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Evaluate Ecosystem Values of the Saihanba Based on Fuzzy Comprehensive Evaluation and Cluster Analysis

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Abstract: *This paper aims to provide a scientific, objective, and comprehensive analysis and assessment of the value of key forest ecosystem services in the area. Firstly, important indicators for evaluating ecological impact were screened through relevant data. Then, the weights of each indicator were determined through factor analysis. A fuzzy comprehensive evaluation model was established to quantitatively analyze the impact of the restoration project of the Saihanba on the environment. The correlation between the indicators was determined by evaluating the ranking of the correlation coefficients and analyzing the impact of Saihanba on the impact of dust resistance in Beijing. The carbon emission coefficient of each province is calculated based on the carbon emission and carbon absorption data of each province in China. Cluster analysis is used to determine which provinces need to establish ecological protection areas. Finally, the number and size of protected areas are determined.*

Keywords: *Factor analysis; Fuzzy comprehensive evaluation; Correlation analysis; Cluster analysis*

1. Introduction

Under the background of green, coordinated, and sustainable development, Great achievements have been made in the construction and protection of Saihanba Forest Farm in China. After half a century of struggle, Saihanba has become the largest artificial forest farm in the world, playing an important role in the improvement of the ecological environment in the surrounding areas. However, in the process of green development, Saihanba people have also encountered some problems. At present, ecological restoration has become the biggest pursuit of the Saihanba people.

2. Model establishment and solution

2.1. The impact of Saihanba restoration on the ecological environment

2.1.1. Evaluation index selection and calculation method

To make the evaluation index more representative, scientific, and comprehensive, the construction area and ecological impact of the Saihanba ecological reserve were analyzed in the index selection according to the subject information. Through definition and calculation, six evaluation indexes of the environmental impact of Saihanba were determined: soil water conservation, forest soil fixation function, carbon dioxide absorption, oxygen release, blocked dust value, and biodiversity value.

(1) The calculation formula of soil storage is as follows:

$$Y = \sum_{i=1}^{n} d_i S_i \tag{1}$$

Y: Total forest soil water storage; d_i: The storage capacity per unit area of the i forest land; s_i—Woodland area of species *i*.

(2) The calculation formula of forest soil fixation function value is as follows:

$$V = AC(x_2 - x_1)/P \tag{2}$$

V: Value of forestland fixation; A: Forest area of the reserve; C: Cost of digging and transporting earthwork per unit volume; x_2: Soil erosion modulus of forestland; x_1: Soil erosion modulus without forestland; P: Soil capacity.

(3) The calculation formula of CO_2 absorption in a forest ecosystem is as follows:

$$w_{CO_2} = \sum_{i=1}^{n} f_i S_i \tag{3}$$

w_{SO_2}: The amount of CO_2 that forests absorb each year; f_i: The amount of CO_2 absorbed per unit area by different types of the forest; s_i: The area of different types of forest.

(4) The oxygen release formula of the Saihanba forest system is as follows:

$$Q = 1.19 A_0 G_i S_i \tag{4}$$

Q: The value of oxygen released by forest systems; A_0: Industrial oxygen production costs; G_i: Net production capacity for all types of vegetation; S_i: Area of various types of vegetation.

(5) The formula for calculating the dust retention value of forest ecosystems is as follows:

$$L = \sum_{i=1}^{n} d s_i \tag{5}$$

L: The annual amount of retarded dust in forests; d: The amount of blocked dust per unit area of different types of forestland; s_i: Different types of the woodland area.

(6) The calculation formula of biodiversity value in the Saihanba forest area is as follows:

$$D = sa \tag{6}$$

D: Woodlands protect biodiversity values; s: Unit woodland conservation biodiversity value; a:Woodland area.

2.1.2. Analysis of indicator weights and fuzzy composite evaluation

The six evaluation indicators were first calculated quantitatively, and the data were classified and summarized, and finally was carried out weight analysis and fuzzy comprehensive evaluation of the evaluation indicators.

Table 1: Factor loading coefficients after rotation

Factor loading coefficients after rotation	Factor	Common factor variance
soil water conservation	0.887	0.787
forest soil fixation function	0.950	0.903
carbon dioxide absorption	0.982	0.964
oxygen release	0.982	0.964
blocked dust value	0.982	0.964
biodiversity value	0.995	0.989

The factor set U that affects the ecological value of Saihanba is established, that is, the set of selected evaluation indicators. The basic factor set U is divided into n subsets according to the types of some attributes, which is written as $U_1, U_2, \ldots, U_n$ and should meet $\bigcup_{i=1}^{n} U_i = U$, $U_i \cap U_j = \phi$, $i \neq j$. Each subset is divided into several evaluation factors $U_i = \{u_{i1,} u_{i2} \ldots, u_{im}\}$, $i = 1,2, \ldots, n$, of which $U_{ij} = (i = 1,2 \ldots n; j = 1,2 \ldots m)$. It is further divided into $U_{ij} = \{u_{ij1,} u_{ij2,} \ldots u_{ijp}\}$ until a complete evaluation factor index system reflecting the evaluation level can be established.

P evaluation sets $V = \{v_{1,} v_{2,} \ldots v_p\}$ composed of test results were established, and this evaluation sets V were graded by corresponding evaluation criteria in U.

The affiliation of each factor in U_i to $V = \{v_{1,} v_{2,} \ldots v_p\}$ is calculated separately according to the fuzzy mathematical theory using the formula, from which the arrangement of the affiliation of all the indicators can be sufficient to form a single-factor evaluation matrix R_i of U_i, as follows:

$$R_i = \begin{bmatrix} \gamma_{i11} & \gamma_{i12} & \cdots & \gamma_{i1p} \\ \gamma_{i21} & \gamma_{i21} & \cdots & \gamma_{i2p} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{im1} & \gamma_{im2} & \cdots & \gamma_{imp} \end{bmatrix}, i = 1,2, \ldots, n \tag{7}$$

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2.1.3. Model solution results

Table 2: Ecological value estimation table of Saihanba

Water conservation/ 100 million m ³	Keep the water and soil/ 10 thousand tons	Windbreak and sand-fixation/ tons	Release oxygen/ 10 thousand tons	Absorption of CO_2/ 10 thousand tons	Preserving biodiversity/ 10 thousand Yuan
2.84	1863.8	98634.5	59.84	86.03	186200.3

Through screening and studying the relevant data of the Saihanba ecological area, the influence of Saihanba on the ecological environment is quantitatively analyzed by using the factor analysis method and fuzzy comprehensive evaluation method. Over time, the overall impact of Saihanba on the ecological environment shows an upward trend.

2.2. The impact of the Saihanba restoration on the sandstorm prevention in Beijing

To evaluate the influence of Saihanba on the process of sand control in Beijing, the indexes that Saihanba plays a decisive role in the process of sand control in Beijing and the climatic data of Beijing should be determined first. Data selection in Saihanba mainly focuses on forest coverage rate, forest area, number of trees, and other indicators, while climate data selection in Beijing mainly focuses on average wind speed, windy days, severe weather, air quality, and other indicators. Through correlation analysis, the correlation coefficients between Saihanba data and Beijing climate data are calculated, and the influence of the restoration of Saihanba on the process of sandstorm prevention in Beijing is finally determined.

To determine the influence of Saihanba on Beijing's sand prevention, we need to determine the specific analysis index first.

Data selection of Saihanba: Forest cover area, Forest coverage.

Climate data selection in Beijing: Air quality, Number of severe weather, Average wind speed.

The correlation analysis of the ecological indicators of the Saihanba forest area with the climate change indicators of Beijing yielded the correlation coefficients for the two sets of data mentioned above.

Table 3: Correlation coefficient

	Forest cover area/10^4m^3	Air quality/ dimensionless	Average wind speed/ m/s	Number of severe weather/day
Forest cover area/10^4m^3	1.000	0.950	-0.844	-0.673
Air quality/ dimensionless	0.946	1.000	-0.887	-0.643
Average wind speed/ m/s	-0.898	-0.887	1.000	0.599
Number of severe weather/day	-0.623	-0.643	0.599	1.000

The correlation coefficients between the impact indicators of the Saihanba and the Beijing climate indicators were obtained by correlation analysis of the two selected data sets, and the correlation coefficients were rated by Table 4.

Table 4: Classification of correlation coefficients

ρ	**$0\leq\rho<0.2$**	**$0.2\leq\rho<0.4$**	**$0.4\leq\rho<0.6$**	**$0.6\leq\rho<0.8$**	**$0.8\leq\rho<1$**
level	Unrelated	Weak correlation	General relevance	Stronger relevance	Extremely relevant

Table 5: Correlation level determination

Comparative indicators	**Comparison of coefficients**	**Level**
Forest cover area/ Air quality	0.946>0.8	Extremely relevant
Forest cover area/ Average wind speed	0.898>0.8	Extremely relevant
Forest cover area/ Number of severe weather	0.623>0.6	Stronger relevance
Forest coverage/ Air quality	0.950>0.8	Extremely relevant
Forest coverage/ Average wind speed	0.844>0.8	Extremely relevant
Forest coverage/ Number of severe weather	0.673>0.6	Stronger relevance

To sum up, the construction of Saihanba Forest Farm has a strong linear correlation with the

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improvement of Beijing's air quality, the reduction of severe weather, and the slowdown of wind speed. Therefore, Saihanba has played an important role in the process of sand prevention in Beijing.

2.3. Identify which areas of China need to build eco-districts

Firstly, the energy consumption of each province in China and the forest area of each province were determined, and the carbon emissions and carbon absorption of each province were calculated; secondly, the ratio of carbon absorption to carbon emissions for each city in China was calculated, and cluster analysis was used to determine which areas needed to build woodlands; finally, by modeling the future carbon emissions and carbon absorption of each province, the number of woodlands and the scale of woodlands needed to be built were determined.

Through data collection and statistical analysis of carbon emission and carbon absorption of each province in China, the carbon neutralization coefficient of each province can be calculated as follows:

$$h = \begin{cases} s/T\,, S < W \\ 1, S \geq W \end{cases} \tag{8}$$

S: Carbon sequestration; *T*: Carbon Emission.

By looking up the data, we can obtain the following maps of forest land distribution and wind distribution in China in 2020.

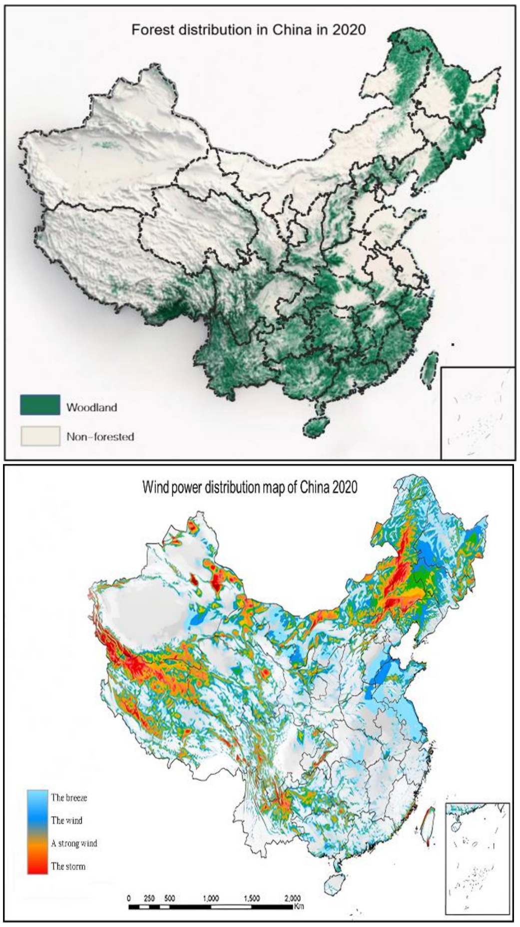

Figure 1: Woodland, wind distribution map

According to the classification of *h* value of each province in each year by cluster analysis, it is concluded that Gansu, Shanxi, and Inner Mongolia are the three provinces that need to build ecological protection areas. The size of ecological zones to be built in these three provinces can be determined according to the number of cities or the carbon-neutral conversion coefficient.

The formula for determining the area of forest land to be built up in each province is as follows.

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$$B = \frac{T\bar{h} - Th}{q} \tag{9}$$

B: Area of plantation woodland required; T: Carbon emissions;q:Carbon absorption per unit of forest land; $\bar{h}$: The average carbon neutralization conversion coefficient of each province.

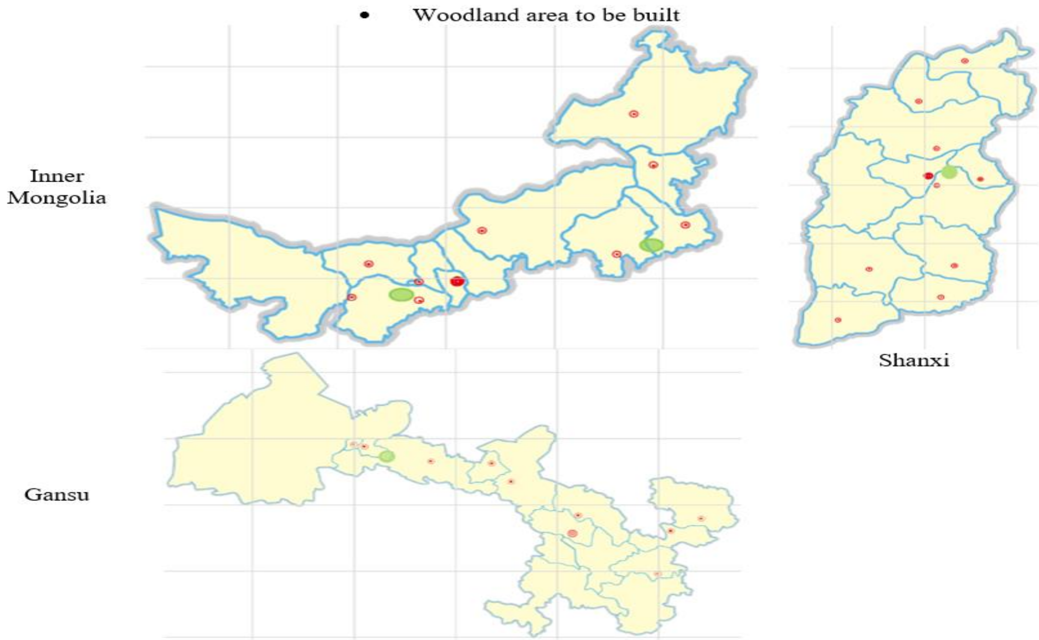

Figure 2: Planned to build woodland area map

Based on the analysis of the data and the number of municipalities and urban distribution in each province, a map of the location and scale of woodland construction can be derived as shown in Figure 2.

To sum up, Inner Mongolia needs to build 12559.7 mu of forest land, Shanxi needs to build 8690.6 mu of forest land, Gansu needs to build 7540.38 mu of forest land, the specific construction location is shown in the figure above.

At the same time, after the completion of forest construction in the three provinces, at least 669739KT of carbon dioxide will be absorbed every year, which will play an important role in improving the climate of the three provinces and have a positive impact on China's carbon neutrality goal.

3. Conclusion

In this paper, factor analysis, fuzzy comprehensive evaluation, correlation analysis, and cluster analysis are mainly used to study the ecological value of the Saihanba forest region and promote it to other areas. By using the above methods, the climate and environment data of the whole country, the main index of forest affecting the ecological environment, the carbon neutralization coefficient of each region, the location and scale of the ecological forest need to be built and so on were obtained.

In the process of determining the location and scale of ecological forest construction, the following principles are mainly used: i. Priority principle: which areas have the most serious environmental problems and which areas should be treated first. ii. Quantitative principles: Translate abstract concepts into concrete data, and make goals and plans that need to be accomplished based on reality. iii. Scientific principles: Through a comprehensive analysis of various indicators, determine the location and scale of the need to build ecological forest areas.

In the above analysis process, the established model accurately evaluated the ecological value of Saihanba, and in the process of promotion to China, the model accurately determined the location of the ecological forest area to be built and its impact on the ecological environment. Therefore, the model established in this paper can be extended to other regions and fields.

Finally, in the construction of ecological forest areas, the author's suggestions are i. In the process of forest area construction, to deal with the development and emission reduction, overall and partial, short-term and long-term relations. ii. In the process of building ecological forest areas, follow up with

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advanced technology, pay attention to the selection of excellent saplings and disease and insect control. iii. In the location of ecological forest area construction, multi-city linkage can be selected to improve efficiency and maximize benefits.

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