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Research on the Effect of Saihanba Ecological Model based on TOPSIS-FCA

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Abstract

China adheres to the development philosophy that "clear waters and lush mountains are invaluable assets" and advocates sustainable development of both man and nature. Under the guidance of this idea, the Saihanba Forest Farm in China has been transformed from a desert into a green barrier, which has had a significant impact on the local surrounding areas. To evaluate the impact of Saihanba restoration on the ecological environment, we constructed TOPSIS-FCA model to explore the generalization of its ecological protection mode. Firstly, from two dimensions of wind resistance and climate improvement, this paper compared the data from 1962 to 2020 and selected 10 indicators respectively to establish the TOPSIS-FCA Model. On the one hand, TOPSIS-entropy weight method is used to determine the index weight. On the other hand, based on the maximum membership theory, it can be known that the comprehensive evaluation result of Saihanba has improved increasingly. Secondly, In the study of Saihanba ecological protection, this paper explores the impact on carbon sink, according to the study of the factors affecting forest carbon sequestration, it is found that Saihanba has great carbon sequestration potential. Finally, this paper focuses on carrying forward the spirit of Saihanba, which has been achieved by three generations, and tries to promote the ecological protection model of Saihanba and the spirit to China and even the world.

Keywords

Saihanba; TOPSIS-FCA; Carbon Sequestration.

1. Introduction

Since the 1980s, the Chinese government has put forward the theory of "sustainable development", advocating simultaneous economic development and ecological protection. Forests provide the world with water, energy, and organic carbon, and their ecological role cannot be underestimated. In order to achieve the goal of sustainable development, the growth of forest resources is an important means. Under the background of more and more serious consumption of forest resources in the last century, Saihanba Forest farm has gradually turned from Mulan Paddock into a barren mountain land, with the aggravation of flood and drought, soil erosion and biodiversity destruction. In order to achieve ecological sustainable development, the Chinese government began in 1962 to improve the current situation of Saihanba and build a forest farm, then gradually realize the transformation of Saihanba from an artificial forest to natural forest, also to create a green barrier, which has had a significant impact on the local surrounding areas. In 2017, General Secretary Xi Jinping pointed out that Saihanba Forest Farm has been afforested, controlled and stopped desert for 55 years by three generations. It has put into practice the ecological concept of "Clear Waters and Lush Mountains are Invaluable Assets" (Qiushi, 2018), which is a vivid demonstration of promoting ecological progress.

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In order to evaluate the impact of Saihanba ecological protection mode on the environment, carry forward the spirit of Saihanba, and promote the construction of ecological civilization, we take Saihanba Forest Farm as the research object, quantify the effect of ecological environmental protection, and make a special description of the effect of carbon sink.

2. Literature Review

In the construction of Saihanba, a green miracle, many experts and scholars have carried out a series of studies on the changes and sustainable development of its forest ecosystem. Zhang Biyao [1] took the forest ecosystem of Saihanba Forest Farm as the object and studied the changes of forest ecosystem in semi-arid areas based on remote sensing time series analysis. Dong Changchun [2] discussed the development path of green industry in Saihanba Forest Farm from five aspects in order to achieve sustainable development. Sun Guoqing [3] analyzed four results of ecological protection and restoration of Saihanba and the three main problems, proposed four principles that should be adhered to in ecological protection and restoration, and put forward four corresponding countermeasures. Cui Meng and Zhao Zhanyong [4] analyzed the three advantages of Saihanba Forest Farm planning area, analyzed the four existing problems, and expounded the three long-term significance of planning. Liu Jing [5] discussed the important measures of sustainable development and ecological protection of Saihanba by analyzing the importance of Forestry resources in Saihanba. Zhong Ziqi [6] took Saihanba as an example to illustrate the concept of ecological civilization in China, and further discussed the five-step road to desertification control. Kang Yi [7] further proposed measures to improve the forestry development speed of Saihanba Forest Farm according to the forestry development status. Based on the successful construction of Saihanba forest, this paper will further analyze the effect of its model on ecological protection.

3. Variable Selection and Data Description

Analytical approach about the effect of the ecological protection model of the Saihanba are mainly analytic hierarchical analysis(AHP), comprehensive evaluation method, fuzzy comprehensive evaluation method, multi-objective planning method, system dynamics, etc. (Xu, Zhongwen, 2016). In this paper, the TOPSIS-FCA Model is used to select the ecological environment-related data of the Saihanba from 1962 to 2020 as the research sample, and indicators for the empirical analysis of the ecological conservation model of Saihanba are also collected.

3.1 Data Source and Description

This paper selects Saihanba from 1962 to 2020 as the research object. The relevant data are obtained from the national forestry and grassland scientific data sharing service platform and relevant reports and documents.

3.2 Index Selection and Definition

Table 1. Index selection and definition

Criterion Layer	Variable Layer	Explanation
Wind resistance and sand stabilization	Annual average gale day	The number of weather days with instantaneous wind speed equal to or greater than 17.0 M / S (equivalent to wind force 8 or above) in a certain place for a period of time (such as month, season, year, etc.).
	Forest coverage rate	Percentage of forest area in land area in an area
	Forest reserves	The total volume of existing trees within a certain forest area

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	Plantation area	The plantation area of Saihanba has increased from 240000 mu before the establishment of the forest farm to 1.12 million mu at present, becoming the largest artificial forest in the world
	Total area	The total operating area of Saihan dam has increased year by year, and now it has reached 1.4 million mu
Improve weather condition	Annual sunshine duration	The sum of the actual exposure hours of the sun in a year.
	Frost-free season	From the last frost in spring to the first frost in autumn
	Average relative humidity	Arithmetic mean of relative humidity of each observation in a certain period of time
	Average temperature	Average value of multi day average temperature
	Precipitation	The total precipitation of Saihanba mechanical forest farm was 4211.6mm in the initial stage of construction, 4576.7mm in the last 10 years, and the average annual increase of precipitation was 36.5mm.

3.3 Model Design

This paper constructs a fuzzy comprehensive evaluation model to evaluate the ecological protection model of Saihanba. FCA, based on fuzzy mathematics, applying the synthesis principle of fuzzy relationship, conducts the multi-level comprehensive evaluation of factors according to the theory of membership degree. On the basis of FCA, this paper combines the Entropy weight & TOPSIS method to determine the objective weight, thereby obtaining the comprehensive weight. According to the comprehensive weight and the fuzzy evaluation vector determine the final evaluation value.

3.4 Steps of Improved FCA Model

(1) Determination of factor set

Constructing the two-level factor set $U=\{u_1,u_2,u_3,\cdots u_n\}$, $u_i=\{u_{i1},u_{i2},\cdots u_{is}\}$, which satisfies $U=\bigcup_{i=1}^{n}u_i$ and $u_i\cap u_j=\varnothing(i=j)$; $u_i=\bigcup_{k=1}^{s}u_{ik}$ and $u_{ik}\cap u_{il}=\varnothing(k\neq l)$. Among them, U, u_i are the first and second level factor sets, $i=[1,n]$,$k=[1,s]$.

(2) Constructing a comprehensive matrix of fuzzy evaluation

Determine comment set $V=\{v_1,v_2,\cdots v_m\}$, we get the comprehensive judgement matrix.

$$R_i=\begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1m} \\ r_{i21} & r_{i22} & \cdots & r_{i2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{is1} & r_{is2} & \cdots & r_{ism} \end{bmatrix}$$

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$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{im} \end{bmatrix}$$

For a positive index whose number's increase leads to the greater ecological protection effect, the calculation formula for the membership degree of the i-th grade comment is as follows:

$$r(i,j)=\frac{x(i,j)}{x_{\max}(i)+x_{\min}(i)}$$

For a positive index whose number's increase leads to the less ecological protection effect, the calculation formula for the membership degree of the i-th grade comment is as follows:

$$r(i,j)=\frac{x_{\max}(i)+x_{\min}(i)-x(i,j)}{x_{\max}(i)+x_{\min}(i)}$$

If $u_i=\{u_{i1},u_{i2},\cdots,u_{is}\}$, the weight set is $A_i=\{a_{i1},a_{i2},\cdots a_{is}\}$, the comprehensive evaluation is :

$$B_i=A_i\cdot R_i(i=1,2,\cdots,n).$$

Similarly, for the first level factor set perform comprehensive evaluation to obtain a comprehensive judgement matrix. If the weight set is:

$$A=\{a_1,a_{2,}\cdots,a_n\}$$

$$R=[B_1\ \ B_2\ \ \cdots\ \ B_n]^T$$

The comprehensive evaluation is $B=A\cdot R$.

4. Empirical Analysis of Saihanba Ecological Protection Model Evaluation based on the FCA Model

4.1 Establishment of Saihanba Ecological Protection Evaluation System

Based on the requirements of hierarchy and operability, referring to the indicators of evaluating the ecological protection, this paper selects the two perspectives of wind and sand prevention and climate improvement. For the measurement of sand fixation, average annual gale days, forest cover, standing wood volume, total area and forest area are selected. For the measurement of climate improvement, annual sunshine hours, frost-free period, average humidity, average temperature and precipitation are selected.

4.2 Determination of the Weight based on Entropy Weight & TOPSIS Method

According to the collected ecological protection data of Saihanba from 1962 to 2020, it is divided into two layers: windbreak and sand fixation and climate improvement. The standardized matrix and weights are obtained after data forward processing using Matlab software. According to the above steps, the two layers are integrated to obtain the comprehensive weight of the first-level index.

Table 2. Index weight

Criterion layer	Variable layer	A1	A
Wind and sand prevention	average annual gale days	0.4275	0.4613
	Forest cover	0.1001	
	Standing Wood Volume	0.3829	
	Total area	0.0007	
	Forest area	0.0888	
		A2	
Climate improvement	Annual sunshine hours	0.0211	0.5388
	Frost-free period	0.0051	
	Average humidity	0.0005	
	Average temperature	0.9698	
	Precipitation	0.0035	

4.3 Calculate the Affiliation Degree of Each Indicator Layer

According to the affiliation formula above, for positive indicator affiliation, such as the affiliation degree of forest cover, $r_{121}=\dfrac{23.5}{77.05+23.5}=0.23$. Similarly, the affiliation degree of other positive indicators can be obtained.

For the negative index affiliation, the affiliation of the annual average windy day, for example, is $r_{111}=\dfrac{76.5+53-76.5}{76.5+53}=0.41$. Similarly, the affiliation degree of other negative indictors can be obtained.

4.4 Determination of Judgment Layer

In the early 1980s, the stage of large-scale artificial forestation in Saihanba mechanical forestry was basically finished, and the full-scale period of forest management, supplemented by afforestation was entered. In 2002, the People's Government of Hebei Province approved the establishment of the Saihanba Nature Reserve. Based on this, this paper explores the impact of the Saihanba Nature Reserve into three stages - 1962-1980, 1981-2000, and 2001-2020, and uses these periods as the judgment set to evaluate the composite score.

4.5 Calculation of Fuzzy Composite Vectors

(1) The second-level fuzzy integrated vector from the indicator layer to the criterion layer

For wind and sand prevention:

$$B_1=A_1\cdot R_1=[0.4275\quad 0.1001\quad 0.3829\quad 0.0007\quad 0.0888]\cdot\begin{bmatrix}0.41 & 0.45 & 0.59\\ 0.23 & 0.57 & 0.77\\ 0.05 & 0.39 & 0.95\\ 0.52 & 0.49 & 0.48\\ 0.25 & 0.56 & 0.75\end{bmatrix}$$

For climate improvement:

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$$B_2 = A_2 \cdot R_2 = [0.0211 \quad 0.0051 \quad 0.0005 \quad 0.9698 \quad 0.0035] \cdot \begin{bmatrix} 0.44 & 0.63 & 0.38 \\ 0.44 & 0.47 & 0.56 \\ 0.48 & 0.51 & 0.52 \\ 0.28 & 0.28 & 0.72 \\ 0.45 & 0.50 & 0.55 \end{bmatrix}$$

(2) The first-level fuzzy integrated vector from the criterion layer to the target layer

$$B = A \cdot R = [0.4613 \quad 0.5387] \cdot \begin{bmatrix} 0.24 & 0.4488 & 0.76 \\ 0.2849 & 0.2892 & 0.7113 \end{bmatrix} = [0.2642 \quad 0.3629 \quad 0.7338]$$

Therefore, the improvement of ecological environment is becoming obvious increasingly, from the restoration of the Saihanba Forest to the establishment of the ecological reserve, which today is 2.5 times higher than the initial stage of the restoration of the Saihanba Forest. It can be proved that there are remarkable achievements in the construction of the ecological protection of the Saihanba.

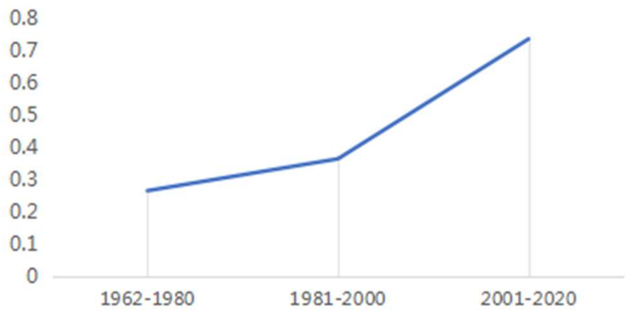

Figure 1. Ecological protection impact trend

5. Forest Carbon Sequestration

Conversion of cropland to forest is an important way to increase the carbon sink of ecosystem. Forest carbon sequestration service mainly refers to the annual carbon sequestration of forests. Forests have the function of converting atmospheric carbon dioxide into carbohydrates fixed in vegetation and soil, known as "carbon sinks". Forest carbon sinks are important ecological services. According to the market economy principle of "Payment for ecosystem Service (PES)", forest carbon sinks can be transformed into financial benefits and serve the sustainable management of forests and sustainable development of human beings.

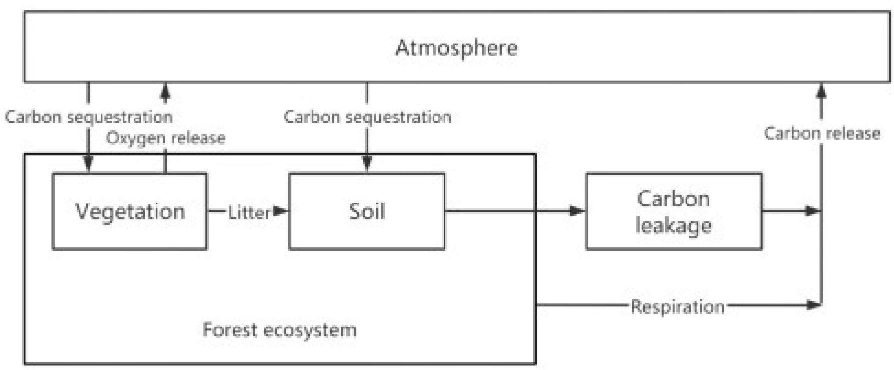

Figure 2. Forest carbon sequestration process

5.1 Status quo of Forest Resources

(1) Tree species structure

Saihanba is rich in plant resources and its regional ecological environment is complex and diverse, which makes it an important species resource bank in North China. Forest vegetation mainly consists of coniferous forest, broad-leaved forest, shrub, grass, meadow and marsh vegetation. Species include ferns, gymnosperms, angiosperms and other autologous vascular plants. Forest area forest coverage rate of 75.5%, including forest coverage rate of 74.3%, shrub coverage rate of 1.2%. The biological characteristics of each tree species are different, and the wood characteristics are different, so the impact on carbon dioxide fixation is also very obvious.

Table 3. Main tree species structure

The Forest Species	Main Tree Species
Arboreal forest	Larix principis-rupprechtii
	Pinus tabulaeformis
	Pinus sywestris var mongovica
	Betula platyphylla
	Populus tremula
Undergrowth	Armeniaca sibirica
	Hippophae rhamnoides
	Malus baccata
	Rosa dahurica
	Ostryopsis davidiana

(2) Standing forest age structure

In the total arbor forest area of Saihanba, the proportions of young forest, middle-aged forest and near-mature over-mature forest are 31.5%, 32.5% and 36% respectively. Among the near-mature and over-mature forests, the proportion of near-mature forests is relatively high, accounting for 31.6%, and the proportions of mature and over-mature forests are only 4.2% and 0.3%.

Table 4. Distribution of standing forest age

Type	Total	Juvenile forest	Semimature forest	Near-mature forest	Mature fores	Over-mature forest
Area	74424.1	23443.6	24187.8	23443.6	3125.8	223.2
Proportion	100.0	31.5	32.5	31.5	4.2	0.3

The lifespan of trees is related to carbon dioxide fixation. The carbon density increased first and then decreased with the increase of forest age. The amount of biomass growth per unit area depends on site conditions and forest type. Especially when the site conditions and forest types are the same, forest age becomes an important factor. According to research, the annual carbon sequestration rate per unit area of forests at different developmental stages is different. Generally, in the young stage, the carbon sequestration rate increases rapidly and quickly reaches a peak, and it continues to decline in the mature stage until the old stage. What really works, however, is the amount of carbon stored.

(3) Standing forest density

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Stand density refers to the number of trees per unit area of forest land. Different stand densities mainly affect the forest litter layer and the hydrological function of the soil, influencing the carbon sequestration content of forest trees eventually. Take the coniferous forest of the Third Township Forest Farm in Saihanba as an example.

Table 5. Factors affecting stand density

Stand density (plant /hm 2)	Thickness of litter			Soil bulk density (g/cm 3)
	Not decomposed	Semi-decomposed	Not decomposed	
600	1.34	1.21	5.87	1.28
800	1.52	1.32	6.38	1.24
1000	1.92	1.54	8.12	1.12
1200	2.01	1.76	9.43	0.98
1400	1.83	1.46	7.31	1.15

The factors affecting the carbon sequestration capacity of trees in Saihanba area are complex. In addition to the various factors listed above, there are many other factors that affect the carbon sequestration capacity of trees in Saihanba Forest Farm, such as climate and the characteristics of trees. Therefore, many factors should be fully considered in the management of plantations, and when evaluating their growth characteristics and carbon sequestration potential, they should also be considered from many aspects to fully predict their development.

5.2 Estimation of Forest Carbon Sequestration

(1) Calculation of biomass carbon savings

$$C_{TB} = M_{Si} \times C_{Si} + M_{Bi} \times C_{Bi} + M_{Li} \times C_{Li} + M_{Ri} \times C_{Ri}$$

In the above formula, C_{TB} it's the biomass carbon stock, M_{Si} is quality of trunk after i years of farming, C_{Si} carbon quality of tree trunk after i years of abandonment, M_{Bi} is Quality of branches for i years, C_{Bi} is carbon content of tree branches abandoned for i years, M_{Li} is quality of leaves after i years of abandonment, C_{Li} is carbon content of leaves after i years of tillage, M_{Ri} is root quality after i years of farming, C_{Ri} is carbon content of roots abandoned for i years.

(2) Carbon storage calculation of litter

$$C_{FF} = M_i \times C_i$$

In the above formula, C_{FF} is litter carbon storage, M_i is quality of litter after i years of tillage, C_i is carbon content of litter after i years of tillage.

Soil organic carbon density (SOCD) is determined by soil organic carbon content, gravel content and bulk density. The formula for SOCD is:

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$$T_0 = \sum_{j=1}^{n} \frac{(1-\delta_j)C_j \rho_j d_j}{10}$$

In the above formula, T_0 is soil organic carbon density at profile depth (Mg/hm^2), n is the number of layers in the soil profile, C_j is soil organic carbon content of the j layer soil(g/kg), ρ_j is average bulk density of layer j(g/cm^3), δ_j is volume percentage of gravel in the j layer, d_j is layer j soil thickness(cm).

(3) Calculation of total carbon storage in ecosystems

$$C_T = C_{FF} + C_{TB} + C_S$$

In the above formula, C_T is total carbon storage of forest communities, C_{FF} is carbon storage in litter, C_{TB} is carbon storage in aboveground biomass, C_S is soil carbon storage.

Total carbon sequestration in forest systems includes total carbon storage of forest communities, carbon storage in litter, carbon storage in aboveground biomass, soil carbon storage. The growth of forest trees in Saihanba area has been improving, and carbon storage has increased significantly. In addition, young trees also occupy a certain proportion. The average carbon density is low and the area is large, so it has a high carbon sequestration potential.

After years of construction and development, Saihanba has achieved outstanding social benefits, which are as follows:

First, it promoted Saihanba spirit.

Saihanba spirit includes "hard work, selfless dedication, innovation, science, truth-seeking, mission first", which is Saihanba people pass on generation after generation with more than half a century. "The great green wall" was built for sand resistance of Beijing and Tianjin. From the vast wilderness to one million mu of artificial forest, an important ecological barrier has been built to guard Beijing and Tianjin.

Second, actively carry out forest carbon sinks.

Take advantage of the existing ecological advantages of Saihanba, expand domestic and international cooperation, and attract social funds to participate in afforestation and reforestation forest carbon sink project, also realize the conversion of forest ecological value and economic value, and create carbon sink industry, to promote the healthy operation of Saihanba and form a new economic growth point.

Third, change the management method.

Moderately selecting and logging pure forests, planting under the forest canopy, clearing dead and dying trees in the forest, planting coniferous and broad-leaved forests in larger forest windows are essential. We will reduce the density of forest stands, improve the community structure, increase stability, and maintain high productivity, vigorously cultivate and develop artificial forests, and make good use of many resources to promote social development, based on local and seasonal conditions.

6. Conclusion

This research is put forward under the background of sustainable development and the concept of carbon neutrality and carbon peak. Since the restoration of Saihanba Forest Farm and the establishment of ecological protection zone in China are the model of wasteland greening, it is especially valuable to popularize the model and make other wasteland restoration reference. The main conclusions of this paper are as follows:

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(1) The effect of ecological protection in Saihanba has been increasing from 1962 to 2020, and the increase can be quantified as 2.5 times.

(2) The model considers the uncertainty and fuzziness of indicators in the process of ecological protection evaluation, and adopts the fuzzy comprehensive evaluation model to evaluate.

(3) The model overcomes the subjectivity of fuzzy comprehensive evaluation by combining TOPSIS-entropy weight method and assigning weight objectively.

(4) From the factors affecting carbon sequestration in the forest system and the method of calculating carbon sink, it can be seen that the carbon sink of Saihanba forest farm has achieved great results and has great potential for solid-state capacity.

The successful practice of Saihanba Mechanical Forestry Field proves that for ecologically fragile and ecologically degraded areas, if scientific positioning and long-term efforts are made, the natural ecosystem can be fully rebuilt, turning sandy and barren mountains into green hills. As long as green development is adhered to, ecological advantages can be fully transformed into economic advantages, making green and green mountains into golden and silver mountains.

References

[1] Wang Xue. Comprehensive Performance Evaluation of Anti-virus Software Based on Fuzzy Comprehensive Evaluation Method [J]. Jiangsu Science & Technology Information. 2021. 33: 44~46.

[2] Wang Jingpu, Liu Lianyou, Jia Kai, Tian Lihui. Spatiotemporal Variation of Vegetable Phenology and Its Affecting Factors in the Mu Us Sandy Land [J]. Journal of Desert Research. 2015. 35(3): 624-631.

[3] An Yun. Analysis of Eco-efficiency on 4 Kinds of Typical Vegetation Restoration Mode in Mu Us Sandy Land [D]. Beijing. Beijing Forestry University. 2013.

[4] Zhang Ying, Zhou Xue, Qin Qingfeng, Chen Ke. Value Accounting of Forest Carbon Sinks in China [J]. Journal of Beijing Forestry University. 2013. 35(6): 124-131.

[5] Sun Jianguo. Research on the Variation of Vegetation Coverage and Land Utilization of Mu Us Sand Land in 2000-2010[D]. Lanzhou. Lanzhou Jiaotong University. 2014.

[6] Chen xiaohong, Yang Zhihui. The Study of Credit Evaluation System Based on Improved Fuzzy Evaluation Method [J]. Chinese Journal of Management Science.2015. 23(1): 146-153.

[7] Zhang Yunling. The Study of Service Function Evaluation of Forest Ecological System In Saihanba Nature Reserve [D]. Hebei. Hebei Normal University. 2011.

[8] Chen Yuanyuan. Research on the Sustainable Development Situation Evaluation in Saihanba Forest Farm [D]. Beijing. Beijing Forest University. 2019.