C_{13} \) (g kg\(^{-1}\)) | Refers to the amount of all carbon-containing organic compounds present in the soil. |
|                     | Duration of soil PWP, \( C_{14} \) (month) | Refers to the time that the soil moisture is reduced to the humidity of the soil when the plant begins to wither. |
|                     | Soil infiltration rate, \( C_{15} \) (mm h\(^{-1}\)) | Refers to the amount of infiltration water per unit area of soil per unit time. |
|                     | Content of mineral nutrients, \( C_{16} \) (g kg\(^{-1}\)) | Refers to the content of various trace elements, such as total N, available P, and available K, in the soil. |
|                     | Ability of soil to preserve moisture and fertility, \( C_{17} \) | Reflects the soil’s ability to sustain moisture and fertility. |
|                     | Soil expansion and contraction, \( C_{18} \) | Refers to the ability of the soil to expand and contract through water absorption and dehydration. |
| Vegetation community quality, \( C_2 \) | Coverage of vegetation, \( C_{21} \) (%) | Ratio of the vertical projection area of vegetation (including leaves, stems, and branches) to the ground. |
|                     | Vegetation survival rate, \( C_{22} \) (%) | Represents the number of plants that survived as a percentage of the total planted. |
|                     | Incidence of pests and diseases in vegetation, \( C_{23} \) (%) | Refers to the percentage of vegetation with pests and diseases. |
|                     | Vegetation species richness index, \( C_{24} \) | Refers to the number of species in the community, reflecting the richness of vegetation species. |
|                     | Rationality of vegetation spatial collocation, \( C_{25} \) (%) | Reflects the biological characteristics of the vegetation population and the reasonable degree of intraspecies and interspecies coordination. |
|                     | Ability of vegetation to resist drought and heat, \( C_{26} \) | Reflects the ability of vegetation to resist low temperatures, heat, and drought. |
|                     | Vegetation tolerance to barrenness, \( C_{27} \) | Reflects the ability of vegetation to grow in soils that lack nutrients and water. |
| Protective performance of slope, \( C_3 \) | Slope resistance to leaching erosion, \( C_{31} \) | Refers to the ability of the soil matrix to resist the infiltration of water and leaching of soil nutrients. |
|                     | Antiscouring ability, \( C_{32} \) | Refers to the ability of the slope as a whole to resist mechanical damage and movement such as that of rain and runoff. |
|                     | Ability of slope to protect against wind and sand, \( C_{33} \) | Refers to the ability of slopes to maintain soil and water and prevent severe weather such as sandstorms. |
|                     | Slope resistance to natural disasters, \( C_{34} \) | Refers to the ability of the slope to resist natural disasters, such as mudslides, earthquakes, landslides, floods, and collapses. |
|                     | Ability of slope to prevent water and soil loss, \( C_{35} \) | Refers to the ability of the slope to resist damage to soil and land productivity under external forces. |

The sum \( d_t \) of the values of the degree of similarity of the evaluations made by the \( r \)-th expert and other experts is expressed by

\[
d_t = \sum_{j=1}^{T} d_{ij}, \quad j = 1, 2, \ldots, T, \quad (3)
\]

where \( T \) is the number of experts while \( d_{ij} \) is the degree of similarity of the evaluations of the \( t \)-th and \( j \)-th experts. The evaluation weight coefficient \( \lambda_i \) of the \( t \)-th expert is calculated as

\[
\lambda_i = \begin{cases} 
\lambda_1 = \lambda_2 = \cdots = \lambda_T = \frac{1}{T}, & d_t = 0; \\
\lambda_t = \frac{1}{d_t} \sum_{j=1}^{T} \left( \frac{1}{d_j} \right), & d_t \neq 0.
\end{cases} \quad (4)
\]

In summary, the subjective weight \( W_i \) determined using the IGAHP method can be calculated as

\[
W_i = \sum_{t=1}^{T} \lambda_i y^{(t)} = \sum_{t=1}^{T} \lambda_i \left( y_1^{(t)}, y_2^{(t)}, \ldots, y_m^{(t)} \right), \quad (5)
\]

#### 4.2. Vector-Angle-Cosine Method [45]

\[Step 1. \] Construct the optimal value vector \( S^* \) and worst value vector \( s^* \) of the evaluation index as

\[
S^* = (S_1^*, S_2^*, \ldots, S_m^*), \quad (6)
\]

\[
s^* = (s_1^*, s_2^*, \ldots, s_m^*), \quad (7)
\]

where \( S_i^* \) and \( s_i^* \) are
$$S_i^* = \begin{cases} \max_{1 \leq j \leq n} [V_{ij}], & i \in I_1, \\ \min_{1 \leq j \leq n} [V_{ij}], & i \in I_2, \end{cases} \quad (8)$$

$$s_i^* = \begin{cases} \min_{1 \leq j \leq n} [V_{ij}], & i \in I_1, \\ \max_{1 \leq j \leq n} [V_{ij}], & i \in I_2, \end{cases} \quad (9)$$

where $S^*$ is the optimal value vector of the evaluation index, $S_i^*$ is the optimal value of the $i$th evaluation index, $s^*$ is the worst evaluation vector of the evaluation index, $s_i^*$ is the worst evaluation value of the $i$th evaluation index, $m$ is the number of evaluation indexes, $n$ is the number of experts, $I_1$ is a positive index set, $I_2$ is a negative index set, and $V_{ij}$ is the basic data of the $i$th index measured by the $j$th expert.

Step 2. Calculate the matrix $R$ of the relative deviation between the evaluation object and the optimal value vector and calculate the matrix $\Delta$ of the relative deviation between the evaluation object and the worst-value vector:

**Figure 2: Evaluation index system.**
Step 3. Determine the value of the vector angle cosine expert.

\[ R = (r_{ij})_{mox} = \left( \frac{|V_{ij} - S_i^*|}{\max_{1 \leq j \leq n}(V_{ij}) - \min_{1 \leq j \leq n}(V_{ij})} \right)_{mox}, \]

\[ \Delta = (\delta_{ij})_{mox} = \left( \frac{|V_{ij} - S_i^*|}{\max_{1 \leq j \leq n}(V_{ij}) - \min_{1 \leq j \leq n}(V_{ij})} \right)_{mox}, \]

where \( r_{ij} \) is the optimal value of the relative deviation of the \( i \)th index calculated from the basic data given by the \( j \)th expert while \( \delta_{ij} \) is the worst value of the relative deviation of the \( i \)th index calculated from the basic data given by the \( j \)th expert.

Step 3. Determine the value of the angle cosine \( c_i \) of the evaluation index (equation (12)) and then normalize it to obtain the objective weight \( W_2 \) (equation (13)):

\[ c_i = \cos(r_i, \delta_i) = \frac{\sum_{j=1}^{n} r_{ij} \delta_{ij}}{\sqrt{\sum_{j=1}^{n} r_{ij}^2} \sqrt{\sum_{j=1}^{n} \delta_{ij}^2}}, \]

\[ W_2 = (w_1^C, w_2^C, \ldots, w_m^C)^T, \]

where the equation \( w_i^C = c_i/\sum_{i=1}^{m} c_i \) is used in normalization and \( w_i^C \) is the vector-angle-cosine weight of the \( i \)th index.

4.3. GT Combination Weighting Model. The GT [46, 47] combination weighting model is constructed by finding the minimum deviation between subjective and objective weights to obtain a compromise value considering the conflict between subjective and objective weights. This achieves the effect of making an interactive decision between subjective and objective weights, so as to obtain the optimal combination of weights.

Supposing \( \theta_1 \) and \( \theta_2 \) are the weighting coefficients of subjective and objective weights and \( L \) is the number of methods used to determine the weights, the combination weight \( W^* \) is calculated as

\[ W^* = \sum_{k=1}^{L} \theta_k W_k^T = \theta_1 W_1^T + \theta_2 W_2^T, \]

where \( W_1^T \) and \( W_2^T \) are the transposed matrices of \( W_1 \) and \( W_2 \).

Specifically, the combination weights are obtained by the following calculation.

The values of \( \theta_1 \) and \( \theta_2 \) are optimized according to the aggregation model of GT:

\[ \begin{align*}
\min & \| \theta_1 W_1^T + \theta_2 W_2^T - W_k^T \|_2^2 \\
\min & \| \theta_1 W_1^T + \theta_2 W_2^T - W_k^T \|_2^2
\end{align*} \]

According to the differential characteristics of the matrix, the optimal first derivative is obtained from equation (15):

\[ \begin{align*}
\theta_1 W_1^T + \theta_2 W_2^T - W_k^T = W_1^T, \\
\theta_1 W_1^T + \theta_2 W_2^T - W_k^T = W_2^T
\end{align*} \]

The weighted coefficients \( \theta_1 \) and \( \theta_2 \) are obtained by solving equation (16) and then normalizing the solution.
\[
\theta_1' = \frac{\theta_1}{\theta_1 + \theta_2}, \\
\theta_2' = \frac{\theta_2}{\theta_1 + \theta_2},
\]

where \(\theta_1'\) and \(\theta_2'\) are the normalized values of \(\theta_1\) and \(\theta_2\).

The optimized combination weight \(W^*\) is then calculated as

\[
W^* = \sum_{k=1}^L \theta_k \cdot W^T_k = \theta_1' W^T_1 + \theta_2' W^T_2.
\]

5. Evaluation Model

5.1. MCGC Model. The MCGC model [48] is a comprehensive evaluation method suitable for solving uncertainty and fuzziness problems. Through the conversion of qualitative concepts and quantitative data, the evaluation and measurement of the uncertainty problem are realized.

Suppose that \(U\) is a quantitative domain composed of precise values and \(C\) is a qualitative concept on the domain \(U\). For any element \(x\), there is a random number \(\mu(x) \in [0, 1]\) with stable tendency, which is called the membership degree of \(x\) to the qualitative concept \(C\). The distribution of membership degree \(\mu\) on the domain \(U\) forms the membership cloud \(C(x)\), and \([x, \mu(x)]\) constitutes a cloud drop [49]. The expectation \(Ex\), entropy \(En\), and hyperentropy \(He\) are introduced to represent the eigenvalues of the cloud. The expectation \(Ex\) is the point value on the domain \(U\) that can best represent the fuzzy qualitative concept \(C\), indicating the central value of the fuzzy concept \(C\) in the domain, which is the central distribution of the cloud.

Entropy \(En\) is the degree of uncertainty of qualitative concept \(C\), which reflects the random probability of cloud droplet of qualitative concept \(C\) and the acceptable range of cloud droplet of qualitative concept \(C\) in domain \(U\), and the greater the entropy value, the greater the randomness. Hyperentropy \(He\) is a measure of the uncertainty of entropy, which reflects the degree of cloud dispersion and cloud thickness, as shown in Figure 3.

In Figure 3, \(Ex\) is the average of the cloud, which represents the qualitative concept. \(En\) represents the value range of qualitative concepts in the domain space, which reflects the “wide” and “narrow” of the cloud. \(He\) represents the randomness of the sample values and provides a method to combine the ambiguity and randomness, which reflects the “thickness” and “thinness” of the cloud [50].

5.2. Determining the Eigenvalues of the Standard Evaluation Level. Experts in relevant fields, such as railway subgrade slope construction, slope green protection, and the natural environment of the DHV area, were invited to give numerical intervals for the five evaluation levels of excellent, good, general, poor, and very poor. The inverse cloud generator of MATLAB software was used to generate eigenvalues of the standard evaluation level. The relevant formulas are

\[
\begin{align*}
Ex_{ij} &= \frac{R^i_{j\text{min}} + R^i_{j\text{max}}}{2}, \\
En_{ij} &= \frac{R^i_{j\text{max}} - R^i_{j\text{min}}}{6}, \\
He_{ij} &= k,
\end{align*}
\]

where \(R^i_{j\text{min}}, R^i_{j\text{max}}, i = 1, 2, \ldots, n; j = 1, 2, \ldots, 5\) is the numerical interval of the \(j\)th standard evaluation level given by the \(i\)th expert; \(Ex_{ij}, En_{ij}\), and \(He_{ij}\) are the values of expectation, entropy, and hyperentropy obtained from the numerical intervals of the standard evaluation levels given by each expert, and \(k\) is a constant that can be set according to needs.

Assuming that the weights of the evaluation experts are the same, the eigenvalues of the standard evaluation level are

\[
\begin{align*}
Ex_j &= \frac{Ex_{i1}En_j + Ex_{i2}En_j + \cdots + Ex_{in}En_j}{En_{i1} + En_{i2} + \cdots + En_{in}}, \\
En_j &= En_{i1} + En_{i2} + \cdots + En_{in}, \\
He_j &= \frac{He_{i1}En_j + He_{i2}En_j + \cdots + He_{in}En_j}{En_{i1} + En_{i2} + \cdots + En_{in}}.
\end{align*}
\]

where \(Ex_{ij}, En_{ij}\), and \(He_{ij}\) are the eigenvalues obtained by integrating the expectation, entropy, and hyperentropy calculated from the numerical intervals of the \(j\)th standard evaluation level given by all experts.

5.3. Aggregation of Evaluation Indexes. Index aggregation refers to determining the corresponding standard evaluation level according to the data of second-level indexes collected by each expert to obtain the eigenvalues of second-level indexes and then performing parallel aggregation to obtain the weighted eigenvalues of second-level indexes. Finally, vertical upward aggregation is performed to obtain the eigenvalues of first-level indexes and the eigenvalues of the evaluation result.

5.3.1. Parallel Aggregation.

\[
\begin{align*}
Ex &= \frac{\sum_{i=1}^n (Ex_i \times \delta_i)}{\sum_{i=1}^n \delta_i}, \\
En &= \frac{\sum_{i=1}^n (En_i \times \delta_i)}{\sum_{i=1}^n \delta_i}, \\
He &= \frac{\sum_{i=1}^n (He_i \times \delta_i)}{\sum_{i=1}^n \delta_i},
\end{align*}
\]
where \( \delta_i (i = 1, 2, \ldots, n) \) denotes the weight of the \( i \)th expert (i.e., the expert weight coefficient determined using the IGAHP method) while \( \text{Ex}, \text{En}, \) and \( \text{He} \), respectively, refer to the expectation, entropy, and hyperentropy of the second-level indexes after parallel aggregation.

5.3.2. Vertical Upward Aggregation.

\[
\begin{align*}
\text{Ex} & = \frac{\sum_{i=1}^{m} (\text{Ex}_i \times \text{En}_i \times W_i^*)}{\sum_{i=1}^{m} (\text{En}_i \times W_i^*)}, \\
\text{En} & = \sum_{i=1}^{m} (\text{En}_i \times W_i^*), \\
\text{He} & = \frac{\sum_{i=1}^{m} (\text{He}_i \times \text{En}_i \times W_i^*)}{\sum_{i=1}^{m} (\text{En}_i \times W_i^*)}.
\end{align*}
\]

where \( W_i^* (i = 1, 2, \ldots, m) \) is the weight of the GT combination of the \( i \)th index while \( \text{Ex}, \text{En}, \) and \( \text{He} \), respectively, refer to the expectation, entropy, and hyperentropy after vertical upward aggregation.

5.4. Generating a Cloud Map of Evaluation Results. The eigenvalues of the evaluation result are finally obtained through parallel aggregation and vertical upward polymerization. The eigenvalues of the evaluation result and the eigenvalues of the five evaluation levels are input to the forward cloud generator of MATLAB software to obtain the cloud map of evaluation results.

6. Case Study

6.1. Generating Eigenvalues of the Standard Evaluation Level.

The standard evaluation levels of excellent, good, general, poor, and very poor do not have precise numerical intervals; i.e., there are no eigenvalues of the standard evaluation level. Therefore, two experts on the construction of railway subgrade slopes, two experts on the green protection of subgrade slopes, and two experts on the natural environment in the DHV area were invited to give numerical intervals for the five standard evaluation levels. The intervals are given in Table 3.

The numerical intervals in Table 3 and equations (19) and (20) are input into the reverse cloud generator of MATLAB software to obtain the eigenvalue of the standard evaluation level, as shown in Table 4.

6.2. Engineering Case. The Sichuan-Tibet railway runs from Chengdu, the capital of Sichuan, to Lhasa, the capital of Xizang, which is divided into three sections: Chengdu to Ya’an (Chengya section), Ya’an to Nyingchi (Yalin section), and Nyingchi to Lhasa (Lalin section). The Chengya section was officially opened to traffic on December 28, 2018, the Lalin section has now entered the track-laying phase, and the most difficult Yalin section is now under construction. Most areas the railway passes through are mountains, hills, and valleys, where the climate is extremely harsh and natural disasters such as floods, sandstorms, and earthquakes are common. In particular, Luding and surrounding areas of the Dadu River Basin, Batang and surrounding areas of the Jinsha River Basin, and parts of the Yapan River and other areas along the Sichuan-Tibet railway have DHV areas.

After consulting the six experts as described above, a section of the railway from Ya’an to Kangding of the Sichuan-Tibet railway, which is mainly located in Dadu River Basin in Luding County and passes through DHV area, is selected as the research object. The area has a subhumid climate on the Qinghai-Tibet Plateau and is influenced by
Table 3: Numerical interval values of standard evaluation levels.

| Experts | Excellent | Good | General | Poor | Very poor |
|---------|-----------|------|---------|------|-----------|
| 1       | (0.82, 0.96) | (0.70, 0.81) | (0.60, 0.69) | (0.47, 0.59) | (0.33, 0.46) |
| 2       | (0.84, 0.97) | (0.73, 0.83) | (0.62, 0.72) | (0.50, 0.61) | (0.35, 0.49) |
| 3       | (0.86, 0.98) | (0.74, 0.85) | (0.61, 0.73) | (0.48, 0.60) | (0.33, 0.47) |
| 4       | (0.83, 0.96) | (0.74, 0.82) | (0.59, 0.73) | (0.45, 0.58) | (0.31, 0.44) |
| 5       | (0.82, 0.93) | (0.75, 0.81) | (0.64, 0.74) | (0.51, 0.63) | (0.32, 0.50) |
| 6       | (0.85, 0.95) | (0.73, 0.84) | (0.61, 0.72) | (0.46, 0.60) | (0.32, 0.45) |

Table 4: Eigenvalue of standard evaluation levels.

| Eigenvalue | Excellent | Good | General | Poor | Very poor |
|------------|-----------|------|---------|------|-----------|
| Ex          | 0.8976    | 0.7790 | 0.6667  | 0.5392 | 0.3985    |
| En          | 0.00608   | 0.0475 | 0.0550  | 0.0617 | 0.0708    |
| He          | 0.0062548 | 0.0063105 | 0.0062621 | 0.0062986 | 0.0062808 |

the southeast and southwest monsoons and the cold air on the Qinghai-Tibet Plateau. The annual precipitation is 664.4 mm, and the evaporation is 1480.9 mm. November to April of the next year is the dry season, which is a typical DHV area [51]. The soil types mainly include red soil, mountain brown soil, and mostly leached soil, which is very likely to cause geological disasters. Vegetation is mostly alpine shrubs and meadows, as well as *Opuntia* sp., succulent shrubs, and *Acacia farnesiana* and *Pistacia weilmannifolia* communities. The six experts were invited to select different locations of the subgrade slope project to measure the index data through on-site investigation and sample testing. Specifically, the subordinate indexes of soil matrix quality, such as volumetric weight of soil and total soil porosity, are measured by the cutting ring method, and the soil infiltration rate and organic matter content are measured by the round block technique and the CODcr method, respectively. The subordinate indexes of vegetation community quality are determined by the plant community sample survey method, and the species richness index refers to the Shannon–Wiener index. The strength of qualitative indexes such as soil expansion and contraction, antiscouring ability, ability of slope to protect against wind, and sand is given by experts using the visual method according to the actual situation of the study area. The specific data are shown in Table 5.

The evaluation levels of each second-level index are obtained from the basic data in Tables 2–5, as shown in Table 6.

6.3. Determining the Combined Weight

6.3.1. IGAHP Weights. The six experts used the AHP method to analyze and compare the importance of the first-level indexes of the soil matrix quality $C_1$, vegetation community quality $C_2$, and protective performance of the slope $C_3$ and then provided their judgment matrix, which passed a consistency test, as shown in Table 7.

According to the judgment matrix in Table 7, the first-level index weights $Y^{(i)}$ determined using the AHP method are obtained, and these weights are then substituted into equations (1)–(4) to obtain the expert’s weight coefficient $\lambda$:

$$\lambda = (0.2161, 0.1512, 0.1792, 0.1498, 0.0954, 0.2083). \quad (23)$$

$$W_1 = (0.3403, 0.5396, 0.1179). \quad (24)$$

Similarly, the IGAHP weights of second-level indexes are obtained, as shown in Table 8. The detailed calculation process is not described here.

6.3.2. Vector-Angle-Cosine Weights. For the qualitative indexes of the evaluation index system, supposing a score of 10 is the highest score, experts provided a score for the actual conditions. The weight of the vector-angle-cosine method of the first-level indexes is obtained by substituting the scores of the first-level indexes given by experts into equations (6)–(13):

$$W_2 = (0.2864, 0.4045, 0.3091). \quad (25)$$

Similarly, the data of quantitative indexes in Table 5 and the scores of qualitative second-level indexes given by experts are substituted into equations (6)–(13), and the weights of the vector-angle-cosine method for the second-level indexes are then obtained, as shown in Table 8. The scores of qualitative indexes and the detailed calculation process are not provided here.

6.3.3. Combined Weights. The GT combination coefficients of the first-level indexes are obtained by substituting the subjective and objective weights of the first-level indexes determined by the IGAHP method and the vector-angle-cosine method into equations (14)–(17):

$$\theta_1^r = 0.4257,$$

$$\theta_2^r = 0.5743. \quad (26)$$

According to equation (18) and the subjective and objective weights calculated above, the combined weights of the first-level indicators are obtained:
Table 5: Index data.

| Indexes                                                                 | 1     | 2     | 3     | 4     | 5     | 6     |
|------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|
| Volumetric weight of soil (g·cm$^{-3}$)                                | 1.15  | 1.19  | 1.23  | 1.13  | 1.11  | 1.21  |
| Total soil porosity (%)                                                | 57.4  | 59.8  | 61.3  | 58.2  | 56.7  | 62.5  |
| Organic matter content (g·kg$^{-1}$)                                  | 18.2  | 17.6  | 17.3  | 19.4  | 18.5  | 17.9  |
| Duration of soil PWP (month)                                           | 4     | 4     | 3     | 3     | 4     | 6     |
| Soil infiltration rate (mm·h$^{-1}$)                                   | 27.3  | 26.5  | 29.7  | 31.2  | 28.4  | 32.2  |
| Total N (g·kg$^{-1}$)                                                  | 1.49  | 1.8   | 1.5   | 1.4   | 2.05  | 1.8   |
| Available P (P$_2$O$_5$) (g·kg$^{-1}$)                                | 0.013 | 0.014 | 0.016 | 0.018 | 0.019 | 0.013 |
| Available K (K$_2$O) (g·kg$^{-1}$)                                    | 0.09  | 0.095 | 0.099 | 0.088 | 0.11  | 0.07  |
| Ability of soil to preserve moisture and fertility                     | Strong| Strong| Medium| Strong| Medium| Strong|
| Soil expansion and contraction                                         | Weak  | Weak  | Weak  | Medium| Weak  | Weak  |
| Coverage of vegetation (%)                                             | 91.3  | 88.4  | 89.7  | 87.9  | 88.2  | 90.8  |
| Vegetation survival rate (%)                                           | 81.7  | 89.2  | 84.5  | 91.5  | 79.6  | 86.1  |
| Incidence of pests and diseases in vegetation (%)                      | 34.5  | 41.7  | 40.9  | 35.3  | 40.1  | 37.5  |
| Vegetation species richness index                                       | 0.97  | 1.03  | 0.95  | 0.99  | 1.06  | 0.92  |
| Rationality of vegetation spatial collocation                          | Reasonable| Reasonable| Reasonable| Reasonable| Reasonable| Reasonable|
| Ability of vegetation to resist drought and heat                       | Very strong| Strong| Strong| Strong| Strong| Strong|
| Vegetation tolerance to barrenness                                     | Strong| Strong| Very strong| Strong| Strong| Strong|
| Antiscouring ability                                                   | Strong| Strong| Medium| Strong| Medium| Strong|
| Ability of slope to protect against wind and sand                      | Strong| Medium| Strong| Strong| Strong| Strong|
| Slope resistance to natural disasters                                  | Medium| Strong| Strong| Medium| Strong| Strong|
| Ability of slope to prevent water and soil loss                        | Strong| Very strong| Strong| Strong| Medium| Strong|

Table 6: Evaluation level of second-level indexes.

| First-level indexes | Second-level indexes | 1   | 2   | 3   | 4   | 5   | 6   |
|---------------------|----------------------|-----|-----|-----|-----|-----|-----|
| $C_1$               |                      |     |     |     |     |     |     |
| $C_{11}$            | Good                 | Good| General| Good| Good| Good| General|
| $C_{12}$            | Good                 | Good| Excellent| Good| Good| Good| Excellent|
| $C_{13}$            | Good                 | Good| General| Good| Good| Good| Good|
| $C_{14}$            | Good                 | Good| Good| Good| Good| Good| General|
| $C_{15}$            | Good                 | Good| Excellent| Good| Excellent| Good|
| $C_{16}$            | General              | Good| Good| Good| Good| Excellent| Good|
| $C_{17}$            | Good                 | Good| General| Good| General| Good|
| $C_{18}$            | Good                 | Good| General| Good| Good| Good|
| $C_{21}$            | Excellent            | Good| Good| Good| Good| Good| Excellent|
| $C_{22}$            | Good                 | Good| Good| Excellent| General| Excellent| General|
| $C_{23}$            | Good                 | General| General| Good| General| Good|
| $C_{24}$            | Good                 | Excellent| Good| Good| Excellent| Good|
| $C_{25}$            | Good                 | Good| Good| Good| Good| Good| Good|
| $C_{26}$            | Excellent            | Good| Good| Good| Good| Good| Good|
| $C_{27}$            | Good                 | Good| Excellent| Good| Good| Good| Good|
| $C_{31}$            | Good                 | Good| Good| Good| Good| Excellent| Good|
| $C_{32}$            | Good                 | Good| General| Good| General| Good|
| $C_{33}$            | Good                 | General| Good| Good| Good| Good| Good|
| $C_{34}$            | General              | Good| General| Good| General| Good|
| $C_{35}$            | Good                 | Excellent| Good| Good| General| Good|

Table 7: Judgment matrix for first-level indexes.

| $C_1$ | $C_2$ | $C_3$ |
|-------|-------|-------|
| $C_1$ | 1     | 1     | 1     | 1     | 1     | 1/2   | 1/3   | 1/3   | 1/3   | 1     | 3     | 1/2   | 1/3   | 1/3   | 1/3   | 1     | 3     | 1     | 3     | 2     | 2     | 3     | 4     | 5     |
| $C_2$ | 2     | 3     | 3     | 1     | 1/3   | 2     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 4     | 7     | 4     | 2     | 3     | 6     |
| $C_3$ | 1/3   | 1/2   | 1/2   | 1/3   | 1/4   | 1/4   | 1/7   | 1/4   | 1/2   | 1/3   | 1/6   | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |
Similarly, the GT combination coefficient of the second-level index is obtained and the combined weights of the second-level indexes are then obtained, as shown in Table 8. The detailed calculation process is not described here.

6.4. Index Aggregation. According to the calculation of the subjective weight adopting the IGAHP, the weight of each expert is $\delta = \lambda = (0.2161, 0.1512, 0.1792, 0.1498, 0.0954, 0.2083)$.

Similarly, the GT combination coefficient of the second-level indexes is obtained and the combined weights of the second-level indexes are then obtained, as shown in Table 8. The detailed calculation process is not described here.

$W^* = (0.3093, 0.4620, 0.2287)$.  

(27)

Table 8: Weights of second-level indexes.

| Indexes | Weights of the IGAHP method | Weights of the vector-angle-cosine method | GT combination weights |
|---------|-----------------------------|-----------------------------------------|------------------------|
| $C_{11}$ | 0.0439                      | 0.0529                                  | 0.0487                 |
| $C_{12}$ | 0.0418                      | 0.0522                                  | 0.0474                 |
| $C_{13}$ | 0.0501                      | 0.0646                                  | 0.0579                 |
| $C_{14}$ | 0.0399                      | 0.0527                                  | 0.0468                 |
| $C_{15}$ | 0.0352                      | 0.0541                                  | 0.0453                 |
| $C_{16}$ | 0.0654                      | 0.0570                                  | 0.0609                 |
| $C_{17}$ | 0.0337                      | 0.0340                                  | 0.0339                 |
| $C_{18}$ | 0.0612                      | 0.0740                                  | 0.0681                 |
| $C_{21}$ | 0.0455                      | 0.0405                                  | 0.0428                 |
| $C_{22}$ | 0.0379                      | 0.0598                                  | 0.0496                 |
| $C_{23}$ | 0.0401                      | 0.0430                                  | 0.0417                 |
| $C_{24}$ | 0.0520                      | 0.0625                                  | 0.0576                 |
| $C_{25}$ | 0.0271                      | 0.0333                                  | 0.0304                 |
| $C_{26}$ | 0.0466                      | 0.0570                                  | 0.0522                 |
| $C_{27}$ | 0.0297                      | 0.0364                                  | 0.0333                 |
| $C_{31}$ | 0.0406                      | 0.0497                                  | 0.0455                 |
| $C_{32}$ | 0.0263                      | 0.0292                                  | 0.0279                 |
| $C_{33}$ | 0.0491                      | 0.0659                                  | 0.0581                 |
| $C_{34}$ | 0.0262                      | 0.0315                                  | 0.0291                 |
| $C_{35}$ | 0.0394                      | 0.0497                                  | 0.0449                 |

Table 9: Eigenvalue of second-level indexes after parallel aggregation.

| First-level indexes | Second-level indexes | Ex           | En           | He           |
|---------------------|----------------------|--------------|--------------|--------------|
| $C_1$               | $C_{11}$             | 0.735484     | 0.050706     | 0.0062901    |
|                     | $C_{12}$             | 0.824958     | 0.053186     | 0.0062871    |
|                     | $C_{13}$             | 0.758876     | 0.048864     | 0.0062937    |
|                     | $C_{14}$             | 0.755608     | 0.049343     | 0.0062990    |
|                     | $C_{15}$             | 0.821471     | 0.052458     | 0.0062901    |
|                     | $C_{16}$             | 0.766046     | 0.050169     | 0.0062795    |
|                     | $C_{17}$             | 0.748162     | 0.049250     | 0.0062996    |
|                     | $C_{18}$             | 0.762177     | 0.048453     | 0.0062975    |
| $C_2$               | $C_{21}$             | 0.829334     | 0.054285     | 0.0062824    |
|                     | $C_{22}$             | 0.803704     | 0.052844     | 0.0062901    |
|                     | $C_{23}$             | 0.731183     | 0.050221     | 0.0062983    |
|                     | $C_{24}$             | 0.808247     | 0.049907     | 0.0063009    |
|                     | $C_{25}$             | 0.779000     | 0.047500     | 0.0063110    |
|                     | $C_{26}$             | 0.804629     | 0.051017     | 0.0062962    |
|                     | $C_{27}$             | 0.800253     | 0.050604     | 0.0063008    |
| $C_3$               | $C_{31}$             | 0.790314     | 0.048185     | 0.0063081    |
|                     | $C_{32}$             | 0.748162     | 0.049250     | 0.0062996    |
|                     | $C_{33}$             | 0.762020     | 0.048471     | 0.0063047    |
|                     | $C_{34}$             | 0.737909     | 0.050436     | 0.0062918    |
|                     | $C_{35}$             | 0.773540     | 0.051064     | 0.0062917    |

Substituting the eigenvalues of the second-level indexes obtained according to Tables 4–6 and the weight of the experts into equation (21) gives the eigenvalues of the second-level indexes after parallel aggregation, as shown in Table 9.

According to the values in Tables 8 and 9, vertical upward aggregation is performed using equation (22), and the eigenvalues of the first-level indexes and the evaluation result are obtained, as shown in Table 10.

6.5. Cloud Map of Evaluation Results. The eigenvalues $(Ex^0, En^0, He^0)$ of the standard evaluation levels in Table 4
and the eigenvalues \((\text{Ex}^*, \text{En}^*, \text{He}^*)\) of the evaluation result in Table 10 are input into the forward cloud generator of MATLAB software, and a contrast cloud map of evaluation results and standard evaluation levels of the green protection effect of the subgrade slope in the DHV area of the Sichuan-Tibet railway is obtained, as shown in Figure 4.

In Figure 4, the blue map is the cloud map of the standard evaluation level “excellent,” the pink map is the cloud map of the standard evaluation level “good,” the yellow map is the cloud map of the standard evaluation level “general,” the green map is the cloud map of the standard evaluation level “poor,” the red map is the cloud map of the standard evaluation level “very poor,” and the black map is the cloud map of the evaluation result. The figure shows that the cloud map of the evaluation result is basically contained in the cloud map of the standard evaluation level “good,” and the evaluation value corresponding to the vertex of the evaluation result cloud map (i.e., the expectation \(\text{Ex}^* = 0.781816\) of the evaluation result) is close to the expectation \(\text{Ex}^0 = 0.7790\) of the standard evaluation level “good.” Therefore, the green protection effect of this railway subgrade slope in the DHV area is “good.” The evaluation result is consistent with the actual protection effect of the expert on-site investigation.

To further determine the accuracy of the evaluation results, an evaluation cloud map comparing the first-level indexes of the soil matrix quality \(C_1\), vegetation community quality \(C_2\), and protective performance of the slope \(C_3\) with the standard evaluation level is also generated, as shown in Figures 5–7.

Figures 5–7 show that the evaluation cloud maps of the soil matrix quality \(C_1\), vegetation community quality \(C_2\), and protective performance of the slope \(C_3\) (i.e., the first-level indexes) are all between the cloud maps of the standard evaluation levels “good” and “excellent” and very close to the cloud map of the standard evaluation level “good.” In particular, the evaluation cloud maps of \(C_1\) and \(C_3\) are basically completely contained in the cloud map of the standard evaluation level “good,” such that the evaluation level of the three first-level indexes is “good.” By determining the evaluation level of the first-level indexes, it is further confirmed that the green protection effect of the railway subgrade slope in this section is “good.”

### 7. Discussion

The evaluation index system basically contains all the factors that affect the green protection effect for the railway subgrade slope in the DHV area, and the evaluation results are thus convincing. However, the limitation of the evaluation index system is that half the evaluation indexes are qualitative and half are quantitative; i.e., there are too few quantitative indexes and too many qualitative indexes. In addition, the qualitative indexes are only giving their status levels according to the actual conditions observed by experts, which makes the assessment of qualitative indexes too subjective because of the influence of experts themselves. Therefore, how to measure and evaluate qualitative indexes needs further research to improve the accuracy of evaluation.
The advantage of the present study is that a subjective weighting method and objective weighting method are combined to determine the weighting, such that the weight distribution is based on not only the effects of subjective human factors but also the effects of objective sample data, which makes the weight more comprehensive and reasonable. In references [41, 44], only a subjective weight method (AHP) is used, which relies too much on a person’s information and fails to consider the importance of experts themselves. However, this paper uses the IGAHP method not only to consider the importance of the experts themselves but also to use the GT to combine the vector-angle-cosine method with the IGAHP method so that the weights are more accurate. As for the evaluation model, reference [41] uses the grey system theory to calculate the grey level of the evaluation object by constructing the definite weighted function so as to evaluate the quality of slope protection engineering. Reference [44] uses fuzzy comprehensive evaluation method to calculate the comprehensive membership of the research object and determine the slope protection effect of the slope protection project by comparison with the standard membership. Both methods above solve the problem by considering the uncertainty and ambiguity of the research problem, and they have their own advantages. However, the MCGC model not only considers the fuzziness of the research problem but also evaluates it by calculating the sample data and drawing the contrast cloud map with MATLAB software. Furthermore, the model intuitively reflects the evaluation results through a combination of graphics and text, making the evaluation process more detailed and the evaluation results more accurate.

The evaluation results are in good agreement with the actual situation of the railway subgrade slope protection project in the studied section of the Sichuan-Tibet railway. This shows that the construction of the subgrade slope protection project complies with the requirements of China to protect the ecological environment when constructing railways. However, only six experts were invited to collect data, and small data sample resulted in slight bias in the calculation results. Therefore, in future research, it will be necessary to take as many sample data as possible to improve the accuracy of the results. Moreover, it is worth mentioning...
that the present research provides a theoretical basis for government to evaluate the quality of the green protection engineering of the railway subgrade slope in the DHV area.

8. Conclusion

(1) Environmental and geographical characteristics were analyzed and combined with the characteristics and requirements of railway subgrade slope protection, and an evaluation index system for the green protection effect of railway subgrade slopes in a DHV area was then established.

(2) Subjective and objective weights of the evaluation indexes were calculated using the IGAHP method and the vector-angle-cosine method, respectively, and GT was then used to combine the subjective and objective weights such that the combined weight not only highlights the particularity of the DHV area but also eliminates the conflict and difference between subjective and objective factors. In addition, an evaluation model was established using the MCGC method, and an evaluation cloud map was drawn with MATLAB software to analyze the evaluation result.

(3) The GT combination weighting model and MCGC evaluation model were used to evaluate the protection effect in a practical engineering case, which is a section of subgrade slope protection engineering passing through the DHV area of the Sichuan-Tibet railway. The evaluation results are in good agreement with the actual engineering situation, demonstrating the applicability and effectiveness of the model.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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