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APPLICATION OF FUZZY OPTIMIZATION MODEL IN ECOLOGICAL SECURITY PRE-WARNING

WU Kai-ya[1], HU Shu-heng[2], SUN Shi-qun[2]
(*1. School of Economics, Xiamen University, Xiamen 361005, P. R. China; 2. School of Resource and Environmental Engineering, Hefei University of Technology, Hefei 230009, P. R. China*)

ABSTRACT: Ecological security is a vital problem that people all over the world today have to face and solve, and the situation of ecological security is getting more and more severe and has begun to impede heavily the sustainable development of social economy. Ecological environment pre-warning has become a hotspot for the modern environment science. This paper introduces the theories of ecological security pre-warning and tries to constitute a pre-warning model of ecological security. In terms of pressure-state-response model, the pre-warning guide line of ecological security is constructed while the pre-warning degree judging model of ecological security is established based on fuzzy optimization. As a case, the model is used to assess the present condition pre-warning of the ecological security of Anhui Province. The result is in correspondence with the real condition: the ecological security situations of 8 cities are dangerous and 9 cities are secure. The result shows that this model is scientific and effective for regional ecological security pre-warning.

KEY WORDS: ecological security pre-warning; fuzzy optimization; pre-warning model; Anhui Province

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1 INTRODUCTION

As the basis of the human existence and sustainable development, the ecological security has become a problem increasingly inviting the attention of the whole society and the government. Ecological security pre-warning is a kind of early information warning to the conjuncture and danger of ecological security, which can provide the quantity and quality judging information for all kinds of potential dangers, of the metabolic situation of time and space, so it is exigent to constitute the system of ecological security pre-warning (YANG and LU, 2002). Eco-environment pre-warning has become a hotspot for the modern environment science studies and scientists have discussed the basic concepts, theories and measures of pre-warning (CHEN, 1996; WEN, 1998; LIU *et al*., 2001). Ecological security pre-warning is a new field, so in this paper, we try to constitute a pre-warning model of ecological security pre-warning on basis of fuzzy optimization to make warning-degree judging on practical examples in order to get the warning degree for pre-warning studies.

2 PRINCIPLES OF ECOLOGICAL SECURITY PRE-WARNING

Based on the sustainable development of resources, community and human beings, the basic principles of the pre-warning system aim at admonishing the world to adopt reasonable measures to make use of the environment, living creatures and ecological system in supporting the stability of the ecosystem (YANG and LU, 2002). We must follow basic principles of ecological security pre-warning.

(1) Integrity. Ecological security is burden security system with nature, social economy and human activity. Change of one factor often gives rise to change of implicative factors. Change of subsystem is also apt to give occasion to change of implicative subsystem.

(2) Stratification. Big system, subsystem and pre-warning factors should be discriminated for ecological security pre-warning, so prominence can be given to the key points.

(3) Simplicity and practicability. For the purpose of providing strategic measures and evidence for the envi-

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Biography: WU Kai-ya (1968−), male, a native of Lixin of Anhui Province, Ph.D., associate professor, specialized in environmental economics and management. E-mail: wuky2000@vip.sina.com

ronmental and regional development, the pre-warning index selection need to be full scaled, compendious, easy acquired and easy manipulative.

(4) Criticality. The development and utilization of resources and environment should have definite threshold. If it is beyond the bounds of the threshold, it will bring irreversible effects to ecosystem and human beings. The criticality standard of index is constituted based on the principles of ecological effect, social demand and economic efficiency.

(5) Generation equity. The environment and resources should be made use of by the contemporary people on the principles that it does not do any damage to the development of the posterity. Ecological security pre-warning is for taking care of generation equity.

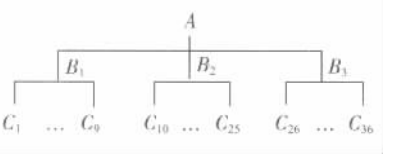
3 INDEX SYSTEM OF ECOLOGICAL SECURITY PRE-WARNING

The index system of ecological pre-warning and estimation has been extensively studied at home and abroad (CHEN, 1998; YIN and FANG, 2000; WALZ, 2000; MEI and CHEN, 2003), and most studies were on the basis of the pressure-state-response model (PSR). So, in this paper, we also prolong PSR model and constitute index system of ecological security pre-warning, and carve up developmental index "+" and limited index "−" (ZOU *et al*., 2002). The index system consists of 36 indexes, which is composed of biophysical state, society and economy pressure, and ensures the scientific and integrate feature of the index′s choice (Fig. 1).

4 FUZZY OPTIMIZATION MODEL OF ECOLOGICAL SECURITY PRE-WARNING

Systematic changes have two developmental aspects of ordering and optimization to make the system functions develop to the best or to make the systematic functions weaken, even lead to crisis (e.g. vicious circle). Systematic ordering is not always optimum, yet optimum must be ordering. Ecological security pre-warning can make a system evolve towards ordering, and prevent the course of disordering (ZHOU and WANG, 2002).

We suppose that the evaluation unit constitutes decision set D, $D=\{d_1, d_2, \cdots, d_n\}$, where n is the number of the unit; m indexes of pre-warning constitute factor set P, where $P=\{p_1, p_2, \cdots, p_m\}$; then factor set P evaluate decision set D by means of representation of target characteristic matrix X:



Notes:
A—Indices system of ecological security pre-warning
B_1—Indices of system state
B_2—Indices of system pressure
B_3—Indices of system response
C_1—Relief degree of land surface
C_2—Degree of fragmentation
C_3—Annual precipitation
C_4—Annual >10℃ accumulated temperature
C_5—Coverage rate of water area
C_6—Quality of water resources
C_7—Forest coverage rate
C_8—Index of biologic diversity
C_9—Erosion modulus of soil
C_{10}—Per capita area of cultivated land
C_{11}—Per capita water resources quantity
C_{12}—Per capita stock volume of forest
C_{13}—Per hectare consumption of chemical fertilizers in agriculture
C_{14}—Per hectare consumption of pesticide
C_{15}—Per square kilometer volume of industrial waste water discharged
C_{16}—Per square kilometer volume of industrial solid wastes produced
C_{17}—Per square kilometer volume of waste industrial gas emission
C_{18}—Per square kilometer volume of industrial SO_2 discharged
C_{19}—Per square kilometer volume of industrial soot discharged
C_{20}—Rate of area with soil and water loss to total regional area
C_{21}—Rate of plague area to natural calamity area
C_{22}—Index of regional exploitation
C_{23}—Density of economics
C_{24}—Density of population
C_{25}—Density of towns
C_{26}—Rate of the volume of treated industrial waste water to the volume of industrial waste water discharged
C_{27}—Rate of the volume of treated industrial waste gas to the volume of industrial waste gas emission
C_{28}—Rate of the volume of industrial solid wastes utilized in a comprehensive way to the volume of industrial solid wastes produced
C_{29}—Rate of investment in environmental protection to GDP
C_{30}—Rate of the execution of the rule of three contemporary principle for construction items
C_{31}—Rate of the nature reserve and protected landscapes area to the territory
C_{32}—Per capita GDP
C_{33}—Rate of tertiary industry production to GDP
C_{34}—Per thousand people human resources working on health science and techniques
C_{35}—Per ten thousand people human resources working on science and techniques
C_{36}—Per hundred thousand people personnel with high education

Fig. 1 Indices system for ecological security pre-warning

$$X=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

The smaller the pre-warning index reflecting restriction is, the higher the indicating extent of ecological security is, thus we adapt subjacent calculated expression superior relative membership degree.

$$r_{ij}=\frac{\max(x_i)-x_{ij}}{\max(x_i)-\min(x_i)}$$
$$(i=1, 2, \ldots, m;\ j=1, 2, \ldots, n) \quad (1)$$

where $\max(x_i)$ is the maximum eigenvalue of index i in the decision set and $\min(x_i)$ is the minimum eigenvalue and r_{ij} is relative superior number of the unit j to index i.

The bigger the pre-warning index reflecting development is, the higher the indicating extent of ecological security is, thus we adapt subjacent calculated expression to superior relative membership degree.

$$r_{ij}=\frac{x_{ij}-\min(x_i)}{\max(x_i)-\min(x_i)}$$
$$(i=1, 2, \ldots, m; j=1, 2, \ldots, n) \quad (2)$$

By formulas (1) and (2) we can obtain target relative superior matrix R from target characteristic matrix X:

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (3)$$

We suppose two polarities of factor set have maximal superior degree $g=(g_1, g_2, \cdots, g_m)^T=(1, 1, \cdots, 1)^T$ and minimum superior degree $b=(b_1, b_2, \cdots, b_m)^T=(0, 0, \cdots, 0)^T$. Relative superior degree of decision j in the multiple goals system is expressed by μ_j. The other degree is expressed by μ_j^c. There is $\mu_j^c=1-\mu_j$ by virtue of property of fuzzy set. We suppose $w=(w_1, w_2, \cdots, w_m)^T$, where w is the weight and is defined by entropy weight and $\sum_{i=1}^{m} w_i=1$. Decision j is presented by $r_j=(r_{1j}, r_{2j}, \cdots, r_{mj})^T$. Generalized distance $S_{jg}=\sqrt{\sum_{i=1}^{m} |(g_i-r_{ij})\cdot w_i|^2}$ presents the discrepancy between decision set and high-grade decision. We suppose $D_{jg}=\mu_j\cdot S_{jg}=\mu_j\cdot\sqrt{\sum_{i=1}^{m} |(g_i-r_{ij})\cdot w_i|^2}$, where D_{jg} presents weighted excellent distance. By the same token, $D_{jb}=\mu_j^c\cdot S_{jb}=\mu_j^c\cdot\sqrt{\sum_{i=1}^{m} |(b_i-r_{ij})\cdot w_i|^2}$ presents weighted bad distance. By virtue of decision criteria $\min\{F(\mu_j)=(S_{jg})^2+(S_{jb})^2\}$, we make a search after μ_j and find $\mu_j=\frac{1}{1+(S_{jg})^2/(S_{jb})^2}$, where μ_j is pre-warning value of ecological security, i.e. vigilant degree.

We use language variables to describe the result of ecological security pre-warning on basis of judgment of vigilant degree. The language variables are the quality description of securer, secure, dangerous and more dangerous. We adopt traffic-control signs that are blue, green, yellow and red to emit pre-warning signs. We compartmentalize pre-warning zone into the void pre-warning, first-degree alarm, second-degree alarm and third-degree alarm. The standard of pre-warning degree is established according to the standard of pre-warning (LI, 2001), which is referred to the average level of the whole country, the average level of the whole province, the level of developed regions and the international general standard (Table 1).

Table 1 Divisionary table of pre-warning zone

Numeric area of μ_j	Pre-warning degree zone	Pre-warning sign	Pre-warning grade
[0.0, 0.2]	More dangerous zone	Red light	Third-degree alarm
[0.2, 0.4]	Dangerous zone	Yellow light	Second-degree alarm
[0.4, 0.7]	Secure zone	Green light	First-degree alarm
[0.7, 1.0]	Securer zone	Blue light	Void alarm

5 APPLICATION OF FUZZY OPTIMIZATION MODEL

5.1 Description of Study Site

Anhui Province lies in the southeast of China. Its area is some 139 000km^2, the cultivated area is 42.5% of the total land area, and the rural population takes up over 75% of the total population. Its wooded area is 3 170 700ha, and forest cover rate is 27.95%. It takes an important position to the eastern zone, especially to the Changjiang (Yangtze) River delta zone with its special geographic location, complicated natural conditions, abundant natural resources, abundant biodiversity, higher ecological efficiency and ecosystem of strong service function. But with the increasing population, quick developmental economy and quickening course of urbanization and industrialization, ecological security of Anhui Province are confronted with rigorous challenge, such as imbalanced distribution of water resources, serious soil erosion, local soil pollution of heavy metals. At the same time, multiform propagation is also in an extinct condition, macro pesticide and fertilizer engender high effects to soil, water mass, atmospheric circulation and human health. It is no time to delay to

make pre-warning of ecological security to protect the environment.

5.2 Calculation of Weight Value

Weight value of pre-warning index is educed by AHP method. With comparison to the others, AHP has its own characteristics and dominances. It is a kind of method of hierarchically established weight and a method of quantitative and qualitative analysis, systematic and layering analysis with altitudinal logicality, systematism, elegance and practicability. It is applied to settle complex problems. First, we constitute model of ladder stratification; second, experts and decision makers construct judgement matrix through pairwise comparison of important degree; last, we obtain the result through collating of administrative levels and consistence check (Table 2).

5.3 Pre-warning Results and Discussion

The analysis of the pre-warning of Anhui Province′s index values is made (Table 3). It is observed that ecological security of Anhui Province can not be optimistic. Nine cities are in the secure zone and have the tendency of exasperation. Eight cities are in the dangerous zone and have got the pre-warning, for example, Huainan, Huaibei and Tongling.

5.4 Countermeasures

(1) Adjust the industrial structure, abate environment contamination, intend the ecological building and environmental protection to ameliorate ecological environment in a short time. For example, in Chizhou, Huangshan, Anqing and Xuancheng, great attention should be paid to protecting the environment and building facilities of environmental protection in the tourism zone while developing tourism. Buozhou, Suzhou, Huaibei, Fuyang, Chuzhou and Liuan should develop preferentially ecological agriculture, strengthen ecological building and quicken the economic development.

(2) Put into effect the strategy of harmonious sustainable development and the science and education devel-

Table 2 Weight of ecological security pre-warning indicator system

Index	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Weight	0.0131	0.0131	0.0045	0.0045	0.0081	0.0081	0.0122	0.0122	0.023	0.0611	0.0248	0.0100
Index	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}
Weight	0.014	0.010	0.0686	0.0313	0.0313	0.0272	0.0150	0.0222	0.0222	0.0472	0.0517	0.0726
Index	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}
Weight	0.0276	0.020	0.011	0.011	0.0456	0.0312	0.0815	0.0382	0.0382	0.010	0.0355	0.0421

Table 3 Pre-warning value, zone and degree of Anhui Province′s ecological security

Region	Distance to superior S_{jg}	Distance to inferior S_{jb}	Relative superior degree μ_j (pre-warning value of ecological security)	Pre-warning degree zone	Pre-warning degree
Hefei	0.1308	0.1061	0.4479	Secure zone	First-degree alarm
Huaibei	0.1422	0.0874	0.3807	Dangerous zone	Second-degree alarm
Bozhou	0.1534	0.0972	0.3879	Dangerous zone	Second-degree alarm
Suzhou	0.1505	0.0920	0.3793	Dangerous zone	Second-degree alarm
Bengbu	0.1315	0.0980	0.4272	Secure zone	First-degree alarm
Fuyang	0.1597	0.0871	0.3528	Dangerous zone	First-degree alarm
Huainan	0.1430	0.0893	0.3844	Dangerous zone	Second-degree alarm
Chuzhou	0.1351	0.1039	0.4371	Secure zone	First-degree alarm
Liu′an	0.1427	0.0921	0.3923	Dangerous zone	Second-degree alarm
Ma′anshan	0.1374	0.1110	0.4466	Secure zone	First-degree alarm
Chaohu	0.1471	0.0835	0.3620	Dangerous zone	Second-degree alarm
Wuhu	0.1362	0.0972	0.4163	Secure zone	First-degree alarm
Xuancheng	0.1296	0.1047	0.4469	Secure zone	First-degree alarm
Tongling	0.1346	0.0768	0.3605	Dangerous zone	Second-degree alarm
Chizhou	0.1209	0.1190	0.4958	Secure zone	First-degree alarm
Anqing	0.1200	0.1080	0.4737	Secure zone	First-degree alarm
Huangshan	0.1326	0.1250	0.4850	Secure zone	First-degree alarm
Anhui Province	0.1301	0.0901	0.4091	Secure zone	First-degree alarm

opment, then optimize, adjust and control the development on the basis of order. The cities of Ma′anshan, Tongling, Hefei, Bengbu and Wuhu must increase new technique launching, make reforms on traditional industries and enlarge the investment in environmental protection.

(3) Take a regard for ecological environment planning of towns and try to design characteristic ecological towns in accordance with local conditions. An attempt should be made to initiate natural population to towns, design greenwood and grassland for towns, reinforce the adjustive functions of plant community to inhabited environment and cleanse and beautify the functional circumstance of towns.

(4) Strengthen the publicity and education to reinforce the civil consciousness of environment protection and initiate actively the ecological culture.

6 CONCLUSIONS

The pre-warning way of ecological security is experimentally studied in this paper. We carry through actuality pre-warning to Anhui Province′s ecological security with pre-warning model of ecological security on the basis of fuzzy optimization, the results indicate that the model is doable. It is attentive that pre-warning result is not an absolute concept but a relative concept. Establishment of pre-warning index system and standard is a difficult and complex problem, its integrity and reliability are dependent on further research and await verification with the others.

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