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Ecological Health Assessment of Urban Ecosystem of Tianjin City

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Abstract. Urban ecological health assessment is the basis of making city planning, construction and management policy. Five elements were selected to build up an evaluation system, including vigor, organizational structure, resilience, and ecosystem service function and population health. Fuzzy comprehensive evaluation were employed to analyze and evaluate the healthy state of Tianjin urban ecosystem over 2008 to 2012 based on the method of mean-squared deviation to determine index weight. Results showed that the healthy status of Tianjin ecosystem was in sub-health level. The favorable factors affecting urban ecosystem healthy state of Tianjin included vigor, resilience and population healthy, while unfavorable factors included organizational structure and ecosystem service function. Main stress factors to healthy development are per capita water consumption, the amount of pesticide per hectare of arable land, per capital road area, urban population density and proportion of high-education people.

Keywords: ecological health assessment, urban ecosystem, Tianjin city, fuzzy comprehensive evaluation.

1. Introduction

With the rapid development of technology and economy, the deterioration of ecological environment has been gradually exacerbated and healthy ecosystems attract more and more attentions all over the world. The major content of ecological health focus on exploring the concept and evolution methods for various types of ecosystem health [1]. While many scholars have done some primary research about ecosystem health from different aspect, one from the perspective of the ecosystem itself defined healthy system could maintain internal stability (i.e. resilience). A change of system would be accompanied by a corresponding change of health status [2]-[4]. The others considered the interaction between human and ecosystem are based on the concept of ecosystem services for human .They thought the criterion of "health" should be whether it could provide continuous and excellent ecosystem services for human survival and development [5].Therefore, the concept of ecosystem health has been evolved from a category of ecology into a comprehensive scope integrated ecological, socioeconomic and human health. Rapport et al. summarized ecosystem health as "a systemic approach to the preventive, diagnostic, and prognostic aspects of ecosystem management, and to understanding of relationships between ecosystem health and human health". In other words, it should not only involve the ability to meet the reasonable demands of human society but also be able to self-sustaining and update of ecosystem [6].

The key procedure of urban ecosystem health assessment is to select appropriate evaluation index system. Rapport et al. (1985) proposed "ecosystem distress syndrome (EDS)" as index of ecosystem unhealthy status [7]. Costanza et al. (1992) provided three indicators (i.e. vigor, organization structure and resilience) to describe system status from the perspective of system sustainable ability [8]. Jerry et al. (2001) adopted

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driving force–pressure–state–exposure–effect–action (DPSEEA) model to solve problems within how to build evaluation index system theory and method of urban ecosystems [9]. However, most scholars would choose vigor, organizational structure, resilience, and ecosystem service function and population health as five main elements for ecological health assessment of urban ecosystem [10]-[12].

2. Methodology

2.1. Study Area

Tianjin is one of the four municipalities in China, located at latitude 38°34N'-40°15'N and longitude 116°43'E-118°04'E with a total area of 11,760 km^2. Tianjin is classified as a warm humid continental monsoon climate which average temperature is around 14℃. Its average annual rainfall is between 360 to 970 mm. Precipitation in this city is unevenly distributed. The city's residential population was 14.37 million at the end of 2013. Tianjin is located in the Hai river basin. The region plays a very important role in China in terms of its economic production. The basin holds one of China's five largest urban agglomerations including Beijing and Tianjin. Tianjin is the largest industrial centre in north China. Facing the severe challenges of socioeconomic development and global climate change, ecological health in Tianjin should be evaluated for the efficient management of urban ecosystem.

2.2. Ecological Health Assessment of Urban Ecosystem

Ecological health assessment is generally composed of comprehensive evaluation method and index system method. The latter method determines the index weight through analytic hierarchy process (AHP), principal component analysis (PCA), and fuzzy comprehensive evaluation (FCE).As urban ecological health has the features of clear connotation and fuzzy extension, application of fuzzy evaluation model is more realistic than traditional evaluation methods [13]. Therefore, ecological health assessment of Tianjin over 2008 to 2012 would be conducted by FCE approach. The followings are the procedure: 1) Construct index system of urban ecosystem; 2) Design membership function; 3) Determine the weight of function corresponding to each health indicator by mean variance method 4) Calculate ecological health assessment results within fuzzy matrix.

2.2.1. Construct index system of urban ecosystem

Five elements (i.e. vigor, organizational structure, resilience, and ecosystem service function and population health) were selected to build up an evaluation index system. The status of urban ecological health are divided into five levels, which is morbid, unhealthy, sub-healthy, healthier, and healthy respectively. According to health standards recommended by domestic and international eco-cities, health cities and environmental cities, the values that floated down 20% of above mentioned are set to threshold between healthy and sub-healthy. Similarly, the national minimum values of similar indicators in "the almanac of China's cities" are defined as morbid and the values that floated up 20% of morbid values are set to threshold between unhealthy and sub-healthy. Urban ecological health assessment index system and classification standards are shown in Table I.

2.2.2. Design membership function

Let r_{kj} be a relative membership of k indicator to j level standard, s_{ij} be j level standard of k indicator, where j=1, 2, 3, 4, 5; x_i be true value of i indicator.

- For positive indexes, the membership function formula is as follows:
  When $x_i < s_{i,1}$, $r_{i1} = 1, r_{i2} = r_{i3} = r_{i4} = r_{i5} = 0$;

  When $s_{i,j} < x_i < s_{i,j+1}$, $r_{i,j+1} = \dfrac{x_i - s_{i,j}}{s_{i,j+1} - s_{i,j}}$,

$r_{i,j} = 1 - r_{i,j+1} \quad (j = 1,2,3,4)$;

  When $x_i > s_{i,5}$, $r_{i5} = 1$, $r_{i1} = r_{i2} = r_{i3} = r_{i4} = 0$.
- For negative indexes, the membership function formula is as follows:
  When $x_i > s_{i,1}$, $r_{i1} = 1$, $r_{i2} = r_{i3} = r_{i4} = r_{i5} = 0$;

When $s_{i,j} > x_i > s_{i,j+1}$, $r_{i,j+1} = \dfrac{s_{i,j} - x_i}{s_{i,j+1} - s_{i,j}}$,

$r_{i,j} = 1 - r_{i,j+1} \quad (j = 1,2,3,4)$;

When $x_i < s_{i,5}$, $r_{i5} = 1, r_{i1} = r_{i2} = r_{i3} = r_{i4} = 0$.

Then statistics value of each indicator is taken into the membership function to calculate the corresponding membership matrix.

Table I: Urban ecological health assessment index system and classification standards

Assessment elements	Indicators	Morbid	Unhealthy	Sub-healthy	Healthier	Healthy
Vigor	Urban per capita GDP (10^4yuan)	0.7	3	5	10	20
	Per capita disposable income of urban residents (10^4yuan)	0.4	0.8	1.2	1.6	2
	Utilized of foreign capital (10^8 dollars)	10	25	50	75	90
	Natural population growth rate (‰)	13	11	9	7	5
	Per capita water consumption (L/d)	120	160	210	260	320
	Energy consumption per 10^4 Yuan GDP (Tons of standard coal)	2	1.5	1	0.7	0.5
Organizational structure	Proportion of the tertiary industry in the GDP (%)	30	40	50	60	80
	Proportion of R & D funding in the GDP (%)	1	2	3	4	5
	Urban population density (10^4 persons/km^2)	3	2.5	2	1.5	1
	Amount of pesticide per hectare (kg/hm^2)	50	40	30	20	10
	Rural per capita net income (Yuan/Year)	2500	3500	4500	5500	6000
	Green coverage (%)	20	25	30	40	50
Resilience	Urban sewage treatment ratio (%)	30	50	70	95	100
	Life garbage treatment rate (%)	40	50	70	90	100
	Comprehensive utilization rate of industrial solid waste (%)	30	50	70	90	100
	Industrial water recycling rate (%)	10	30	50	70	90
	Industrial wastewater discharge compliance rate (%)	70	75	85	95	100
	Proportion of environmental investment in the GDP (%)	1.0	1.5	2.0	3.0	5.0
Ecosystem service function	Per capita public green (m^2/ Person)	4	7	10	16	20
	Per capita living space (m^2/ Person)	7	10	15	17	20
	Road area per capita (m^2/ Person)	6	10	15	20	28
	Bus per ten thousand people have (Units)	5	10	20	30	40
	Ratio of the days which air quality is not less than II level (%)	20	40	60	80	100
	Urban air comprehensive pollution index	5	4	2.5	2	1.5
	Environmental noise of urban area dB(A)	85	70	50	45	40
	Annual average urban traffic noise dB(A)	100	80	65	55	50
	Hospital beds per ten thousand people have (Units)	10	30	50	70	90
Population health	Engel coefficient (%)	50	45	35	30	25
	College students in per ten thousand people (Persons)	50	150	300	450	600
	Libraries per million people have (Units)	1.5	1.8	2	2.5	3

2.2.3. Calculate evaluation index weight

Evaluation index data of Tianjin ecological health is obtained by referring to "Tianjin Statistical Yearbook" (2008-2012), "Tianjin Environmental Quality Bulletin" (2008-2012).The weight of each assessment element is calculated by the method of subjective weight assignment. The weight subset of first level evaluation index are as follows: W= [W1, W2, W3, W4, W5] = [0.2, 0.2, 0.2, 0.2, 0.2]. And then the weight of each index within their assessment elements would be obtained by the method of mean-squared deviation. The steps are as follows:

- Nondimensionalization of the original data by maximum difference normalization method. The equations are:

  For positive indexes: $X_{ij} = \dfrac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}}$, $X_{ij} \in [0,1]$;

  For positive indexes: $X_{ij} = \dfrac{x_{j\max} - x_{ij}}{x_{j\max -} x_{j\min}}$, $X_{ij} \in [0,1]$;

  Where x_{ij}, $x_{j\max}$, $x_{j\min}$, X_{ij} is original value, maximum, minimum and standardized value of j indicator in i year.

- Calculation mean square error of j indicator. The equation is:

$$\sigma_j = \sqrt{\sum_{i=1}^{n} \frac{(X_{ij} - \overline{X_j})^2}{n-1}};$$

- Where $\overline{X_j}$ is mean of a random variable, The equation is:

$$\overline{X_j} = \frac{1}{n}\sum_{i=1}^{n} X_{ij},\ n = 1,2,3,4,5$$

2.2.4. Compound operation of fuzzy matrix

Ecological health assessment model like this:

$$H = W \cdot R$$

Where H - the result of ecological health assessment; W - weight matrix of overall health status within five assessment elements; R - membership matrix of each level health standard within every assessment element.

$$R = \begin{bmatrix} R_{11} & R_{12} & \cdots & R_{15} \\ R_{21} & R_{22} & \cdots & R_{25} \\ \vdots & \vdots & \vdots & \vdots \\ R_{51} & R_{52} & \cdots & R_{55} \end{bmatrix}$$

Where R_{ij} - membership of k indicator to j level standard.

$$R_{ij} = \begin{bmatrix} W_{i1} & W_{i2} & \ldots & W_{ik} \end{bmatrix} \times \begin{bmatrix} r_{1j} \\ r_{2j} \\ \vdots \\ r_{kj} \end{bmatrix}$$

Where: k - the number of indicators in each assessment element; W_{ik} - the weight of i k indicator in i element to this element, r_{kj} - membership of k indicator to j level standard.

3. Results and Discussion

3.1. Results of Comprehensive Evaluation

The analysis result for membership of each assessment element in 2008 of Tianjin city is as follows:

$$R_{2008} = \begin{bmatrix} 0.1353 & 0.0410 & 0.2338 & 0.2285 & 0.3614 \\ 0.1952 & 0.2724 & 0.3842 & 0.1483 & 0 \\ 0 & 0 & 0.3046 & 0.3101 & 0.3853 \\ 0.0147 & 0.3235 & 0.3624 & 0.0963 & 0.2032 \\ 0 & 0 & 0.2596 & 0.6002 & 0.1402 \end{bmatrix}$$

The computational process of $R_{2009} - R_{2012}$ is omitted。The overall health status of urban ecosystem in Tianjin are calculated as followed. (Table II)

Table II: Comprehensive evaluation result of Tianjin ecosystem health over 2008 to 2012

Year	Morbid	Unhealthy	Sub-healthy	Healthier	Healthy
2008	0.0690	0.1274	0.3089	0.2767	0.2180
2009	0.0675	0.2179	0.4195	0.1491	0.1460
2010	0.0695	0.2197	0.3448	0.1903	0.1758
2011	0.0678	0.1147	0.4540	0.2184	0.1451
2012	0.0668	0.0938	0.4534	0.3980	0.1576

According to the principle of maximum degree of membership, the overall health status of urban ecosystem in Tianjin are sub-healthy. The membership is 0.31, 0.42, 0.34, 0.45, and 0.45.

3.2. Trend Analysis of Urban Ecosystem Health

Fig. 1 shows the urban ecosystem of Tianjin from 2009 to 2012 was in a sub-healthy state. Although the level of morbid in 2010 increased slightly, the membership of unhealthy level had shown a downward trend obviously. Meanwhile, the membership of healthier level was rising. For 2008, the membership of five status is 0.069, 0.1274, 0.3089, 0.2767 and 0.2180. Urban ecosystem health level was higher than the other four years. The reason may be that China held the 2008 Olympic Games, so it strengthened the coordination of urban ecosystem and social development. The overall environmental quality improved significantly in this period.

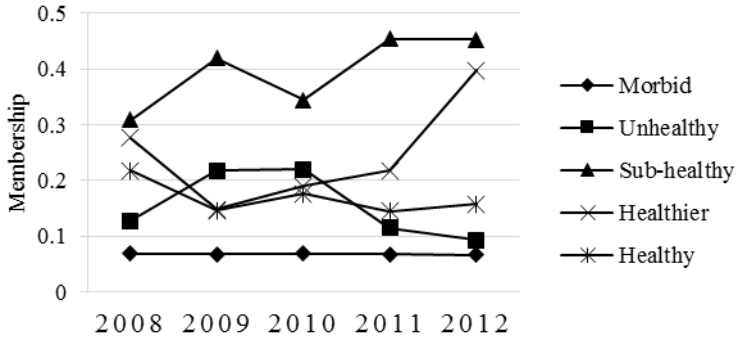

Fig. 1: Evaluation result of Tianjin ecosystem health over 2008 to 2012

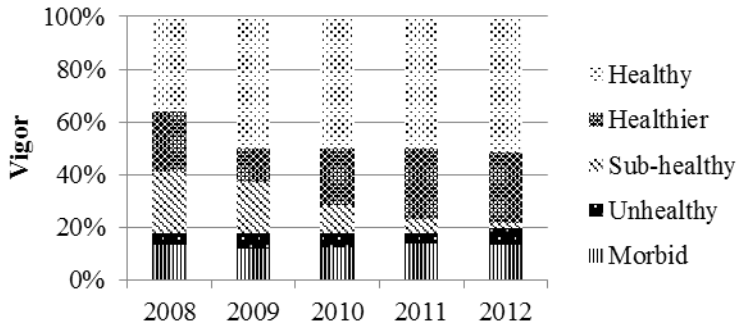

Fig. 2: The evaluation results of vigor element over 2008 to 2012

3.3. Assessment Elements Analysis

3.3.1. Vigor

The vigor element of Tianjin ecosystem health was fluctuating over 2008 to 2012, which mainly was in the positions of healthier and healthy level (Fig. 2).The value of these two levels changed from 59.99% to 80.11% over 2008 to 2012. For each specific evaluation indicator, per capita disposable income and actual use of foreign capital and natural population growth rate were significantly optimized; urban GDP per capita decreased year by year. On the other hand per capita water consumption had always been in a morbid level. So Tianjin municipal government should focus on increasing the ways to acquire water resource, developing the economic and improving urban GDP per capita.

3.3.2. Organizational structure

The organizational structure status of Tianjin ecosystem health had been kept sub-heathy level over 2008 to 2012 (Fig. 3).The sum value of healthier and healthy increased from 14.83% to 28.92%. For each specific evaluation indicator, hand per capita water consumption was always in a morbid level. The amount of pesticide per hectare of arable land had always been in a morbid level, which was a stress factor in organizational structure. Urban population density tented to deteriorate. Other indicators were gradually optimized at a high level every year. Reducing the amount of pesticide per unit area and urban population density should be two main points in the future development.

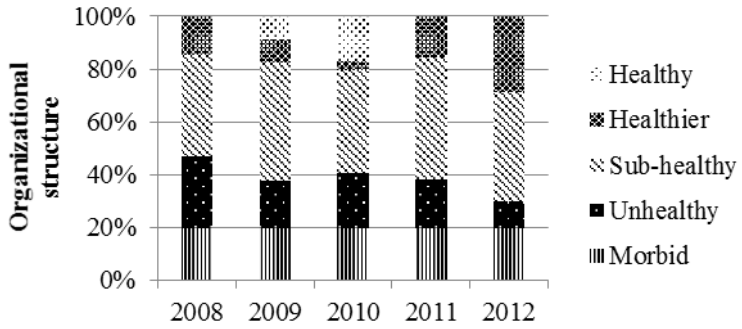

Fig. 3: The evaluation results of organizational structure element over 2008 to 2012

3.3.3. Resilience

The resilience status of Tianjin ecosystem health had been kept heathy level over 2008 to 2012 (Fig. 4). The sum value of healthy and healthier increased from 69.54% to 90.84%. It is indicated that status of resilience were toward a healthy direction because Tianjin municipal government paid more attention to energy conservation and recycling economy as well as improving comprehensive utilization rate of industrial solid. However, life garbage treatment rate was fluctuating, the government should make efforts to increase the urban sewage treatment rate steadily.

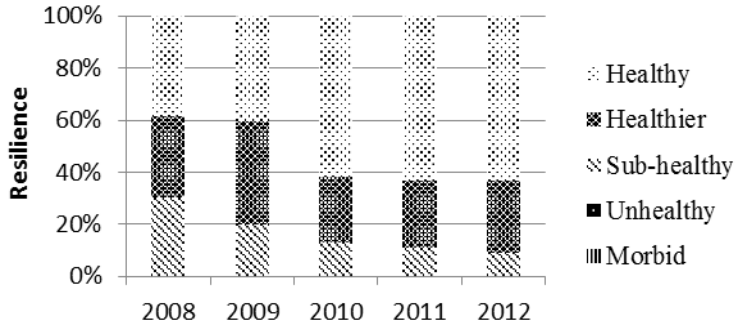

Fig. 4: The evaluation results of resilience element over 2008 to 2012

3.3.4. Ecosystem service function

The ecosystem service function status of Tianjin ecosystem health had been kept sub-heathy level over 2008 to 2012 (Fig. 5). Meanwhile, the sum value of healthy and healthier decreased from 29.95% to 23.15% over 2008 to 2009 and then increased to 31.30% in 2012. It is suggested that the indicators of ecosystem service function element tended to be increasing. The reason is because China held the 2008 Olympic Games, and road area per capita significantly increased, urban environmental quality improved significantly. However, with the increasing population, the number of beds that ten thousand people had decreased in

fluctuation. Hence the government should strive to improve the level of medical care and increase hospital hardware facilities.

3.3.5. Population health

The population health of Tianjin ecosystem health had been in the state of fluctuating (Fig. 6). The sum value of healthy and healthier decreased from 74.04% in 2008 to 54.15% in 2012 gradually. The status of Engel coefficient and the number of college students per ten thousand people were always kept healthy level. It showed that urban consumption began to transfer attentions to education and entertainment, but the number of libraries per ten thousand people own was decreasing every year. So the government should strengthen the infrastructure construction and educational quality.

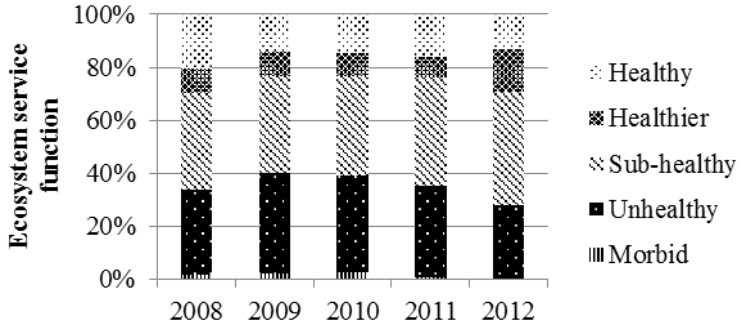

Fig. 5: The evaluation results of ecosystem service function element over 2008 to 2012

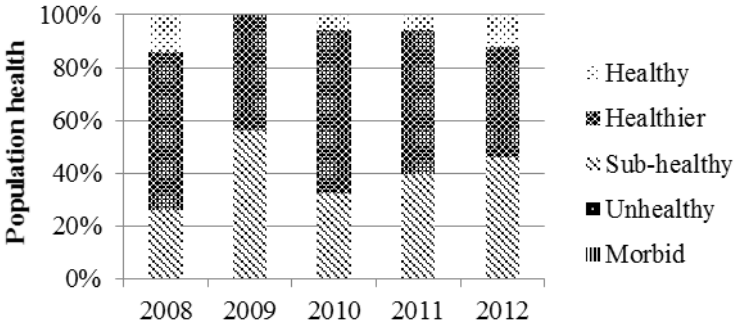

Fig. 6: The evaluation results of population health element over 2008 to 2012

4. Conclusion

This study was based on the actual situation in Tianjin city and ecological health assessment method. 27 indicators within five elements (i.e. vigor, organizational structure, resilience, and ecosystem service function and population health) were selected to build up an evaluation system. Fuzzy mathematical models were employed to analyze and evaluate the healthy state of Tianjin urban ecosystem over 2008 to 2012 based on the method of mean-squared deviation to determine index weight. The results could basically reflect the growing trends of ecosystem health.

- Urban ecosystem health in Tianjin changed significant over 2008 to 2012 and the status of urban ecosystem health was always an increasing tendency. The comprehensive status of Tianjin ecosystem was in sub-health level. For the membership of unhealthy level, it showed a significant decline. Simultaneously, the membership of healthy level was kept increasing.
- The favorable factors affecting urban ecosystem healthy state of Tianjin included vigor, resilience and population healthy, while unfavorable factors included organizational structure and ecosystem service function. Ways to enhance urban ecosystem health level in the future include that continue to emphasize urban ecological construction, strengthen the construction of urban ecosystem health management capabilities. The main points should focus on improving per capita domestic water situation, increasing the amount of foreign capital actually utilized, the proportion of R & D funding and per capita income, reducing energy consumption per 10^4 yuan of GDP and making greater efforts to attract high-level personnel.

- Fuzzy comprehensive evaluation could deal with uncertainty in the subjective judgment of health standard. Application of urban ecological health assessment is feasible. However, theoretical system of urban ecosystem health assessment are still not enough perfect and how to construct better evaluation to determine the scope of ecosystem health, the index weight, especially predict the development of urban ecology accurately need to be further explored.

5. Acknowledgements

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6. References

[1] C. Chen, H. C. Shi. Health evaluation on urban ecosystem of Baiyin City. *Journal of Gansu Agricultural University.* 2013, 48 (4): 94-99.(In Chinese)

[2] D. J. Schaeffer, E. E. Henricks, H. W. Kerster, et al. Ecosystem health: I. Measuring ecosystem health. *Environmental Management*. 1988, 12 (2): 445-455.

[3] D. J. Rapport. *Ecosystem health*. Blackwell Science Press, 1998.

[4] R. Costanza, B. G. Norton, B. D. Hashell, et al. *Ecosystem health: New goals for environmental management.* Island Press. 1992, (3): 23-41.

[5] D. J. Rapport, R. Costanza, A. J. McMichael, et al. *Trends in Ecology & Evolution*. 1998, 13 (10): 397-402.

[6] D. J. Rapport, G. Bohm, D. Buckingham, et al. Ecosystem health: the concept, the ISEH, and the important tasks ahead. *Ecosystem Health*. 1999, 5 (2): 82-90.

[7] D. T. Rapport, P. R. Regier, T. C. Hutchinson. Ecosystem behavior under stress. *American Naturalist*. 1985, 125 (5): 617-640.

[8] R. Costanza. Toward an operational definition of health. *Ecosystem Health*. 1992, 6 (5): 239-256.

[9] M. S. Jerry, B. Mariano, Y. Annalee, et al. Developing ecosystem health indicators in Centro-Habana: A community-based Approach. *Ecosystem Health*. 2001, 7 (1): 15-26.

[10] X. R. Guo, J. R. Yang, X. Q. Mao. Primary studies on urban ecosystem health assessment. *China Environmental Science*. 2002, 22(6): 525-529. (In Chinese)

[11] S. Zhao, L. H. Chai, P. F. Li, et al. Urban ecosystem health assessment model and its application: A case study of Tianjin. *Acta Scientiae Circumstantiae*. 2013, 33 (4): 1173-1179. (In Chinese)

[12] K. L. Chen, M. L. Su, S. C. Li, et al. The health assessment of the urban ecosystem of Xining city. *Geographical Research*. 2010, 29 (2): 214-222. (In Chinese)

[13] W. H. Zhou, R. S. Wang. An entropy weight approach on the fuzzy synthetic assessment of Beijing urban ecosystem health, China. *Acta Ecologica Sinica*. 2005, 25 (12): 3244-3251. (In Chinese)