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A study on the evaluation of environmental factors based on TOPSIS method to construct ecological reserves

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Abstract: In this paper, in order to make a comprehensive evaluation of the environment and promote its ecological protection construction, a TOPSIS evaluation model under the CRITIC assignment method was built based on the data of the Seyhanba forestry site by selecting indicators of three aspects: geographic environment, ecological quality and climate mediation. Pearson correlation analysis was done between the indicators of Seyhanba and those of Beijing, and some indicators with strong correlation were selected. Then, using principal component analysis, the environmental condition of Beijing, was scored. After solving for the scores, the impact effect of the Sehanba mechanical forestry site on Beijing was evaluated.

1. Introduction

During China's two sessions in 2021, "carbon neutral and carbon peaking" was included in the government work report for the first time, striving to peak CO2 emissions by 2030 and achieving carbon neutrality by 2060. Carbon neutrality" means that the direct and indirect CO2 emissions from human activities in a certain area within a certain period of time (usually one year) are offset by the CO2 absorbed through afforestation, and a "net zero" CO2 emission is achieved[1]. Forests are the mainstay of terrestrial ecosystems and play an important role in maintaining ecological balance and improving ecological environment, and are natural resources essential for human social development.

China has been upholding the sustainable development model of "both golden mountains and green mountains", and has been strengthening its ecological management through afforestation and natural improvement of planted forests, etc. After more than half a century of struggle, the Seyhanba forest has become a green farm with sand control function, providing 137 million cubic meters of clean water to Beijing and surrounding areas, and producing 54 million cubic meters of oxygen. It provides 137 million cubic meters of clean water and produces up to 545,000 tons of oxygen for Beijing and surrounding areas, playing a huge role in protecting the environment and maintaining ecological balance[2].

The successful transformation of the Seyhanba Forest Farm has an important role in maintaining the ecological balance and improving the ecological environment. In this paper, we will select appropriate indicators, collect relevant data and establish a data model to evaluate the impact of Seyhanba on the ecological environment, so as to quantitatively evaluate the impact of the restored Seyhanba on the environment.

The Sekhamba forest also plays a significant role in combating dust storms in Beijing. In this paper, appropriate indicators will be selected, relevant data will be collected, and a mathematical model will be built to evaluate the impact of the Seyhan Dam on Beijing's ability to resist sand and dust storms, so as to quantitatively evaluate the impact of the restored Seyhan Dam on the environment[3].

2. Construction and solution of eco-environmental evaluation model based on TOPSIS method

2.1 Selection of indicators

First of all, it is necessary to evaluate the environmental conditions in Seyhanba, and valid indicators of various aspects can be selected to quantitatively reflect the impact of Seyhanba forestry on the local environment. The indicators may be divided into three main categories: geographical environment, ecological quality and climate mediation[4]. For the geographical environment, the following indicators were selected: forest cover, water content, forest stock, nature reserve area; for ecological quality, the following indicators were selected: oxygen release, incidence of forest pests and diseases, carbon dioxide absorption, soil quality; for climate regulation, the following indicators were selected: monthly precipitation, monthly average temperature, monthly average of maximum temperature, monthly average of minimum temperature.

2.2 TOPSIS model building and solving

In this paper, we use TOPSIS method for comprehensive evaluation of the environment of Sekhangba and choose CRITIC method to obtain the initial weights. Approximating ideal solution ranking method (TOPSIS) is a method to achieve comprehensive evaluation by comparing the distance between sample values and ideal values. Firstly, the reference points are determined in space, including the optimal and the worst points, and then the distance between each evaluation object and the reference point is calculated, and the closer to the optimal point or the farther to the worst point indicates the better comprehensive characteristics of the evaluated object[5].

2.2.1 TOPSIS model steps

Let there be n evaluation objects, each of which contains m parameter indicators. The n×m original matrix is obtained by arranging the parameter indicators of the n evaluation objects, i.e., the decision matrix.

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \ddots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{1}$$

Constructing the weighted norm matrix, the attributes are vector normalized, i.e., each column element is divided by the norm of the current column vector.

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{2}$$

This results in the normalized matrix after the normalization process.

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1m} \\ z_{21} & z_{22} & \cdots & z_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{nm} \end{bmatrix} \tag{3}$$

Determining matrix consistency.

Define the consistency index *CI*, the more the value tends to 0 means the better the consistency, i.e. the matrix construction is reasonable.

Define the consistency ratio *CR, RI* is the random consistency index, obtained from Table 1.

$$CR = \frac{CI}{RI} \tag{4}$$

CR < 0.1, then the inconsistency of the matrix is within the tolerance range and the eigenvectors can be used as the weight vectors.

Table 1 Stochastic consistency index

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The TOPSIS method uses distance scales to measure sample disparity, and the use of distance scales requires isotropization of the indicator attributes, and for subsequent processing, we need to convert all types of indicators to extreme value indicators, and we need to convert all indicator types to their corresponding positive indicators uniformly.

$$x_i' = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \tag{5}$$

Determine the optimal and inferior solutions.

The optimal solution Z^+ consists of the maximum value of the elements in each column of *Z*.

$$\begin{aligned} Z^+ &= \left(\max\left\{z_{11}, z_{21}, \cdots, z_{n1}\right\}, \max\left\{z_{12}, z_{22}, \cdots, z_{n2}\right\}, \cdots, \max\left\{z_{1m}, z_{2m}, \cdots, z_{nm}\right\}\right) \\ &= \left(Z_1^+, Z_2^+, \cdots, Z_m^+\right) \end{aligned} \tag{6}$$

The worst solution Z^- consists of the smallest value of each element in each column of *Z*.

$$\begin{aligned} Z^- &= \left(\min\left\{z_{11}, z_{21}, \cdots, z_{n1}\right\}, \min\left\{z_{12}, z_{22}, \cdots, z_{n2}\right\}, \cdots, \min\left\{z_{1m}, z_{2m}, \cdots, z_{nm}\right\}\right) \\ &= \left(Z_1^-, Z_2^-, \cdots, Z_m^-\right) \end{aligned} \tag{7}$$

Calculate the proximity of each evaluation object to the optimal solution and the worst solution.

$$D_i^+ = \sqrt{\sum_{j=1}^{m} w_j \left(Z_j^+ - z_{ij}\right)^2}, \quad D_i^- = \sqrt{\sum_{j=1}^{m} w_j \left(Z_j^- - z_{ij}\right)^2} \tag{8}$$

Calculate the closeness of each evaluation object to the optimal solution C_i.

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{9}$$

$0 \le C_i \le 1, C_i \to 1$ Calculate the closeness of each evaluation object to the optimal solution C_i.

2.2.2 Data pre-processing

The information on the environmental elements of Seyhanba used in this study was obtained from the information of Seyhanba Mechanical Forestry in Hebei Province and the Hebei Provincial Statistical Yearbook, and the correlations of the indicators are shown in Figure 1.

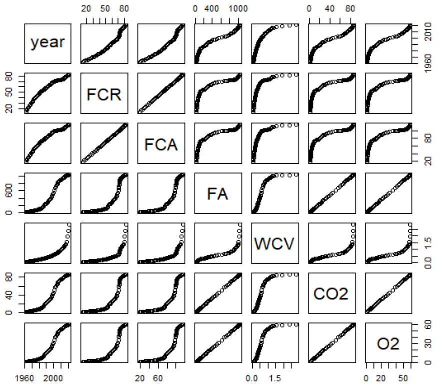


Figure 1 Relationship chart of each data item

There is a strong positive correlation between the metrics.

For partially missing or interrupted data, we take the average of some data in its adjacent time range and perform interpolation. If the missing data is defined by Xi, its size can be expressed as.

$$X_i = \frac{\sum_{T=m}^{n} \frac{X_{i-T} + X_{i+T}}{2}}{n-m} \tag{10}$$

m denotes m unit time lengths after which data starts to be available. *n-m* indicates the interval length of the later data.

$$\varepsilon \sim N(0, \sigma^2) \tag{11}$$

$$y_i = \beta_0 + \beta_1 t_i + \varepsilon_i \tag{12}$$

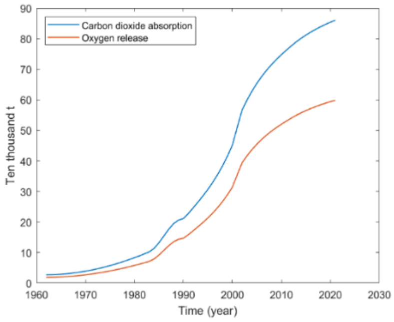
For a long series of missing data, a univariate linear regression is used to predict and interpolate. Let the complete index to be filled be the dependent variable *y* and the time be the independent variable *t*. After estimating the parameters, the predicted values are obtained by substituting the time corresponding to the missing places as the approximate valid data.

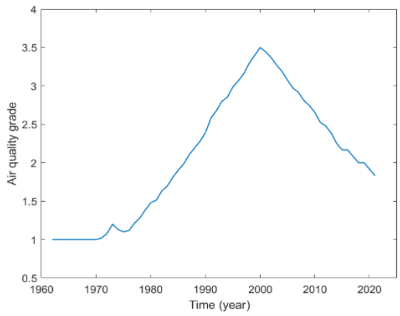
$$\hat{\beta}_1 = \frac{\sum_{i=1}^{n} (t_i - \bar{t})(y_i - \bar{y})}{\sum_{i=1}^{n} (t_i - \bar{t})^2} \tag{13}$$

After mining the data, the CRITIC method was chosen to assign objective weights to each index, followed by gradually building the TOPSIS evaluation model, and finally finding the overall score.

2.2.3 Solution of TOPSIS model

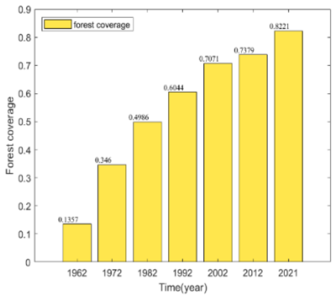
After screening the indicators, the data of Seyhanba from 1962 to 2021 were collected as the original data set, which were normalized by the extreme value indicator, and the normalized matrix Z was constructed after vector normalization, and the optimal and inferior solutions were found for each column of the matrix of Z. The maximum and minimum values of the elements of Z_i were obtained to find their closeness to the optimal solution C_i, and finally the evaluation results of each data sample TOPSIS were ranked according to the size of C_i as shown in Figure 2.

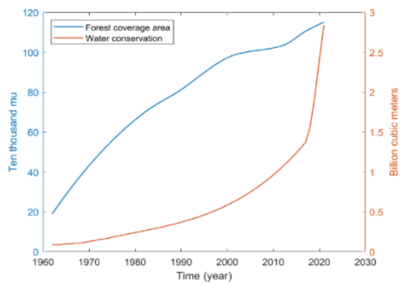




(a) Air quality change map of Seyhanba

(b) Sekhangba carbon dioxide oxygen mass change graph





(c) The map of forest area change in Sehanba

(d) The change of water content in Sekhangba

Figure 2 Evaluation results of TOPSIS for each data sample

After analyzing and evaluating the indicators by the topsis method, the relationship between forest cover and scoring was fitted, and thus an evaluation model of the ecological and environmental impact of the Seyhanba was established. Since it is difficult to collect data from 1962 to 2010, the forest cover area of Seyhanba was counted and scored every 10 years, and the change of forest cover area and score of Seyhanba from 1962 to 2021 was obtained as Table 2 and Figure 3, and the score closer to 1 indicates better environment.

Table 2 Table of forest cover area and score changes in Seyhanba from 1962-2021

Year	Forest coverage area	Overall Rating
1962	19.00	0.244
1972	48.43	0.255
1982	69.80	0.250
1992	84.62	0.260
2002	99.00	0.3965
2012	103.30	0.546
2021	115.10	0.9048

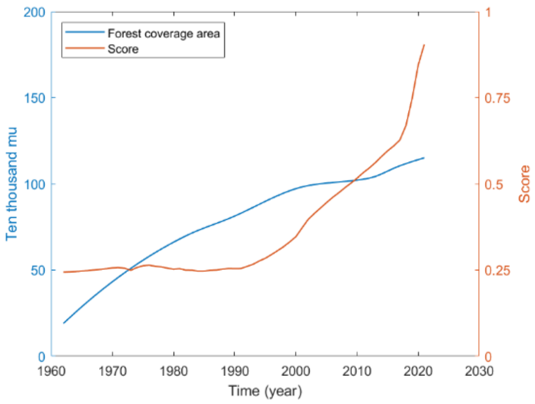


Figure 3 Table of forest cover area and score changes in Seyhanba from 1962-2021

It can be seen that the score tends to increase year by year as the forest cover of Seyhanba increases, indicating that the environmental conditions before the restoration of Seyhanba were poor, so the evaluation model was applied to produce a low score of 0.244; while after the restoration of Seyhanba, the evaluation model was applied to produce a high score of 0.9048, indicating that the evaluation model we built is consistent with the factual situation.

3. Downscaling analysis of dust storm resistance in forestry sites

In order to analyze the positive effect of the Sekhamba forestry site on the anti-sandstorm in Beijing, it is necessary to quantify the environmental and climatic level of Beijing and analyze the trend of its change. After the initial selection of some indicators, the correlation analysis was done between these indicators and the forest cover of the Seyhanba Forestry Reserve, and some indicators with relatively weak correlation were directly excluded. The remaining indicators were used to give a comprehensive score to describe the environmental improvement of Beijing. Since there are many influencing factors, we use principal component analysis for dimensionality reduction, which transforms the original multiple indicators into a few comprehensive indicators with good representativeness, and these few indicators can reflect most of the information of the original indicators, and each indicator remains independent.

3.1 Mathematical modeling and solving

Denote the value of each random variable by a_{ij} $(i=1, ..., m; j=1, ..., k)$ normalize the data to the same magnitude and denote the normalized value by a_{ij}`.

$$\text{Z-Score Standardization}: a_{ij}' = \frac{a_{ij} - \mu_j}{\sigma_j}$$

$$\text{The jth indicator is normalized to}: x_j' = \frac{x_j - \mu_j}{\sigma_j}$$

According to the above method, the correlation coefficient matrix R, R has m rows and k columns, and is the correlation coefficient between the i-th indicator and the j-th indicator.

Calculate the k eigenvalues of R of the correlation coefficient matrix, $\lambda_1 > \lambda_2 > \lambda_3 > ... \lambda_k > 0$ and the corresponding normalized eigenvectors $u_1\, u_2, u_3 ... u_k$ which can generate k components as new indicator variables as follows.

$$
\begin{cases}
z_1 = u_{12}x_1 + u_{12}x_2 + \cdots u_{1k}x_k \\
z_2 = u_{22}x_1 + u_{22}x_2 + \cdots u_{2k}x_k \\
\cdots\cdots \\
z_k = u_{k2}x_1 + u_{k2}x_2 + \cdots u_{kk}x_k \\
\cdots\cdots \\
z_k = u_{k2}x_1 + u_{k2}x_2 + u_{kk}x_k
\end{cases}
\tag{14}
$$

Select p principal components, $(p < k)$, and calculate the information contribution of each component of the composite evaluation value of environmental conditions in Beijing.

$$
b_j = \frac{\lambda_j}{\sum_{s=1}^{k} \lambda_s} \tag{15}
$$

The cumulative contribution of the P principal components.

$$
a_p = \frac{\sum_{s=1}^{p} \lambda_s}{\sum_{s=1}^{k} \lambda_s} \tag{16}
$$

The cumulative contribution of the P principal components.
Find the overall score.

$$
Z = \sum_{s=1}^{p} b_j y_j \tag{17}
$$

3.2 Correlation Analysis

The correlation coefficient matrix can be run to generate an 8-row and 8-column pixel plot of correlation coefficients, reflecting the correlation degree between 7 indicators of total water supply, air quality, average wind speed, frequency of major pollution, percentage of severe weather per month, population growth rate, precipitation and the forest cover area of Seyhanba, as shown in Figure 4.

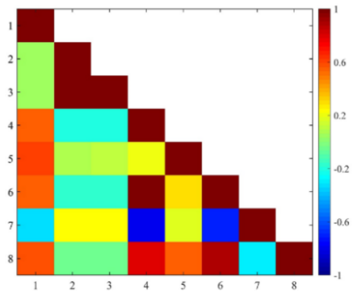


Figure 4 Schematic diagram of correlation coefficient matrix

The principal component analysis method can be solved using SPSS software. Firstly, k factor numbers are extracted, and the feature vectors corresponding to the k components can be derived, and the regression parameters are obtained after normalization, followed by the scores Z1 under component 1 and Z2 under component 2 for each row, and the cumulative contribution of the first 4 components is calculated to reach 96%, and finally the scores of Beijing's dust storm resistance are evaluated by these 4 principal components in a comprehensive manner.

4. Trends and Conclusion

The Asia-Pacific region is the fastest growing and most promising region in the world today, but like other regions of the world, its development is based on the destruction of resources and the environment. The rapid population expansion and unsustainable economic growth patterns, the massive depletion of resources, the destruction of the environment, and the major problems caused by climate change continue to damage the ecosystems and habitats on which the people of the Asia-Pacific region depend, making the Asia-Pacific region face serious challenges in achieving sustainable development.

In this paper, a corresponding mathematical evaluation model based on TOPSIS method was developed, and valid indicators were selected from various aspects for analysis, comparing the comprehensive scores before and after the restoration of the Sekhangba forest, and deriving trends.

The following more scientific governance ideas are summarized.

When selecting areas for the establishment of nature reserves, the inferior is given priority, i.e. the areas with the worst environmental quality are identified by analyzing the data, and priority is given to focus on treating the areas, thus improving the current poor air quality levels in these areas.

Consider practicality, i.e., assign a ranking based on the comprehensive evaluation results, with the lower the score, the greater the attention and the rational allocation of resources. If it is not too serious, it is not appropriate to sacrifice too much economic benefit.

Countries adhere to the value of a community of human destiny, promote energy conservation and emission reduction, and create a better ecological environment for the global village. We share the experience of environmental management and plantation technology with each other to make progress together.

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