Assessment of City Ecological Security Based on Projection Pursuit Model

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Abstract: Assessing and understanding the level of city ecological security are of great importance to sustainable urban development. According to the pressure-state-response model, the indexes of city ecology security assessment were chosen. Subsequently, the assessment model based on projection pursuit technology was set up and used for a case of Hefei city. The result shows that the ecological security level of the city in 2003 belongs to critical security situation. The conclusion is the same to that of matter element model and reflects the real eco-environment state of Hefei city. Therefore, the model is feasible and accurate.

Keywords: assessment; ecology security; projection pursuit model; Hefei city

I. INTRODUCTION

With the global deterioration of ecological environment, ecological security issue has become one of the challenges faced in the 21st century. In many cities, traffic congestion, resource shortages and environmental pollution were caused by intensification of the process of urbanization, rapid population concentration and socio-economic activities. So, urban ecological security has become the bottleneck to the development of many cities. Moreover, deterioration of ecological environment constitutes a potential threat to the health of urban residents, living conditions and living space. Therefore, the study of urban ecological security is imminent.

II. REVIEW OF ECOLOGICAL SECURITY ASSESSMENT

As for the assessment of ecological security, it has developed from the initial qualitative description to more precise quantitative assessment. And the assessment methods show the diversity. Xiao Rong-Bo *et al*[1] conducted an evaluation of ecological security for Hainan Island by means of the composite index; Liu Yong *et al*[2] used the analytic hierarchy principle to assess the security of regional land resources; Chen Hao *et al*[3] done regional ecological security assessment based on the gray correlation method; Xie Hua-Lin *et al*[4] completed a case study for a few large cities by the matter-element model. In addition, the ecological footprint method [5], the principal component projection method[6] and digital terrain model approach[7] were used. On the advantages and disadvantages of the above methods, Liu Hong *et al*[8] done a description in detail.

To overcome the defects caused by a single mathematical model, many scholars have developed several combined evaluation model, such as the FDA (fuzzy comprehensive evaluation-analytic hierarchy principle - principal component

analysis) model, multi-level fuzzy comprehensive evaluation - gray correlation advantage analysis model, fuzzy-variable weight model, analytic hierarchy-variable weights-fuzzy-gray correlation model[8].

The above methods achieved certain results from different emphases. Aimed at the feature of multi-index decision making on the ecological security evaluation, how to use effectively assessment standard to form a common evaluation method and how to determine rationally the index weight are still room for improvement.

This paper adopts a new dimension reduction approach - projection pursuit model to assess the ecological security status of Hefei city. The method can effectively deal with the characteristics of multiple variables, non-normal distribution of variables, complex non-linear relationship among the variables faced in urban ecological security evaluation. In addition, it can determinate objectively weightS of indexes to avoid the impact from the subjective factor.

III. PROJECTION PURSUIT MODEL

Projection pursuit method appeared initially in the late of 1960s. Kruskal [9] used firstly projection pursuit method to transform the high-dimensional data into low-dimensional space by maximizing an indicator reflecting the degree of data aggregation. After computing the indicator reflecting the structural feature of the data, the optimal projection direction can be found. Presently, as a new statistical method, it has been used to analyze and process high-dimensional observation data, especially for non-linear, non-normal distribution of high-dimensional data. It has been widely used in classification, pattern recognition, remote sensing classification, image processing and other fields [10]. Its specific application process is as follows:

Set the sample set as

$$(x(i, j)) | i = 1, \dots, m; j = 1, \dots, n,$$

where i is the sample number, j is the number of indicators. The establishment of projection pursuit model is the following steps:

(1) Preprocess data

The sample index set is normalized to eliminate the impact of each index dimension and unit so that it is uniformed the same range. For the bigger and more excellent indicators: formula (1) is used; for the smaller and more excellent indicators: formula (2) is used.

$$x^*(i, j) = x(i, j) / x_{\max}(j) \quad (1)$$

$$x^*(i, j) = 1 - x(i, j) / x_{\max}(j) \quad (2)$$

where $x_{\max}(j)$ is the maximum value of j^{th} indicator.

(2) Construct projection index function [10]. Set $a(j)$ as the projection vector, the projection value of the sample i in the direction is

$$Z(i) = \sum_{j=1}^n a(j) * x^*(i, j) \quad (3)$$

The objective is to construct a projection index function $Q(a)$ as a basis for determining optimal projection direction. When the indicator reached the maximum value, the optimal projection direction is found. In optimizing the projection value, the distribution character of $Z(i)$ should be met: the projection points are as dense as possible locally and as spread as possible in the whole. Therefore, the projection index function is constructed: $Q(a) = S_z \cdot D_z$, where S_z -scatter degree among the classes, the standard deviation is often as a substitute; D_z -the intensity within the same class, can be expressed by the local density of $Z(i)$. Detailed formula is following:

$$S_z = \left\{ \sum_{i=1}^m [Z(i) - \bar{Z}]^2 / (m - 1) \right\}^{\frac{1}{2}} \quad (4)$$

$$D_z = \sum_{i=1}^m \sum_{j=1}^m (R - r_{ij}) * I(R - r_{ij}) \quad (5)$$

where, $\bar{Z}$ - the mean of sequence $(Z(i) | i = 1, \dots, m)$, R -the local width parameter determined by the data characters, its value is generally set to $0.1 * S_z$. The distance between two sample points is computed by the equation $r_{ij} = |Z(i) - Z(j)|$.

If the distance is less than or equal to R , they are thought the same class, otherwise, different class. Sign function $I(R - r_{ij})$ is unit step function, when $R \geq r_{ij}$, I is 1, otherwise 0.

(3) Compute optimal projection direction

By solving the following optimization model to calculate the optimal projection direction:

$$\max Q(a), \quad \text{subject to } \sum_{j=1}^n a_j^2 = 1$$

(4) Make sure of assessment grade of unknown samples

After getting the optimal projection direction, the projection value of sample points of each grade is computed and grade evaluation method is gotten. Subsequently, normalizes the unknown samples and computes their projection values by the optimal projection direction, then determines the classes of the unknown samples according to grade evaluation model.

IV. CASE STUDY

A. Overview of Hefei city

Located in the middle of Anhui Province, Hefei is the capital of Anhui Province. The city is located in the hinterland of Jianghuai region and Jianghuai watershed going through the city from southwest to northeast to form a weak and gentle topography of the fish-shaped back. The region has rich natural resources, good ecological environment, but with the social and economic development, local environmental pollution rises and water quality of urban river gets worse.

B. Index System and Assessment Standard

Multi-factor comprehensive evaluation takes into account the different aspects of impacting urban ecological security. It includes not only the indexes of biological and environmental resources, but also the indexes of life-support system impacting on the socio-economic system and human health[8]. At present, what is widely used is the pressure-state-response (PSR) framework model reflecting human and environmental systems put forward by the United Nations Organization of Economic Cooperation Development (OECD) to describe the environmental issues initially. On its basis, the United Nations Commission on Sustainable Development (UNCSD) also raised the driving force-state-response (DSR) conceptual model[11].

In view of the integrated features of urban ecological security assessment, according to systematic, forward-looking, scientific, operational and people-oriented principle, urban ecological security index system was constructed based on the pressure-state-response model. It included concretely three hierarchy: the pressure from resources and environment, the state of resources and environment, the respond of humanism environment [11,12,13], specifically shown in Table 1.

According to national standards, taking into account China's national conditions and mean level of ecological safety of the international regional cities, combined with Anhui long-term goal indicators of ecological construction, the index system and standard in this paper are decided[14], specifically in Table 1.

C. Model Solution

According to the assessment criteria in Tab.1, the standard samples were built. Taking into account the range of values, the middle values of range were adopted to solve the best projection direction in this paper. The nature of the projection pursuit model is a complex nonlinear optimization problem, but traditional optimization methods are difficult to resolve. We solved the optimization problem based on real-coded genetic algorithm. Applied genetic algorithm and direct search toolbox based on MATLAB language, edited the objective function and constraint function referred to [15]. After a combination of experimental parameters, the optimal projection direction was obtained. Projection vector is $a = [0.1256, 0.2706, 0.2941, 0.2230, 0.1985, 0.2432, 0.2323, 0.2671, 0.1908, 0.1083, 0.0929, 0.0901, 0.0216, 0.1496, 0.0406, 0.0856, 0.2613, 0.2523, 0.2676, 0.2579, 0.1946, 0.268, 0.2729]$. According to the vector a , projection value of the standard samples were

computed. Their values were respectively 3.9795, 3.0075, 2.0783, 1.1733 from the ideal security to insecurity. Then, relationship figure of projection values and grades can be obtained, as seen in figure 1.

Figure. 1 Relationship of projection values and grades

The above-mentioned indexes of Hefei city in 2003 are as follows:2550,6.15,10720,1.3,7.48,19.61,7.45,130,13.8,35.5, 5.3,298,100,38,100,52.8,15,0.31,4.4,24,6.34,3,2 (limited space, the unit is ignored). By the normalization of the data, the projection value of Hefei city in 2003 is 2.3347 based on the vector *a* .By right of the equation in Fig.1, its grade value is 2.2595.According to the principle of approaching the grade closer to 2, so the level of ecological security in Hefei in 2003 is critical security status, which is consistent with that of matter-element evaluation model. The above result is accordant with the real status of the city. In recent years, with rapid development of city construction, the lands are occupied and natural landscapes at the urban fringe area are constantly destroyed. Adding the large convergence of population, coupled with industrial pollution, so urban land and water resources pressure and so forth increase continuously. The above integrated factors result in the critical security status of Hefei city.

Table 1 Ecological security evaluation index system and standard

First layer index(A)	Second Layer index (B)	Third layer index (C)	Ideal security	Quite security	Critical security	Insecurity
Index of urban ecological security (A)	Pressure from resources and environment (B1)	C1-population density	2500~3000	3000~3500	3500~4000	4000~4500
		C2-natural population growth rate	0.8~3	3~5	5~7	7~9
		C3-per capita gross domestic product	40000~30000	30000~20000	20000~10000	10000~2500
		C4- unit of GDP energy consumption	0.5~0.8	0.8~1.2	1.2~1.5	1.5~2.0
		C5-per capita public green areas	15~12	12~9	9~7	7~5
		C6-per capita road area	28~20	20~15	15~10	10~5
		C7-per capita power consumption	8~6.5	6.5~5	5~3.5	3.5~1.5
		C8-per capita domestic water	450~350	350~250	250~150	150~50
	State of resources and environment, (B2)	C9-coverage rate of forest	15~13	13~11	11~8	8~5
		C10-green coverage rate of built-up area	40~35	35~32	32~28	28~24
		C11-emission intensity of major pollutants	4~4.5	4.5~5	5~5.5	5.5~6
		C12-the days up to grade II of urban air quality	330~300	300~270	270~250	250~220
		C13-the water quality of concentrative drinking water resource	100~98	98~96	96~94	94~92
		C14-repetition rate of industrial wastewater	52~46	46~39	39~32	32~25
		C15-disposal rate of industrial solid waste	100~97	97~94	94~90	90~85
		C16-equivalent sound level of urban noise	45~50	50~55	55~60	60~65
	Respond of humanism environment (B3)	C17-higher education enrollment rate	50~40	40~30	30~15	15~10
		C18-income ratio in urban-rural region	1~0.7	0.7~0.5	0.5~0.3	0.3~0.2
		C19-unemployment rate of urban residents	1~3	3~5	5~7	7~9
		c20-number of sickbeds per ten thousand persons	90~70	70~50	50~30	30~15
		C21-investment proportion of GDP in the public basic establishment	12~10	10~8	8~6	6~4
		C22-the investment proportion of GDP in science and education	7~5	5~3	3~2	2~1
		C23-investment proportion of GDP in environmental protection	2.5~2	2~1.5	1.5~1	1~0

V. CONCLUSION

Assessing and understanding urban ecological security situation is of great significance to achieve sustainable city development. Aimed at the multi-index, non-normal and non-linear characters, dimension reduction technology-projection pursuit hierarchical model was established to assess the level of ecological security of Hefei city. The method can avoid the subjective interference in deciding the weights of index by solving an optimization problem. In addition, its assessment result is objective and satisfactory. Combined with the matter-element evaluation model, it can accurately describe a security status of specific value, with a higher classification accuracy.

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