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A Comprehensive Evaluation Model Based on the Environmental Impact of Saihanba

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Abstract

China Saihanba Forest Farm has become an ecological green farm with stable sand control function, and an ecological environmental impact assessment model is constructed according to the ecological model of Saihanba Forest Farm. According to the seven data indicators collected, this article uses principal component analysis to analyze. From the principal component scores, it can be seen that there is a significant difference in the scores before and after restoration, indicating that the impact of Saihanba Forest Farm on the ecological environment before and after restoration is very significant. At the same time, in order to establish ecological regions more accurately and extend the ecological protection model to the whole country, based on the AHP (Analytic Hierarchy Process) and TOPSIS (Distance between superior and inferior solutions), a model is established to calculate the comprehensive evaluation indicators of the ecological environment in Liaoning, Ningxia, and Shanxi provinces. The scores of the comprehensive evaluation indicators are used to determine the establishment of ecological zones in Ningxia and Shanxi provinces.

Keywords: AHP method; principal component analysis method; TOPSIS method.

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1 Introduction

With the help of the Chinese government, China Saihanba Forest Farm has recovered from the desert and become an ecological green farm with stable sand control functions. Therefore, it is analyzed that those areas also need to pay attention to the establishment of ecological regions, practice China's concept of sustainable development, and give priority to protecting the ecological environment. In recent years, the comprehensive evaluation of the ecological environment mainly adopts the AHP method, TOPSIS method, and factor analysis method [1-7], which shows that the comprehensive evaluation of the ecological environment is meaningful.

In addition, evaluation models have also been widely applied in other industries. In recent years, Li Xiaohan [8] has combined entropy weight TOPSIS method and rank sum ratio method to study the evaluation of financial risks of enterprises; Wang Dainan and Chen Qiong [9] studied the competency of VTS duty officers based on AHP and TOPSIS; Liang Peili and Xiao Jihong [10] constructed an evaluation model by combining the weighted TOPSIS method with the rank sum ratio method to comprehensively evaluate the medical quality of hospitals; Lu Shijia [11] Research on health assessment of Urban ecosystem in Beijing based on principal component analysis.

This article uses principal component analysis to objectively evaluate the significant impact of the restoration of Saihanba Forest Farm on the ecological environment. Taking Liaoning, Ningxia, and Shanxi provinces as examples, the comprehensive evaluation indicators of ecological environment were calculated based on AHP and TOPSIS methods, and the ecological environment of each province was divided.

2 Ecological Environmental Impact Assessment Model

In order to study the impact of the restoration of Saihanba forest farm on the ecological environment, principal component analysis is mainly used for research. Principal component analysis is a statistical analysis method that converts multiple indicators into a small number of comprehensive indicators. Since different indicators involve large differences in fields, and have different units and orders of magnitude, the accuracy of the results will be affected, it is necessary to standardize the indicators before conducting analysis.

Note $x_1, x_2, \cdots, x_p$ as the variable indicator, let $E(x_k) = \mu_k, Var(x_k) = \delta_k$. After normalizing the original data, the correlation coefficient matrix of the variables is solved as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \cdots & \vdots \\ r_{p1} & r_{p2} & \cdots & r_{pp} \end{bmatrix} \tag{1}$$

Where $r_{ij} = \dfrac{\sum_{k=1}^{n} (x_{ki} - \overline{x}_i)(x_{ij} - \overline{x}_j)}{\sqrt{\sum_{k=1}^{n} (x_{ki} - \overline{x}_i)^2 \sum_{k=1}^{n} (x_{ij} - \overline{x}_j)^2}}$

Then to solve the eigenvalue of R, the corresponding eigenvector and the corresponding variance contribution rate. The common method to solve the characteristic equation $|\lambda I - R| = 0$ here is to use the Jacobi method to find the eigenvalue, arrange the solved eigenvalues $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \geq 0$ in order of size, and extract the common factor according to the eigenvalues greater than 1, so that the utilization rate of data information is higher. Then, the eigenvector $a_i \left(i = 1, 2, \cdots, p\right)$ with the eigenvalue λ_i is found

$$a_1 = \begin{bmatrix} a_{11} \\ a_{21} \\ \vdots \\ a_{p1} \end{bmatrix}, a_2 = \begin{bmatrix} a_{12} \\ a_{22} \\ \vdots \\ a_{p2} \end{bmatrix}, \cdots, a_p = \begin{bmatrix} a_{1p} \\ a_{2p} \\ \vdots \\ a_{pp} \end{bmatrix}$$

Finally, the linear expression of the principal component is found

$$F_i = a_{1i}x_1 + a_{2i}x_2 + \cdots + a_{pi}x_p \quad i = 1, 2 \cdots, p \tag{2}$$

According to the linear expression, the score of each component factor is calculated, and the variance contribution rate is used as the weight, and the comprehensive score is obtained and then evaluated.

The 11 basic data indicators collected on the official statistical website of Saihanba include forest coverage, coverage area (10000 acres), forest accumulation (10,000 cubic meters), water content (100 million cubic meters), carbon dioxide absorption (10,000 tons), oxygen release (10,000 tons), tourist number (10,000 tons), tourism revenue (100 million), urban air quality compliance days, PM2.5 concentration (micrograms/cubic meter), surface water quality compliance rate (%) were recorded as $x_1, x_2 \cdots x_{11}$ respectively, and the original data indicators were standardized first. The principal component analysis method was used for screening and comprehensive analysis [12]. Then, SPSS is applied to principal component analysis to solve the following results:

Table 1. The total variance of the interpretation

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	9.011	81.916	81.916	9.011	81.916	81.916
2	1.386	12.599	94.515	1.386	12.599	94.515
3	0.384	3.489	98.004			
4	0.128	1.163	99.176			
5	0.059	0.535	99.702			
6	0.017	0.159	99.861			
7	0.013	0.116	99.977			
8	0.003	0.023	100			
9	1.751E-8	1.592E-7	100			
10	1.176E-8	1.069E-7	100			
11	3.212E-9	2.920E-8	100			

According to the solution results in Table 1 above, it can be seen that the initial eigenvalues, variance contribution rate and cumulative contribution rate of each component follow the principle of eigenvalues greater than 1 when extracting common factors. From the results of the above table, it can be seen that there are 2 data indicators with feature values greater than 1, Therefore, two common factors are mainly extracted, and the variance contribution rate of the first common factor is 81.916%; The variance contribution rate of the second common factor was 12.599%, and the cumulative variance contribution rate of the extracted two common factors reached 94.515%. When the cumulative variance contribution rate of the common factor is larger, it means that the extracted common factor reflects more information about the original data, and the 2 common factors we extracted this time can reflect 94.515% of the information of all original indicators, which can be seen that the extracted common factor has been able to reflect the information of the original data well. The extracted common factors are represented by F_1 and F_2 respectively.

Subsequently, factor analysis was performed to obtain the principal component coefficient matrix, which illustrate the loading of each principal component on each indicator. In order to analyze the correlation between the index and the component more clearly, the maximum variance method is selected to rotate the factor to obtain the factor rotation matrix, as shown in Table 2.

Table 2. Rotate the component matrix

Variable	Component	
	1	**2**
Forest cover	0.909	-0.286
Coverage area	0.909	-0.286
Forest accumulation	0.986	-0.079
Contains water	0.937	0.210
Absorbs the amount of carbon dioxide	0.986	-0.079
Amount of oxygen released	0.806	-0.059
Number of tourists	0.274	0.620
Tourism revenue	0.499	0.684
The number of days the air quality standard is met in the urban area	0.916	-0.011
PM2.5 concentration	0.811	-0.551
Surface water quality compliance rate	0.989	0.055

The rotational component matrix in Table 2 is the main content of factor analysis, and none of the 11 indexes have a factor load greater than 0.5 on the first principal component and the second principal component, indicating that the 11 indicators do not need to be deleted and the components are clearly divided. It can be seen that the first factor F_1 mainly includes nine indicators: forest coverage, cover area, forest accumulation, water content, carbon dioxide absorption, oxygen release, urban air quality compliance days, PM2.5 concentration and surface water quality compliance rate, reflecting the impact of tree conditions. The second factor F_2, mainly includes the number of tourists and tourism revenue, reflecting the impact of the tourism industry.

The principal component coefficient matrix is obtained by dividing the principal component load vector by the arithmetic square root of the corresponding principal component characteristic value, and the result is shown in Table 3. The first principal component score and the second principal component score can be used to express the characteristics of the ecological environment, and the dominant expression of the principal component function is calculated as follows

$$\begin{aligned} F_1 = {} & 0.909x_1 + 0.909x_2 + 0.986x_3 + 0.937x_4 + 0.986x_5 + 0.806x_6 + 0.274x_7 + 0.499x_8 \\ & + 0.916x_9 + 0.811x_{10} + 0.989x_{11} \\ F_2 = {} & -0.286x_1 - 0.286x_2 - 0.079x_3 + 0.210x_4 - 0.079x_5 - 0.056x_6 + 0.620x_7 + 0.684x_8 \\ & - 0.011x_9 - 0.551x_{10} + 0.055x_{11} \end{aligned}$$

Here, 11 standardized data indicators are respectively substituted into the above equation, and then converted to a percentage system. The first principal component score, the second principal component score and the percentage score of each year can be obtained, as shown in Table 3 (only a portion of the principal component scores are shown):

Table 3. Principal Component Score

Year	First Principal Component Score	Second Principal Component Score
1962	-1.367	1.174
1969	-1.052	0.747
1976	-0.857	0.462
1983	-0.582	-0.093
1990	-0.416	-0.428
2004	0.742	-1.539
2018	1.826	2.875

Plot the main component scores for each year as follows:

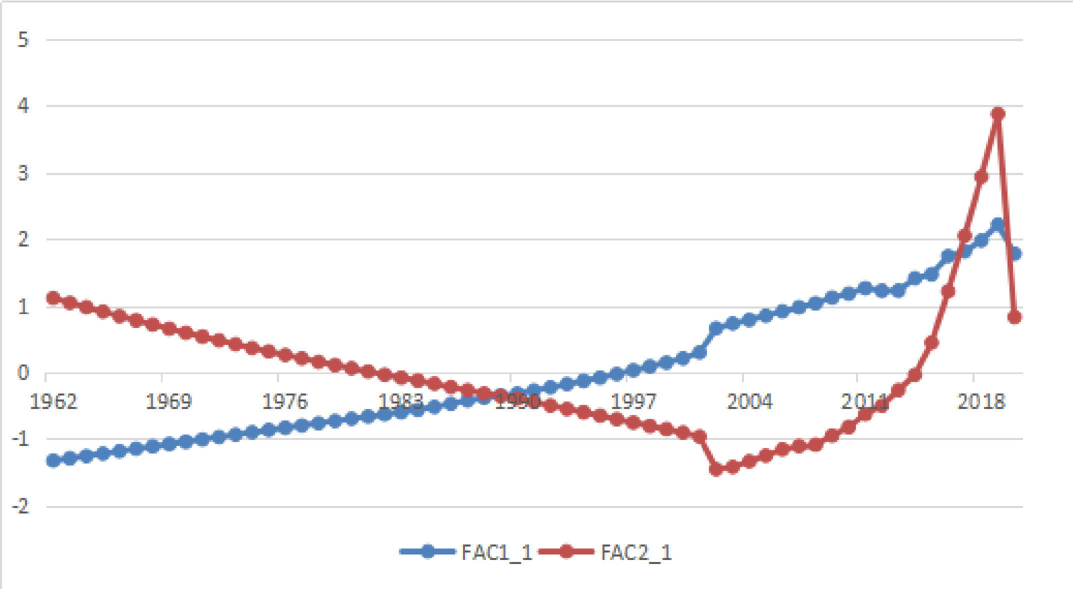

Fig. 1. Principal component score

From Table 3 and Fig. 1 above, it can be seen that in the first principal component score, with the increase of years, the change of ecological environmental factors is gradually increasing, in the second principal component score, although there are ups and downs of changes, but in general, the score of each component in 2019 is higher than in 1962, indicating that with the change of time, the impact on the development of the ecological environment after the restoration of Saihanba forest farm is significant.

3 Establishment of Eco-Regions

After Saihanba became an eco-friendly green farm with stable sand control functions, in order to promote the better development of the ecological environment, in order to be able to more accurately determine which geographical locations in China need to establish ecological zones. In the Statistical Yearbook, we collected data indicators from Liaoning, Ningxia and Shanxi provinces, which mainly included five data indicators: average temperature, average relative humidity, total water resources, days of air quality reaching or better than grade II, and forest coverage. We combined AHP with TOPSIS to obtain an evaluation index score to determine whether the three provinces of Liaoning, Ningxia and Shanxi also need to focus on the establishment of ecoregions.

Due to the complex and numerous factors that affect the ecological environment, a combination of AHP method and TOPSIS method was chosen for analysis. AHP method can reasonably combine qualitative and quantitative decision-making, analyze various indicators and influencing factors, and then obtain corresponding weights. The TOPSIS method can effectively eliminate the subjective opinions brought by the AHP method to a certain extent, and can more accurately obtain a combination of subjective and objective scores, thereby accurately determining whether Liaoning, Ningxia, and Shanxi provinces still need to focus on establishing ecological zones [13].

3.1 AHP model establishment

Firstly, determine whether an ecological zone needs to be established as the target layer. Then, select five data indicators: average temperature, average relative humidity, total water resources, days of air quality reaching or better than level 2, and forest coverage as the criterion layer. Liaoning, Ningxia, and Shanxi provinces will be used as the plan layer.

Table 4. Relative importance values

Relative importance a_{ij}	**Meaning**
1	The impact of C_i and C_j is the same
3	C_i has a slightly stronger impact than C_j
5	C_i has a stronger impact than C_j
7	The impact of C_i is significantly stronger than that of C_j
9	The impact of C_i is absolutely stronger than that of C_j
2,4,6,8	The absolute strength ratio of the influence of C_i over C_j is between the two adjacent levels mentioned above
1,1/2, $\cdots$1/9	The absolute strong ratio of C_i to C_j is the reciprocal number of a_{ij} above

The comparison matrix can be constructed from Table 4:

$$A = (a_{ij})_{n\times n} \quad a_{ij} > 0 \quad a_{ji} = \frac{1}{a_{ij}}$$

Paired comparison matrices can be obtained by comparing each criterion layer as follows:

$$A = \begin{bmatrix} 1 & 1 & 5 & 5/7 & 5/3 \\ 1 & 1 & 5 & 7/5 & 5/3 \\ 1/3 & 1/3 & 1 & 1/7 & 1/3 \\ 7/5 & 7/5 & 7 & 1 & 7/3 \\ 3/5 & 3/5 & 3 & 3/7 & 1 \end{bmatrix}$$

Using consistency indicators $CI = \frac{\lambda_{\max} - 5}{4}$, obtain random consistency indicators $RI = 1.12$ through table lookup, perform consistency check and calculate consistency ratio:

$$CR = \frac{CI}{RI} = 0.0951 < 0.1$$

Subsequently, construct a combination weight vector

$$B_1 = \begin{bmatrix} 1 & 5 & 3 \\ 1/5 & 1 & 1/2 \\ 1/3 & 2 & 1 \end{bmatrix}, B_2 = \begin{bmatrix} 1 & 2 & 5 \\ 1/2 & 1 & 2 \\ 1/5 & 1/2 & 1 \end{bmatrix}, B_3 = \begin{bmatrix} 1 & 5 & 8 \\ 1/5 & 1 & 3 \\ 1/8 & 3/8 & 1 \end{bmatrix}$$

$$B_4 = \begin{bmatrix} 1 & 1/2 & 1 \\ 2 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, B_5 = \begin{bmatrix} 1 & 1/3 & 1/5 \\ 3 & 1 & 1/2 \\ 5 & 2 & 1 \end{bmatrix}$$

Calculate the weight vector B_k, maximum feature root $w_k^{(3)}$, and consistency indicators CI_k and CR_k of the paired comparison matrix λ_k, as shown in the table below:

Table 5. Consistency check

k	**1**	**2**	**3**	**4**	**5**
	0.6483	0.5954	0.7393	0.2599	0.1095
	0.1220	0.2764	0.1831	0.4126	0.3090
	0.2297	0.1283	0.0775	0.3275	0.5816
λ_k	3.0037	3.0055	3.0076	3.0536	3.0037
	0.00185	0.00275	0.0038	0.0268	0.00185
	0.00319	0.00474	0.0055	0.0462	0.00319

Subsequently, a consistency test was conducted on the combination. According to the table, all combination weight vectors passed the consistency test.

$CI^{(3)} = 0.00232, RI^{(3)} = 0.58, CR^{(3)} = 0.004$ thus $CR^* = 0.0991$, Combination consistency test passed.

Finally, calculate the weights of five data indicators on whether to establish an ecological zone, and obtain $w = (0.2257, 0.2656, 0.0572, 0.3160, 0.1354)^T$

3.2 TOPSIS method

The entropy weight method determines the weight by using the degree of variation of the indicator itself to determine the size of the information reflected, thereby determining its corresponding weight value. It can objectively determine the weight of the evaluation indicator. When a certain data indicator changes significantly, the more information it reflects, and the greater the weight it occupies.

Here are the three existing evaluation objects and the forward matrix of five evaluation indicators

$$D = \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} \\ d_{21} & d_{22} & d_{23} & d_{24} & d_{25} \\ d_{31} & d_{32} & d_{33} & d_{34} & d_{35} \end{bmatrix}$$

Calculate the final score

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \tag{3}$$

where $D_i^- = \sqrt{\sum_{j=1}^{5} (d_j^- \cdots d_{3j})^2}$ is the distance between the i-th indicator and the minimum value, $D_i^+ = \sqrt{\sum_{j=1}^{5} (d_j^+ \cdots d_{3j})^2}$ is the distance between the i-th indicator and the maximum value.

Calculate the evaluation scores of the impact of five indicators on the ecological environment $E_i = C_i \times w$. So as to sort the ecological environment of each province

Table 6. Sort results

	D_i^+	D_i^-	E_i
Liaoning Province	0.388	0.1066	0.2155
Shanxi Province	0.4057	0.0812	0.1668
Ningxia Province	0.4263	0.0843	0.1625

Then use the Rank Sum Ratio (RSR) method to rank or rank the evaluation objects [14]. Convert the comprehensive evaluation value C_i into a matrix of one $M_{3\times5}$, determine the distribution of RSR, and determine the rank order R, average rank $\bar{R}$, and Probit values based on the various RSR values,

$$RSR = \frac{\sum_{j=1}^{3} R_{ij}}{15}, i = 1, 2 \cdots 5, \quad \Pr obit = \frac{\bar{R}}{3} \tag{4}$$

Use formula (4) to obtain the RSR value, rank R, and average rank $\bar{R}$ of each province. Then, with the RSR value as the dependent variable and Probit as the independent variable, use least squares estimation to obtain the parameter values and obtain the linear regression equation.

$$RSR = -0.417 + 0.164 \times \Pr obit$$

From the results of the F-test in the following table, we can see that the significance *P* value is 0.000 * * *, the level is significant, the original hypothesis that the regression coefficient is 0 is rejected, and the Goodness of fit of the model is R^2 It is 0.909, and the model performs well, so the model basically meets the requirements. For variable collinearity performance, *VIF* is all less than 10, so the model does not have multicollinearity problem, and the model is well constructed.

Table 7. F-test results

	Non standardized coefficient		Standardized Coefficient	t	p	VIF	R2	Modifyr2	F
	B	standard error	Beta						
Constant	-0.417	0,053	-	-7.91	0.000***	-	0.909	0.906	F=260.186
Probit	0.164	0.01	0.953	16.13	0.000***	1			P=0.000***
Dependent variable：RSR									

**** represents a significant level of 1%*

Finally, based on the normal distribution, the variances of all grades are consistent and the difference is significant. According to the reasonable grading method

Table 8. Ranking results

Tem	RSR Value	RSR Ranking	RSR Fitting value	Level
Shanxi Province	0.237	26	0.219	1
Liaoning Province	0.406	16	0.481	2
Ningxia Province	0.237	27	0.219	1

Rank and sort the evaluation objects according to the size of the rank sum ratio. The larger the rank sum ratio, the better the ecological environment [15]. From the above table, it can be concluded that Ningxia and Shanxi should pay attention to the establishment of ecological zones, and the scale of the proposed ecological zone should be close to that of Liaoning, the second tier. Only in this way can we better improve ecological civilization and implement sustainable development strategies.

4 Conclusion

Establish an evaluation model for the impact of Saihanba restoration on the ecological environment. Using principal component analysis, it can be seen from the principal component score graph in Fig. 1 that the score is continuously increasing. The first principal component score increased from -1.367 to 1.826 from 1962 to 2018, and the second principal component score increased from 1.174 to 2.875 from 1962 to 2018. This shows that the restoration of Saihanba Forest Farm has a significant impact on the ecological environment.

Subsequently, an evaluation was conducted on whether Liaoning, Ningxia, and Shanxi provinces need to pay attention to the establishment of ecological zones. It was found that Ningxia and Shanxi still need to pay attention to the establishment of ecological zones, and continuous efforts were made to expand the ecological protection model to the whole country and implement sustainable development strategies.

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Competing Interests

Author has declared that no competing interests exist.

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