Quantitative analysis of ecosystem health based on HEL-BP evaluation model

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Abstract. Based on the PSR model, Fuzzy Comprehensive Appraisal (FCA) and analytic Hierarchy Process (AHP) were used to evaluate the health of the system and establish HEL evaluation model. The evaluation model was used to compare and quantitatively analyze the ecosystem health before and after the establishment of Saihanba forest farm.

Keywords: AHP, FCA, BP networ.

1. Introduction

On the road to development, China has always adhered to the concept of respecting, living in harmony with and protecting nature, and the sustainable development strategy of giving priority to conservation, protection and natural restoration [1]. Located in the northern part of Hebei Province, Saihanba was once a wasteland. For more than half a century, three generations of people in Saihanba Forest Farm have planted trees and built one million mu of artificial forest with indomitable fighting spirit and unyielding responsibility [2-4]. Therefore, on the one hand, we respond to the call of national policies to build ecological civilization and take Saihanba as a typical example to carry forward the spirit of Saihanba. On the other hand, we protect the environment and the only home we have[5-8]. To protect the environment, the construction of green and sustainable development strategy into everyone's heart, to build our beautiful China.

2. Hel Model Establishment

2.1. The Analytic Hierarchy Process Determines the Weight

2.1.1. Build a hierarchy

AHP is applied to analyze and make decisions[9]. Firstly, the problems to be solved are organized and hierarchical, and the factors affecting the ecological environment are expressed hierarchically as shown in Figure 1.

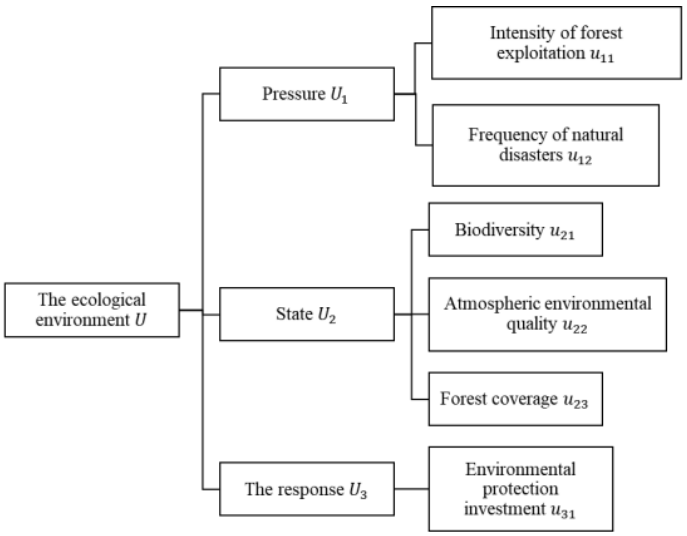


Figure 1. Indicator system diagram of Saihanba's impact on ecological environment

2.1.2. Establish the judgment matrix

The judgment matrix represents a comparison of the importance of the elements at this level with the relevant elements at the next level. Through the comparison between the two, the judgment matrix is determined and calculated, and the scale of each factor index is shown in Table 1.

Table 1. Scale table of factor indicators

Level of scale	Evaluation factor A over B
1	As important
3	A little important
5	Obviously important
7	Very important
9	Prime importance
2, 4, 6, 8	Judge the intermediate value of adjacent scales
1/X	Inverse comparison of two factors

2.1.3. Calculate the weight

After the judgment matrix is established, the maximum eigenvalue λ of each matrix and its corresponding eigenvector w are calculated, so as to calculate the weight value of each element. The consistency test is carried out by $CR = \frac{CI}{RI}$.

Normalize each column vector of judgment matrix A, get:

$$\overline{w_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, j = 1, 2, \cdots, n \tag{1}$$

Sum $\overline{w_{ij}}$ over rows, and get:

$$\overline{w_{ij}} = \sum_{j=1}^{n} \overline{w_{ij}}, i = 1, 2, \cdots, n \tag{2}$$

Normalize $\overline{w_{ij}}$, get:

$$\overline{w_{ij}} = \frac{\overline{w_i}}{\sum_{j=1}^{n} \overline{w_i}} \tag{3}$$

Then:

$$w = (w_1, w_2, \cdots, w_n)^T \tag{4}$$

Calculate the maximum characteristic root λ of the judgment matrix *A*, i.e

$$\lambda = \frac{1}{n} \sum_{i=1}^{n} [\frac{(Aw)_i}{w_i}] \tag{5}$$

Conduct consistency test on the judgment matrix, calculate CI first, i.e

$$CI = \frac{(\lambda - n)}{n-1} \tag{6}$$

To calculate the CR, and

$$CR = \frac{CI}{RI} \tag{7}$$

The RI in the expression is given by a large number of experiments (Table 2)

Table 2. Average random consistency index values of AHP method

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54

Where n is the order of the judgment matrix. When CR <0.1, the consistency of the judgment matrix is considered acceptable; otherwise, the judgment matrix should be adjusted.

2.2. HEL Model Construction Based on Fuzzy Comprehensive Evaluation Method

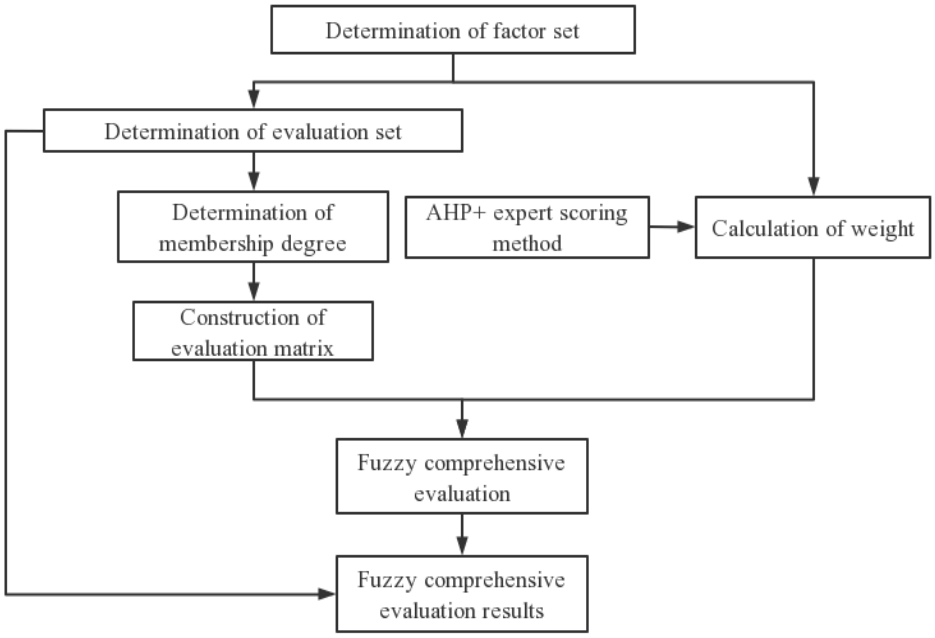


Figure 2. Flow chart of fuzzy comprehensive evaluation model

Firstly, the factors and evaluation set are determined, and the membership degree of each factor is determined by membership degree function and the weight is calculated[10]. Then, the comprehensive fuzzy evaluation matrix is constructed and the evaluation result is finally obtained.

2.2.1. Determination of factor set

In establishing a comprehensive evaluation system, according to the assessment of ecological environmental impact factors of indicators, divided into basic factors set U into three subsets, $U_i = \{U_{i1}, U_{i2}, \cdots, U_{ik}\}$, among them $(i = 1,2,3)$, k each subset into a number of evaluation factors, and among them, each set the number of secondary factors, establish assessment sihanba for grading index system of ecological environmental impact, Ahp and expert scoring were used to assign weight to these factors[11].

2.2.2. Determination of evaluation set

The grade set of evaluation set for ecological environmental impact is $V=\{v_1,v_2,v_3,v_4\}$ = {excellent, good, average, poor}. The assessment grade was divided into four grades: ecological environment health (excellent), ecological environment good (good), ecological environment general (general), ecological environment unhealthy (poor), and the ecological environment impact grade was evaluated.

2.2.3. Construction of membership function

In the trapezoidal membership function, the distribution function form of the combination of small, middle and large is selected. Below a means that the ecological health of the region is very poor, around b means that the ecological health of the region is average, around c means that the ecological health of the region is good, and above d means that the health of the country is excellent(Table 3).

Table 3. Distribution table of trapezoidal membership functions

Partial small	The middle type		Partial large
$u_1(x)=\begin{cases}1, & x<a\\ \frac{b-x}{b-a}, & a\le x\le b\\ 0, & x>b\end{cases}$	$u_2(x)=\begin{cases}0, & x\le a\\ \frac{x-a}{b-a}, & a<x\le b\\ \frac{c-x}{c-b}, & b<x\le c\\ 0, & x>c\end{cases}$	$u_2(x)=\begin{cases}0, & x\le b\\ \frac{x-b}{c-b}, & b<x\le c\\ \frac{d-x}{d-c}, & c<x\le d\\ 0, & x>d\end{cases}$	$u_4(x)=\begin{cases}0, & x\le c\\ \frac{x-c}{d-c}, & c<x<d\\ 1, & x>d\end{cases}$

2.2.4. Determine the comprehensive fuzzy judgment matrix

1) Determine the secondary judgment matrix

Fuzzy comprehensive evaluation is carried out on secondary factor set $U_i=\{U_{i1},U_{i2},\cdots,U_{ik}\}$.

Its membership matrix is:

$$R_i=\begin{bmatrix} r_{11}^{(i)} & r_{12}^{(i)} & \cdots & r_{1m}^{(i)} \\ r_{21}^{(i)} & r_{22}^{(i)} & \cdots & r_{2m}^{(i)} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1}^{(i)} & r_{n2}^{(i)} & \cdots & r_{nm}^{(i)} \end{bmatrix}_{m\times 4} \tag{8}$$

Where, m is the number of indicators contained in i second-level factor sets.

Next, AHP and expert scoring method are used to assign the index weight, where the weight matrix is:

$$A_i=[a_{11},a_{12},\cdots,a_{1m}]_{1\times m} \tag{9}$$

The second level fuzzy comprehensive evaluation matrix is obtained:

$$B_i=A_iR_i \tag{10}$$

2) Determine the final judgment matrix

Fuzzy comprehensive evaluation is carried out on the first-order factor set $U=\{U_1,U_2,U_3\}$.

Fuzzy comprehensive evaluation is carried out on the first-order factor set $U=\{U_1,U_2,U_3\}$.

Where, the membership matrix is:

$$R = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_j \end{bmatrix}_{i\times 4} \tag{11}$$

Where j is the number of second-order factor sets contained in first-order factor sets.

AHP and expert scoring method are used to assign the index weight, and its weight matrix

$$A = [a_1, a_2, \cdots, a_i]_{1\times i} \tag{12}$$

A 1×4 fuzzy comprehensive evaluation matrix is obtained:

$$B = AR \tag{13}$$

The final $HEL_1 = \max\{B\}$ is the evaluation set corresponding to the maximum membership degree in the comprehensive fuzzy evaluation matrix.

3. Comparative analysis of Saihanba Forest Farm before and after establishment

By querying the relevant data before and after the restoration of Saihanba, the results as shown in Figure 3 are obtained by solving the HEL model with MATLAB.

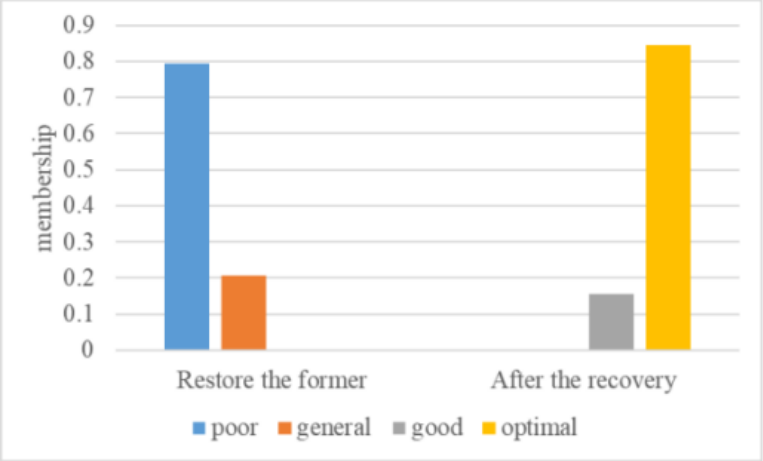


Figure 3. Comparison diagram of ecological environment membership degree before and after restoration of Saihanba

According to the result of the Figure 3, it can be concluded that the restoration of Saihanba has a favorable impact on the ecological environment.

4. Analysis of Analysis of Newly Built Protected Areas In Different Regions of China

4.1. The Relationship Between the Area Size of New Urban Protection Area and Index Set in HEL Model Is Determined

4.1.1. Description of the algorithm

Genetic algorithm (GA) and BP neural network algorithm were combined to constantly adjust the parameters, and finally the relationship between the size of new urban protection area and HEL model index was obtained (Figure 4).

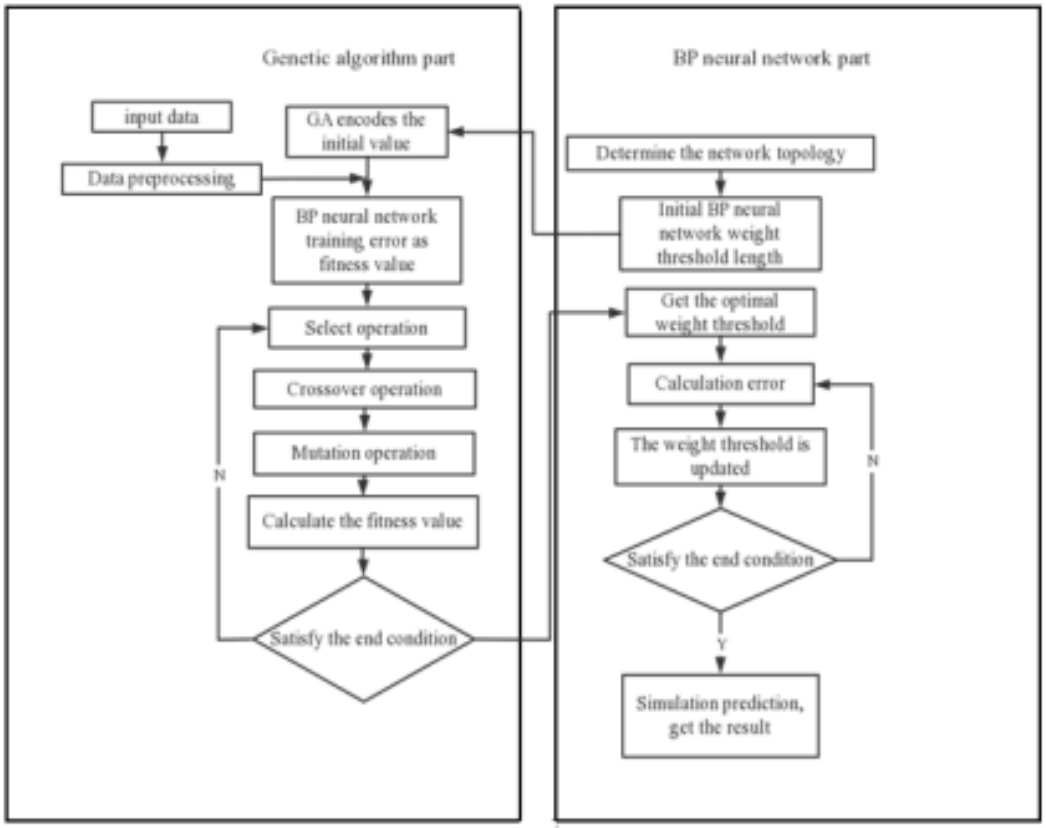


Figure 4. Algorithm flow chart

4.1.2. Data selection

In this question, the data of cultivated land area, woodland area, residential area, industrial and mining land in China from 2001 to 2020 are all from the National Bureau of Statistics.

4.1.3. Determination of relation

After BP neural network training, get

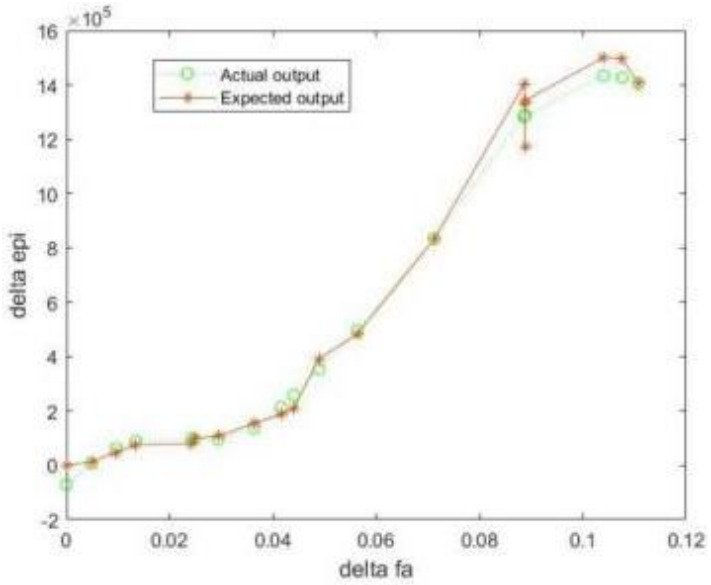


Figure 5. Forest coverage rate and environmental protection into the fitting function diagram

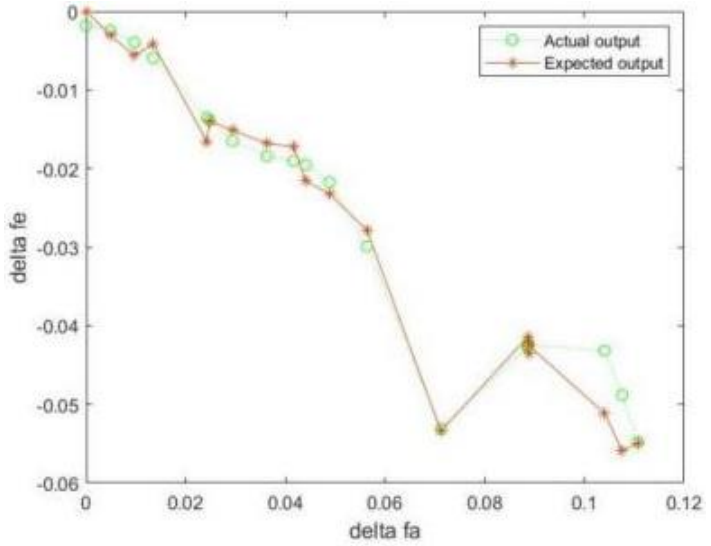


Figure 6. Forest coverage rate and development intensity of fitting function diagram

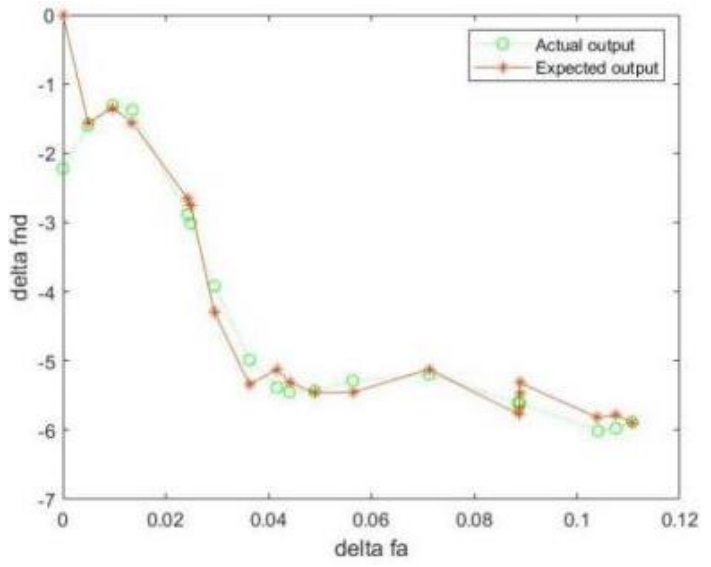


Figure 7. Fitting function diagram of forest coverage rate and natural disaster frequency

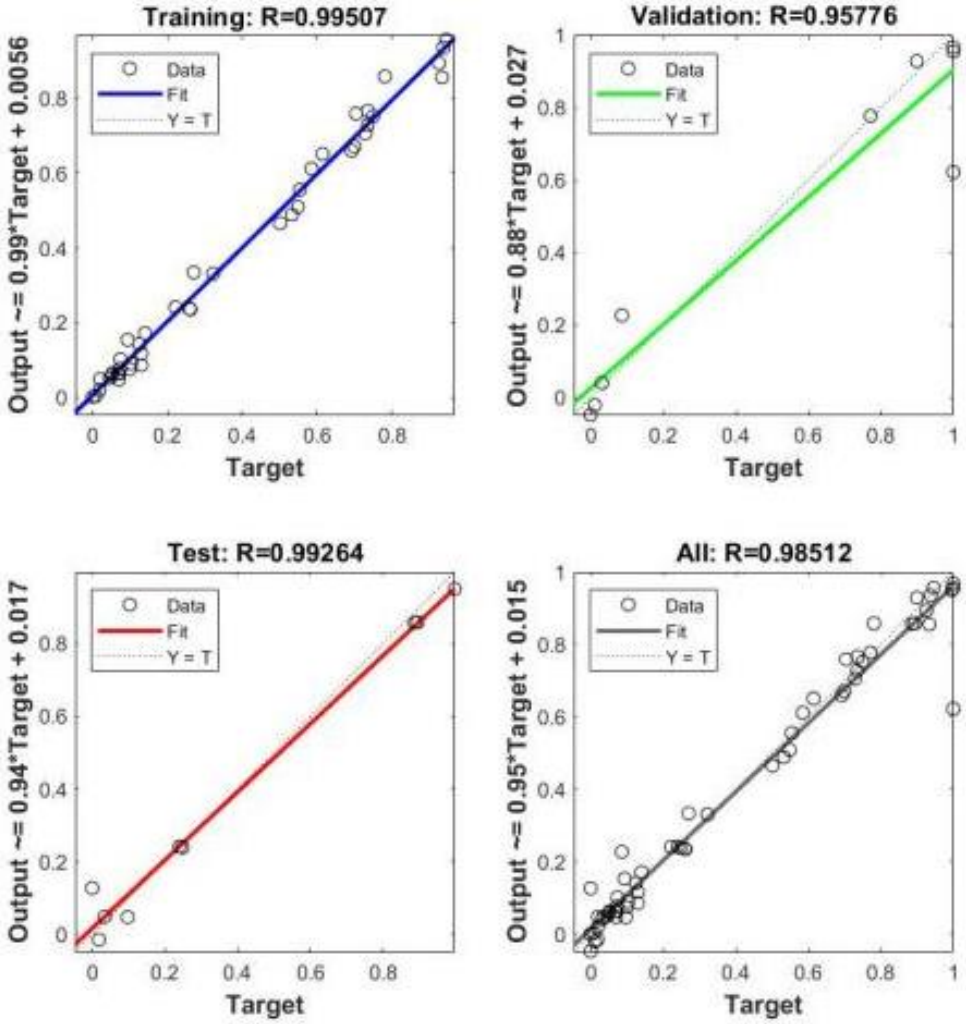


Figure 8. Goodness of fit diagram

According to the Figure 5 and Figure 6 and Figure 7 fitting function diagram can be seen that the forest coverage rate and intensity of environmental protection investment, forest development, the variation of the frequency of natural disasters, fitting curve is better, so you can according to the function of the fitting out Figure to forecast the unknown data.

According to the Figure 8 can get the above three fitting function of goodness-of-fit $R^2 = 0.98$, also expressed once again we are fitting out the function of image is very appropriate, including the area of the area is fixed, then you can get forest coverage by the change of forest land area, finally can according to the forest coverage rate to judge the environmental protection investment, the strength of forest development, the change of the natural disaster frequency index, That is, if the forest coverage rate increases by 1%, the input of environmental protection, the intensity of forest development and the frequency of natural disasters will change by 504,647,891 million yuan, -0.0076 unit intensity and -1.9970 times respectively.

4.2. Establishment of HEL-BP Optimization Model

4.2.1. The objective function is

$$B_{j4} = 0.2973P_{j4} + 0.5290S_{j4} + 0.1638R_{j4} \tag{14}$$

B_{j4} represents the membership degree of the j city to the excellent set.

4.2.2. Influencing factors This variable is described Forest development intensity is

$$fe_j^{new} = f(\Delta x_j) + fe_j^{old} \tag{15}$$

Δx_j is the newly built protected area of city j, fe_j^{new} is the intensity of forest development after increasing the area of new protected areas, fe_j^{old} is the forest development intensity without adding new protected area.

Natural disaster frequency is

$$fnd_j^{new} = f(\Delta x_j) + fnd_j^{old} \tag{16}$$

Δx_j is the newly built protected area of city j, fnd_j^{new} is the frequency of natural disasters after increasing the area of newly built protected areas, fnd_j^{old} is the forest development intensity without adding new protected area.

Biodiversity is:

$$bio_j^{new} = f(\Delta x_j) + bio_j^{old} \tag{17}$$

Δx_j is the newly built protected area of city j, bio_j^{new} is biodiversity after increasing the area of new protected areas, bio_j^{old} is the biodiversity without adding new protected area.

The atmospheric environmental quality is

$$Aeq_j^{new} = f(\Delta x_j) + Aeq_j^{old} \tag{18}$$

Δx_j is the newly built protected area of city j, Aeq_j^{new} is the atmospheric environment quality after increasing the area of newly built protected areas, Aeq_j^{old} is the atmospheric environmental quality of the newly built protected area.

The forest coverage is:

$$Fcr_j^{new} = f(\Delta x_j) + Fcr_j^{old} \tag{19}$$

Δx_j is the newly built protected area of city j, Fcr_j^{new} is the forest coverage rate after increasing the area of new protected areas, Fcr_j^{old} is the forest coverage rate without adding new protected area.

Environmental protection input

$$Epi_j^{new} = f(\Delta x_j) + Epi_j^{old} \tag{20}$$

Δx_j is the area of newly-built protected area in the jth city, Epi_j^{new} is the input of environmental protection after increasing the area of newly-built protected area, Epi_j^{old} is the input of environmental protection without adding the area of newly-built protected area. The above f represents the functional relationship between the change of forest coverage rate and each index value of HEL model by using BP-GA algorithm.

In terms of pressure of the jth city, the membership degree P_{j4} of excellent set is

$$P_{j4} = 0.6u_4(fe_j^{new}) + 0.4u_4(fnd_j^{new}) \tag{21}$$

In terms of the state of the jth city, the membership degree S of excellent set is:

$$S_{j4} = 0.4u_4(bio_j^{new}) + 0.2u_4(Aeq_j^{new}) + 0.4u_4(Fcr_j^{new}) \tag{22}$$

In terms of the response of the jth city, the membership degree R_{j4} of excellent set is:

$$R_{j4} = u_4(Epi_j^{new}) \tag{23}$$

4.2.3. Constraints

1) Constraints on the balance of protected areas in the total area:

$$\frac{\Delta x_j + x_j}{Ta_j} \le \max\left\{\frac{x_m}{Ta_m}\right\} \tag{24}$$

That is, the area of newly built and previously built nature reserves should not be larger than the area of the most excellent urban planning among all excellent cities.

2) Constraints on the balance between protected areas and cultivated land:

$$\frac{\Delta x_j + x_j}{ca_j - \Delta x_j} \le \max\left\{\frac{x_m}{ca_m}\right\} \tag{25}$$

That is, the ratio of newly built land and the area of the existing natural protected area to the area of cultivated land minus the area of newly built protected area should not be greater than the ratio of the area of the most excellent nature protected area to the area of cultivated land in all excellent cities.

3) Constraint on the balance between protected area and urban area:

$$\frac{\Delta x_j + x_j^2}{ua_j - \Delta x_j} \le \max\left\{\frac{x_m}{ua_m}\right\} \tag{26}$$

That is, the ratio of the newly built land and the existing nature protection area to the urban area minus the newly built nature protection area should not be greater than the ratio of the most excellent urban planning nature protection area to the arable land area in all excellent cities.

Where, represents the area of nature reserve in the best city of x_m, Ta_m represents the total area of the best city, ca_m represents the area of arable land in the best city, ua_m represents the area of the best city, and j represents the city of j. Then we can establish a mathematical programming model as

$$maxB_{j4} = 0.2973P_{j4} + 0.5290S_{j4} + 0.1638R_{j4} \tag{27}$$

$$s.t\begin{cases}\dfrac{\Delta x_j + x_j}{Ta_j} \le \max\left\{\dfrac{x_m}{Ta_m}\right\} \\ \dfrac{\Delta x_j + x_j}{ca_j - \dfrac{\Delta x_j}{2}} \le \max\left\{\dfrac{x_m}{ca_m}\right\} \\ \dfrac{\Delta x_j + x_j^2}{ua_j - \dfrac{\Delta x_j}{2}} \le \max\left\{\dfrac{x_m}{ua_m}\right\}\end{cases} \tag{28}$$

4.3. Application and Analysis of HEL-BP in Various Regions of China

4.3.1. Based on HEL model with provincial data

The complete data in Table 4 are in the attachment, so we can also make the following visualization and deeper analysis of the obtained data.

Table 4. Set table of quantity and membership degree of each urban nature reserve

The city name	Nature reserve	Optimal (%)	Good (%)	General (%)	Poor (%)	Under collection
Beijing	2	40.47	25.33	19.96	14.26	Optimal
Tianjin	3	21.72	6.82	32.66	38.81	Poor
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Ningxia	9	17.25	11.31	36.63	34.81	General
Xinjiang	15	23.33	5.21	10.84	60.62	Poor



Figure 9. Map of the subordination degree of ecological environment difference in different regions of China

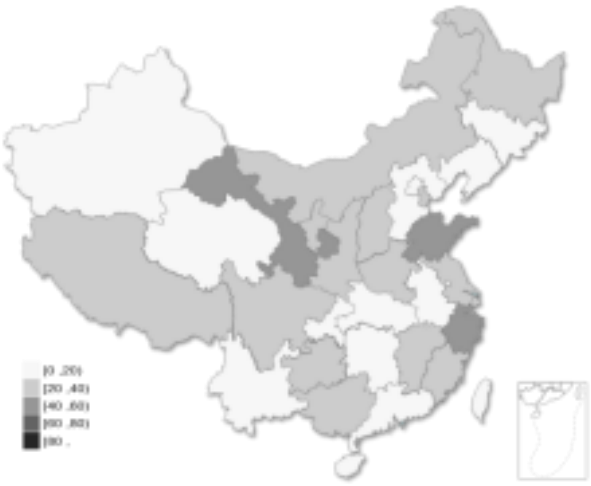


Figure 10. Map of general membership degree of ecological environment in various regions of China



Figure 11. Map of ecological environment good subordination degree of eachregion in China



Figure 12. Map of ecological environment optimum subordination degree of each region

Data description: The data selected this time are the data of all other regions in China except Hong Kong, Macao and Taiwan. Figures 9-12 are all in.

4.3.2. Results Analysis

According to Figure 9, you can see that China's each region ecological environment worse, represented by the color of the deeper.

Figure 10 shows that, with economic growth, people's income in Gansu has increased, and people abuse and overuse resources.

Figure 11 shows the Chinese each region ecological environment is a good collection of membership degree scale map.

Figure 12 shows the proportion of membership degree belonging to the optimal set in each region in China. The greener the color, the better the ecological environment in the region. A.

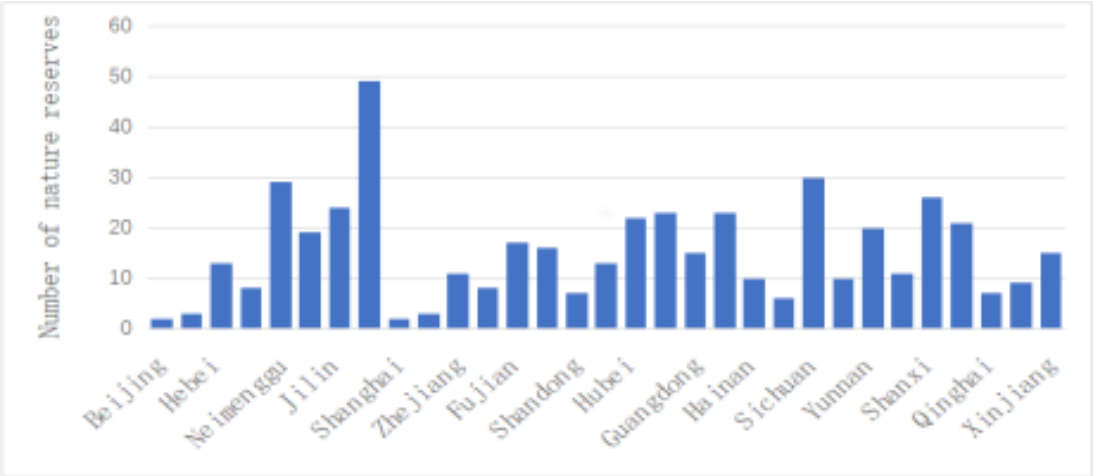


Figure 13. Statistics of the number of existing nature reserves in various regions of China

As shown in Figure 13, it is still a set with poor ecological environment or general membership. We need to establish more nature reserves on this basis.

Results: According to the analysis of HEL-BP model, Tianjin, Shanxi, Inner Mongolia, Gansu, Qinghai, Ningxia and Xinjiang need to establish ecological areas in China. The forest coverage rate of established nature reserves is 12%, 1%, 1%, 13%, 6%, 13% and 19% respectively.

4.3.3. Before and After Comparison Was Made to the Areas Where Nature Reserves Were Established

Table 5. Membership degree table of nature reserve before and after constructio

Under collection Area	Poor	General	Good	Optimal	Poor	General	Good	Optimal
Tianjin	0.3881	0.3266	0.0682	0.2172	0.3481	0.0579	0.3768	0.2172
Shanxi	0.3389	0.2553	0.3256	0.0802	0.3210	0.2732	0.3256	0.0802
Neimenggu	0.0000	0.3598	0.3548	0.2855	0.0000	0.3538	0.3608	0.2855
Gansu	0.2455	0.4692	0.0521	0.2333	0.0809	0.3138	0.3199	0.2855
Qinghai	0.5303	0.0123	0.1720	0.2855	0.3135	0.2168	0.0892	0.3805
Ningxia	0.3481	0.3663	0.1131	0.1725	0.3315	0.0289	0.3542	0.2855
Xinjiang	0.6062	0.1084	0.0521	0.2333	0.1486	0.2568	0.3093	0.2855

According to the change of membership degree before and after the establishment of nature reserves in 7 cities that need to establish nature reserves in Table 5, it can be concluded that:

Table 6. Membership set change table

Under collection Area	Membership set variation
Tianjin	Poor→Good
Shanxi	Poor→Good
Neimenggu	General→Good
Gansu	General→Good
Qinghai	Poor→Optimal
Ningxia	General→Good
Xinjiang	Poor→Good

As can be seen from Table 6, after the establishment of nature reserves, the membership sets of all cities that need to establish nature reserves have been improved. Among them, the membership sets of Qinghai have risen from poor to excellent due to the establishment of nature reserves, and the membership sets of other regions have also been improved.

4.3.4. Evaluate the Impact of Carbon Neutrality in China

BP neural network was used to establish the relationship between forest area and CO_2 absorption f in Saihanba Forest. Establish as follows (Figure 14-16):

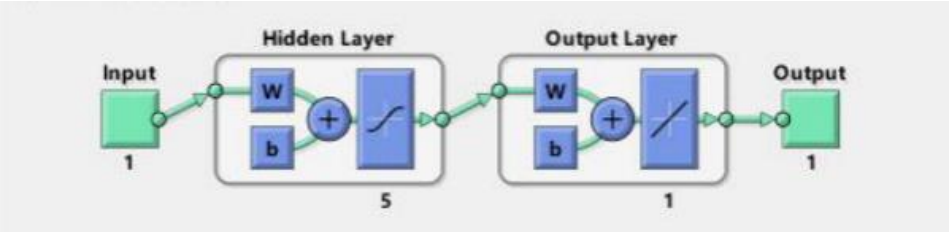


Figure 14. Structure diagram of BP neural network

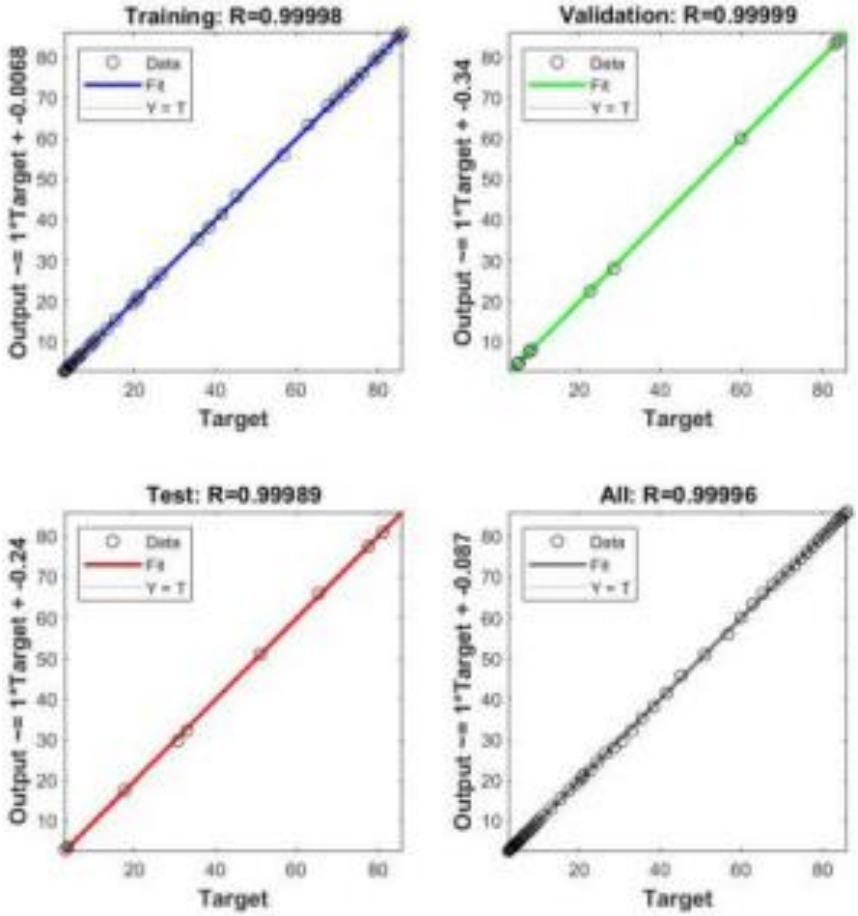


Figure 15. Schematic diagram of goodness of fit of BP neural network

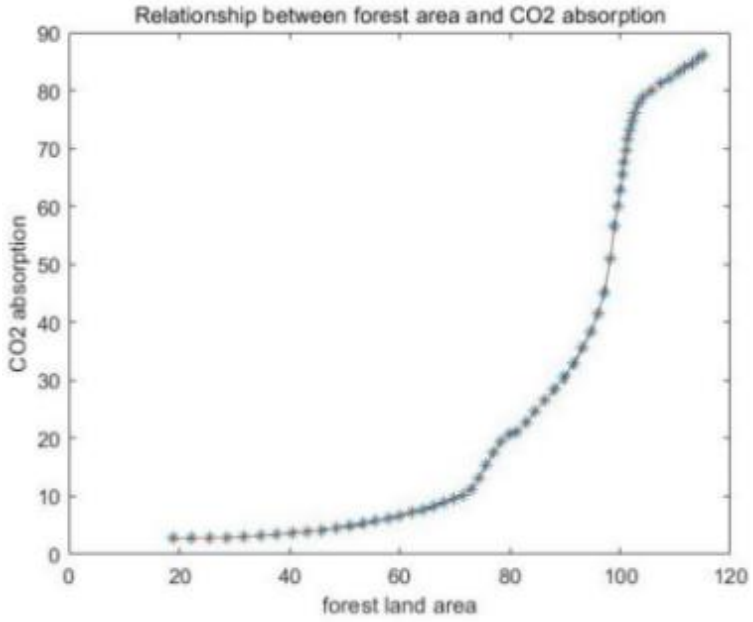


Figure 16. BP neural network fitting effect diagram

Using this network, it is predicted that a total of 441,191 square kilometers of newly built forest land will absorb 1,661,145 million tons more, accounting for 0.2539 of the total co2 emissions in 2019. Go a long way towards achieving carbon neutrality.

5. Conclusion

In this paper, HEL, RS and HEL-BP models were established to evaluate the impact of Saihanba on the ecological environment and the anti-dust ability of Beijing, and to determine which regions of China and Mongolia need to build ecological zones and the scale and quantity of ecological zones. First of all, according to the data required by the relevant indicators of each model collected by us, we evaluated, compared and quantitatively analyzed the influence of Saihanba on the local ecological environment and the anti-dust ability of Beijing before and after the establishment of Saihanba. Secondly, we applied HEL model and HEL-BP model to China and Mongolia, respectively, and obtained the amount of CO_2 that could be more fixed in the area requiring ecological protection and the newly added forest area. At the same time, we also provided feasible plans and suggestions for China and Mongolia in the construction of ecological reserves, hoping to improve the environmental quality as much as possible. Finally, we also analyze that establishing nature reserves in corresponding areas is a long and difficult process for Mongolia as well as any other country.

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