

Wetland Ecological Health Evaluation and Restoration Measures in Yellow River Delta Wetland in China

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Abstract

Based on the information about the Yellow River Delta wetland and socio-economic and natural environment obtained from on-site field tests, remote sensing image interpretation, literature and so on, this paper selected 26 diagnostic indicators for the wetland health to construct the index system to diagnose the ecosystem health of the Yellow River Delta wetland by the fuzzy comprehensive evaluation model. It showed that the whole Yellow River Delta wetland ecosystem was in a sub-health state caused not only by new land increase, serious soil salinization, the Yellow River swing and other natural factors, but also by irrational development of wetland, environmental pollution and other human factors, which had practical significance for wetland management and future research. We should protect and develop the Yellow River Delta wetland rationally.

Keywords: *The Yellow River Delta; Wetland Ecosystem; Health Diagnosis; The Weighted Average-based Model; Two-grade Fuzzy Comprehensive Evaluation*

1 INTRODUCTION

Wetland is a special kind of ecological system, different from water and terrestrial ecosystems. According to the definition of International Convention on Wetland (Ramsar Convention): wetland refers to natural or artificial, permanent or temporary marshes, peat land and waters of static or flowing fresh water, half-salt water, salt water including the sea water, the tide of which doesn't exceed six meters [1]. Wetland not only puts land, water, biology and other natural resources together as a body to provide a large amount of life and the means of production for human survival and social development, but also has significant ecological environmental functions.

The Yellow River Delta wetland located in the Yellow River estuary is the youngest and most typical delta wetland in the world. Because of its unique indiginity, growth, vulnerability and extremely high scientific research value, the wetland draws extensive attention from both domestic and foreign wetland organizations and experts, and becomes a research focus of global wetland ecology. Experts from more than 10 countries and regions, such as China, the United States, Japan, Australia and Holland, have done a lot of investigations about wetland [2]. Ecosystem health derived from human health is a new concept belonging to a new field. At present, experts at home and abroad have not conducted any deep research yet nor formed a set of complete systems. There are a number of concepts about wetland ecosystem health [3], but generally they only refer to the stability and sustainability of the wetland ecosystem.

This paper chooses the Yellow River Delta wetland as research area, and diagnoses the wetland health by a fuzzy mathematic method. One of the main purposes is to ascertain the present condition by diagnosing and provide a scientific basis for the rational exploitation and protection of the Yellow River Delta wetland. The second purpose is to explore the health of wetland diagnosis methods and provide technical reference for various parts of the world's

wetland ecosystem health diagnosis. The third is to advocate ecological civilization and promote harmony between man and nature through the wetland ecological research. This paper is just put forward based on this meaning and consideration.

2 STUDY AREA

Though it has a shorter history than other deltas, it brings billions of silt into the ocean to create new land every year, according to the history, the Yellow River Delta can be divided into ancient, modern and contemporary delta. This paper refers to the modern delta formed in 1855 when the Yellow River burst at Tongwaxiang, then occupied Daqing River and poured into Bohai Sea in Lijin County, Shandong Province. It takes Ninghai as the apex, with the southeast to the Zhimai estuary, the northwest to the Tuhai River (Taoer River) estuary. The entire fan-shaped area amounts to more than 5400 km². The geographic coordinate is between longitude 118°07'~119°23'E and latitude 36°55'~38°16'N. The administrative area includes Kenli County, Hekou District, Dongying District, a part of Guangrao and Lijin County, four townships of Zhanhua County and a small part of Wudi County.

3 METHODS AND PROCEDURES OF WETLAND HEALTH DIAGNOSIS

3.1 Diagnostic Methods

By checking a lot of data, we acknowledge that Indicators Species Act and Index System Act are commonly used in diagnosing the wetland health at home and abroad. Sonstegard and Leatherland who advocate Indicator Species Act think that *Oncorhynchus kisutch* can indicate the ecosystem health of the North America's Great Lake areas. Australian scholars who apply Index System Act to diagnose the wetland ecosystem health using the indicators of environment background, environmental change trend indicators, and economic trend indicators. However, both methods are not perfect at present. Indicators Species Act has some problems in the aspects of sensitivity and reliability of the indicated species while Index System Act shows some disadvantages in representativeness and quantitativeness of indicators, and lacks models. This paper tries to find a new method to diagnose the wetland health.

The method of fuzzy comprehensive evaluation is a kind of method which uses the principle of fuzzy transformation and fuzzy evaluation system. It is also a method of analysis and evaluation based on fuzzy inferencing and combining qualitiveness and quantitiveness. Since it shows unique advantages in dealing with complex issues which are difficult to describe by precise mathematical methods, this method is widely used in all scientific fields. Wetland ecosystem health is a blur phenomenon, which is hard to be accurately measured and has no strict boundary of division. So this paper selects the fuzzy comprehensive evaluation model to diagnose the health of the Yellow River Delta wetland.

3.2 Procedures of Diagnosis

We can obtain the basic information of the Yellow River Delta wetland and its socio-economic situation by on-site field tests, remote sensing image interpretation and literature, and construct a complete index system by choosing wetland ecological characteristics, functions and man-social environment, covering 26 indicators. Then we determine the index weight of different levels and construct corresponding weight vectors through consulting experts, make evaluation grades and determine the grading standards of various indicators. Next, we make a fuzzy processing of the indicators, determine membership grade and construct the discriminant matrix by methods such as membership function. In the end, we establish the fuzzy comprehensive evaluation model and diagnose the health of the wetland.

4 HEALTH DIAGNOSIS FOR WETLAND ECOSYSTEM

4.1 Diagnosis Index System Construction

Wetland health is affected by many factors which should be considered while diagnosing the wetland health. Generally speaking, 4 basic principles including integrity, representativeness, independence and operability, should

be taken into account when selecting indicators. Based on the principles, we select 26 diagnostic indicators to construct the index system, which concludes 3 sub-category index systems: ecological function, ecological characteristics and man-social environment index system. Each sub-category index system contains a number of indicators (Table 1a-c).

During the process of health diagnosis, the history of the Yellow River Delta wetland system, future management target, the critical value of some indicators that affect the growth and survival of some living creatures, and classification standards in other related researches have been consulted [4]. Diagnostic indicators are ultimately classified into 4 grades as excellent health, health, sub-health and illness. Classification standard can be referred to in Table 1 and the original indicators data of the Yellow River Delta wetland can be referred to in Table 2.

TABLE 1 INDICATORS AND CLASSIFICATION STANDARD OF WETLAND ECOSYSTEM HEALTH

Sub-category index system	Single indicator	Excellent health	Health	Sub-health	Illness
Index system of ecological functions of wetland	Water quality purification function	Purification rate>85%	Purification rate 70%~85%	Purification rate 50~70%	Purification rate<50%
	Material production function	Increase rate of production >5%	Increase rate of production >5%	Decrease rate of production<5%	Decrease rate of production>5%
	Saline improvement function	Overall system improvement function is significant	Overall system improvement function is considerable	Overall system improvement function is deficient	Overall system improvement function is lost
	Vegetation revetment function	Rate of vegetation area against the area appropriate for grass>90%	Rate of vegetation area against the area appropriate for grass 70~90%	Rate of vegetation area against the area appropriate for grass 40~70%	Rate of vegetation area against the area appropriate for grass<40%
	Hydrological regulatory function	Strong hydrological regulatory function under natural condition	The function gets strong after adding artificial facilities or projects	No obvious change after adding artificial facilities or projects	The function shows a decreasing trend after investing large project surcharge
	Sightseeing function	High aesthetic value of sightseeing and high volume of tourists	High volume of tourists in special days	Low aesthetics value and small volume of tourists	Little aesthetics value and no tourists
Index system of ecological characteristic of wetland	Water assurance level	>70%	50%~70%	30%~50%	<30%
	Dominant plants coverage	>40%	25%~40%	10%~25%	<10%
	Individual changes of sensitive animals	A marked increase in weight of the individual	A slight increase in weight of the individual	A slight reduction in weight of the individual	A marked reduction in weight of the individual
	Primary productivity level	Reed growth density >160/m ²	Reed growth density 130~160/m ²	Reed growth density 100~130/m ²	Reed growth density<100/m ² ,
	Water quality	II category corresponding to state standard	III category corresponding to state standard	IV category corresponding to state standard	V category or inferior V category
	Soil properties	Moisture soil	Moisture soil or Shajiang black soil	Salted moisture soil	Inshore salted moisture soil
	Community structure of aquatic organisms	Stronger self-stability capacity	Maintaining self-stability basically	Depending on artificial mass-energy	Depending on artificial mass-energy strongly
	Species diversity	Increase stably	No change	Decrease slightly	Decrease obviously
	Wetlands natural disasters	Strong resistance capacity against threats	Some resistance capacity against threats	Disaster occurs frequently	Disaster destroy the system seriously
	Primordial of wetland	Natural wetland>85%	Natural wetland 75~85%	Natural wetland 65~75%	Natural wetland < 65%

	Growth rate of the wetland	No change in the area of wetland	Small change in the area of wetland	Rapid change in the area of wetland	Great change in the area of wetland
	Stability of river channel	No possibility of being diverted	little possibility of being diverted	with the possibility of being diverted	Easy to be diverted
Index system of man-social environment	Environmental investment index	>2.5%	1.5~2.5%	1~1.5%	<1%
	Wastewater treatment index	>90%	70~90%	50~70%	<50%
	Physical life index	>4500	3500~4500	2500~3500	<2500
	Natural population growth rate	<5.5‰	5.5~6‰	6‰~6.5‰	>6.5‰
	Intensity of chemical fertilizer use	<250	250~300	300~400	>400
	Intensity of pesticide use	<2.5	2.5~3	3~4.5	>4.5
	Wetland protection rate	>30%	15~30%	5~15%	<5%
	Wetland management level	Managers have high quality	Managers need training	Management institutions are not perfect enough	Lacking related management institutions

TABLE 2 ORIGINAL INDICATORS DATA OF THE YELLOW RIVER DELTA WETLAND

Sub-category index system	Single indicator	Original data	Sub-category index system	Single indicator	Original data
Index system of ecological functions of wetland	Water quality purification function	70-80%	Index system of ecological functions of wetland	Vegetation revetment function	70%
	Material production function	4%		Hydrological regulatory function	Quantitative description
	Saline improvement function	Quantitative description		Sightseeing function	Quantitative description
Index system of ecological characteristic of wetland	Water assurance level	69%	Index system of ecological characteristic of wetland	Community structure of aquatic organisms	Quantitative description
	Dominant plants coverage	12.59%		Species diversity	Species distribution and increase or decrease of species number
	Individual changes of sensitive animals	Average individual weight change of <i>Scapharca subcrenata</i>		Wetlands natural disasters	Frequency of occurrence and destructive degree of storm surges and coastal wetlands pest
	Primary productivity level	Density, height and thickness of reed		Primordial of wetland	68.79%
	Water quality	III category		Growth rate of the wetland	Quantitative description
	Soil properties	Quantitative description		Stability of river channel	Quantitative description
Index system of man-social environment	Environmental investment index	2.4%	Index system of man-social environment	Intensity of chemical fertilizer use	242 kg/hm ²
	Wastewater treatment index	70%		Intensity of pesticide use	2.21 kg/hm ²
	Physical life index	4763 RMB		Wetland protection rate	10.2%
	Natural population growth rate	6.03%		Wetland management level	Quantitative description

4.2 Diagnosis Model Establishment

Since the diagnosis index system includes single indicator and sub-category index system, it is appropriate to adopt two-grade fuzzy comprehensive evaluation model. The model is as follows:

$$B = A \circ R = A \circ \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = A \circ \begin{bmatrix} A_1 \circ R_1 \\ A_2 \circ R_2 \\ A_3 \circ R_3 \end{bmatrix} \quad W = B \circ C^T$$

Where A and A_i ($i=1, 2, 3$) are weight vectors of indicators at different levels; R and R_i ($i=1, 2, 3$) are the fuzzy membership evaluation matrix of indicators at different levels; B and B_i ($i=1, 2, 3$) are diagnosis results of indicators at various levels; W is the integrate marking; C is the scoring vector, C^T is the transposed matrix. In this paper, the grade standard is as follows: 1 for excellent health; 0.75 for health; 0.5 for sub-health; 0.25 for illness.

4.3 Ascertaining Diagnosis Indicators Weight

During the process of wetland health diagnosis, weighting ascertainment is vital, since it reflects the position or role of each indicator during the comprehensive evaluation. In the wetland health diagnosis, through consulting the opinion of experts, the normalized weight vectors are gained as follows:

$$A = (0.336, 0.380, 0.284)$$

$$A_1 = (0.180, 0.154, 0.123, 0.153, 0.210, 0.180)$$

$$A_2 = (0.120, 0.110, 0.090, 0.090, 0.060, 0.060, 0.090, 0.110, 0.080, 0.060, 0.070, 0.060)$$

$$A_3 = (0.140, 0.165, 0.070, 0.083, 0.126, 0.126, 0.150, 0.140)$$

Where A is the weight vector in the sub-category index system, A_i ($i=1, 2, 3$) is the weight vector in I sub-category index system.

4.4 Ascertaining the Membership Grade of Each Grade for Diagnosis Indicators

The key to construct the evaluation matrix is how to ascertain the membership grade for indicators. In order to eliminate the leaping phenomena that the numerical value has not too much discrepancy between each grade while comment grades may have one-grade discrepancy and to make a smooth slide between grades, the membership function is fuzzily processed as follows:

$$r_{i1}(u_i) = \begin{cases} 0.5(1 + \frac{u_i - k_1}{u_i - k_2}) & (u_i > k_1) \\ 0.5(1 - \frac{k_1 - u_i}{k_1 - k_2}) & (k_2 < u_i \leq k_1) \\ 0 & (u_i \leq k_2) \end{cases} \quad r_{i2}(u_i) = \begin{cases} 0.5(1 - \frac{u_i - k_1}{u_i - k_2}) & (u_i > k_1) \\ 0.5(1 + \frac{k_1 - u_i}{k_1 - k_2}) & (k_2 < u_i \leq k_1) \\ 0.5(1 + \frac{u_i - k_3}{k_2 - k_3}) & (k_3 < u_i \leq k_2) \\ 0.5(1 - \frac{k_3 - u_i}{k_3 - k_4}) & (k_4 < u_i \leq k_3) \\ 0 & (u_i \leq k_4) \end{cases}$$

$$r_{i3}(u_i) = \begin{cases} 0 & (u_i > k_2) \\ 0.5(1 - \frac{u_i - k_3}{k_2 - k_3}) & (k_3 < u_i \leq k_2) \\ 0.5(1 + \frac{k_3 - u_i}{k_3 - k_4}) & (k_4 < u_i \leq k_3) \\ 0.5(1 + \frac{u_i - k_5}{k_4 - k_5}) & (k_5 < u_i \leq k_4) \\ 0.5(1 - \frac{k_5 - u_i}{k_4 - u_i}) & (u_i \leq k_5) \end{cases} \quad r_{i4}(u_i) = \begin{cases} 0 & (u_i > k_4) \\ 0.5(1 - \frac{u_i - k_5}{k_4 - k_5}) & (k_5 < u_i \leq k_4) \\ 0.5(1 + \frac{k_5 - u_i}{k_4 - u_i}) & (u_i \leq k_5) \end{cases}$$

Where r_{ik} ($i=1, 2, \dots, 23; k=1, 2, 3, 4$) is the membership grade in the k grade of the i indicator; k_1 is the critical value between grade V_1 and V_2 ; k_2 is the midpoint value of the interval of V_2 grade; k_3 is the critical value between grade V_2 and V_3 ; k_4 is the midpoint value of the interval of V_3 grade. The converse quantitative indicator that is smaller and more super, when accounted, is exchanged between “>” and “<”, and between “ $\geq$ ” and “ $\leq$ ” under the value-taking condition. Refer to Table 3 to ascertain the membership grade of qualitative indicators.

TABLE 3 MEMBERSHIP MATRIX OF QUALITATIVE INDICATORS DIAGNOSIS

Membership grade for comment grades	V_1	V_2	V_3	V_4
V_1	0.70	0.30	0	0
V_2	0.25	0.50	0.25	0
V_3	0	0.25	0.50	0.25
V_4	0	0	0.30	0.70

4.5 Evaluation Matrix of Diagnosis Indicators

Membership evaluation matrix and scoring vectors are gained as follows:

$$R_1 = \begin{bmatrix} 0.485 & 0.515 & 0.000 & 0.000 \\ 0.352 & 0.648 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.300 & 0.700 \\ 0.000 & 0.500 & 0.500 & 0.000 \\ 0.000 & 0.250 & 0.500 & 0.250 \\ 0.250 & 0.500 & 0.250 & 0.000 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0.000 & 0.755 & 0.245 & 0.000 \\ 0.000 & 0.000 & 0.673 & 0.327 \\ 0.000 & 0.000 & 0.300 & 0.700 \\ 0.120 & 0.280 & 0.440 & 0.160 \\ 0.000 & 0.000 & 0.300 & 0.700 \\ 0.298 & 0.054 & 0.253 & 0.395 \\ 0.000 & 0.250 & 0.500 & 0.250 \\ 0.000 & 0.000 & 0.300 & 0.700 \\ 0.000 & 0.000 & 0.300 & 0.700 \\ 0.000 & 0.000 & 0.879 & 0.121 \\ 0.000 & 0.250 & 0.500 & 0.250 \\ 0.000 & 0.250 & 0.500 & 0.250 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.400 & 0.600 & 0.000 & 0.000 \\ 0.000 & 0.500 & 0.500 & 0.000 \\ 0.672 & 0.328 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.193 & 0.807 \\ 0.621 & 0.379 & 0.000 & 0.000 \\ 0.769 & 0.231 & 0.000 & 0.000 \\ 0.000 & 0.020 & 0.980 & 0.000 \\ 0.250 & 0.500 & 0.250 & 0.000 \end{bmatrix}$$

$$C = (1.000, 0.750, 0.500, 0.250)$$

4.6 Diagnosis Results

The diagnosis results are different because of different operators and information approaches. The traditional model of Max-min of Algorithm ($B = A \circ R$) is based on the “ $\wedge$ - $\vee$ ” composite operation. Although the outstanding factors are focused on, the other factors are omitted, so most of the information is wasted. If it is applied to the health of the wetland ecosystem, it will be one-sided to some extent. The improved weighted average-based evaluation model is

$B = A \circ R$ or $b_j = \sum_{i=1}^n (a_i \bullet r_{ij})$ ($j=1, 2, \dots, m$) in which each of the evaluation factors has contributed to the evaluation results. The weighted average-based model is used in this paper. The results are as follows:

$$B_1 = A_1 \circ R_1 = (0.187, 0.411, 0.263, 0.139) \quad B_2 = A_2 \circ R_2 = (0.029, 0.174, 0.423, 0.374)$$

$$B_3 = A_3 \circ R_3 = (0.313, 0.339, 0.281, 0.067) \quad B = A \circ R = A \circ (B_1, B_2, B_3)^T = (0.163, 0.300, 0.329, 0.208)$$

$$W = B \circ C^T = 0.605$$

From the diagnosis results, the Yellow River Delta wetland ecosystem, when at the level of 0.163, is in a very healthy state; it is in a healthy state when at the level of 0.300; in a sub-healthy state when at the level of 0.329; in an illness state when at the level of 0.208. The system is in a sub-healthy state with a score of 0.605 as a whole.

In order to verify the diagnosis results, we returned to the study area and found out that the diagnosis method in this paper is feasible. The sub-health state of the Yellow River Delta wetland mainly has some actual indications: A large amount of *Sophora* died as a result of higher salinity. New wetlands are being generated because of the continuous deposition of the Yellow River Delta which are very fragile and easy to be destroyed. Frequent storm surges lead to the degradation of some wetlands. Oil production resulting in the damage to wetlands and soil is contaminated by organic matter. The interference to the wetland is caused by tourism. Birds build their nests on high poles in order to avoid visitors. Reed is reaped in the natural reserve. These natural and human factors involved in the natural wetland system have changed the original habitats, reduced the stability of the system itself, thus putting the wetland in the sub-health state.

5 WETLAND ECOLOGICAL RESTORATION MEASURES

This paper does not focus on the wetland ecological restoration, but puts forward some suggestions concerning the causes leading to the sub-health of the wetland: first, we should strengthen the exploration and development of Shengli Oil Field in order to reduce the damage to the wetland ecosystem. Since the natural recovery of contaminated soil is slow, the soil condition can be improved by changing the soil or adding organic matter, and by artificial planting or transplanting strong resistant woody plants or shrubs to encourage more plant species. Second, in the heavy saline area, salt-tolerant species can be planted such as *Suaeda glauca* Bge, *Aeluropus sinensis*, and so on while we can selectively introduce a number of foreign salt-tolerant species. We can plant a number of salt-tolerant species such as *Apocynum venetum*, *Phragmites australis*, and so on when the soil salinity falls to an appropriate extent. And restoration projects can be promoted through testing and demonstration after the gradual accumulation of experience [5-6]. Third, we should strengthen the protection and management of natural reserves, especially the strict protection of the central area. Scientific research can be carried out in the test area while tourism can be properly developed in the buffer zone. At last, people will understand the functions and value of the wetland and strengthen the protection of the wetland through publicity and education.

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