Research on the evaluation of ecological environment quality based on Fuzzy and PCA-AHP

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Abstract. Since the natural ecological environment tends to change slowly and the indicators are easy to quantify in a graded manner, while the social ecological environment tends to change rapidly under the intervention of human production and life, and it is difficult to quantify with the same grading standard in different regions and at different times. Therefore, we propose a Fuzzy comprehensive evaluation model for the evaluation of the quality of natural ecological environment and a PCA-AHP comprehensive evaluation model for the evaluation of the quality of social ecological environment. Based on the hierarchical analysis method, 12 indicators were selected from five criteria levels, namely water and soil conservation, ecological stability, water conservation, soil improvement and air purification, and the affiliation degree of each indicator to the set of comments was calculated using the Fuzzy comprehensive evaluation method. Taking the evaluation of ecological and environmental quality of 31 provincial regions in China as an example, 12 indicators were selected from three criterion levels, namely natural conditions, social economy and environmental pollution, and the combined weight values of each indicator were calculated using PCA and AHP, and the final ecological and environmental quality ranking of each province was obtained based on the data of each of the 31 provinces. The two experimental results were highly consistent with the actual expert evaluations, verifying the rationality of the Fuzzy comprehensive evaluation model and the PCA-AHP comprehensive evaluation model.

Keywords: Fuzzy evaluation model,PCA,indicator system,ecological environment quality,weight.

1. Introduction

Ecological quality assessment refers to the quantitative or qualitative evaluation of the ecological quality of a region in a specific spatial and temporal context through the establishment of a reasonable index system and the use of scientific evaluation methods, which reflects the impact of the environmental elements of the region on the sustainable development of nature and human society [1-5]. The evaluation of ecological quality to study the value of its services has received increasing attention and importance from scholars worldwide [6-9]. At present, the evaluation of ecological environment quality internationally has entered the stage of comprehensive evaluation, a stage that covers the ecological research network of almost all ecological factors such as species [10], vegetation [11], hydrology [12] and soil [13], and the comprehensive analysis of the impact of human activities, land use and management policies on the ecological environment [14-16]. However, from the perspective of research objects, most of the current studies focus on natural ecosystem types such as biomes, forests, wetlands, and marine nature reserves [16-18], and there is a lack of research on the evaluation of social ecological environment quality, and most of the evaluation methods rely on the analytic hierarchy process [19-22], with many qualitative components, making it difficult to make an objective quantitative evaluation of It is difficult to make an objective quantitative evaluation of ecological environment quality. Therefore, this paper proposes a fuzzy comprehensive evaluation model based on index hierarchy for the evaluation of natural ecological environment quality, and quantitatively describes the ecological environment quality before and after the restoration of the Seyhanba mechanical forestry site as an example. It is also considered that the social ecological environment is a multi-level, multi-structural, complex and huge system with a large number of interventions from human production and life, and the ecological environment indicators are changing rapidly, and there are large differences not only in different regions, but also in the same region at different times, so it is difficult to set grading standards for each indicator. This paper proposes a comprehensive evaluation method based on principal component analysis and hierarchical analysis, and quantifies and ranks the ecological quality of 31 provincial regions in China as an example, and makes suggestions for improving ecological quality in areas with low rankings.

2. Principles and Methods of Eco-environmental Quality Assessment Natural Ecosystem Assessment Model

2.1 Natural ecological environment evaluation model

2.1.1 Selection of indicators

According to the principles of comprehensiveness, objectivity, accessibility, representability and measurability in the selection of indicators, and taking into account the characteristics of the vast forest areas, complex terrain and landscape, and significant climatic differences in the Seyhanba region.In this study, five factors were selected as the first level of criteria, namely soil and water conservation, ecological stability, water conservation, soil improvement, air purification, and from these five first level criteria, forest area, forest cover, forest wood storage, average annual wind days, average annual frost-free days, forest water storage capacity, annual precipitation, percentage of wind and sandy soil, soil Organic matter content, carbon sequestration capacity and oxygen production capacity are the 12 indicators used as influencing factors in the first level of the criteria layer. Quantitative analysis was carried out by means of an evaluation model with a time dimension. The table below shows the evaluation indicator system and the observed values of each indicator, using the example of the Seyhanba mechanical forestry site.

Table 1 Evaluation indicator system and observation values for each indicator

Target level	Level 1 guideline level indicators	Tier 2 guideline level indicators	Observed values of evaluation indicators	
			Before restoration (1962)	After restoration (2021)
Ecological impact	Soil and Water Conservation B1	Woodland area / million mu C_{11}	24.00	115.10
		Forest cover/% C_{12}	11.40	82.00
		River sand content/% C_{13}	29.50	11.00
	Ecosystem stability B2	Forest stock/10^4m^3 C_{21}	33.00	1036.80
		Average annual number of windy days/day C_{22}	83.00	53.00
		Average annual frost-free days/days C_{23}	42.00	64.00
	Water Conservation B3	Woodland water storage/10^8m^3 C_{31}	0.59	2.84
		Annual precipitation/mm C_{32}	417.60	479.00
	Improved soil B4	Percentage of wind and sandy soils/% C_{41}	54.35	4.31
		Soil organic matter content/% C_{42}	1.70	8.81
	Purifying the air B5	Carbon sequestration capacity/ million tonnes C_{51}	2.59	86.03
		Oxygen production capacity/tonne C_{52}	1.84	59.84

The evaluation indicators are divided into five evaluation levels, assigned as 1, 2, 3, 4 and 5, which are excellent, good, fair, poor and poor respectively. The five levels of evaluation criteria form the rubric setV = {excellent, good, average, poor, poor}, which is represented by V = { Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ } in the subsequent discussion of this paper. The grading criteria for each evaluation indicator are determined for the classification of evaluation levels. For those with national or industry standards, they are determined according to national or industry standards, and for those without relevant clear regulations, the classification is mainly made with reference to survey results, expert opinions or research conclusions.For indicators that are not clearly defined, the classification is made mainly by reference to the results of surveys, expert opinions or research findings.

2.1.2 Hierarchical analysis to determine weights

Using the hierarchical analysis method, there are generally these steps.

(1) Identify the research questions and the scope of the study, as well as the correspondence between the various elements included in and about the content of the study.

(2) Establish a hierarchical structure, generally divided into a target level, a guideline level and an indicator level.

(3) Construction of judgement matrices: compare two and two factors with each other, when relative scales are used to minimise the difficulty of comparing factors of different nature with each other, in order to improve accuracy. For example, for a certain criterion, the options under it are compared two by two and graded according to their degree of importance. a is a matrix ofy_i andy_j are two factors taken from the set of factors y = $\{y_1, y_2, \cdots, y_n\}$ of the two factors taken out of p_{ij} arey_i andy_j For the results of the comparison of the importance of the W factors, the following table shows the rules of the nine-level scoring system.

Table 2 compares the methods of taking values for assignments

y_i/y_j	Equivalent	Slightly more important	Obviously important	Strongly Important	Extremely important
p_{ij}	1	3	5	7	9

of which

$$\begin{cases} p_{ij} > 0, \\ p_{ij} = \dfrac{1}{p_{ji}}, (i \neq j) \end{cases} \tag{1}$$

If the degree of importance is not odd, then the values are 2, 4, 6, 8.

(4) Calculate the weights: use the obtained judgment matrix as the basis for calculating the final weights, assuming that A passes the consistency test, calculate the maximum eigenvalue of matrix A firstλ_{max}, then use the formula.

$$AW = \lambda_{max} W \tag{2}$$

Solve for λ_{max} The eigenvalues w of the pairs, w after normalisation, gives the result of the weighting of the influence of all the factors at the next level on a factor at the previous level, and the ranking of the weightings tells which factor has a greater influence, i.e. a greater weight, on a factor at the upper level.

(5) Consistency test: Although the use of paired judgment matrices can objectively exclude some influencing factors, there will be a certain degree of non-consistency when used for all the results, so it is necessary to do a consistency test on paired judgment matrices before getting the final results, using the formula.

$$CI = (\lambda_{max} - n) / n\text{-}1 \tag{3}$$

Where CI is is the degree of consistency indicator and n is the order of A. When the calculated result CI is equal to 0, i.e.λ_{max} = n, the judgment matrix A has perfect consistency at this time, and the larger the calculation result of CI, the worse the consistency of the judgment matrix A. Let CR=C1/RI, C1 is the consistency index, RI is the average random consistency index, then CR is called the random consistency ratio. The calculated result in which CR appears less than 0.10 is said to be that matrix A is with satisfactory consistency.

2.1.3 Fuzzy integrated evaluation

Steps in Fuzzy Integrated Evaluation:

Step 1: Determine the set of evaluation factors Q consisting of evaluation indicators. q = $\{q_1, q_2, q_3, \cdots, q_m\}$$q_i$ {i =1,2,⋯,m} are the evaluation indicators.

Step 2: Determine the rubric level set G. G={$g_1, g_2, g_3, \cdots, g_n$ },g_j (j =I,2,⋯, n) denote the levels of evaluation from highest to lowest.

Step 3: Determine the weight set W of the evaluation indicator system. w = {$w_1, w_2, w_3, \cdots, w_m$ } is an indicator indicating the importance of each indicator in the indicator system, and $w_i(i = 1,2,\cdots,m)$ denotes the weight of each indicator.

Step 4: Determine the evaluation affiliation matrix R. Let the evaluation of the first$i$ indicatorq_i of the evaluation$R_i = \{r_{i1}, r_{i2}, r_{i3}, \cdots, r_{in}\}$.$r_{ij}$ denote the evaluation of the$i$ indicator's affiliation with the$j$ affiliation of the first rank. Evaluation vectors from individual indicatorsR_i (i =1,2, - - -,n) form a judgement matrix.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{4}$$

Step 5: Using the synthetic operation of the fuzzy matrix, a comprehensive evaluation model is obtained$T = W°R = (t_1, t_2, t_3, \cdots, t_n)$. T is the affiliation degree of each level indicator to the evaluation level.

Step 6: Let D = $(f_1, f_2, f_3, \cdots, f_n)^T$,wheref_j $(j = 1,2,\cdots,n)$ denotes the$j$ actual data for the level rubric.

Step 7: Calculate the final composite evaluation result M by multiplying the vectors, M =T · D .

The affiliation function is the basis for the application of the fuzzy comprehensive evaluation principle, and whether the affiliation function is correctly constructed is one of the keys to whether the fuzzy comprehensive evaluation can be used well. For the characteristics of comprehensive evaluation of natural ecological environment quality, the more commonly used ascending (descending) semi-trapezoidal affiliation function is used for research. Among them, the descending semi-trapezoidal affiliation function is applicable to positive effect indicators, the larger the value the better the ecological environment impact. The ascending semi-trapezoidal affiliation function is used for the negative effect indicators, the larger the value the worse the ecological impact.The higher the value, the worse the ecological impact.

Affiliation function for positive effect indicators.

When j =1

$$f(x) = \begin{cases} 1, \ x \geq x_j \\ \dfrac{x - x_{j+1}}{x_j - x_{j+1}}, \ x_{j+1} < x < x_j \\ 0, \ x \leq x_{j+1} \end{cases} \tag{5}$$

When $j = 2,3,\cdots,n-1$

$$f(x) = \begin{cases} 0, \ x \geq x_{j-1} \\ \dfrac{x_{j-1} - x}{x_{j-1} - x_j}, \ x_j < x < x_{j-1} \\ \dfrac{x - x_{j+1}}{x_j - x_{j+1}}, \ x_{j+1} < x < x_j \\ 0, \ \ x \leq x_{j+1} \end{cases} \tag{6}$$

When j =n

$$f(x) = \begin{cases} 0, \ x \geq x_{j-1} \\ \dfrac{x - x_{j-1}}{x_j - x_{j-1}}, \ x_j < x < x_{j-1} \\ 1, \ x \leq x_j \end{cases} \tag{7}$$

Affiliation function for negative effect indicators.

When j =1

$$f(x) = \begin{cases} 1, \ x < x_j \\ \dfrac{x_{j+1} - x}{x_{j+1} - x_j}, \ x_j \leq x \leq x_{j+1} \\ 0, \ x > x_{j+1} \end{cases} \tag{8}$$

When $j = 2,3,\cdots,n-1$

$$f(x)=\begin{cases}0, & x \le x_{j-1}\\ \dfrac{x-x_{j-1}}{x_j-x_{j-1}}, & x_{j-1}\le x\le x_j\\ \dfrac{x_{j+1}-x}{x_{j+1}-x_j}, & x_j < x < x_{j+1}\\ 0, & x\ge x_{j+1}\end{cases} \tag{9}$$

When $j = n$

$$f(x)=\begin{cases}0, & x < x_{j-1}\\ \dfrac{x-x_{j-1}}{x_j-x_{j-1}}, & x_{j-1}\le x\le x_j\\ 1, & x\ge x_j\end{cases} \tag{10}$$

In the above equation. $f(x)$ is the affiliation function of individual indicators in the evaluation object set to the evaluation level. x is the actual measured value of each indicator, and x_j, x_{j-1}, x_{j+1} is the corresponding grading standard value of each indicator, respectively.

Taking the evaluation of the ecological environment quality of the Seyhanba mechanical forestry site as an example, the corresponding graded standard values for each indicator are as follows.

Table 3 Corresponding graded standard values for each indicator in level 2

Indicator positivity or negativity	Evaluation indicators	I	II	III	IV	V
Positive indicators	Woodland area / million mu	1	5	25	100	250
	Mori Li coverage/%	10	20	30	40	50
	Forest stock / million m3	50	100	500	1000	2000
	Woodland water storage capacity/billion m3	0.25	1	2.5	10	50
	Annual precipitation/mm	350	400	450	500	550
	Soil organic matter content/%	1.5	2	3.5	6	13
	Carbon sequestration capacity/tonne	2.5	10	50	250	1250
	Oxygen production capacity/tonne	2	8	40	200	1000
	Average annual frost-free days/days	60	90	120	150	180
Negative indicators	River sand content/%	1	5	10	20	30
	Average annual number of windy days/day	20	40	60	80	100
	Percentage of wind and sandy soils/%	5	10	20	30	50

By substituting the second level criterion level indicators into the constructed affiliation function, the affiliation degree of the second level criterion level indicators can be obtained.

Based on the results of the calculation of the weight and affiliation of the indicators at the second level of the criterion layer, the affiliation of each indicator at the first level of the criterion layer Tj, is calculated by the weighted average type fuzzy synthetic operator as follows

$$T_j = \sum_{i=1}^{n}(w_j r_{ij}) \quad (j = 1,2,\cdots,m) \tag{11}$$

This results in the calculation of an affiliation matrix of the indicators at the first level of the criterion layer for each evaluation level.

Based on the first level of criteria level affiliation and the corresponding weight values, the fuzzy operator model is used to calculate the affiliation of the target level to obtain the weight vector of the ecological condition, and the most intuitive and clear principle of maximum affiliation is used to determine the level of the ecological evaluation.

The comprehensive evaluation value of the natural ecological environment is calculated based on the weight vector of ecological conditions and the formula of the comprehensive evaluation value, equation 12.

$$M_k = \sum_{j=1}^{n} t_j \times g_j \quad (k = 1961,2021) \tag{12}$$

2.2 Socio-ecological quality assessment model

2.2.1 Selection of indicators

The socio-ecological environment is a multi-layered, multi-structured and complex system. The scientific selection of correct, well-founded and representative indicator data can help to effectively make a reasonable assessment of the urban ecological environment. This paper has been developed with the advice of experts and with the help of the In this paper, on the basis of expert opinion and the principles of indicator selection, the target level of ecological environment is divided into three criterion levels, namely natural conditions (B1), socio-economic (B2) and environmental pollution (B3), from which the influencing factors are selected.

(1) Natural Conditions Subsystem Indicators :

Forest cover ratio (C_{11}): The ratio of the total forest area of the study area to the total land area of the study area, which indicates how green the study area is. The unit is %.

Annual precipitation (C_{12}): the average annual precipitation for the whole year, characterizing the climatic environment. Unit mm.

Regional water resource share (C_{13}): The percentage of all water resources in the study area, including available surface water and groundwater, to the overall water resources, which gives an indication of the abundance of water resources in the study area. Unit %.

Arable land area (C_{14}): Area of regional agricultural land, indicator of reserve land use, flanking the amount of forest land. Unit ha. Unit %.

(2) Socio-economic subsystem indicators :

Total GDP growth rate (C_{21}): The rate of growth of the Gross National Product (GDP) of the study area in the current year, compared to the GDP of the previous year, indicating the rate of economic development of the city. Unit %.

Share of tertiary sector in GDP (C_{22}): The contribution of tertiary industries such as services, finance and real estate, and high-tech industries to the overall GDP, characterising whether the economic structure is reasonable. Unit %.

Population density (C_{23}): This indicator describes how densely populated a town is and is calculated as the total number of people in a defined unit area. Unit people/k m2 .

The proportion of agricultural workers (C_{24}): The size of a city's agricultural population indicates the city's primary sector, calculated as a percentage of the number of registered agricultural households to the total registered population Example. Unit %.

Natural population growth rate (C_{25}): The ratio of the annual natural increase in the population (births minus deaths) of a region to the total population of the region, indicating the development of the population, and the state of ageing. Unit %.

(3) Environmental pollution subsystem indicators:

Air emissions of sulphur dioxide (C_{31}): All monitoring stations in the study area, the amount of sulphur dioxide contained in the air detected and the average value calculated for the whole year. It shows what is the average amount of sulphur dioxide in the air during the whole year, and serves as an important indicator for evaluating environmental pollution. Unit million tonnes.

Air emissions of nitrogen oxides (C_{32}): The amount of nitrogen oxides in the air monitored at all monitoring stations in the study area for a full year, divided by the number of days the monitoring is valid, to calculate the average of the nitrogen oxides content for the whole year, again as an important indicator for evaluating environmental pollution. Unit mg/m3. Unit million tonnes.

Smoke (dust) emissions (C_{33}): the average amount of smoke (dust) in the atmosphere for the whole year in the study area. Unit million tonnes.

Table 4 Selection of indicators for the evaluation system

Target level	Level 1 guideline level indicators	Level 2 guideline level indicators
Ecological quality	Natural conditions B_1	Forest cover/% C_{11}
		Annual precipitation/mm C_{12}
		Total regional water resources available / % C_{13}
		Arable land area/thousand hectares C_{14}
	Socio-economic B_2	Total GDP growth rate / % C_{21}
		Tertiary sector share of GDP / %C_{22}
		Population density per person/k m2C_{23}
		Proportion of population in agriculture / %C_{24}
		Natural population growth rate / %C_{25}
	Environmental pollution B_3	Sulphur dioxide emissions / million tonnesC_{31}
		Nitrogen oxide emissions/million tonnesC_{32}
		Emissions of smoke (dust) per tonneC_{33}

2.2.2 Indicator data pre-processing

The selected indicator factors, because the data itself varies and the size of the data varies greatly, are calculated directly using the raw data, which affects the calculation results. Therefore, the raw data obtained should be pre-processed and the data should be calculated and compared under a unified standard, i.e. the standardisation of the data. Firstly, the relevance of the data is judged by comparing the obtained indicator factors with the ecological environment and determining whether the selected influence factors have a positive or negative impact on the ecological environment. For example, the forest cover ratio (C_{11}), the share of tertiary sector in GDP (C_{22}) is a positive impact on the ecological environment, then use the formula

$$C_{ij}^{'} = \frac{C_{ij} - C_{ijmin}}{C_{ijmax} - C_{ijmin}} \times 100 \tag{13}$$

Where $C_{ij}^{'}$ represents data normalisation indicators, the C_{ij} represents the original data, C_{ijmin}, C_{ijmax} represent respectively the minimum and maximum values in the data indicators.

If the data indicator has a negative impact on the ecosystem, then use the formula

$$C_{ij}^{'} = \frac{C_{ijmax} - C_{ij}}{C_{ijmax} - C_{ijmin}} \times 100 \tag{14}$$

2.2.3 PCA-AHP Hybrid evaluation

The principal component analysis method is to extract a few representative indicators instead of the whole evaluation index after analysing and ranking several evaluation indicators, all of which reflect the information and characteristics of the whole index and do not duplicate the characteristics of the information contained. This method of extracting principal components simplifies the problem and reduces the amount of calculation without missing the valid information of the whole indicator. When studying the ecological environment, we have to select a number of factors that influence the ecological environment from a number of aspects, which are complex and cumbersome to calculate. The problem can be simplified by using principal component analysis. The main methods used to extract representative indicators are eigenvalue decomposition, SVD, NMF, etc. In this way it is possible to evaluate the whole system using fewer indicators and each of the so-called principal components is independent and does not influence each other. The general steps of the principal component analysis method are.

(1) Standardized collection of raw index data, construction of sample matrix, standardized transformation of sample matrix elements to obtain standardized matrix

(2) Solve the correlation coefficients between each indicator based on the standardized matrix to derive the correlation coefficient matrix

(3) Calculate the contribution of the characteristic variance of each indicator based on the obtained correlation coefficient matrix

(4) The top ranking indicators in the contribution of the variance of the characteristics and after summing, the contribution rate is greater than a certain standard as the principal component

(5) The extracted principal components are evaluated and calculated.

The experiment mainly used SPSS analysis software, in calculating the correlation coefficients between each indicator to list a matrix of correlation coefficients between the data on indicators, using KMO test and Bartlett's spherical test, to test all indicator data, the purpose is to see whether the principal component analysis method is applicable to all indicators and the final results. The KMO test and Bartlett's spherical test are required if the principal component analysis method is to be carried out. The structural validity of the data indicators is only valid when the KMO obtained is > 0.5 and the p-value < 0.05, and the higher the KMO value obtained, the better the effect of using factor analysis; whether the indicator data are independent and the degree of independence is verified using the Bartlett's sphericity test is used to verify whether and to what extent the indicator data are independent. The option to perform the Bartlett's sphericity test directly using SPSS analysis software can be used. In the test results, if the p-value is less than 0.05, then the indicator data is spherically distributed, proving that the individual principal components are independent of each other. According to the obtained correlation coefficient matrix, use SPSS to calculate the characteristic variance contribution of each indicator and select the appropriate principal component, according to the formula

$$W_i = \sum_{i=1}^{n} \lambda_i (N_i) \tag{15}$$

Calculate the weight value of each indicator, whereW_i represents the first$i$ the weight value of the first selected data indicator, andλ_i represents the weight value of the first$i$ the eigenvalues of the corresponding principal components, the proportion of the eigenvalues extracted from the correlation coefficient matrix to the total eigenvalues extracted, and$(N_i$ denotes the indicator data after standardisation of the indicators.

The AHP hierarchical analysis method and PCA principal component analysis method are both methods for evaluating urban ecological environment indicators. The AHP method has both qualitative and quantitative analysis, but is more subjective, while the PCA principal component analysis method solves the problem of excessive influence of subjective factors to a certain extent, but there are limitations in the selection of indicators. Therefore, we adopt the hybrid method of AHP-PCA, which can eliminate the subjective factors and the influence of sample differences between the two methods and make up for the shortcomings.

After obtaining the factor weights of the two indicators separately, using the formula

$$W_i = \frac{u_i v_i}{\sum_{i=1}^{n} u_i v_i} (0 \le W_i \le 1, \sum_{i=1}^{n} W_i = 1) \tag{16}$$

The new weight value calculated eliminates the disadvantage, where W_i is the new weight value calculated by the hybrid AHP-PCA method, and u_i represents the weights calculated by AHP, and v_i represents the weights calculated by PCA.

The overall ecological score is then calculated according to the formula.

$$M = C_{ij} W_{ij} \times 100 \tag{17}$$

3. Results and analysis

3.1 Results and analysis of the ecological environment of the Seyhanba

Using the example of the Seyhanba Mechanical Forestry Station, we quantified the quality of the ecological environment before and after the restoration of Seyhanba (1962 and 2021) using a natural ecological environment quality evaluation model based on fuzzy integrated evaluation.

We determined the evaluation factor weights through the hierarchical analysis method. By reviewing the literature, consulting expert opinions and combining with the actual situation of the local ecological environment of the Seyhanba, we used the nine-level scoring method to construct the judgment matrix, calculated the indicator weight sequence of the judgment matrix using the square root method, and calculated the CR value through MATLBAB to test the consistency. After calculating the target layer matrix, the first level criterion layer matrix and the second level criterion layer have full consistency. After standardisation, the results of the weights of each indicator of the same level of ecological impact species were obtained as the following table.

Table 5 Weighting of evaluation indicators at all levels

Level 1 guideline level indicators	Weighting	Level 2 guideline level indicators	Weighting
Soil and Water Conservation B1	0.1649	C_{11}	0.4615
		C_{12}	0.4615
		C_{13}	0.0769
Ecosystem stability B2	0.5638	C_{21}	0.7838
		C_{22}	0.1349
		C_{23}	0.0813
Water Conservation B3	0.1649	C_{31}	0.8889
		C_{32}	0.1111
Improved soil B4	0.0664	C_{41}	0.2500
		C_{42}	0.7500
Purifying the air B5	0.0399	C_{51}	0.6667
		C_{52}	0.3333

This resulted in the calculation of the following matrix of affiliation of the first level of criteria level indicators to each evaluation level in 1962 and 2021.

$$R_{2021} = \begin{bmatrix} 0.508 & 0.415 & 0.069 & 0.008 & 0.000 \\ 0.029 & 0.802 & 0.088 & 0.011 & 0.070 \\ 0.000 & 0.105 & 0.895 & 0.000 & 0.000 \\ 0.551 & 0.449 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.161 & 0.839 & 0.000 & 0.000 \end{bmatrix}, R_{1962} = \begin{bmatrix} 0.000 & 0.000 & 0.438 & 0.092 & 1.347 \\ 0.000 & 0.000 & 0.000 & 0.115 & 0.885 \\ 0.000 & 0.000 & 0.039 & 0.475 & 0.486 \\ 0.000 & 0.000 & 0.000 & 0.300 & 0.700 \\ 0.000 & 0.000 & 0.000 & 0.008 & 0.992 \end{bmatrix} \tag{18}$$

The results of the affiliation of the indicators at the second level of the criteria layer are shown in the following table.

Table 6 Indicator affiliation at the second guideline level

Evaluation Indicators	Before restoration (1962)					After restoration (2021)				
		II	III	IV	V		II	III	IV	V
C_{11}	0.000	0.000	0.950	0.050	0.000	0.101	0.899	0.000	0.000	0.000
C_{12}	0.000	0.000	0.000	0.140	0.860	1.000	0.000	0.000	0.000	0.000
C_{13}	0.000	0.000	0.000	0.000	1.000	0.037	0.963	0.000	0.000	0.000
C_{21}	0.000	0.000	0.000	0.453	0.547	0.000	0.045	0.955	0.000	0.000
C_{22}	0.000	0.000	0.352	0.648	0.000	0.000	0.580	0.420	0.000	0.000
C_{23}	0.000	0.000	0.000	0.400	0.600	0.401	0.599	0.000	0.000	0.000
C_{31}	0.000	0.000	0.000	0.012	0.988	0.000	0.180	0.820	0.000	0.000
C_{32}	0.000	0.000	0.000	0.000	1.000	0.000	0.124	0.876	0.000	0.000
C_{41}	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.133	0.867
C_{42}	0.000	0.000	0.000	0.050	0.950	0.000	0.000	0.900	0.100	0.000
C_{51}	0.000	0.000	0.000	0.850	0.150	0.000	0.350	0.650	0.000	0.000
C_{52}	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	0.000	0.000

The pre-restoration (1962) and post-restoration (2021) ecological condition weighting vectors are

$$\begin{aligned} T_{1962} &= (0.000 \quad 0.000 \quad 0.079 \quad 0.178 \quad 0.887) \\ T_{2021} &= (0.000 \quad 0.000 \quad 0.079 \quad 0.178 \quad 0.887) \end{aligned} \tag{19}$$

The combined ecological assessment values before and after the restoration of the Seyhanba are.

$$M_{1962} = 5.384, \ M_{1962} = 2.239 \tag{20}$$

Using the most intuitive principle of maximum affiliation, the maximum affiliation of the ecological quality of the pre-restoration area is 0.887, which is a "poor" rating, and the overall ecological environment of the pre-restoration area is considered poor. After the restoration, the maximum affiliation of the ecological quality of the area is 0.574, which is "good", and the overall ecological environment of the restored area is considered to be good. A comparison of the ecological quality of the Seyhanba before and after restoration shows that the restoration of the Seyhanba has had a positive impact on the local ecological environment.

In this analysis, the overall environmental quality of the ecological condition of the Seyhanba area before restoration is close to level V; the overall ecological quality of the ecological condition of the Seyhanba area before and after restoration is resolved to level II. The comprehensive evaluation shows that through the adoption of reasonable afforestation and reforestation measures, the ecological environment of the Seyhanba area is showing a positive trend, but the Seyhanba area is currently at level II and should maintain the current positive trend and continue to improve the means of ecological management in order to keep the ecological environment of the Seyhanba area at a higher level.

3.2 Results and analysis of ecological environment assessment by province in China

The KMO test and Bartlett's test after constructing the correlation coefficient matrix in this paper are:

Table 7 KMO test and Bartlett's test

KMO Sampling Suitability Quantities		. 702
Bartlett's test	Approximate cardinality	240.198
	Freedom	66
	Significance	. 000

The total variance is explained by

Figure 1 Total variance explained

a

	Ingredients 1	2	3	4
Forest coverage	.009	.619	.664	.196
Annual precipitation	.094	.615	.697	-.258
Total regional available water resources	-.601	.070	.306	-.350
Total GDP growth rate	.041	.483	-.481	-.534
Share of tertiary sector in GDP	.747	-.372	.099	-.128
Total crop area sown	.772	.174	-.292	-.091
Population density	-.558	.461	-.358	.535
Percentage of agricultural population	-.750	.388	-.198	.320
Natural population growth rate	.080	-.592	.442	.422
Sulfur dioxide emissions	.847	.180	.029	.187
Nitrogen oxide emissions	.810	.290	-.175	.304
Smoke (dust) emissions	.832	.374	.021	.121

Extraction method: principal component analysis.

a. Four components were extracted.

The component matrix obtained is

Figure 2 Component matrix

The weights were calculated from the principal component analysis as

Table 8 Principal component analysis method of counting weights

Indicators	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{14}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}
Weighting	0.149	0.128	0.002	0.002	0.076	0.103	0.002	0.002	0.026	0.17	0.166	0.182

A hierarchical analysis was used to calculate the weights for each indicator as

Table 9 Weights obtained by hierarchical analysis

Indicators	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{14}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}
Weighting	0.179	0.169	0.043	0.124	0.108	0.052	0.07	0.052	0.034	0.068	0.068	0.034

The results of the weights obtained using the hybrid AHP-PCA method were

Table 10 AHP-PCA hybrid method weights

Indicators	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{14}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}
Weighting	0.291	0.236	0.002	0.002	0.089	0.059	0.002	0.002	0.01	0.125	0.122	0.067

The ecological quality scores for each province are as follows.

Table 11 Ecosystem quality scores by province

Province	Ecological Environment Overall Quality Score	Province	Ecological Environment Overall Quality Score	Province	Ecological Environment Overall Quality Score
Hainan Province	85.7	Shanghai	60.4	Liaoning Province	42.6

Fujian Province	80.4	Hubei Province	57.2	Qinghai Province	39.7
Guangxi Zhuang Autonomous Region	75.2	Guizhou Province	54.5	Gansu Province	36.3
Zhejiang Province	74.6	Jilin Province	52.3	Ningxia Hui Autonomous Region	35.4
Guangdong Province	70.7	Sichuan Province	51.1	Henan Province	34.8
Beijing	69.6	Shaanxi Province	50.4	Shanxi Province	29.7
Chongqing	69.2	Tianjin	50.2	Inner Mongolia Autonomous Region	24.4
Jiangxi Province	68.3	Anhui Province	48.2	Hebei Province	22.5
Hunan Province	64.7	Tibet Autonomous Region	46.8	Shandong Province	19.6
Yunnan Province	62.4	Heilongjiang Province	43.1	Xinjiang Uyghur Autonomous Region	18.5
Jiangsu Province	61.2				

From the experimental results, it is clear that the overall quality of the ecological environment varies greatly among Chinese provinces, with the southern regions generally having good ecological environment quality, with Hainan and Fujian being the best, central regions such as Hubei and Anhui having better ecological environment quality, northern regions such as Ningxia Hui Autonomous Region and Tibet Hui Autonomous Region having poorer ecological environment quality, and Shandong Province and Xinjiang Uyghur Autonomous Region having greatly disadvantage, and measures are urgently needed to improve the quality of the ecological environment.

4. Conclusions

The model constructed in this paper takes into account the indicators of natural conditions, socio-economics, and environmental pollution, which helps to analyze the trends of these ecological and environmental composite scores with each indicator. In evaluating the ecological environment quality of the Seyhanba before and after restoration, it was concluded that the establishment of the Seyhanba Nature Reserve led to a significant improvement in the ecological environment quality of the Seyhanba, which is highly consistent with the results of existing surveys and studies [23-25]. The model is more accurate and reliable due to the influence of multiple factors, and finally obtained the ecological environment quality ranking of 31 provincial regions in China, with higher ecological environment quality scores in the eastern coastal regions and lower scores in the western and northern regions, which is highly consistent with the results of currently available studies [26-28].

From the results of the study on the quality of ecological environment in Seyhanba Mechanical Forestry and 31 provincial regions in China, it is clear that for the natural ecological environment, building an ecological forest area requires, on the one hand, a change of concept and good planning and design of biodiversity, biological corridors, wetlands and special areas; on the other hand, it is necessary to find a suitable route for local development according to local conditions. For the social ecological environment, improving the quality of ecological environment needs to give equal importance to three major benefits: economic, ecological and social, and take into account ecology in addition to economic development.

In the decision to improve the ecological environment quality, specific analysis should be conducted in conjunction with the local environment, and the ecological environment quality should be assessed using a scientific ecological environment evaluation model so as to provide a basis for decision makers [29]. In the future, the use of fuzzy evaluation integrated model and principal component-hierarchical analysis integrated evaluation model can further study the different influences of different regions by natural conditions, socio-economic, environmental pollution and other indicators, add more dimensions to evaluate the ecological environment quality of different regions more comprehensively, and provide suggestions and references for the country and regions in managing the environment [30].

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