# Research and application based on hierarchical analysis and factor analysis

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**Abstract.** In this paper, a series of indicators were selected for the comprehensive evaluation of the capacity of the Sekhangba dataset, and factor analysis was used to synthesize the capacity ratings of the combined indicators. The results show that the rating of Beijing was 0.1014 in 2012, compared to -1.1332 in 1980. this indicates that the rating of the city has improved 11 times during the 32-year period. In order to make a suitable selection for model replication across the country, we screened indicators and used hierarchical analysis for fuzzy site selection eventually, and selected a multi-objective 0-1 planning model for further accurate site selection. The results obtained through hierarchical analysis and factor analysis are good, with a view to providing some implications for other fields.

**Keywords:** AHP, 0-1 programming, factor analysis.

## 1. Introduction

Factor analysis is based on the idea of dimensionality reduction, in the case of losing as little or as much information as possible from the original data, the intricate numerous variables are aggregated into a few independent common factors, which can reflect the main information of the original numerous variables, while reducing the number of variables and at the same time reflecting the intrinsic connection between variables. Usually, factor analysis has three roles: first, it is used for factor dimensionality reduction, second, it calculates factor weights, and third, it calculates weighted factor summary composite scores[1].

Hierarchical analysis is a simple decision-making method for complex decision-making problems with multiple objectives, multiple criteria or unstructured characteristics by mathematizing the thinking process of decision-making with less quantitative information based on an in-depth analysis of the nature of complex decision-making problems, influencing factors and their intrinsic relationships[2].

It is a combined qualitative and quantitative decision analysis method for solving complex problems with multiple objectives[3]. The method combines quantitative analysis with qualitative analysis, uses the decision maker's experience to judge the relative importance among the criteria that measure whether the objectives can be achieved, and gives the weights of each criterion for each decision option in a reasonable way, and uses the weights to find out the order of advantages and disadvantages of each option, which is more effectively applied to those topics that are difficult to be solved by quantitative methods[4].

## 2. Data acquisition and pre-processing

The modeling ideas are shown in the figure1.

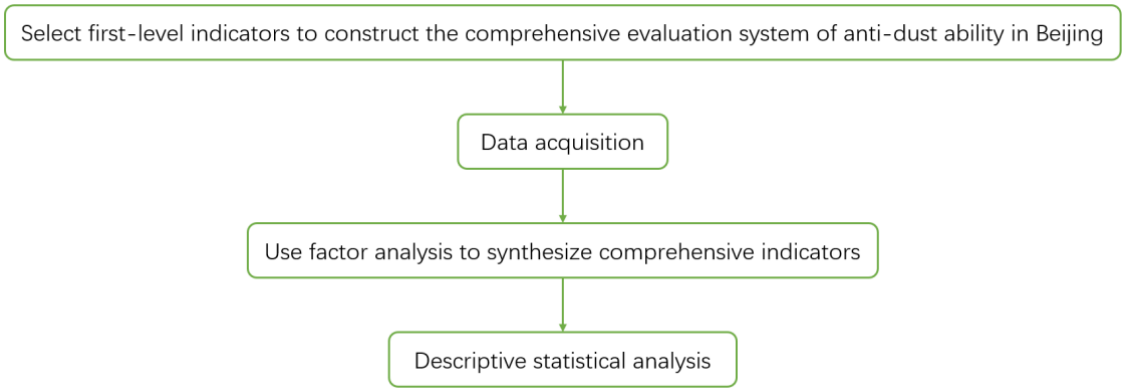



**Figure 1.** The flow chart of ecological assessment model

The data of average wind speed, the number of strong wind day and the number of rain day are obtained from the China Environmental Statistics of Yearbook. And the data of sandstorm days, blowing sand days and floating dust days are found from Beijing Meteorological Observatory.Before factor analysis, the data need to be normalized[5].

## 3. Establishment of the Model for evaluating the ability on sandstorm resistance in Beijing based on factor analysis

Through the normalization of the data in the factor analysis, we can obtain the scores of the six first-level indicators from 1980 to 2012 based on the comprehensive evaluation model of Beijing's anti-dust ability.According to the principle of factor analysis[6], we know that the closer the score is to 1, the better the performance. And if the scores is equal to 0, then it is the smallest one in the original data. The scores of two first-level indicators of Beijing province in different years is shown in figure 2

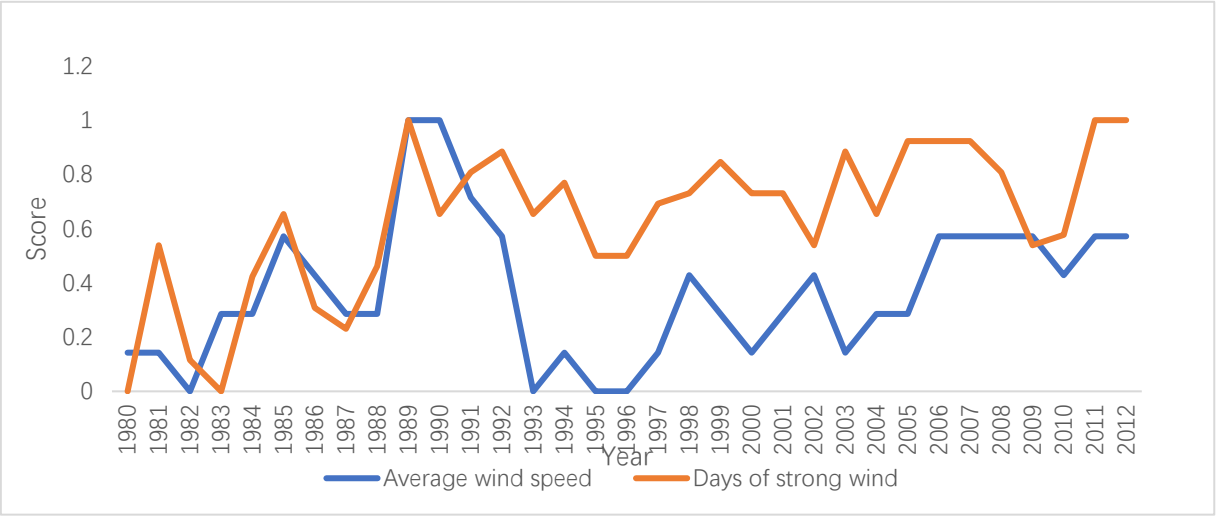



**Figure 2.** The scores of two first-level indicators of Beijing province in different years

For average wind speed factors, the scores of it showed an upward trend before 1990 and reached a maximum of 1 in 1989 and 1990, but it showed a downward trend from 1990 to 1993 and its score fell to 0 in 1993. This is probably because the average wind speed is influenced by many aspects[7], such as climate and environment. During the establishment of Saihanba Tree Farm, the wind speed was the highest. After the completion of Saihanba Tree Forest Farm, that is, after 1993, the score showed an upward trend[8], indicating that the wind speed had a downward trend after the completion of Saihanba Tree Farm.

Additionally, we can see that the score of days of strong wind factor was not higher than 0.6 in the early and middle 1980s, but it was on an upward trend and reached the maximum value of 1 in 1989.

And it can be known that Saihanba Forest farm was being built at this time. After that, although the days of strong wind factor score fluctuated, but it still had an upward trend. The scores of two first-level indicator of Beijing province in different years is shown in figure 3.

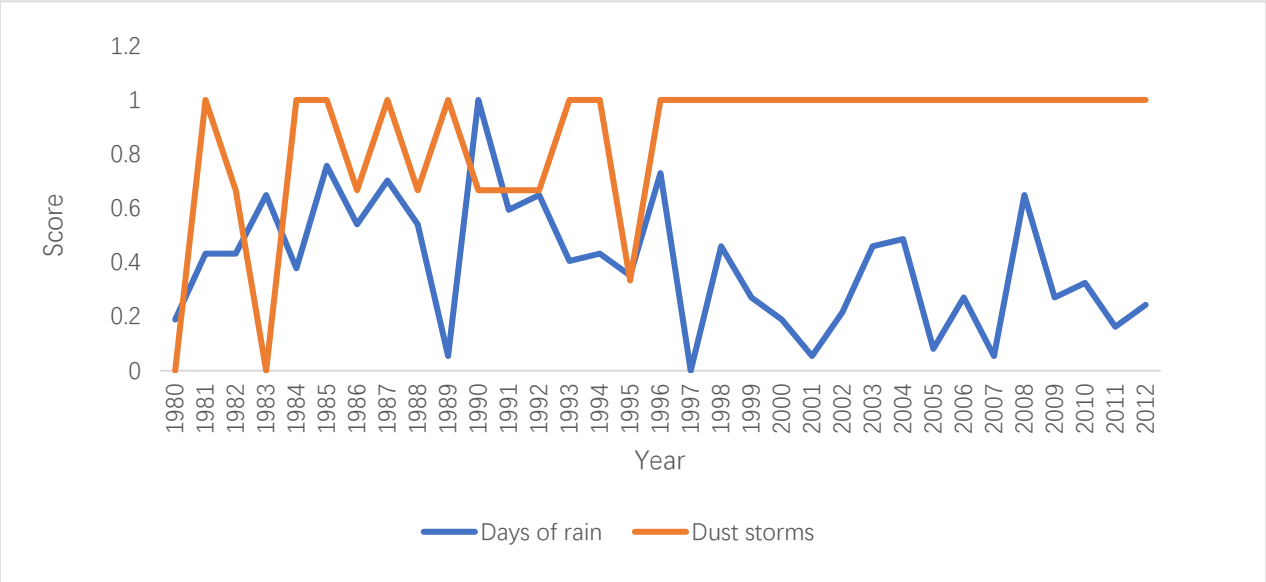



**Figure 3.** The scores of two first-level indicator of Beijing province in different years

When it comes to days of rain factors,the scores of it increased firstly and then decreased[9], and reached the maximum value of 1 in 1990 which means that the number of rainy days was the highest in 1990. Apart from that, the number of rainy days was the lowest in 1997 since the score of this year is 0.

As for dust storm factors, before 1993, the score of it fluctuated and reached 1 in a few years. However, since 1993, the score of dust storm factors has been stable at 1 every year, that is, the dust storm factors has been stable at an optimal level since then. The scores of two first-level indicator of Beijing province in different years is shown in figure 4[10].

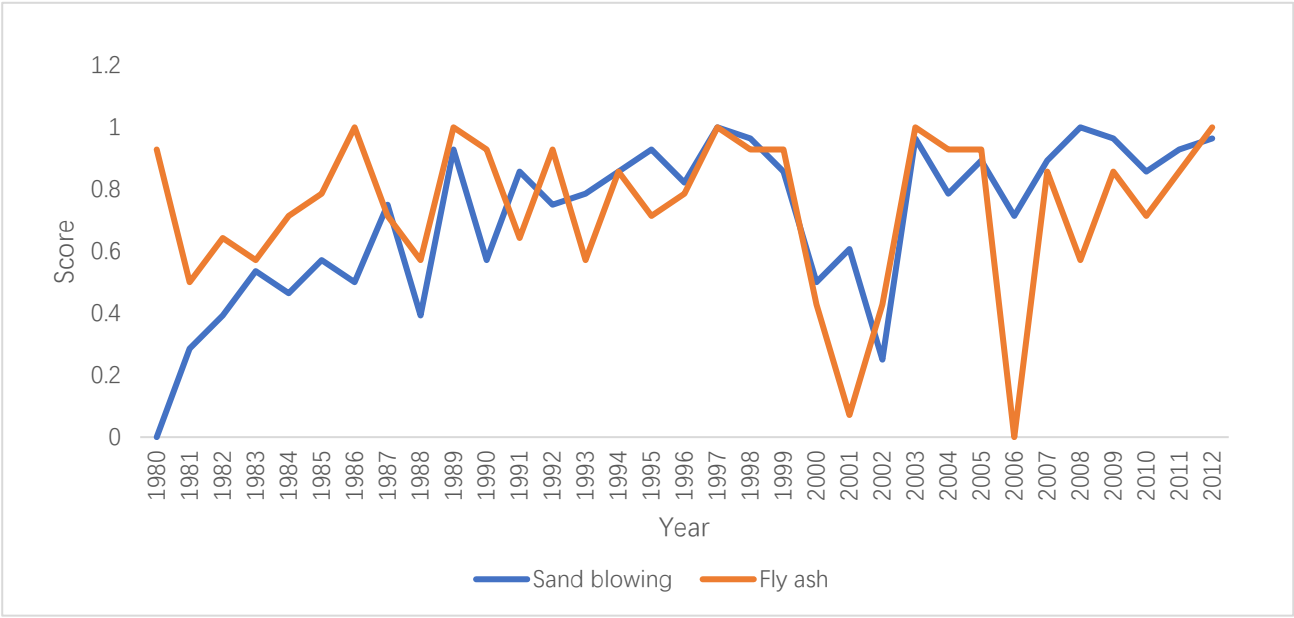



**Figure 4.** The scores of two first-level indicator of Beijing province in different years

For the left two indicators of Beijing province which are sand blowing factor and fly ash factor,The scores of the two factors fluctuated greatly from 1980 to 2012, and both of them shares a similar trend. From 1981 to 1990, the scores of Sand blowing and Fly ash factors showed a trend of increase. Specifically, the score of sand blowing factor and fly ash factor approximately reached the maximum

value 1 in 1989. And then they showed a relatively stable fluctuation in the following years, except for a significant decline in 2000 and 2006.

We use factor analysis to synthesize the anti-dust ability score of comprehensive indicators. The result shows that Beijing's dust resistance rating is 0.1014 in 2012, compared with -1.1332 in 1980. This indicates that an eleven-fold increase in the city's dust resistance during the 32-year period.

## 4. Establishment of rough identification of alternative areas for ecological forests model

### 4.1. the AHP in ecological forests model

According to the factors affecting ecology, a three-layer rough identification of alternative areas for ecological forests with target layer, criterion layer (6 indicators) and scheme layer (31 schemes) is established,as shown is figure5.

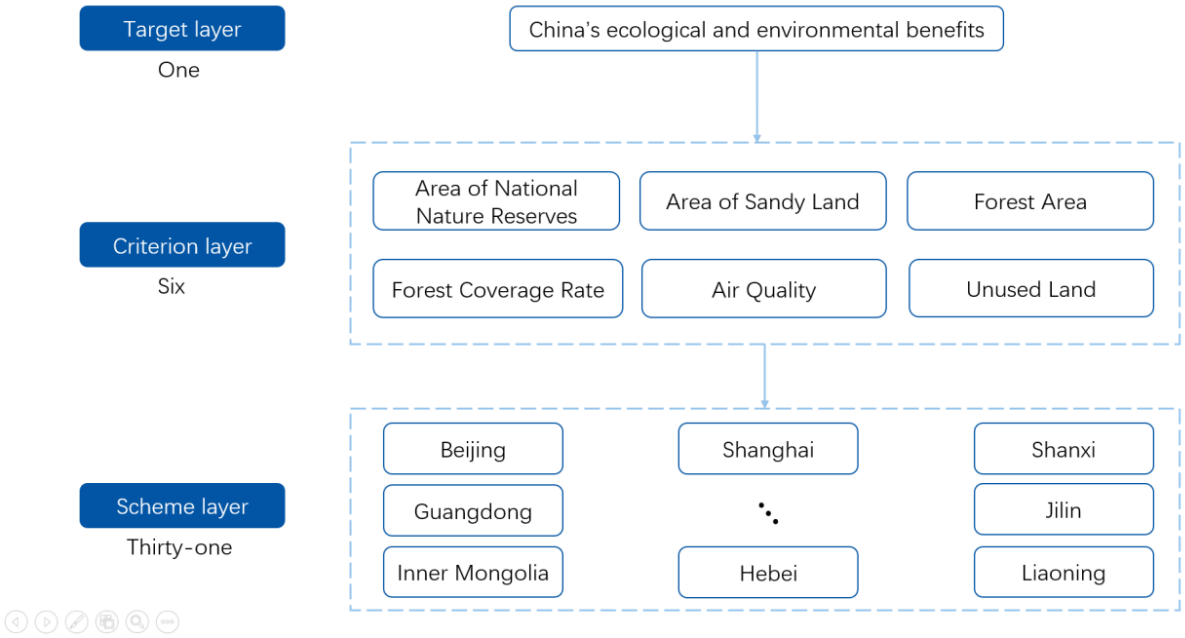



**Figure 5.** The flow chart of the AHP in ecological forests model

(1) Target layer

The target layer is the purpose of using AHP to maximize China's ecological and environmental benefits.

(2) Criterion layer

Six ecological indicators affected by the different region and cities are taken as the standard level indicators, which are area of national nature reserves (10000 hectares), area of sandy land, forest area (10000 hectares), forest coverage rate (%), air quality and Unused area (Square kilometers). In particular, The score of air quality is obtained by analyzing the following factors: Average Concentration of SO2 (μg/m3), Annual Average Concentration of NO2 (μg/m3), Annual Average Concentration of PM10 (μg/m3), 95th Percentile Daily Average Concentration of CO (μg/m3), 90th Percentile Daily Maximum 8 Hours Average Concentration of $O_3$ (μg/m3) and Annual Average Concentration of PM2.5(μg/m3), Days of Air Quality and Equal to or Above Grade II(day).

(3) Scheme Layer

The thirty cites of China, namely the election of the alternative areas for ecological forests.

### 4.2. The construction of judgment matrix

When determining the judgment matrix, this paper refers to a large number of essays which are as table1.

**Table 1.** The judgment matrix of the AHP

| M | x1 | x2 | x3 | x4 | x5 | x6 |
|---|---|---|---|---|---|---|
| x1 | 1 | 0.2 | 5 | 3 | 0.2 | 0.2 |
| x2 | 5 | 1 | 9 | 7 | 3 | 1/3 |
| x3 | 0.2 | 1/9 | 1 | 1/3 | 1/9 | 1/9 |
| x4 | 1/3 | 1/7 | 3 | 1 | 1/7 | 0.125 |
| x5 | 5 | 1/3 | 9 | 7 | 1 | 0.25 |
| x6 | 5 | 3 | 9 | 8 | 4 | 1 |

The reason of determining the judgment matrix:

This paper ranks the importance of six decision-making indicators, of which the most important is unused area, followed by area of sandy land, and air quality.The least important index was forest area, followed by forest coverage rate and area of national nature reserves.

The reason why unused area is the most important is that it is the most basic condition for an ecological forest to be built. Contrary to this basic condition, the forest area, forest coverage rate and area of national nature reserves rank last. In addition, the area of sandy land and air quality rank in the top two, because they are important indicators of the need for ecological forests in the region.

### 4.3. Consistency test for the judgment matrix

This paper use the arithmetic mean method to calculate the weight vector.The calculation steps are as follows:

(1) Calculate the product of each row element of the judgment matrix

$$M_i = \prod_{j=1}^{n} a_{ij} \ (i = 1,2,\dots,n) \tag{1}$$

(2) Calculate the mean value of the $M_i$

$$\overline{W_i} = \frac{1}{n}\sum_{i=1}^{n} M_i \ (i = 1,2,\dots,n) \tag{2}$$

（3) Calculate the weight vector and eigenvalue

$$W_i = \frac{\overline{W_i}}{\sum_{j=1}^{n} \overline{W_j}} (j = 1,2,\dots,n) \tag{3}$$

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(AW)_i}{W_i} \tag{4}$$

The consistency test method for the judgment matrix A is the follows:

(1) Calculate the consistency index

$$C.I. = \frac{\lambda_{max}-n}{n-1} \tag{5}$$

(2) Calculate the agreement ration

$$C.R. = \frac{C.I.}{R.I.} \tag{6}$$

Where $R.I.$ is the consistency indicator. When $C.R. < 0.1$, the judgment matrix is acceptable; otherwise, the judgement matrix should be rejected.

### 4.4. The result of weight and the rank

The Weight of the indicator in AHP is shown as table2.

**Table 2** The Weight of the indicator in AHP

| Indicator | Area of National Nature Reserves (10000 hectares) | Area of Sandy Land | Forest Area (10000 hectares) | Forest Coverage Rate (%) | Air Quality | Unused area (square kilometre) | Area of National Nature Reserves (10000 hectares) |
|---|---|---|---|---|---|---|---|
| Weight | 0.0796 | 0.2577 | 0.0238 | 0.0419 | 0.1882 | 0.4087 | 0.0796 |

As can be seen from the Table 3, The unused land factor has the highest weight. And by the weight from above, the rank of regions can also be found.

**Table 3** The result of AHP

| Region | Rank |
|---|---|
| Xinjiang | 1 |
| Inner Mongolia | 2 |
| Hebei | 3 |
| Shanxi | 4 |
| Shandong | 5 |
| Gansu | 6 |
| Qinghai | 7 |
| Henan | 8 |
| Tianjin | 9 |
| Tibet | 10 |
| Shaanxi | 11 |
| Liaoning | 12 |
| Hubei | 13 |
| Jiangsu | 14 |
| Anhui | 15 |

## 5. Precise determination of ecological forest site selection based on 0-1 programming problem

According to the problem analysis, set $x_i$ are decision variables.

$$x_i = \begin{cases} 1, Establish\ an\ ecological\ area\ in\ ith\ region \\ 0, Not\ Establish\ an\ ecological\ area\ in\ ith\ region \end{cases} \quad (7)$$

According to the principle of multi-objective programming, objective one function is set as

$$max\ Z_1 = C_1 \cdot \sum_{i=1}^{15}(x_i \cdot S_i) \quad (8)$$

Where d is the amount of carbon sequestration of ecological forest and $S_i$ is the unused area of ith region.

And the objective two function is the following:

$$min\ Z_2 = C_2 \cdot \sum_{i=1}^{15}(x_i \cdot S_i) \quad (9)$$

$C_2$ is the total cost per hectare of ecological forest construction and maintenance

Finally, the objective function is obtained as the following:

$$max\, Z = Z_1 - Z_2 \tag{10}$$

Then, we can find the constraints.

$$s.t.\begin{cases} n \le \sum_{i=1}^{15} x_i \le m \\ x_i = \{0,1\} \end{cases} \tag{11}$$

Where $n = 2$, and $m = 7$ which means that the numbers of the ecological forest site needed to be built is in the range of $[2,7]$

In the preliminary selection of 15 candidate regions by Analytic Hierarchy Process, we select the following 7 regions. The exact areas of the seven proposed ecological forests are as follows.

**Table 4.** The result of Proposed ecological forest area

| Province | Proposed ecological forest area ($km^2$) |
|---|---|
| Xinjiang | 741669.3 |
| Inner Mongolia | 336446.2 |
| Shandong | 52838.31 |
| Gansu | 166053.3 |
| Qinghai | 278801.3 |
| Henan | 54315.85 |
| Tibet | 491601.8 |

According to 0-1 planning results, the seven ecological forests can absorb 95286716.8143 tons of carbon on a year. China has announced its goal of Carbon Neutrality: To achieve the goal of peak carbon dioxide emissions by 2030 and carbon neutrality by 2060. In order to evaluate its impact on achieving China's target, the result shows that assuming that the ecological forest construction plan can be carried out in 2021, 56.6% of the Carbon Peak Standard can be achieved in that year.

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