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Comprehensive Evaluation of Forestry Desertification Based on Grey Relational Analysis

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Abstract

In china, forestry desertification is the one of the severest ecological problems, as well as the hot research of global environmental protection. Therefore, it is important to establish a scientific, reasonable, and feasible comprehensive evaluation system for forestry desertification to guide them to achieve multi-optimization of their monitoring, prediction, and control performance. This paper aims to get a comprehensive evaluation using the grey relational analysis method. Unlike the mathematical-statistics method, the grey relational analysis also is suitable for irregular data. On the basis of the proposed evaluation method, ten samples of Dumeng County were carried out to determine and evaluate the status quo by grey desertification system included fifteen indicators. This research offered new ideas for the desertification comprehensive evaluation and protection.

Keywords: *Desertification, Comprehensive Evaluation, Grey Relational Analysis*

1. Introduction

Forestry desertification is the natural expansion of deserts, which results from climate change and human activity, leads to vegetation destruction and bares sand on sandy soil. The Law on Desertification Prevention and Control claims that Land desertification is the sandiness and expansion of natural deserts, mainly due to the human unreasonable activities. Desertification has only brought great harm and threat, as follows: land resource decreases; productivity recesses; the production development of agriculture, forestry, and animal husbandry has been hindered; the deterioration of ecological environment has been accelerated; human survival development space and land ecological security were threatened seriously[1]. From the Fourth National Desertification Monitoring, it is known that anti-desertification has made remarkable achievement in China, but the desertification situation is still serious. Meanwhile, the fifth desertification monitoring is being prepared. Therefore, both desertification monitoring and early warning researches still need to sequentially develop and make progress. And comprehensive evaluation of desertification is the key and direction to effectively prevent desertification. Furthermore, establishing a scientific, reasonable, and feasible comprehensive evaluation system for desertification is imperative.

In view of these, many scholars have studied on the evaluation methods of desertification. Sun and Li used dominant factor analysis, extracted four dominant factors that included social-economic development situation, climate action, regional disasters and weather conditions, and applied these factors to the research of WuMengHou in Inner Mongolia and Hebei region [2]. Based on the extraction method of hyper-spectral data, Fan (2000) proposed a new approach to desertification spectral information, and built a evaluation system of desertification monitoring [3]. Li (2001) used the Shazhuyu area of Qinghai province as an example of desertification evaluation with landscape ecology applied, analyzing the diversity, dominance, and evenness and Markov transition matrix

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model [4]. Geerken and Ilaiwi (2004) evaluated Syria desertification of the pastoral areas using TM images and NDVI index [5]. From remote sensing data, Shen completed a physical mode of desertification spatial pattern analysis, using GIS system, Erdas, ARC/INFO and ARCVIEW software. So there was a landscape entropy model, a dynamic simulation model [6]. In 2009, Hu used statistical method and geographic information technology, monitoring the thirty-year spatial and temporal process of land desertification of Ruoergai area [7]. On the recent research methods ,desertification researches were given priority to quantitative study, using statistics, forecasting method, computer simulation technology and remote sensing technology to establish dynamic model of land desertification, which includes predictive model, simulation model, energy conversion model and input-output model, *etc.*, so as to achieve the business monitoring and assessment analysis of land desertification.

In the above previous studies, in order to establish comprehensive evaluation or prediction model for anti-desertification, the mathematical statistic methods has usually been used for system analysis and data mining. Among mathematical statistic methods, regression, variance analysis, dominant factor analysis and principal component analysis were used to systematically multivariate statistical analysis, generally combined with the theory of fuzzy and rough. But such methods must meet the following three requirements: 1) data size should be large; 2) samples considered must obey some typical probability distribution; 3) there should be a certain linear relationship between factors data and system-characteristics data. However, to some extent, they still belonged to qualitative analysis. Meanwhile, uncertainties still existed but not were analyzed or eliminated. For example, because large amount of data was difficult to be compute, the statistical methods were generally carried out with computer technology; the unreasonable phenomenon also appeared in the process of discussion and analysis. Even worse, in previous system analysis of the status quo of desertification, the statistical methods hindered the science and rationality of result and conclusion.

Generally, in the comprehensive evaluation of the performance of a complex system, such as land desertification, the indicators used for the evaluation should not be independent of each other, but correlated; such a condition accords with the characteristics of a ‘‘grey system’’. The grey relational analysis (GRA) method is a comprehensive evaluation approach for the grey system. Since its introduction in 1982, it has been widely used in the field of science, because of its advantages in modeling, control, prediction, and decision-making [8]. For example, Xu used the GRA method to achieve a comprehensive evaluation of the multi-objective performance of power plants [9]. In addition, although the GRA method is a widely used evaluation method that is suitable for the grey system, thus so far, few open literatures have reported the use of this method in the comprehensive evaluation of forestry desertification. Considering the above, this article proposed the desertification evaluation of Dumeng with grey relational analysis.

2. Preliminary

2.1. Study Area

Dorbod Mongol Autonomous County (Dumeng County for short), one county of Daqing City, is located in the west of Heilongjiang Province, east coast of Nen River, within longitudes 123°45' to 124°42' E and latitudes 45°53' to 47°08' N. The monsoon-type climate of Dumeng is temperate and continental, with strong windy spring, warm rainy summer, and dry and cold winter. There is perennial gale, annual mean wind velocity is 2.5 m/s^{-1}, and the number of gale days (> 8.0 m/s^{-1}) is 17 [10].

Dumeng, over an area of 605,014 hm^2, is the nation-focus one of desertification monitoring counties. There are Aeolian sandy soil and desertification phenomena, mainly distributed in Ao Lin Xibo, HU Ji Tomo, Ta Laha, Bayanchagan and Yaoxin, where they account for 62.2% of the county's sandy area. Besides, All the towns distribute the fixed sand land, of which Ao Li Xibo has the area of 60,949.7 hm2. The semi-fixed sandy land was distributed in Yaoxin, Bayanchagan, Ta Laha, and Kerrta, among which Yaxin accounted for 43.6%.

2.2. Evaluation Indicators of Forestry Desertification

The indicator pool of desertification assessment was generated with reference to a range of existing studies and consultations. First, we searched related literature databases, including SCI, EI and China National Knowledge Infrastructure (CNKI). All the studies, which used the similar indicators, showed that there were the final results of desertification in qualitative and quantitative expression. Second, all related indicators were independently selected by two authors, and minor discrepancies were resolved by discussion. Meanwhile, expert consultations were also conducted to collect suitable indicators, and these experts were from forestry, ecology, geography. Finally, all collected indicators were gathered to generate a primary indicator pool which included 15 indicators [11] (Table 1). Each indicator from the indicator pool was quantitative with the character of the current situation in the study area. But, measuring the desertification degree depends primarily on the surface physical morphology and ecological conditions. Thus evaluation indicators selected not only were representative but they also reflected the desertification degree. Most important of all, by these factors such as change situation, land-use status, etc., the dynamic change of desertification status could be evaluated and predicted macroscopically.

Table 1. Indicator Pool

Number	Evaluation indicators	Definition
C_1	Sandy harnessing rate	% of land governed with total area of sandy land area
C_2	Bare sand covering rate	% of the vegetation coverage less than 10%
C_3	Land utilization rate	% of land utilization in different regions
C_4	Woodland cover	% of the woodland, shrub land, four-side tree
C_5	Three-wild vegetation cover	% of barren sand, wasteland and desolate sands
C_6	Main vegetation coverage	% of the vertical projection of main vegetable in the unit area
C_7	Total vegetation coverage	% of the vertical projection of vegetable in the unit area
C_8	Soil erosion modulus	Number of soil erosion per unit area and per year($t \cdot km^{-2} \cdot a^{-1}$)
C_9	Soil texture index	Difficulty of erosion in different soil(%)
C_{10}	SOM content	% of Soil Organic Matter(SOM for short)
C_{11}	Yearly Aeolian days	Number of sand, dust and sand storm per year(d)
C_{12}	Drought index	Rate of potential evaporation and precipitation(%)
C_{13}	Year relative humidity	% of water vapor pressure and vapor pressure in the air
C_{14}	Anthropogenic index	Degree of excessive reclamation, overgrazing ,et.(%)
C_{15}	Engel's coefficient	Life quality of farmers in the region(%)

2.3. Data Collection

The evaluation index of desertification was obtained from the National forth Census, Heilongjiang Statistical Yearbook, and the monitoring data of 2009 in Dumeng of Heilongjiang province.

3. Grey Relational Analysis

3.1. Grey System (GS)

The theory of grey system is founded in 1982 by Deng, the cybernetics expert professor. After decades of development, it formed the theoretical system based on the grey dim sets, the analysis system based on grey relational space, the method system based on the grey sequence, the model system with grey model (GM) as the core, and the technology system included system analysis, evaluation, modeling, forecasting, decision-making, control and optimization. [12]. the analysis of grey system mainly includes grey relational analysis, grey clustering and grey statistics. And grey decision-making includes grey relational decision-making. So, GRA was proposed as the important part of analysis and decision-making in the grey system theory, so as to seek regular of subsystems (or factors). It was suitable for small sample data, even for irregular data. But the case that the quantitative results is inconsistent with the results of qualitative analysis has not appeared [14]. Meantime, the GRA provided change of system development with a quantitative measure, very suitable for dynamic process analysis. In this research, desertification was a poor-information uncertain system where the partial information was known but the others were unknown, namely, the grey system. Therefore, the paper aims to establish a grey-relational-degree model for desertification evaluation using the grey system theory.

3.2. Grey Relational Degree (GRD)

From grey theory, it is known that relational degree is the metrics of relation size, which change with time or different objects between two systems. With system developing, if the variation trend of two factors is consistent, namely their synchronous change degree is higher; there is a high degree of relation. Otherwise, there is a lower one. Grey relational analysis method, therefore, was based on the similar or dissimilar degree between factors that is grey relation, so as to make decision. The GRD saw the value of the study object and influence factors as one point on a line, compared with the curve from objects and influence factor, which are not identified, and quantified the nearness respectively. Sequentially the relational degree of nearness was calculated. Eventually, we determined the influence degree for the study object by comparing the size of the relation degree.

3.3. Grey Relational Analysis (GRA) Process

Grey relation analysis is in quantitative description and comparison to a system development trend, and its basic idea is to make non-dimensional processing of the preprocessing indicators, to calculate relation coefficient and relation degree, and to sort according to the size of the relation degree. In the point of view, GRA belongs to the scope of the geometry processing, but its essence is to reflect the geometric comparison between the factor sequences of change characteristics, and to measure relation degree between factors. There are five features on grey relational analysis, as follows[13]: 1) the overall, although the relation degree described the distance degree between the discrete function of system, GRA emphasized the relative degree that a number of discrete function compare to a discrete function, and respective factor is placed into a unified system for comparing and analyzing; 2) the asymmetry, in the objective world, there exists a complex relationship between factors, in the same system, GRA objectively reflected the real gray relation between factors; 3) the non-uniqueness, the relation degree is different in different sequence, distinguish coefficient varies, et.; 4) the ordering, unlike correlation analysis, the discrete function of individual data can't exchange, or it will change the nature of the original sequence; 5) the dynamic, grey relation degree between factors change with the length of the sequence.

In the following, we apply GRA method to solve comprehensive assessment of desertification with incompletely known information. The method involves the following steps:

Step1. Determine the reference sequence and sequence for comparison. The reference sequence reflect the characteristics of the system behavior, and the comparative sequence affect the behavior of the system.

Step2. Determine the data sequence for dimensionless processing. Due to different physical significance of respective factors, it is difficult to get the correct conclusion without non-dimensional processing.

Step3. Calculate the grey relational coefficient. According to the definition of grey relation coefficient, the relation coefficient of each single indicator was introduced as follow:

$$\xi_{0i}(j) = \frac{1}{1 + \Delta_{0i}(j)}$$

Where $\xi_{0i}(j)$ is the relation coefficient, $\Delta_{0i}(j)$ is the deviation sequence of reference sequence $U_0(u_{oj})$ and comparability sequence $U_i(u_{ij})$, namely, $\Delta_{0i}(j) = \left| U_0(u_{oj}) - U_i(u_{ij}) \right|$. Because the value range of $\Delta_{0i}(j)$ is (0, 1), the scope of $\xi_{0i}(j)$ is (0.5, 1).

Step4. Estimate the grey relational grade. Because the relation coefficient is a relation value of sequence and reference in each object, its number is more than one, and the information is too scattered to compare integrality. The better is to focus on the relational coefficient (the curve of each point) in each object, and then the grey relational grade was calculated using the average value of equal weight, as follows: $\gamma_{0i} = \frac{1}{m}\sum_{j=1}^{m} \xi_{0i}(j)$.Where γ_{0i} is the grey relational grade, m is the number of indicators. The lager the relation grade, the greater the desertification severity. On the contrary, the lighter the desertification degree.

4. Results and Discussion

In this paper, we selected ten samples as an example (Table 2). After data preprocessing, both the reference sequence $U_0 = (u_{0j}), (u_{oj} = 1, j = 1, 2, ..., m)$ and comparability sequence $U_i = (u_{ij}), (i = 1, 2, ..., n; j = 1, 2, ..., m)$ were set. The U_0 is that the numerical value of assessment indexes through transition function is 1, namely, the standard severe desertification.

Table 3. Desertification Sample

S_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
1	1	82	70	8	70	80	60	40	0.20	3.0	130	1.2	65	60	33
2	0	75	62	24	65	60	60	50	0.10	2.6	140	1.1	68	50	29
3	0	64	75	5	72	75	60	30	0.15	2.7	90	1.2	66	68	35
4	0	70	58	10	56	70	50	35	0.1	3.1	105	1.0	60	40	34
5	0	86	80	0	45	0	0	10	0.2	2.5	98	1.3	65	45	25
6	0	78	73	46	76	75	35	90	0.2	2.6	70	1.2	58	20	27
7	1	90	88	33	84	80	64	5	0.1	3.5	74	1.0	64	59	30
8	0	83	85	0	28	0	0	0	0	3.8	110	1.0	70	34	33
9	1	76	59	48	75	85	17	105	0.15	2.0	95	1.2	67	28	28
10	0	81	67	0	88	60	40	85	0.10	2.4	75	1.2	65	55	30

In order to achieve unified desertification-grading standards, the evaluation indicators were converted using the following corresponding function:

(1)Sandy harnessing rate

$$f(x_1)=\begin{cases}1, x_1 f > 0.15\\ 6\times x_1, 0.02 \le x_1 \le 0.15\\ 0, x_1 < 0.02\end{cases}$$

(2) Land utilization rate

$$f(x_2)=\begin{cases}1, x_2 < 0.45\\ 0.1\times 1/x_2 - 0.45, 0.45 < x_2 \le 0.85\\ 0, x_2 \ge 0.85\end{cases}$$

(3) Woodland cover

$$f(x_3)=\begin{cases}1, x_3 < 0.20\\ 0.1\times 1/x_3 - 0.19, 0.20 \le x_3 < 0.60\\ 0, x_3 \ge 0.60\end{cases}$$

(4) Three-wild vegetation cover

$$f(x_4)=\begin{cases}1, x_4 < 0.10\\ 0.8, 0.10 \le x_4 < 0.20\\ 0.6, 0.2 \le x_4 < 0.25\\ 0.2, 0.25 \le x_4 < 0.35\\ 0, x_4 \ge 0.35\end{cases}$$

(5) Main vegetation coverage

$$f(x_5)=\begin{cases}1, x_5 < 0.50\\ 0.9, 0.50 \le x_5 < 0.65\\ 0.6, 0.65 \le x_5 < 0.75\\ 0.3, 0.75 \le x_5 < 0.85\\ 0, x_5 \ge 0.85\end{cases}$$

(6) Total vegetation coverage

$$f(x_6)=\begin{cases}1, x_6 < 0.50\\ 0.9, 0.50 \le x_6 < 0.65\\ 0.6, 0.65 \le x_6 < 0.75\\ 0.3, 0.75 \le x_6 < 0.90\\ 0, x_6 \ge 0.90\end{cases}$$

(7) Soil erosion modulus

$$f(x_7)=\begin{cases}1, x_7 < 0.40\\ 0.9, 0.40 \le x_7 < 0.50\\ 0.6, 0.50 \le x_7 < 0.65\\ 0.3, 0.65 \le x_7 < 0.75\\ 0, x_7 \ge 0.75\end{cases}$$

(8) Soil texture index

$$f(x_8)=\begin{cases}1, x_8 > 8000\\ 0.3\times \lg(x_8/10), 200 \le x_8 \le 8000\\ 0, x_8 \le 200\end{cases}$$

(9) Soil texture index

$$f(x_9)=\begin{cases}1, x_9 > 0.40\\ 2.4\times x_9, 0.10 < x_9 \le 0.40\\ 0, x_9 \le 0.10\end{cases}$$

(10) SOM content

$$f(x_{10})=\begin{cases}1, x_{10} < 0.70\\ 0.9, 0.70 \le x_{10} < 0.14\\ 0.6, 0.14 \le x_{10} < 2.0\\ 0.3, 2.0 \le x_{10} < 2.70\\ 0, x_{10} \ge 2.70\end{cases}$$

(11) Yearly Aeolian days

$$f(x_{11})=\begin{cases}1, x_{11} > 300\\ 0.4\lg x_{11}, 150 < x_{11} \le 300\\ 0.3\lg x_{11}, 50 < x_{11} \le 150\\ 0, x_{11} \le 50\end{cases}$$

(12) Drought index

$$f(x_{12})=\begin{cases}1, x_{12} > 2.4\\ x_{12}/3, 0.6 < x_{12} \le 2.4\\ 0, x_{12} \le 0.6\end{cases}$$

(13) Year relative humidity

(14) Anthropogenic index

$$f(x_{13})=\begin{cases}1, x_{13} < 0.35\\ 0.8, 0.35 \le x_{13} < 0.45\\ 0.5, 0.45 \le x_{13} < 0.65\\ 0.2, 0.65 \le x_{13} \le 0.80\\ 0, x_{13} > 0.80\end{cases}$$

$$f(x_{14})=\begin{cases}1, x_{14} > 0.80\\ 0.05\lg(100 x_{14}), 0.65 < x_{14} \le 0.80\\ 0, x_{14} \le 0.65\end{cases}$$

(15) Engel's coefficient

$$f(x_{15})=\begin{cases}1, x_{15} > 0.70\\ 0.9, 0.50 < x_{15} \le 0.70\\ 0.6, 0.35 < x_{15} \le 0.50\\ 0.3, 0.10 < x_{15} \le 0.35\\ 0, x_{15} \le 0.10\end{cases}$$

It is obvious that there is different non-dimensional processing of each indicator, then, the ordering characteristic of GRD had been destroyed. However, even if GRD had not order-preserving property because of different non-dimensional processing, the final result is consistent with the actual and there are still some practical value with the GRA method (Zhou). Thus the dimensionless desertification indicators is reasonable.

After all the indicator converting, the deviation sequence $\Delta_{0i}(j)$ of reference sequence $U_0(u_{oj})$ and comparability sequence $U_i(u_{ij})$ was calculated. So the coefficient was calculated in Table 3. Among the table, the $\xi_{0i}(j)$ value of woodland cover, three-wild vegetation cover, main vegetation coverage, total vegetation coverage is lager than the others, illustrating that government and department monitoring should focus on the vegetable status.

As we have known, there are fifteen indicators selected, namely, the number of m is fifteen. Thus, the next step was to calculate relation the degree of desertification status by the equation, $\gamma_{0i} = \frac{1}{15}\sum_{j=1}^{15}\xi_{0i}(j)$. The size of relational degree reflected the seriousness of desertification situation. In the FAO/UNEP view, the extent of desertification is divided into four grades: potential desertification, mild desertification, severe desertification, and very severe desertification. However, in our study, with the GRA method and analysis of Dumeng County, the grade is considered to be a five-rating system that evaluates small plaques as an evaluation unit. Therefore, the land desertification is classified into five following grades: class 1: 0.5< γ_{0i} ≤0.6, non-sandy land; class 2: 0.6< γ_{0i} ≤0.7, potential desertification land; class 3: 0.7< γ_{0i} ≤0.8, mild desertification land; class 4: 0.8< γ_{0i} ≤0.9, severe desertification land; class 5: 0.9< γ_{0i} ≤1, very severe desertification land.

Table 4. Grey Relational Coefficient

ξ_{0i}(	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
1	0.5	0.56	0.5	1	0.58	0.58	0.71	0.5	0.66	0.5	0.72	0.63	0.55	0.5	0.58
2	0.5	0.59	0.5	0.71	0.71	0.71	0.71	0.5	0.5	0.71	0.74	0.61	0.55	0.5	0.58
3	0.5	0.63	0.5	1	0.58	0.58	0.71	0.5	0.6	0.5	0.70	0.63	0.55	0.52	0.58
4	0.5	0.63	0.57	0.83	0.90	0.71	0.71	0.5	0.5	0.5	0.71	0.59	0.67	0.5	0.58
5	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0

	.5	.5	.5					.5	.65	.58	.70	.64	.55	.5	.58
6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	.5	.58	.5	.5	.58	.58		.5	.65	.58	.69	.63	.67	.5	.58
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	.5	.5	.5	.55	.58	.58	.71	.5	.5	.5	.68	.59	.55	.5	.58
8	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
	.5	.57	.5					.5	.5	.5	.71	.59	.55	.5	.58
9	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	.5	.59	.57	.5	.58	.58		.5	.60	.58	.70	.63	.55	.5	.58
1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	.5	.58	.5		.5	.9	.9	.5	.5	.58	.69	.63	.55	.5	.58

Table 5. Sample' GRA Result and Field Test

S	Grey relational degree	Grade	Field monitoring results
1	0.60	Non-sandy land	Non-sandy land
2	0.60	Non-sandy land	Non-sandy land
3	0.59	Non-sandy land	Non-sandy land
4	0.62	Potential desertification land	Non-sandy land
5	0.68	Potential desertification land	Non-sandy land
6	0.60	Non-sandy land	Non-sandy land
7	0.55	Non-sandy land	Non-sandy land
8	0.67	Potential desertification land	Non-sandy land
9	0.59	Non-sandy land	Non-sandy land
10	0.63	Potential desertification land	Non-sandy land

From Table 5, we can see that the ten samples had been evaluated by the GRA method, but the field testing shown that the precision is only 60%. There are two reasons to explain the precision loss. On the one hand, all the GRD calculated of desertification is positive, and they can not fully reflect the relationship between indicators. The truth is that there is a positive relation between indexes, as well as a negative one. On the other hand, the GRD definition lack of strict theoretical basis. Only in according to the proximity of geometric shape and the development trend of data column, the GRD can be created in many different formulas. However, according to the relation analysis of the results from this formula, experiments come to various inconsistent conclusions [14]. In further study; we will study the negatively relational grey model. Meanwhile, this method will actually be used in the software in order to evaluate the desertification situation and predict desertification trends in business.

5. Conclusion

Although the GRA method is a lower accuracy in this study, it can also be applied to many other areas of management decision problems or strategy selection problem. However, using grey relational analysis, the desertification assessment avoided information distortion and losing which occur formerly in the statistical analysis process. Furthermore, we believe that the grey relational analysis method can play an active role in guiding desertification in adjusting their operations or carrying out technical reformation to obtain satisfactory results, as well as in making sustainable development policies of China's anti-desertification with fully consideration of natural and anthropogenic factors.

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