Applying Back Propagation Algorithm and Analytic Hierarchy Process to Environment Assessment

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Abstract. This paper designs a new and scientific environmental quality assessment method, and takes Saihan dam as an example to explore the environmental improvement degree to the local and Beijing areas. AHP method is used to assign values to each weight.7 primary indicators and 21 secondary indicators were used to establish an environmental quality assessment model. The conclusion shows that after the establishment of Saihan dam, the local environmental quality has been improved by 7 times, and the environmental quality in Beijing has been improved by 13%. Then, the future environmental index is predicted. Finally, the Spearson correlation coefficient is analyzed, and it is proved that this method's correlation is 99%. Finally, the back-propagation algorithm is used to test and prove that the error is little.

Keywords: Hierarchical Analysis Method; Spearson Model Carbon Storage.

1. Introduction

1.1 A. Problem Background

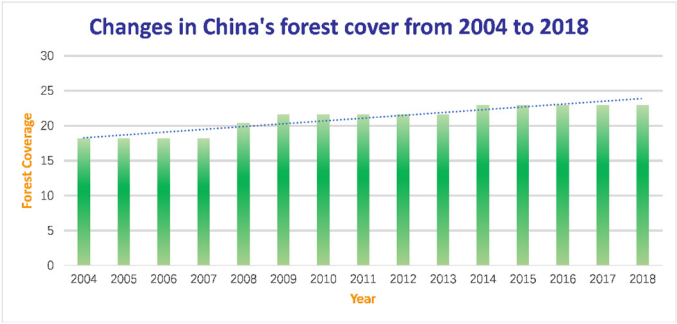

Fig 1. Changes in China's forest coverage from 2004 - 2018

With the development of human society and human's claim on nature, ecological damage and environmental pollution have posed a great threat to the survival and development of human beings. Protecting and improving the ecological environment to achieve sustainable development of human society is the most urgent task for all mankind. The protection of ecological environment is to contribute to the sustainable development of human society. In recent years, people have built a green barrier against sand and dust storms, and there have been numerous activities to improve the ecological environment, such as afforestation, sand and water consolidation, etc. People have gone on to devote themselves to improving ecological environment, advanced wave upon wave, which has also achieved great success. According to collected statistics, by the end of 2018, China's forest coverage had reached 22.96%, with a cumulative forest area of 2.2 hectares, and the ratio keeps going up, making China the fastest-growing forest region in the world.

The improvement in ecological environment will bring quantities of benefits to all creatures on Earth. By analyzing the weather data of cities around the reforested areas, we can get the first-hand information of changes in the urban ecological environment before and after the reforestation. At the same time, modeling different regions of China and the world, we can predict suitable locations for the establishment of ecological reservation, which is a great guide for the improvement of the global ecological environment.

1.2 Motivations and Our Work

Firstly, in order to quantitatively assess the effect of the establishment of the Saihanba Forest on the local ecological environment, the data of the local ecological conditions now and before the establishment of the Saihanba Forest is collected. Then substitute the data into the formula and obtain the results finally.

Secondly, a specific model called the Sandstorm Risk Index Model is established and the coefficient of each weight is computed by AHP algorithm. Thus, the sandstorm risk index of Beijing before and after the establishment of the Saihanba is quantified by using the model.

Then, the Spearson Model is used to perform correlation tests against the model. Thirdly, this study select Gansu Province as our research object and calculated the area of nature reserves to be established in Gansu province. For carbon emissions, another model called Carbon Storage Model based on the carbon storage within the forest and calculated the annual average carbon storage of the newly established nature reserves is built to estimate the carbon emissions. Then, this study select Mongolia as an example, where the pollution level is more severe, to assess environmental pollution status and carbon emissions, carbon storage status. After quantifying the pollution level of Gobi Sumbeer province, the results show that the province needs to establish a nature reserve of 94,430 km2 . For the carbon emissions, carbon storage status, this study finally shows that the average annual carbon storage is 535,927,760 tons by using the carbon storage model.

Finally, combining the established sandstorm risj index model and the carbon storage model, this study suggests the establishment of the ecological model of Saihanba and the coordination of the ecosystem respectively. Factors such as adjusting the structure of forest leaves and controlling environmental impacts are applied to the protection of ecological environment, so that sustainability can develop along with human civilization.

2. Model Preparations

2.1 Assumptions and Justifications

For the model, the assumptions are given in the following.

• Nine indicators such as visibility and wind speed can be used to quantify the quality of the ecological environment.

• Data from IKH nature reserves can be used for calculating data related to newly established nature reserves.

• The collected data is real and reliable.

• External conditions do not interfere with carbon neutrality.

2.2 Abbreviations and Acronyms

The primary notations used in our paper are listed in Tab 1.

Table 1. The primary notations used in our paper

Symbol	Defination
EI	Ecosystem Status Index
CR	Consistency Ratio
CI	Consistency Indicator

RI	Stochastic Consistenct Index
H	Risk Degree of Sandstorm
DV	Visibility Indicator
U	Wind Index
ΔT	Cooling Index
P	Sand Transport Index
TR	Sandstorm Development Trned Indicator
C	Carbon Storage of Different Forests
EH	Ecological Hazard Index

3. Method

3.1 Model

In order to accurately simulate the ecological environment of Saihanba area, information is collected from the Saihanba Mechanical Forestry Station, and data is obtained on relevant indicators. These indicators are forested land area, forest cover, forest stock, live wood stock, average annual number of windy days, average annual precipitation, and frost-free period. Then, based on the Technical Specification of Ecological Environment Status Evaluation of the Ministry of Ecology and Environment of China, we define the composite indicator EI as the ecological environment score which can be calculated by the Eq. 9 in the following:

$$EI = 62.42FC + 15.12FR + 4.51S + \frac{5.24D}{365} + \frac{3.04DF}{365} + 3.02RF \quad (1)$$

FC(hm^2): Area of mechanical forestry.
FR: Forest cover ratio.
S: Total Accumulation.
D: Average annual number of high wind days.
DF: Frost-free period.
EF: Average annual precipitation.

3.2 Solutions

Firstly, in terms of area of mechanical forestry(FC), we queried and obtained the forest area before and after the establishment of Saihanba Forestry which are shown as follows.

$$Pre_s = 24 \quad (2)$$

$$After_s = 115.1 \quad (3)$$

Then, according to the Technical Specification of Ecological Environment Status Evaluation of the State Ministry of Ecology and Environment, we speciated the data:

$$Pre = AIO \times 0.35 \times \frac{24}{140} = 30.675 \quad (4)$$

$$After = AIO \times 0.35 \times \frac{115}{140} = 147.116 \quad (5)$$

where AIO is 511.264.So. And we show the results in Fig. 2(a):

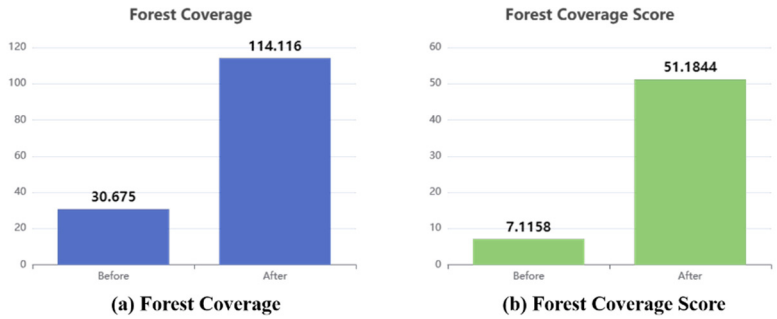

Fig 2. Forest Coverage and Forest Coverage Score

According to the Technical Specification for the Evaluation of the Ecological Environment Status of the Ministry of Ecology and Environment of the State, the weighting coefficients are obtained from the related description. Then, after calculation, the score(Fcs) is obtained by using Equ(6) And the results are shown in Fig 2(b).

$$f_{cs} = \frac{A_1 \times F_c}{sq} \tag{6}$$

It is calculated that the Saihanba forestry site has made a great ecological achievement, and in the official indicator given for the area of forest land In the past, it rose sharply from 7.1158 to 51.1844 now, which is almost 7 times more.

Using the same method, the comparison of forest cover scores can also be obtained, which is shown in Fig3(a).

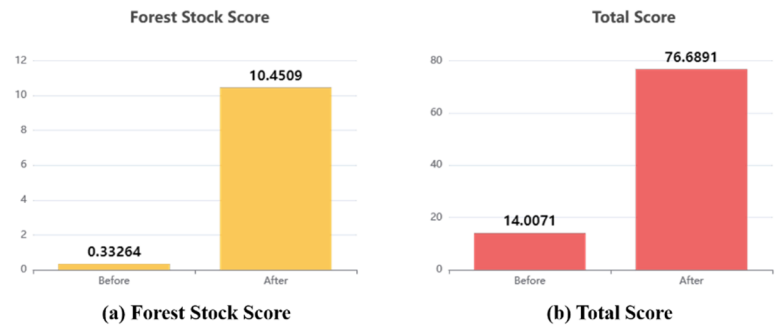

Fig 3. Forest Stock Score and Total Score

From 0.33264 in the past to 10.4509 now, it has increased by 10.4509/0.33264 = 30.41 times.

Continuously, using the method above, all the matrics are calculated represented them in Tab 2:

Table 2. All the metrics

	FC	FR	S	D	EF	DF
Before	0.17	0.114	0.096	0.46	0.891	7.21
After	0.82	0.82	0.784	0.15	1.04	8.87

Then the total calculated scores are obtained and shown in Fig 3(b).

The ecological score of Saihanba Forestry Reserve has made a great leap from 14.0071 points in 1962 to 76.6891 points now. According to the measure of protected area score of developed countries released by National Bureau of Statistics, protected areas with more than 48 points are considered outstanding nature reserves. Saihanba has gone from a low score at the early stage of its establishment

to meeting the measure of protected areas of developed countries, which is an outstanding achievement of China in the field of nature conservation.

3.3 Establishment of the Impact Evaluation System

Analysis method selection

There are many methods of data analysis, what commonly used are methods such as AHP method, fuzzy method, TOPSIS method, etc. This study uses AHP method to analyse Saihanba's impact on Beijing's ability on sandstorm resistance. The general ideas of AHP method are as follows:

(1) Analyze the hierarchy and structure of the target problem. Then clarify and construct a network of the relationships between the levels.

(2) Use the scaling method to construct the judgement matrix. The matrix is constructed layer by layer from the lower level to the higher level. In this paper, we choose Saaty 1-9 scale method. The importance of indicators is divided into the following levels: equally important, one slightly more important than another, one is significantly more important another, one is strongly more important than another, one is extremely more important than another, and the median value in the above adjacency judgment. The details are showing in Tab 3.

Table 3. The details

Scales	Events
1	Equally important.
3	Slightly more important.
5	Significantly more important.
7	Strongly more important.
9	Extremely more important
2,4,6,8	The median value.
Countdown	If the value of i compared with j is a_{ij}, then the value of j compared with i is $\frac{1}{a}$.
Negative numbers	If the Pearson correlation coefficient between i and j is negative, then a_{ij} is negative.

(3) Results consistency test. If the consistency ratio CR < 0.1, then the consistency is considered to satisfy the allowable accuracy. The consistency ratio can be calculated by the following formula Eq(8).

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

$$CI = (\lambda - \mathrm{n})/(\mathrm{n} - 1) \tag{8}$$

In the formula, while CI represents consistency indicator, λ represents the maximum eigenvalue of the judgement matrix, and n is dimension of the judgement matrix. If CI = 0, then there is absolute consistency in the results; If CI is close to 0, the results have satisfactory agreement.

Also, RI denotes stochastic consistency index, and its values are showing in Tab 4.

Table 4. Values of RI

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	149

AHP method quantitative process is not objective enough, we add Pearson correlation coefficient in the analysis to help build a more scientific and reasonable judgment matrix.

Maximum Eigenvalue Approximation Method

When finding the maximum eigenvalue, to avoid finding all eigenvalues and then finding the maximum eigenvalue, we use the summation method to simplify the process. The steps are shown in Fig.4

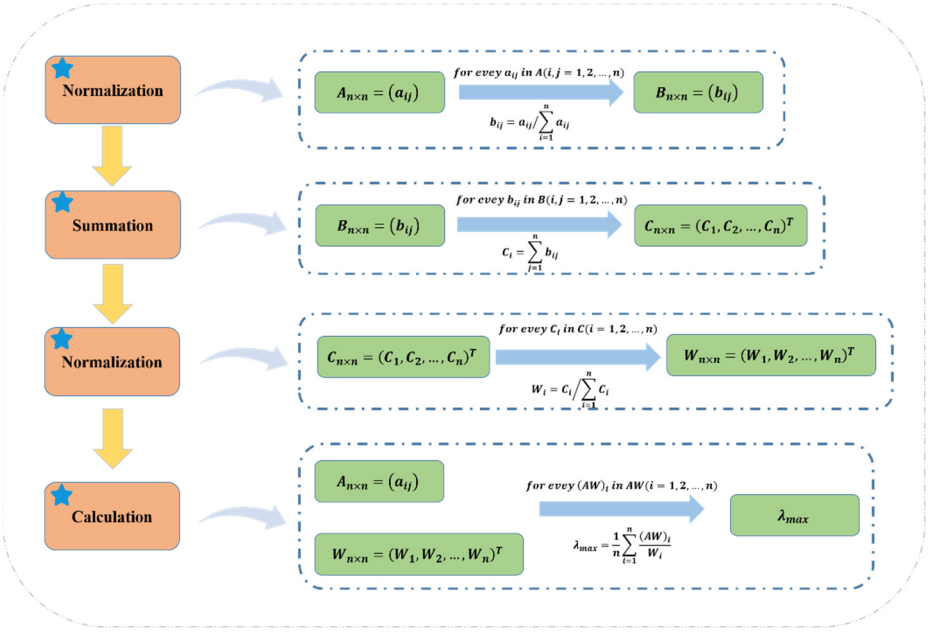

Fig 4. The Steps of Maximum Eigenvalue Approximation Method

Data Positivization and Dimension Removal

When performing data processing, positive dimensionless data is required, so we use the threshold method to nondimensionalize the original data, the formula is as follows.

$$(a_{ij})_{new}=\frac{(a_j)_{max}+(a_j)_{min}-a_{ij}}{(a_j)_{max}} \tag{9}$$

In the formula 9, $(aj)max$ is the maximum value of all the values in column j. Likewise, $(aj)min$ is the minimum value of all the values in column j. Meanwhile, aij represents the current data, and $(a_{ij})_{new}$ represents the new data after nondimensionalizing.

In order to detect the environmental conditions of Beijing, the weather data of Beijing from 1956 to 2021. Meanwhile, this study selected March - May, when dust storms are frequent in each year, as the research object, and used temper- ature, visibility, wind speed, sea level pressure, precipitation, dew point difference, and 24-hour temperature difference as the measurement indexes to establish the evaluation system shown in Fig. 5:

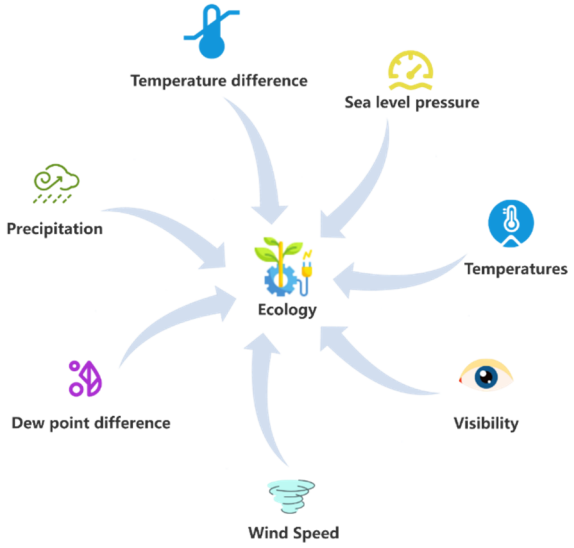

Fig 5. The Evaluation System

Considering the magnitude of the influence of different indicators on the resistance to dust storms and the simplicity of the formula, 5 influencing factors are chosen which include Visibility, Wind Index, Cooling Index, Sand Transport Index and Trend Indicator. Meanwhile, to enhance the holistic nature of metrics, the weight occupied by each indicator is given separately according to the magnitude of the influence of each indicator. This resulted in the establishment of a comprehensive index that can reflect the influence of the Saihanba mechanical forest on the wind and sand resistance of Beijing called Risk Degree of sandstorms(abbreviated as H).

Then, the structure of AHP method is demonstrated through the hierarchical diagram which is built with the factors above. And the layer structure is shown in Fig. 6.

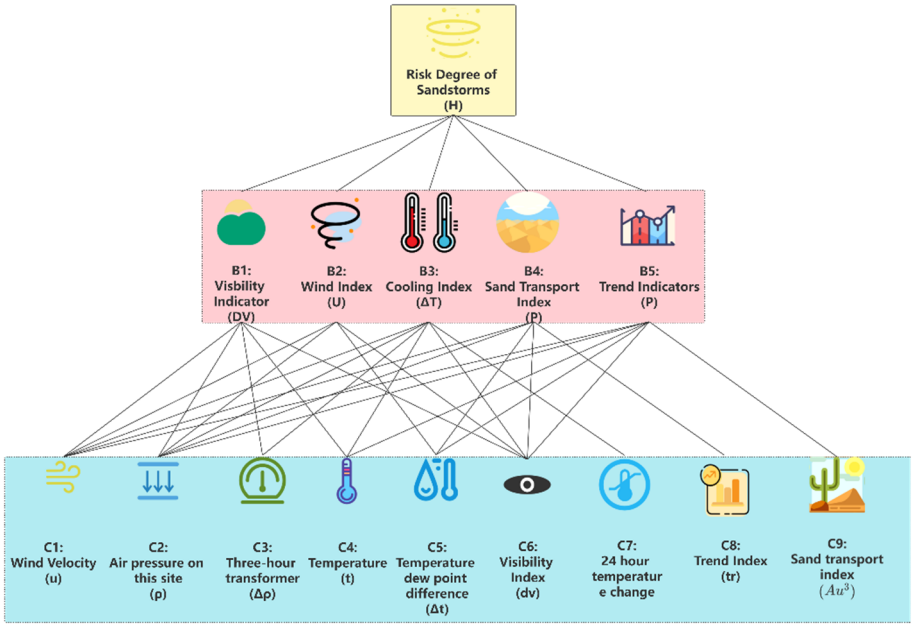

Fig 6. The structure of the evaluation system

As can be seen in Fig 5, the factors in layer C are used to build the judgment matrix for the indicators in layer B, and finally get the composite score based on the relationship between the indicators and the indicators' weights.

Calculation of the Indicators

Risk Degree of Sandstorms Expression includes 5 known indicators and 1 unknown indicator. The following is a description of how each indicator is calculated

$$\mathrm{DV} = \mathrm{dv} + \mathrm{x}_1 \tag{10}$$

where dv is visibility index, and x1 can be concluded from the correlation analysis between meteorological factors.

Visibility Index is determined by visibility and human eye recognition target contrast thresholds. It can be computed by the following equations

$$\mathrm{V} = \frac{1}{a} ln \frac{1}{\varepsilon} \tag{11}$$

$$dv = \ln a \tag{12}$$

where V is visibility and ε is human eye recognition target contrast thresholds.

Calculation of Wind Index(U)

In this context, the wind which we discussed here means wind at ground level. In that case, the Wind Index(U) can be calculated by the formula as follows.

$$U = u + x_{1\,\#} \tag{13}$$

where u is the wind velocity at ground level, and x_2 represents meteorological factors related to wind speed.

Calculation of Cooling Index(ΔT)

Cooling Index reflects the change of temperature during the day.

$$\Delta T = \Delta t_{24} - (\Delta t_{24})_{\min} + x_3$$

where Δt_{24}denotes the temperature change in the last 24 hours, and $(\Delta t_{24})_{min}$ the minimum temperature change in the last 24 hours. x_3 is uncertainty factor.

Calculation of Sand Transport Index(P)

$$P = Au^3 + x_4 \tag{14}$$

where A represents lower bedding surface factor; u^3 is the cube of wind velocity also called sand transport factor. Meanwhile, x4 denotes the uncertainty of other factors.

Calculation of Sandstorm Development Trend Indicator (TR)

$$TR = tr + x_4 = u - u_s + x_4 \tag{15}$$

where tr is sand storm trend values; u and us represents wind speed and wind speed of sand initiation respectively.

3.4 Calculation Process

The judgement matrix of Visibility Indicator(DV):

$$\begin{bmatrix} 0.236 & 0.279 & 0.234 & 0.187 & 0.223 \\ 0.170 & 0.201 & 0.214 & 0.270 & 0.236 \\ 0.192 & 0.179 & 0.190 & 0.240 & 0.210 \\ 0.196 & 0.175 & 0.186 & 0.155 & 0.136 \\ 0.206 & 0.166 & 0.177 & 0.147 & 0.195 \end{bmatrix} \tag{16}$$

By calculation, the maximum eigenvalue of matrix B1: λ = 5.137, CI = 0.034 and CR = 0.031. Since CR < 0.1, the judgment matrix passes the consistency test. And the weight vector of B1 n_1 is

$$n_1 = (0.218 \quad 0.202 \quad 0.170 \quad 0.178 \quad 0.232 \quad 0 \quad 0 \quad 0)^T \tag{17}$$

The judgement matrix of Wind Index(U):

Also, the maximum eigenvalue of matrix B2: λ = 4.0097, CI = 0.0032 and CR = 0.00359. Since CR < 0.1, the judgment matrix passes the consistency test. And the weight vector of B2 n_2 is

$$n_2 = (0.296 \quad 0.246 \quad 0 \quad 0 \quad 0.229 \quad 0.228 \quad 0 \quad 0 \quad 0)^T \tag{18}$$

The judgement matrix of Cooling Index(Δ T):

$$\begin{bmatrix} 0.211 & 0.216 & 0.178 & 0.173 & 0.158 & 0.365 \\ 0.152 & 0.156 & 0.163 & 0.165 & 0.167 & 0.126 \\ 0.172 & 0.138 & 0.145 & 0.146 & 0.149 & 0.112 \\ 0.175 & 0.136 & 0.142 & 0.143 & 0.146 & 0.110 \\ 0.185 & 0.129 & 0.135 & 0.136 & 0.138 & 0.104 \\ 0.105 & 0.225 & 0.236 & 0.238 & 0.242 & 0.182 \end{bmatrix} \quad (19)$$

Then, the maximum eigenvalue of matrix B3: λ = 6.1172, CI = 0.0234 and CR = 0.0189. Since CR < 0.1, the judgment matrix passes the consistency test. And the weight vector of B3 n3 is

$$n_3 = (0.155 \quad 0.144 \quad 0.142 \quad 0.138 \quad 0 \quad 0.205 \quad 0.217 \quad 0 \quad 0)^T \quad (20)$$

The judgement matrix of Sand Transport Index(P):

$$\begin{bmatrix} 0.258 & 0.408 & 0.202 & 0.199 & 0.249 \\ 0.129 & 0.204 & 0.275 & 0.276 & 0.259 \\ 0.213 & 0.124 & 0.167 & 0.167 & 0.157 \\ 0.215 & 0.122 & 0.165 & 0.166 & 0.156 \\ 0.186 & 0.141 & 0.191 & 0.191 & 0.180 \end{bmatrix} \quad (21)$$

Finally, the maximum eigenvalue of matrix B4: λ = 5.112, CI = 0.028 and CR = 0.025. Since CR < 0.1, the judgment matrix passes the consistency test. And the weight vector of B4 n4 is

$$n_4 = (0.229 \quad 0 \quad 0 \quad 0.165 \quad 0.178 \quad 0 \quad 0.263 \quad 0.165 \quad 0)^T \quad (22)$$

The judgement matrix of Sand Transport Index(P):

$$\begin{bmatrix} 0.211 & 0.356 & 0.178 & 0.161 & 0.169 & 0.225 \\ 0.108 & 0.181 & 0.232 & 0.236 & 0.234 & 0.219 \\ 0.172 & 0.113 & 0.145 & 0.148 & 0.147 & 0.137 \\ 0.183 & 0.107 & 0.137 & 0.140 & 0.138 & 0.129 \\ 0.178 & 0.110 & 0.141 & 0.143 & 0.142 & 0.133 \\ 0.149 & 0.132 & 0.168 & 0.171 & 0.170 & 0.158 \end{bmatrix} \quad (23)$$

The maximum eigenvalue of matrix B5: λ = 6.109, CI = 0.0218 and CR = 0.0176. Since CR < 0.1, the judgment matrix passes the consistency test. And the weight vector of B5 n_5 is

$$n_5 = (0.202 \quad 0.144 \quad 0 \quad 0.139 \quad 0.141 \quad 0.158 \quad 0 \quad 0 \quad 0.217)^T \quad (24)$$

The importance of each sub-indicator in the composite index is different. Thus, according to the literature, the weights of the sub-indicators are summarized and shown in Tab 5.

Table 5. The weights of the sub-indicators are summarized

Indicators	DV	U	ΔT	P	TR
Weights	0.159	0.403	0.088	0.077	0.274

According to Tab. 5, the greatest influence on the danger of sandstorms in Beijing is wind speed, accounting for 0.403 of the total degree of influence, followed by the trend indicator TR, indicating that the trend of dust storms also has a greater influence on dust storms, visibility indicators have a dramatic influence on the danger, while the factors with less influence are sand transport indicators and cooling indicators.

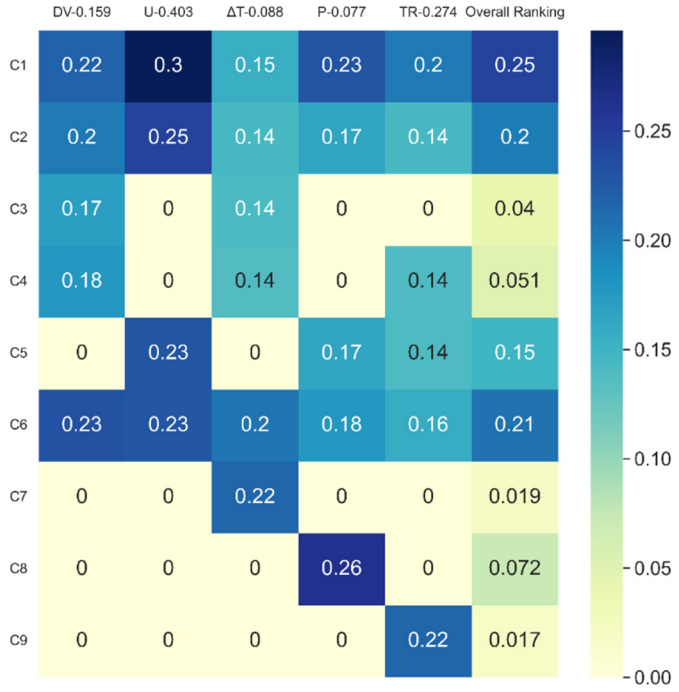

Fig 7. Overall Ranking of Sand Storm Danger in Beijing area

From Fig 7, the formula for H can be obtained as:

$$H = f(DV, U, \Delta\mathrm{T}, \mathrm{TR}, \mathrm{P}) = 0.159DV + 0.403U + 0.088\Delta\mathrm{T} + 0.077\mathrm{TR} + 0.274\mathrm{P} \quad (25)$$

3.5 Data Substitution

As can be seen from equation (28), in Beijing, the most influential meteorological factor for dust storms is wind speed, with a weight of 0.246, followed by visibility, which are the classical factors for dust storm research, but there are other high-impact factors in the region, such as pressure at this site and temperature dew point difference, both of which have a weight of more than 0.14, and the degree of influence cannot be ignored.

Taking the temperature indicator as an example, according to the above calculation method, 20877 pieces of data are collected in days for Beijing from 1956 to 2021, some of which are shown in Tab 6.

Table 6. Beijing 1956-2021 partial data collection

DATE(1956)	Temperature(◦C)	DATE(2020)	Temperature(◦C)
1956-10-1	15.4398	2020-3-1	2.9854
1956-10-2	11.0556	2020-3-2	3.5542
1956-10-3	11.7678	2020-3-3	1.6745
1956-10-4	14.4359	2020-3-4	1.1965
1956-10-5	15.2574	2020-3-5	2.8745
1956-10-6	15.7229	2020-3-6	5.5098
1956-10-7	13.5874	2020-3-7	8.8265
1956-10-8	17.0215	2020-3-8	4.7458
1956-10-9	17.5784	2020-3-9	5.3856
1956-10-10	10.3539	2020-3-1	4.2487

For the temperature metric, we measure in annual units of measure. The average temperature (AVG_T)values are obtained as follows.

Table 7. Average Temperature of 2012-2016

DATE	2012	2013	2014	2015	2016
AVG_T	14.274	13.190	16.150	15.232	15.368

Table 8. Average Temperature of 2017-2021

DATE	2017	2018	2019	2020	2021
AVG_T	16.258	15.082	15.416	14.724	14.763

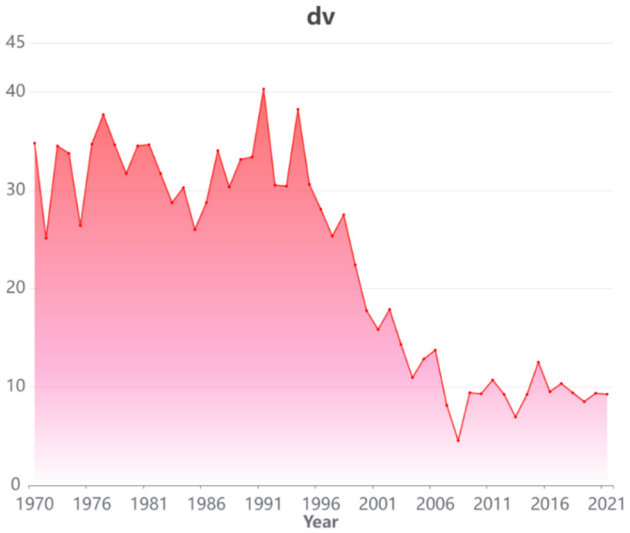

Fig 8. The average temperature

Then, for the visibility indicators that directly reflect the ability to resist dust storms, the relevant results are collected and counted in the same way as Average Temperature. The results are shown in Tab 9.

Table 9. Visibility

DATE	2012	2013	2014	2015	2016
V	4.968	6.719	6.550	6.385	6.284
DATE	2017	2018	2019	2020	2021
V	6.305	5.259	5.715	5.971	5.562

The detailed information is in Fig 9:

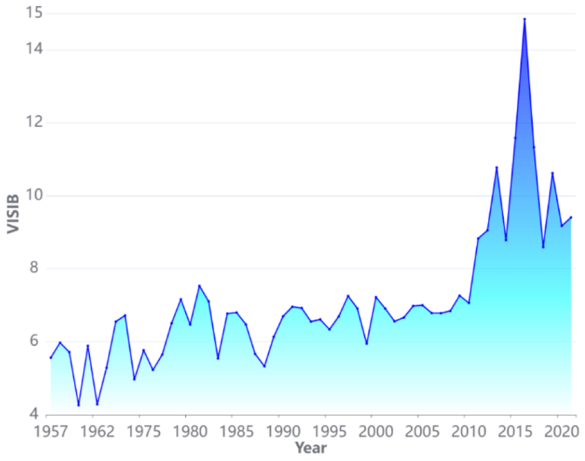

Fig 9. Visibility

Using time series analysis, the following visible capacity of Beijing is obtained for the next 10 years (PDC).

Table 10. Predictions

DATE	2022	2023	2024	2025	2026
PDC	4.968	6.719	6.550	6.385	6.284
DATE	2027	2028	2029	2030	2031
PDC	6.305	5.259	5.715	5.971	5.562

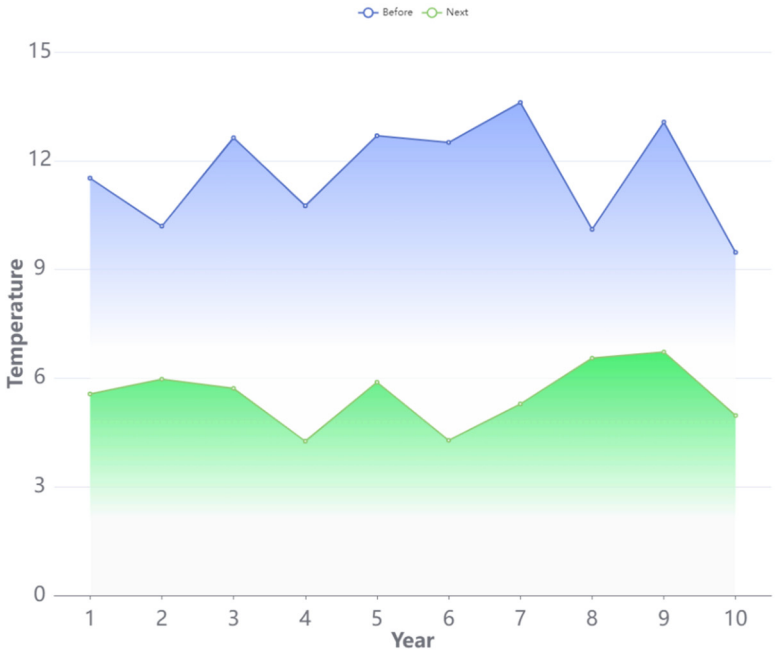

Fig 10. The annual statistics of Beijing

Repeating the above steps, the annual statistics of Beijing can be derived on these five indicators.

3.6 Conclusion

Finally, the study concludes that after the establishment of the Saihanba in 1962, the visibility of Beijing in March-May, when dust storms are frequent, has steadily increased and has been greatly improved, with 2010 as the dividing line. Meanwhile, the visibility capability will continue to grow at a high acceleration in the coming decade, which is inseparable from China's ecological efforts and strong investment in the Saihanba.

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