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APPLICATION OF ANALYTIC HIERARCHY PROCESS TO ASSESSING THE ECOLOGICAL VULNERABILITY OF WETLANDS IN THE JIANGHAN PLAIN

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ABSTRACT: Wetlands in the Jianghan Plain are important components of wetland types in lake area in the middle and lower reaches the Changjiang (Yangtze) River and they fulfill many uses and functions related to hydrology, waste assimilation, ecosystem productivity and biodiversity. Owing to natural factors and human activities, especially excessive reclamation from lakes, the shrinking process of the lakes has been accelerated. Wetland ecosystem has shown the characteristics of vulnerability. According to the analysis of wetland ecological function in the Jianghan Plain, this paper presented an index system related to productivity, stability and environmental capacity. By using the method of Analytic Hierarchy Process, we computed the values of the relative weights of the indexes, and evaluated the vulnerability level of the wetland ecosystem by the method of multi-indexes. The case study showed that the fragile extent of wetland ecosystem in the Jianghan Plain is 5.6. This means that the wetland ecosystem in the Jianghan Plain is laid to the state of middle vulnerability. Therefore, the wetland conservation and eco-rehabilitation in the Jianghan Plain should be paid attention to.

KEY WORDS: wetland; ecological vulnerability; AHP; the Jianghan Plain

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1 INTRODUCTION

The study on ecological vulnerability has been paid much attention to in the world. Many international research programs have taken ecological vulnerability study as one of the main study fields, such as IBP (International Biology Plan) in the 1960s, MAB (Man and Biosphere) in the 1970s, and IGBP (International Geosphere-Biosphere Plan) in the 1980s. The vulnerability of ecosystem is a wide confining term and is regarded as an inherent property of an ecosystem. The vulnerability of ecosystem could display only when the ecosystem exposed to disturbance, which causes the degradation of ecosystem, however it is impacted by both natural and man-made factors. With the development of human society and the increasingly close relationship between human and environment, the eco-environment stress on human is increasing rapidly and eco-environment vulnerable zone has an expanding trend clearly. The threat that nature resources are confronted with is enhancing rapidly, therefore study on eco-environment vulnerability is paid more and more attention to (MITSCH *et al.*, 1986; BENIOFF *et al.*, 1993).

Wetland is a natural body existing between water body and terrene as a transitional conformation, which decides its special functions and processes of biology, physics and chemistry, and distribution rules. As the mode and intensity of their enduring pressure are different, the zones between water body and terrene have an unstable characteristics, which makes wetland ecosystem be in a vulnerable and unstable state. So study on wetland eco-environment vulnerability is beneficial to the rational protection and utilization of wetland.

The Jianghan Plain is located in the middle reaches of the Changjiang River, the mid-south part of Hubei Province. Wetlands in the Jianghan Plain are important components of wetland types in lake area in the middle and lower reaches of the Changjiang River. In

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the plain, the wetland system is classified into three groups: riverine wetland, lacustrine wetland and man-made wetland according to landscape characteristics (CAI and ZHOU, 1996; WANG and WU, 2001).

2 APPLICATION PRINCIPLE OF AHP

The Analytic Hierarchy Process (AHP) is a kind of evaluation method that combines quantitative analysis with qualitative analysis by matrix calculation based on structure model. For the basic principle of AHP, first is to find out relative factors about a complicated environmental problem, and to make sure of their hierarchies, then to make certain of their comparative significance by comparing these factors each other, and finally give their weights (WEN *et al*., 2000; FAN *et al*., 2000).

The procedure of assessment on ecological vulnerability with AHP method is as follows:

(1) Establishing the index system.

(2) Constructing the judgment matrix and single permutation of layer. The indexes of the same level are compared one by one to create judgment matrix. For example, if the elements of layer A have relation to the elements of lower layers B_1, B_2, ..., B_n, the judgment matrix is shown in Table 1.

Table 1 Judgment matrix of the significant extent of the indexes in layer B

A	B_1	B_2	⋯	B_n	W_i
B_1	B_{11}	B_{12}	⋯	B_{1n}	W_1
B_2	B_{21}	B_{22}	⋯	B_{2n}	W_2
⋮	⋮	⋮	⋮	⋮	⋮
B_n	B_{n1}	B_{n2}	⋯	B_{nn}	W_n

In the above matrix, b_{ij} shows the significance extent of corresponding B_i and B_j, which takes 1, 2, 3, ⋯, 9 and their reciprocals as its value. When b_{ij} equals to 1, it shows that B_i and B_j are the same significance; when b_{ij} equals to 3, it shows that B_i is a little more significant than B_j; when b_{ij} equals to 5, it shows that B_i is more significant than B_j; when b_{ij} equals to 7, it shows that B_i is much more significant than B_j; when b_{ij} equals to 9, it shows that B_i is extremely more significant than B_j; when b_{ij} is 2, 4, 6 or 8, it shows that the significance is between above adjacent values; and the corresponding reciprocal shows the insignificance extent.

First is to figure out eigenvector (W_i), which shows the significance extent of each element in the same layer of judgment matrix, and the biggest eigenvalue λ_{max}, the equation is :

$$\lambda_{max}=\sum_{i=1}^{n}(AW_i)/nW_i \quad (1)$$

The next is to make statistical test about uniformity. The value of CI is an index evaluating the departure of judgment matrix from uniformity. The equation is:

$$CI=(\lambda_{max}-n)/(n-1) \quad (2)$$

RI is the index of average random uniformity that judges uniformity (the value can be gotten in the statistics table). The proportion of the random uniformity is CR, which can be calculated by equation (3):

$$CR=CI/RI \quad (3)$$

If $CR<0.1$, it shows that judgment matrix has a uniformity. Otherwise, the judgment matrix must be adjusted.

(3) Sequencing the all layers. This step is to sort the values of relative importance of the layer C.

(4) Grading of single element and comprehensive evaluation. Single element grading is to disposal single element as a standardized value through dividing each grade by its accumulation. The comprehensive evaluation (P_i) is to multiply the elevated value of single element multiplied by its weight, then to sum those values to get P_i, and to compare the results P_i, and finally to confirm their grades.

$$P_i=\sum_{j=1}^{n}C_{ij}\times E_{ij} \quad (4)$$

In the above expression, C_{ij} is the standardized data; E_{ij} is weight(W_i) in the aim layer j, n is the number of the aim layer.

3 INDEX EVALUATION OF ECOLOGICAL VULNERABILITY OF WETLANDS IN THE JIANGHAN PLAIN

3.1 Establishment of Index System

In the Jianghan Plain, the rivers, lakes and farmlands all suffer from the menace of ecological vulnerability and deterioration. The ecological vulnerability of wetlands of in the Jianghan Plain is very complicated. It has not only the characteristic and intrinsic attribution of ecological vulnerability of general ecosystem, but also peculiar attribution of river-lake wetland ecosystem. And it not only takes on natural evolution induced by inner mechanism of the ecosystem, but also has overlap function with non-linear and ungradual change induced by exterior environment of the ecosystem. Therefore it is difficult to use single index to trace out the ecological vulnerability of the whole wet-

land completely. In order to evaluate the process of wetland's environmental deterioration or ecological rehabilitation in the Jianghan Plain, to disclose the change laws of inner characteristics of the wetland ecosystem, to reflect the extent of harmonious development between economy and environment and the benign circulation of the ecosystem, and to put forward effective measures on wetland ecological rehabilitation and regional sustainable development, it is necessary to establish the evaluation index system of wetland system. And the indexes selected should embody the exertion of wetland ecological function and the satisfying extent to economic increasing and human aims (ZHU and ZHOU, 1998; LIU and CAO, 1998).

Wetlands contribute significantly to the socio-economic status of the Jianghan plain-lake district. The natural environmental change and human activities influence the functions and structure of lakes, in which, human activities (i.e. lake reclamation) generally result in significant negative impacts on the number, biodiversity, and function of wetlands in the Jianghan Plain. With the social development and the progress in the implements of production, human being uninterruptedly reclaimed land from lakes and played more and more important role in the evolution process of river-lake environment. The number of natural wetlands in this region has declined. The wetland functions have been degraded, the wetland ecosystems showed off the characteristics of ecological vulnerability, which is caused by unstable combination of its inner mechanism and unreasonable exploitation and utilization (WANG, 1999; CAI *et al.*, 1997). So the evaluation on wetland ecological vulnerability of the Jianghan Plain should be mainly the comprehensive evaluation of ecological function and attribute and take its comprehensive productivity, stability and environmental capacity as its index characteristics (Table 2).

3.2 Evaluation Process

On the basis of the evaluation index system of ecological vulnerability of wetlands in the Jianghan Plain, these evaluation indexes are divided into three layers according to AHP, the relations among layers and factors are lined out and comparing judgment matrixes, which are composed of the ratios of comparative importance of every pair of factors, are established by layers (Table 3, 4, 5, 6); and then the values of the relative weight are calculated; finally, the coefficients (P_{ij}) of the values of the relative weight of all indexes are computed layer by layer. P_{ij} is confirmed mainly

Table 2 Evaluation index system of ecological vulnerability of wetlands in the Jianghan Plain

Aim layer *A*	Guideline layer *C*	Sub-guideline layer *P*	
Ecological vulnerability of wetlands	C_1 Indexes of porductivity and function	P_{11}	Structure of biotic community of wetlands
		P_{12}	Primary productivity of natural wetlands
		P_{13}	Quantitiy of weland resources
		P_{14}	Biodiversity
		P_{15}	Quality level of wetland environment
		P_{16}	Storage capability of lakes
		P_{17}	Nutrition index of lake wetlands
	C_2 Stability indexes	P_{20}	Regional micro-physiognomy condition
		P_{21}	Change ratio of drought and waterlogging
		P_{22}	Soil structure
		P_{23}	Proportion of lake water surface
		P_{24}	Structure of land use
		P_{25}	Coefficient of river and lake mudflat
		P_{26}	Lake swamping
		P_{27}	Loss by flooding disaster
		P_{28}	Combination of eco-environment
		P_{29}	Landscape fragmentation
	C_3 Indexes of environmental capacity	P_{31}	Population density
		P_{32}	Development scale of regional economy
		P_{33}	Urbanization level
		P_{34}	Quantity of resources reserve
		P_{35}	Purifying capability of lake wetland
		P_{36}	Reclamation intensity

Table 3 Judgment matrix of aim layer and guideline layer

A	C_1	C_2	C_3	W_i
C_1	1	1/3	1/2	0.164
C_2	3	1	2	0.539
C_3	2	1/2	1	0.297

λ_{max}=3.0092; *CI*=0.0046; *CR*=0.0079<0.1

Table 4 Guideline layer C_1 and its relative judgment matrix

C_1	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	E_{i1}
P_{11}	1	3	1/2	1/3	2	1/2	1	0.112
P_{12}	1/3	1	1/4	1/5	1/2	1/4	1	0.052
P_{13}	2	4	1	1	3	1	3	0.223
P_{14}	3	5	1	1	3	2	3	0.270
P_{15}	1/2	2	1/3	1/3	1	1/2	1	0.081
P_{16}	2	4	1	1/2	2	1	2	0.181
P_{17}	1	1	1/3	1/3	1	1/2	1	0.081

Table 5 Guideline layer C_2 and its relative judgment matrix

C_2	P_{20}	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	P_{26}	P_{27}	P_{28}	P_{29}	E_{i2}
P_{20}	1	1/2	1/2	1/3	1/2	3	1/3	1/2	1	2	0.064
P_{21}	2	1	2	1	2	4	1	1	3	3	0.150
P_{22}	2	1/2	1	1/2	1	3	1/3	1	2	2	0.089
P_{23}	3	1	2	1	2	4	1/2	1	3	3	0.146
P_{24}	2	1/2	1	1/2	1	3	1/3	1	2	3	0.096
P_{25}	1/3	1/4	1/3	1/4	1/3	1	1/5	1/3	1/2	1/2	0.031
P_{26}	3	1	3	2	3	5	1	2	4	4	0.212
P_{27}	2	1	1	1	1	3	1/2	1	2	3	0.115
P_{28}	1	1/3	1/2	1/3	1/2	2	1/4	1/2	1	1	0.052
P_{29}	1/2	1/3	1/2	1/3	1/3	2	1/4	1/3	1	1	0.045

λ_{max}=10.1772; *CI*=0.0197; *CR*=0.0131<0.1

Table 6 Guidelline layer C_3 and its relative judgment matrix

C_3	P_{31}	P_{32}	P_{33}	P_{34}	P_{35}	P_{36}	E_{i3}
P_{31}	1	2	1	3	3	1	0.238
P_{32}	1/2	1	1/2	2	1	1/2	0.117
P_{33}	1	2	1	3	2	1/2	0.199
P_{34}	1/3	1/2	1/3	1	1/2	1/4	0.064
P_{35}	1/3	1	1/2	2	1	1/3	0.102
P_{36}	1	2	2	4	3	1	0.280

λ_{max}=6.0748; CI=0.01496; CR=0.0113<0.1

by relative expertise method, which is based on the effect extent of each factor and the relative extent among factors in the development and evolvement of ecosystem of wetlands in the Jianghan Plain.

After getting the relative weight of each layer, the relative weight of each vulnerability evaluation index is obtained (Table 7). Meanwhile, each index is evaluated from its comprehensive influence on ecological vulnerability of wetlands in the Jianghan Plain. Because it is difficult or impossible to quantify some evaluation indexes, expertise method is used to decide the value of grade (V_i). For study on wetlands in the Jianghan Plain, each index is divided into 10 vulnerability grades from 1 to 10 (V_i in Table 7). The higher the grade is, the more fragile the wetland is. The extent of ecological vulnerability of wetlands in the Jianghan Plain is calculated by the following equation:

Table 7 Sequencing of all evaluation indexes of wetland vulnerability in the Jianghan Plain

Layer P	C_1	C_2	C_3	Weight of layer $P(P_i)$	Values of evaluated indexes(V_i)
	0.164	0.539	0.297		
P_{11}	0.112			0.018	2
P_{12}	0.052			0.008	1
P_{13}	0.223			0.037	3
P_{14}	0.270			0.044	4
P_{15}	0.081			0.013	2
P_{16}	0.181			0.030	6
P_{17}	0.081			0.013	2
P_{20}		0.064		0.034	5
P_{21}		0.150		0.081	4
P_{22}		0.089		0.048	7
P_{23}		0.146		0.079	7
P_{24}		0.096		0.052	6
P_{25}		0.031		0.017	2
P_{26}		0.212		0.114	8
P_{27}		0.115		0.062	5
P_{28}		0.052		0.028	5
P_{29}		0.045		0.024	4
P_{31}			0.238	0.071	6
P_{32}			0.117	0.035	5
P_{33}			0.199	0.059	6
P_{34}			0.064	0.019	4
P_{35}			0.102	0.030	3
P_{36}			0.280	0.083	9

$$R=\sum_{i=1}^{m} P_i \times V_i \quad (5)$$

where m is the number of evaluation indexes (m=23).

From the above analysis, the extent of ecological vulnerability of regional wetlands is assessed: from 1 to 2, not frangibility; from 3 to 4, a little frangibility, from 5 to 6, middle frangibility; from 7 to 8, high frangibility; from 9 to 10, extreme frangibility (LIU and LIU, 2001).

4 RESULTS AND DISCUSSION

The evaluation result of each indexes of ecological vulnerability of wetlands in the Jianghan Plain is obtained by the above analysis (Table 7). From the sequencing of the values of the relative weights of the indexes, the important indexes impacting ecological vulnerability are lake swamping, reclamation intensity, land-use structure, population density, urbanization level, proportion of lake water surface, change ratio of drought and waterlogging, which reflect main ecological problems of the wetlands in the Jianghan Plain and the relationship between human and environment. Meanwhile, by the calculation of comprehensive indexes, the fragile extent of wetland ecology in the Jianghan Plain is 5.6. This means that wetland's ecosystem in the Jianghan Plain is laid on the state of middle vulnerability. Therefore, the wetlands conservation and eco-rehabilitation in the Jianghan Plain should be paid much attention to.

In order to rationally uilize wetland resources and protect wetland environment, the following main measures should be taken: 1) coordinating the relationship between lakes and rivers from the view of the valley management; 2) rehabilitating flood regulating function of wetlands, this means, in this region, the lakes play an important role in regulating flooding and it is necessary to keep enough lake area to regulate flood; 3) combining wetlands protection with wetlands exploitation; 4) optimizing the structure of wetlands ecosystem for the ecological balance and biodiversity of the lakes area.

In short, the application of AHP proceeds from the inherent rules of wetland ecosystem. The evaluation of ecological vulnerability of wetlands in the Jianghan Plain is mainly the comprehensive evaluation of ecological function and attribute, and the wetland ecological vulnerability index system is set up according to the index characteristics of productivity, stability and environmental capacity. This kind of evaluation

method is comparatively objective and comprehensive. The Analytic Hierarchy Process has been fully testified, which is a comparatively mature theory. The evaluation result of ecological vulnerability of wetlands in the Jianghan Plain accords comparatively with ecological actuality of the Jianghan Plain.

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