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Ecological Security Assessment of Tianjin by PSR Model

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Abstract

Urban environmental pressure is increasing with acceleration of urbanization and urban ecological situation is not optimistic any more. It's very necessary to conduct ecological security assessment on cities. This paper employed the PSR (pressure-state-response) model and determined the weight of index based on improved analytic hierarchy process (IAHP) and entropy method. Index system of ecological security assessment of Tianjin with time scale from the year 2001 to 2007 was also established. From the evaluation result, the urban ecological security state in Tianjin from 2001 to 2007 was getting better, which can measure situation of ecological security in Tianjin in the past seven years and in order to assist early-warning, management and decision-making of city ecological safety.

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Keywords: ecological security;IAHP;entropy method;PSR model

1. Introduction

Urban ecology environment is a system with much less abundance of resources and comparatively high density population accumulated; it is flooded with various commercial and industrial as well as human daily activities[1].The ecological system in urban seems to be more fragile with such a great load to bear. Furthermore, population growth and increasingly worsening situation of industrial environmental pollution with acceleration of urbanization are beyond the bearing capacity of the urban ecological system [2], and the ecological security situation is not optimistic.

Urban ecological security relates to many aspects, which include urban ecological security planning, environmental protection as well as the formulation for the strategy of sustainable development, and thus causes great concern among researchers and policy makers. Tianjin is the biggest coastal city in the north of China; it is also the economic centre in the Bohai rim region. Along with the rapid development of economy, ecosystem of Tianjin will face more pressure. This paper chooses Tianjin as the research object, the evaluation index are established based on the PSR model-frame, the index weights are determined by using IAHP method and entropy method, and integrated evaluation index method is used to characteristic the ecological security status in Tianjin.

2. Establishment of evaluation index

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Various methods have been used for ecological evaluation: exposure-response method, integrated index number method, ecological capacity analysis as well as some ecological models are generally used [3]. This paper adopted environmental index: concept model of environmental index PSR (pressure-state- response), which was proposed by Organization of Canadian Economic Co-operation and Development (OECD) and United Nations Environment Programme (UNEP) [4]. The index system is established from three aspects that affect or relate to urban ecological security, i.e. urban ecological pressure (the pressure from population growth, environmental resources assumption) state of eco-environment and response (measures and policies to be adopted to solve eco-environment issues). With the help of frequency statistics, expert consultation and literatures investigate and survey [5-7], the evaluation index of Tianjin is finally determined, which is shown in Table1.

Table 1. Ecological security evaluation index of Tianjin

Objective layer	Project layer	Index layer
Integrated number of ecological security evaluation	Pressure layer(P)	Natural growth rate P1，per capita area of paved roads P2，number of public transport vehicle per 10000 population P3，per capita public green areas P4，per capita gross domestic production P5，per capita floor space of urban residential building P6，energy consumption per 10000 RMB gross domestic production P7，per capita daily water consumption P8
	State layer(S)	Industrial waste water meeting discharge standards S1，treatment rate of consumption wastes S2，ratio of industrial solid wastes utilized S3，percentage of sewage disposal S4,standardization areas of city environment noise S5,days of air quality equal to or above grade Ⅱ S6
	Response layer(R)	coverage rate of afforestation in developed areas R1, the proportion of science education funding in GDP R2，the proportion of environmental protection in GDP R3, the proportion of urban infrastructure investment in GDP R4，number of hospital beds per10000 population R5, college students per 10000 population R6

3. Evaluation methodology

3.1 Index standardization

As different indexes have no comparability due to the fact that they differ completely in dimensions, it’s necessary to convert original data to dimensionless form. In this case, efficacy evaluation method is used in this study. It is assumed that a city is going to be evaluated during m years period, and the number of index is n, then the original data can be expressed in the following way: $X = \{x_{ij}\}_m$, and the matrix standardized as: $Y = \{y_{ij}\}_m$.

(1) Standardization of positive effect indexes: for some indexes, the higher their values are, the greater the positive effect they will bring to urban ecological security, which means this kind of indexes has much less risk to ecological security. Their standardization method is:

$$y_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \qquad (1)$$

(2) Standardization of negative effect index: for other indexes, the higher their values are, the greater the negative effects they will bring to urban ecological security, which means this kind of indexes has much more risk to ecological security. Their standardization method is:

$$y_{ij} = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}} \tag{2}$$

Where, x_{max} is biggest value of this index, and x_{min} is the minimum value of this index.

3.2 Determination of index weight

There're two ways to determine the index weight, subjectively or objectively determination of the index weight. This paper combined the IAHP (objectively) and entropy method (subjectively) so as to overcome their respective shortcomings.

3.2.1 Improved analytic hierarchy process (IAHP)

Traditional AHP method uses 1-9 scale method as a way to construct judgment matrices so as to compare relatively importance of each index. And there're certain errors existing in human's objective judgments, those errors will definitely cause deviation to the result. Furthermore, the results need consistency check to prove that the result is credible and accurate. Consequently, in order to reduce errors and avoid consistency check, this paper employs 3 scale methods with self-regulation way to establish comparison matrix, calculates best transmitting matrix and then transform it to consistency matrix. This matrix meets the requirement of consistency, therefore there's no need to do consistency check [8].

(1) Construction of judgment matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{3}$$

Where,

$$a_{ik} = \begin{cases} 1 \text{ element i is better than k;} \\ 0 \text{ two elements are equal importance;} \\ 1 \text{ element i is inferior to element k.} \end{cases}$$

(2) Calculation of optimal transfer matrix B:

$$b_{ik} = \frac{1}{n} \sum_{j=1}^{n} (a_{ij} + a_{jk}) \tag{4}$$

The optimal transfer matrix B is transferred into consistent matrix, the element of matrix is $d_{ik} = e^{b_{ik}}$, and then the biggest eigenvalue and its corresponding eigenvector are calculated. The eigenvector is weight vector of the index. The calculation methods for eigenvector are square root law, power law and integrated method. This paper adopts square root law: $W=[w_1\ w_2\ \ldots\ w_i\ \ldots\ w_n]^T$, where,

$$w_i = \frac{\sqrt[n]{\prod_{k=1}^{n} d_{ik}}}{\sum_{k=1}^{n} \sqrt[n]{\prod_{k=1}^{n} d_{ik}}} \tag{5}$$

3.2.2 Information entropy method

Information entropy represents the uncertainties of things and issues, which can measure effective information the data provided, the entropy and entropy weight decrease with the reduction of information amount, and vice versa [9]. The computation of entropy and entropy weight is as following [10]:

$$H_i = -k \sum_{j=1}^{n} f_{ij} \ln f_{ij} \tag{6}$$

Where, H_i is entropy of i index, $f_{ij} = \frac{1 + y_{ij}}{\sum_{j=1}^{n} 1 + y_{ij}}$, $k = \frac{1}{\ln n}$.

Suppose ω_i is entropy weight of i index, then

$$\omega_i = \frac{1 - H_i}{n - \sum_{i=1}^{n} H_i}, \ 0 \le \omega_i \le 1, \ \sum_{j=1}^{n} \omega_i = 1. \tag{7}$$

3.2.3 Determination of combined weight

$$\theta_i = \frac{W_i \omega_i}{\sum_{i=1}^{n} W_i \omega_i}, \ 0 \le \theta_i \le 1, \ \sum_{i=1}^{m} \theta_i = 1 \tag{8}$$

W_i is index weight that IAHP determined, and ω_i is the index weight determined by entropy method.

3.3 Integrated evaluation index value

Ecological security value of Tianjin in different years is calculated by linear weighting function. The greater the comprehensive index value, the higher the degree of urban ecological security, otherwise the greater the ecological risk, the lower the degree of ecological security. Calculation of integrated evaluation index value is:

$$CAI_j = \sum_{i=1}^{n} y_{ij} \theta_i \tag{9}$$

Where, CAI_j is integrated index value of *j*th year, y_{ij} is the standardized value of i index for *j*th year, while θ_i is the combined weight. The security grading details are showed in Table 2[11].

Table 2. Grading standard of urban ecological security

Security status	insecure	less secure	safer	secure
Integrated evaluation grading	<0.45	0.45~0.55	0.55~0.75	>0.75

4. Result discussion

Data being used in the paper is from "Statistical Yearbook of Tianjin", "The Yearbook of China's Cities" and Environmental State Bulletin in Tianjin. According to the combined weight as is showed in Table 3, we can say that population pressure, energy consumption, the attainment rate and processing rate of three wastes, and environment protection investments contribute greatly to urban ecological security with relatively high weight, on the contrary, college students per 10000 population and number of public transport vehicle per 10000 population have minor effects to ecological security.

Table 3. Ecological security evaluation index weight of Tianjin

Index	IAPH weight	Entropy weight	Combined weight
natural growth rate	0.11006	0.08885	0.18126
per capita area of paved roads	0.03001	0.05403	0.03005
per capita public green areas	0.02451	0.05741	0.02609
per capita gross domestic production	0.04473	0.05232	0.04338
energy consumption per 10000 RMB gross domestic production	0.08155	0.04864	0.07352
per capita floor space of urban residential building	0.04047	0.04768	0.03577
per capita daily water consumption	0.04946	0.03861	0.03539
number of public transport vehicle per 10000 population	0.01643	0.05874	0.01789
Industrial waste water meeting discharge standards	0.09959	0.0405	0.07477
treatment rate of consumption wastes	0.07376	0.08065	0.11026
ratio of industrial solid wastes utilized	0.09023	0.03528	0.05901
percentage of sewage disposal	0.06673	0.06354	0.07859
standardization areas of city environment noise	0.02222	0.04191	0.01726
days of air quality equal to or above grade Ⅱ	0.03664	0.03622	0.0246
coverage rate of afforestation in developed areas	0.03315	0.05978	0.03674
the proportion of science education funding in GDP	0.02715	0.06315	0.03178
The proportion of environmental protection in GDP	0.06039	0.04229	0.04734
the proportion of urban infrastructure investment in GDP	0.05465	0.03789	0.03838
number of hospital beds per 10000 population	0.02009	0.05773	0.0215
college students per 10000 population	0.01817	0.0488	0.01644

The integrated evaluation index value，pressure index, environment state index, and response index of urban ecological security from the year 2001 to 2007 are presented in figure 1. The ecological security status of Tianjin can be concluded as following: both 2001 and 2002 stay unsafe, 2003 is relatively unsafe, while 2004 to 2006 are positioned in safer state, 2007 is much better than former six years. For the purpose of measuring the overall state of the past seven years, the average index value is used the result is calculated to be 0.54, which means relatively unsafe state.

Integrated index value of ecological security in 2001 is the lowest with 0.2477, and the other three index values (pressure index, state index, response index) are kept comparatively low. The main reasons are due to great pressure of population and environment resources, which show that energy consumption in 2001 is the biggest one among the seven years (1.53), and the amounts of pollutants discharge in the whole city can hardly meet the requirement of environment quality, and stay at high level as compared to other years. The overall trend goes from worse to better with slight fluctuations, the construction of ecological city in Tianjin since 2006 was in full swing. Ecological status in 2007 is safe with the highest index values. The government issued policies of pollution-reducing and carried out measures to enhance eco-city construction and environment investments in this year.

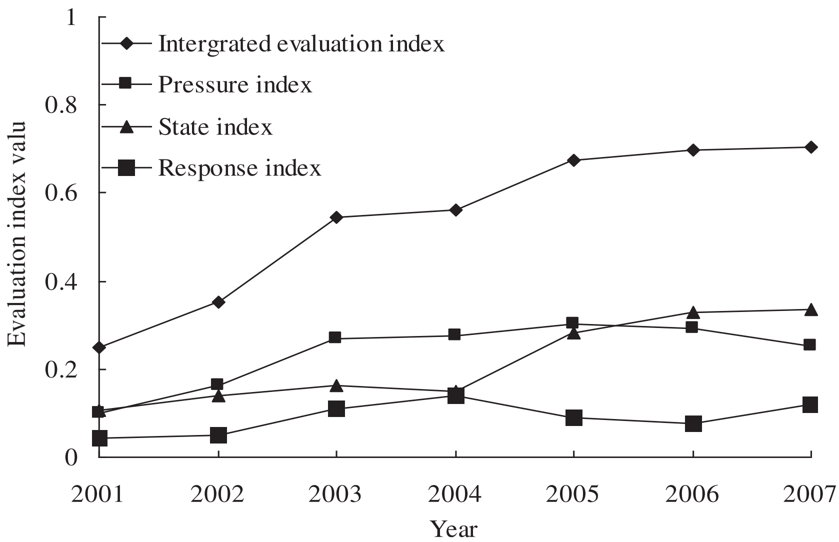

Figure 1. Ecological security trend of Tianjin from the year 2001 to 2007

Pressure index value present a stable state from 2003 to 2005, energy consumption decrease gradually to the lowest in 2007, but population nature growth reach the peak point. From the year 2004, the response index value show escalating trend, and three wastes meeting the discharge standards are relatively high. However, corresponding response index values appear downtrend, and the ratio of environment protection investments and urban infrastructure investments decrease.

5. Conclusion

Although the evaluation result fails to meet the need of accuracy as the determinations of urban ecological evaluation index, index weight and ecological security grading have no unified standards, the result is still supposed to be able to characteristic general situation of ecological security. It's hard to enlarge time scale due to incomplete data acquisition. From the evaluation result, the urban ecological security state in Tianjin from 2001 to 2007 was getting better. To further maintain and improve the urban ecological status of Tianjin, the urban infrastructure and environment protection investment such as urban sewage and garbage treatment of urban construction, etc should be intensified. It is also crucial to improve industrial structure and to increase the proportion of the third industry, save energy and reduce emission as well as improvement of the quality of atmosphere and water ecosystem.

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