*Original Research*

# Health Evaluation of a Lake Wetland Ecosystem Based on the TOPSIS Method

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## Abstract

Wetlands, sea, and forest are the three most important ecosystems on our planet. Considering the rapid degradation rate of wetlands, health evaluation of wetlands has become one of the hot points in the research field of wetlands. In this research, health and the pressure-state-response model of ecosystem was used as the tool, data was collected with remote sensing technology, field investigation and social statistics were used as the basis, and a health evaluation index system for Poyang Lake Wetland was created, which was composed of a pressure subsystem, a state subsystem, and a response subsystem with an established evaluation criteria. The values of weight of the subsystems were determined through the analytic hierarchy process (AHP), which were then introduced into the TOPSIS model for calculation. Furthermore, the index values were compared with the ideal values and the grade criteria, through which health conditions of Poyang Lake Wetland were evaluated and the limiting factors of wetland health were determined. Through the comparison between the approach degree of ideal alternatives in 2008-13 and that of 5 evaluation grade and ideal alternatives, the health states in 2008-13 were finally determined as: sub-healthy, sub-healthy, sub-healthy, sub-healthy, sub-healthy, sub-healthy. Finally, countermeasures for the ecological restoration and protection of the wetland were put forward.

**Keywords:** TOPSIS method, ecosystem, analytic hierarchy process, health evaluation, Poyang Lake

## Introduction

Wetlands are important natural resources and ecosystems in nature that play an important role in maintaining ecological balance, which is why they are called "the kidneys of the Earth" [1, 2]. However, in recent decades, under a variety of human interference and natural factors, wetland area have been rapidly reduced and the service function has been degenerated seriously [3]. Therefore, health evaluation on the ecosystem of wetlands is very important and urgent.

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Health evaluation on wetland ecosystem is a new concept, new area in the field of research on wetland, and also a new direction in the field of ecosystem health evaluation. In foreign countries, health evaluation on the ecosystem of wetlands started earlier. An EPA research team in the United States carried out a large number of research about health evaluation on the ecosystem of wetlands nationwide [4, 5]. In recent years, Chinese experts also have conducted a number of studies on aspects of health evaluation on wetland, focusing on selecting chemical, biological, economic, social, and other related indicators of a single wetland for evaluation. For example: Jiang Weiguo et al. evaluated and analyzed the health condition of a wetland ecosystem in Panjin City, adopting remote sensing and geographic information system technology on the basis of remote sensing data and statistics monitoring data [6]; Cui Baoshan and Yang Zhifeng integrated ecological indicators, function integrated indicators, and social environment indicators of wetlands to evaluate the health of riverine wetland of Raoli River of Three River Plain [7].

Utilizing the TOPSIS model to analyze and research, this research reveals the current health condition of the wetlands ecosystem of Poyang Lake, providing a scientific basis for reasonably developing Poyang Lake wetland, protecting the wetland ecological environment, and achieving sustainable development of wetland areas.

## Overview of Research Area

Poyang Lake is China's largest freshwater lake and is important to the regulation and storage lakes of the Yangtze River, receiving the water flowing from the Ganjiang, Fuhe, Xinjiang, Raohe, and Xiu rivers. Poyang Lake is located at 28º22′~29º45′ northern latitude, 115º47′~116º45′ east longitude [8]. Length of the lake from south to north is 173 km and average width from east to west is 16.9 km [9]. Its water level fluctuation is dually impacted by water from the five rivers and the Yangtze. It has the unique natural geographical landscape of "high water forms lake and low water forms river." In the flood season every year, bottomland will be exposed and water surface shrinks. Soil resources in the lake region are rich with different types [10].

## Research and Evaluation Methods

### Research Method

The wetlands ecosystem of Poyang Lake is complicated. The evaluation of health conditions mainly contains analysis evaluation on ecological characteristics, service function and human social consciousness around the wetland, policy implementation, etc. In line with *Regulation for Water Environmental Monitoring, Technical Specification for Soil Environmental Monitoring*, and other relayed technical specifications, multi-sampling points, regular monitoring, and survey analysis are conducted for water quality, soil, vegetation, biodiversity and other ecological characteristics of the wetland ecosystem of Poyang Lake, a large number of measured data are accumulated and ecological characteristics of the wetland are basically mastered.

### TOPSIS Method

The TOPSIS method is a multi-objective decision making approach more commonly used in systems engineering, which can make full use of the data. The results accurately reflect the distance between the evaluation units with visualized geometrical significance. It is a sorting method approximating the ideal solution, requiring that the sub-utility function has a monotonically increasing or decreasing resistance. The basic idea of TOPSIS is first defining the ideal solution and negative ideal solution of the decision problem, and then finding out a program from the feasible options, making it nearest to the ideal solution and furthest from the negative ideal solution. The so-called ideal solution is an optimal solution envisaged, and the corresponding attributes of it reach at least the best value in various programs. Negative ideal solution is the worst program envisaged, and the corresponding attributes of it are at least not superior to the worst value in various programs. Decision rule of alternatives ranking is comparing the alternatives with the ideal solution and negative ideal solution. If one of the programs is the closest to the ideal solution, while the most away from the negative ideal solution, this program is the best program in the alternatives [11].

In TOPSIS evaluation, the concept that is relatively close to measurement is adopted. Assuming that the problem has *m* evaluation objects and *n* feasible evaluation indicators, then the data matrix of the problem is:

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

Conduct normalization processing to the above matrix, then the normalized matrix *B* is obtained. Then:

$$b_{ij} = (x_{ij} - \min(x_{ij})) / (\max(x_{ij}) - \min(x_{ij})) \tag{2}$$

Next is determining the weights of all evaluation indicators, multiplying weight by normalized matrix to get the weighted decision matrix $Z=(z_{ij})_{m\times n}$.

$$z_{ij} = W_j \times b_{ij} \tag{3}$$

And then seek for ideal solution $Q^*$ and negative ideal solution $Q^-$ of the problem. For the goals, the greater the better:

$$Q^* = \max z_{ij}, \qquad Q^- \min z_{ij} \tag{4}$$

For goals the smaller the better:

$$Q^* = \min z_{ij}, \qquad Q^- \max z_{ij} \tag{5}$$

Calculate the distance from all programs to the ideal solution and Euclidean distance to the negative ideal solution:

$$d^* = \left\| z_i - Q^* \right\| = \sqrt{\sum_{j=1}^{n} (z_{ij} - q_j^*)^2}$$
$$d^- = \left\| z_i - Q^- \right\| = \sqrt{\sum_{j=1}^{n} (z_{ij} - q_j^-)^2} \tag{6}$$

Compute the approach degree $C_i$ between programs and ideal solutions:

$$C_i = d_i^- / (d_i^* - d_i^-) \quad (7)$$

The approach degree is 1 if program is the same with the ideal solution, and the approach is 0 if the program approaches the negative ideal solution. Consequently, the closer the approach degree to 1, the better the program will be.

## Health Evaluation on the Ecosystem of Poyang Lake Wetland

### Establishment of the Indicator System

In the principle of purpose, integrity, feasibility, dynamics, and static combination and qualitative and quantitative combination, combining actual conditions of Poyang Lake Wetland, according to the Pressure-State-Response framework model, taking all factors into consideration such as the impact of the Three Gorges Project on Poyang Lake, characteristics of Poyang Lake, and information obtained. This study selects indicators that can truly reflect health conditions of the ecosystem of Poyang Lake to establish the indicator system from aspects of pressure, state, and response.

#### *Selection of Pressure Layer Indicators*

A pressure-type indicator is an important element in health evaluation on the ecosystem of Poyang Lake, the reason representing the changes in ecosystem state of Poyang Lake, and an indicator measuring pressure from external activities applied to it. According to the related document and current data, this paper selects 13 indicators to describe the pressure borne by the ecosystem of Poyang Lake (Table 1).

#### *Selection of State Layer Indicators*

State type indicators can comprehensively reflect the health of the Poyang Lake ecosystem and change with the changes in pressure type indicators, playing certain indicative roles in the health state of the ecosystem of Poyang Lake. According to the related document and current data, this paper selects 14 indicators to describe the pressure borne by the ecosystem (Table 2).

#### *Selection of State Response Indicators*

A response-type indicator refers to the indicator in aspects of policies, measurements, etc., made by humans to reduce pressure and improve the ecosystem state of a lake in allusion to changes in health state of the Poyang Lake ecosystem. According to related documents and current data, this paper selects 5 indicators to describe the pressure borne by the ecosystem (Table 3).

Table 1. Evaluation indicator system of pressure subsystem.

| Object layer | Criterion layer | Indicator layer | SN |
|---|---|---|---|
| Health Evaluation of Poyang Lake Ecosystem | Pressure subsystem | Water use amount per 10,000 Yuan GDP | P1 |
| | | Water consumption per capita | P2 |
| | | Rate of polluted rivers | P3 |
| | | Oncomelania hupensis area | P4 |
| | | Applying quantity of agricultural fertilizer | P5 |
| | | Flood affected area rate | P6 |
| | | Droughts affected area rate | P7 |
| | | The proportion of daily mean water level lower than 13m | P8 |
| | | The proportion of daily mean water level lower than 9m | P9 |
| | | Mean value of mean water level in 1-10 in June | P10 |
| | | The proportion of water level lower than 13 m in October | P11 |
| | | Density of population | P12 |
| | | Use of pesticides | P13 |

Table 2. Evaluation indicator system of state subsystem.

| Object layer | Criterion layer | Indicator layer | SN |
|---|---|---|---|
| Health Evaluation of Poyang Lake Ecosystem | State subsystem | Woodland coverage rate | S1 |
| | | Urbanization rate | S2 |
| | | Urban Engel coefficient | S3 |
| | | Per capita water resources quantity | S4 |
| | | Per capita GDP | S5 |
| | | Per capita food | S6 |
| | | Number of birds (example of white crane living through the winter) | S7 |
| | | The probability with monthly average water level at 10-19 m in Xingzi station | S8 |
| | | Proportion of natural reserve areas accounting for national territorial area | S9 |
| | | Water quality in dry season | S10 |
| | | Water quality in wet season | S11 |
| | | Eutrophication rated value in April-September | S12 |
| | | Per capita arable land area | S13 |
| | | The per capita income of farmers | S14 |

Table 3. Evaluation indicator system of response subsystem.

| Object layer | Criterion layer | Indicator layer | SN |
|---|---|---|---|
| Health Evaluation of Poyang Lake Ecosystem | Response subsystem | Standard discharge rate of industrial wastewater | R1 |
| | | Urban sewage treatment rate | R2 |
| | | Rate of soil erosion control | R3 |
| | | Proportion of water funds total investment accounting for GDP | R4 |
| | | Recycling rate of industrial consumption | R5 |

## Establishment of Evaluation Criteria

Standard values of the evaluation indicators are closely related to the condition of Poyang Lake itself, the impact of the reservoir of the three gorges on it, etc. The basis for establishing the indicator criteria of health evaluation on the ecosystem of Poyang Lake is:

(1) Reference or analog of status quo values of excellent cities or lakes at home and abroad
(2) Reference literature and national standards, etc.
(3) For some national standards that have been established for a long term and not suitable, change the standard value appropriately
(4) Evaluation criteria shall be consistent with the existing national and local policy objectives [12].

In the indicator system, since the types of evaluation indicator are complex and the standard values are not uniform, various indicators are incomparable. Therefore, the factors for evaluating must be normalized. The normalization scores are set between 0 and 1 according to the impact of indicators on the health of the regional ecosystem and standard grade. See Tables 4, 5, and 6 for standardized scores of subsystem evaluation indicators.

## Determination of Indicator Weight by Analytic Hierarchy Process

Set the evaluation standard indicator system as $X$, and the evaluation standard indicator system matrix with a rating of five can be shown as:

$$X = \begin{bmatrix} x_{11}, x_{12}, \cdots, x_{15} \\ x_{21}, x_{22}, \cdots, x_{25} \\ \vdots \qquad \vdots \\ x_{m1}, x_{m2}, \cdots, x_{m5} \end{bmatrix} \tag{8}$$

Among them, $m$ is the number of indicators. Set the samples for evaluating as $Z$, then:

$$Z = \begin{bmatrix} z_{11}, z_{12}, \cdots, z_{1n} \\ z_{21}, z_{22}, \cdots, z_{2n} \\ \vdots \qquad \vdots \\ z_{m1}, z_{m2}, \cdots, z_{mn} \end{bmatrix} \tag{9}$$

Where $n$ is the number of samples for evaluating. Combine $X$ and $Z$ and then get matrix $P$, then:

Table 4. Grading standard values of evaluation indicator of pressure subsystem.

| Evaluation indicator | Grade of scoring | | | | |
|---|---|---|---|---|---|
| | Very healthy | Healthy | Sub-healthy | Slightly morbid | Morbid |
| Water use amount per 10,000 Yuan GDP ($m^3$) | [50, 100] | [100, 150] | [150, 200] | [200, 250] | [250, 300] |
| Water consumption per capita ($m^3$) | [200, 250] | [250, 300] | [300, 400] | [400, 450] | [450, 500] |
| Rate of polluted rivers (%) | [0, 10] | [10, 20] | [20, 30] | [30, 70] | [70, 100] |
| Oncomelania hupensis area (10,000 mu) | [0, 100] | [100, 150] | [150, 200] | [200, 300] | [300, 360] |
| Applying quantity of chemical fertilizer (kg/$Km^2$) | [0, 225] | [225, 500] | [500, 750] | [750, 1000] | [1000, 1500] |
| Flood-affected area rate (%) | [0, 5] | [5, 10] | [10, 15] | [15, 20] | [20, 100] |
| Drought-affected area rate (%) | [5, 11] | [11, 17.5] | [17.5, 22] | [22, 27] | [27, 32] |
| The proportion of daily mean water level <13 m (%) | [0, 10] | [10, 20] | [20, 40] | [40, 60] | [60, 100] |
| The proportion of daily mean water level <9 m (%) | [0, 10] | [10, 20] | [20, 40] | [40, 60] | [60, 100] |
| Mean value of mean water level 1-10 June (m) | [12, 14] | [14, 16] | [16, 18] | [18, 20] | [20, 22] |
| The proportion of water level lower than 13 m in October (%) | [0, 20] | [20, 40] | [40, 60] | [60, 80] | [80, 100] |
| Density of population (thousand person/$km^2$) | [0, 0.1] | [0.1, 0.2] | [0.2, 0.3] | [0.3, 0.4] | [0.4, 0.5] |
| Use of pesticides | [0, 5] | [5, 20] | [20, 50] | [50, 80] | [80, 120] |

Table 5. Grading standard values of evaluation indicator of state subsystem.

| Evaluation indicator | Grade of scoring | | | | |
|---|---|---|---|---|---|
| | Very healthy | Healthy | Sub-healthy | Slightly morbid | Morbid |
| Forest coverage rate (%) | [50, 75] | [27, 50] | [20, 27] | [10, 20] | [0, 10] |
| Urbanization rate (%) | [70, 90] | [60, 70] | [40, 60] | [20, 40] | [10, 20] |
| Urban Engel coefficient | [0.2, 0.3] | [0.3, 0.4] | [0.4, 0.5] | [0.5, 0.59] | [0.59, 1] |
| Per capita water resources quantity ($m^3$/person) | [2,500, 4,000] | [2,000, 2,500] | [1,500, 2,000] | [1,000, 1,500] | [0, 1,000] |
| Per capita GDP (10,000 yuan) | [6, 4.5] | [4.5, 3] | [3, 2.4] | [2.4, 1.6] | [1.6, 0.08] |
| Per capita food (kg) | [600, 500] | [500, 400] | [400, 300] | [300, 200] | [200, 100] |
| Number of birds (thousands) | [4, 3.5] | [3.5, 3] | [3, 2] | [2, 1] | [1, 0] |
| The probability with monthly average water level at 10-19 m in Xingzi station (%) | [0.9, 0.8] | [0.8, 0.7] | [0.7, 0.6] | [0.6, 0.4] | [0.4, 0] |
| Proportion of natural reserve areas (%) | [8, 6] | [6, 5] | [5, 4] | [4, 2] | [2, 0] |
| Water quality in dry season | [90, 100] | [80, 90] | [70, 80] | [60, 70] | [40, 60] |
| Water quality in wet season | [95, 100] | [90, 95] | [80, 90] | [70, 80] | [60, 70] |
| Eutrophication rated value in April-September | [0, 10] | [10, 25] | [25, 40] | [40, 60] | [60, 100] |
| Per capita arable land area (mu/person) | [4, 5] | [3, 4] | [2, 3] | [0.5, 2] | [0, 0.5] |
| The per capita income of farmers (thousand yuan) | [5, 10] | [3, 5] | [2, 3] | [1, 2] | [0, 1] |

Table 6. Grading standard values of evaluation indicator of response subsystem.

| Evaluation indicator | Grade of scoring | | | | |
|---|---|---|---|---|---|
| | Very healthy | Healthy | Sub-healthy | Slightly morbid | Morbid |
| Standard discharge rate of industrial wastewater (%) | [90, 100] | [80, 90] | [60, 80] | [40, 60] | [0, 40] |
| Urban sewage treatment rate (%) | [80, 100] | [60, 80] | [40, 60] | [20, 40] | [0, 20] |
| Rate of soil erosion control (%) | [80, 100] | [60, 80] | [40, 60] | [20, 40] | [0, 20] |
| Proportion of water funds total investment accounting for GDP (%) | [0.8, 1] | [0.6, 0.8] | [0.4, 0.6] | [0.2, 0.4] | [0, 0.2] |
| Recycling rate of industrial consumption (%) | [80, 90] | [70, 80] | [60, 70] | [40, 60] | [0, 40] |

$$P = \begin{bmatrix} x_{11}, x_{12}, \cdots, x_{15}, z_{11}, z_{12}, \cdots, z_{1n} \\ x_{21}, x_{22}, \cdots, x_{25}, z_{21}, z_{22}, \cdots, z_{2n} \\ \vdots \quad\quad \vdots \quad \vdots \quad\quad \vdots \\ x_{m1}, x_{m2}, \cdots, x_{m5}, z_{m1}, z_{m2}, \cdots, z_{mn} \end{bmatrix} \quad (10)$$

Conduct normalization processing to the above matrix, then the normalized matrix $B=(b_{ij})_{m\times(5+n)}$ is obtained. Calculate the weights of indicators $W_j$ by analytic hierarchy process, i. e. the weighted matrix $Y=W_j*B$. Obtain the ideal solution $L^*$ and negative ideal solution $L^{-1}$ of weighted decision matrix by the computing method of ideal solution and negative ideal solution. Compute the Euclidean distances $D^*=(d_{ij})_{1\times(5+n)}$, $D^-=(d_{ij})_{1\times(5+n)}$ and between indicators in Y and and $L^*$ and $L^{-1}$. Calculate the approach degree between programs and the preferred plan.

Pressure system weight obtained by analytic hierarchy process is shown in Table 7.

Then $RI$=1.56, $CI$=0.0134, $CR$=0.086<0.1 after computation passes the consistency check.

State system weight obtained by analytic hierarchy process is shown in Table 8.

Then $RI$=1.59, $CI$=0.0408, $CR$=0.0259<0.1 after computation passes the consistency check.

Response system weight obtained by analytic hierarchy process is shown in Table 9.

Table 7. Pressure subsystem weight by analytic hierarchy process.

| SN | Pressure subsystem indicators | Indicator weight |
|---|---|---|
| P1 | Water use per 10,000 Yuan GDP ($m^3$) | 0.2448 |
| P2 | Water consumption per capita ($m^3$) | 0.0721 |
| P3 | Rate of polluted rivers (%) | 0.1176 |
| P4 | Oncomelania hupensis area (10,000 mu) | 0.0252 |
| P5 | Application of agricultural fertilizer (t/ha.) | 0.0416 |
| P6 | Flood-affected area rate (%) | 0.1176 |
| P7 | Drought-affected area rate (%) | 0.0252 |
| P8 | The proportion of daily mean water level lower than 13 m | 0.0721 |
| P9 | The proportion of daily mean water level lower than 9 m | 0.0416 |
| P10 | Mean value of mean water level 1-10 June | 0.0416 |
| P11 | The proportion of water level lower than 13 m in October | 0.0416 |
| P12 | Density of population (person/$km^2$) | 0.0416 |
| P13 | Use of pesticides | 0.1176 |

Table 8. State subsystem weight by analytical hierarchy process.

| SN | State subsystem indicators | Indicator weight |
|---|---|---|
| S1 | Woodland coverage rate | 0.1561 |
| S2 | Urbanization rate % | 0.1105 |
| S3 | Urban Engel coefficient | 0.0512 |
| S4 | Per capita water resources quantity | 0.0225 |
| S5 | Per capita GDP (10,000 yuan) | 0.0157 |
| S6 | Per capita food (kg) | 0.0512 |
| S7 | Number of birds | 0.0512 |
| S8 | The probability with monthly average water level at 10-19 m in Xingzi station | 0.0119 |
| S9 | Proportion of natural reserve areas accounting for national territorial area | 0.0225 |
| S10 | Water quality in dry season | 0.0225 |
| S11 | Water quality in wet season | 0.0339 |
| S12 | Eutrophication rated value in April-September | 0.1561 |
| S13 | Per capita arable land area | 0.0771 |
| S14 | Rural per capita net income | 0.2174 |

Then $RI$=1.12, $CI$=0.0033, $CR$=0.003<0.1 after computation passes the consistency check.

## Evaluation Results and Analysis

Bring the indicator weights of subsystems into the TOPSIS model based on analytical hierarchy process weighting, and then calculate $D^*$, $D^-$, and $C$ of subsystems, then the results are as shown in the following Tables 10 and 11.

The results of health evaluation on ecosystem in 2008-13 are obtained through comparing the computation results and evaluation standards in 2008-13, as shown in the following Table 12.

As can be seen from Tables 11 and 12, the sort of conditions in each year in the pressure system is: $P_{2008}<P_{2009}<P_{2010}<P_{2011}<P_{2012}<P_{2013}$. Because the indicator, water use amount per 10.000 Yuan GDP (which accounts for a relatively large weight) is decreasing annually, and weights of other indicator values are small and the monotonicity trend of values are not obvious. From 2008 to 2013, the values of water use amount per 10,000 Yuan GDP are in the grade of seriously morbid, and the majority of other indicator values is in the state below sub-healthy, hence the state of the pressure is slightly morbid. The sort of conditions in each year in the state system is: $P_{2008}<P_{2009}<P_{2010}<P_{2011}<P_{2012}<P_{2013}$. The sort of conditions in each year in the response system is: $P_{2011}<P_{2013}<P_{2009}<P_{2010}<P_{2012}<P_{2008}$.

Because the majority of indicator values with larger weights in the three subsystems was in a state below sub-healthy in 2008-13, the overall evaluation result is in a state

Table 9. Response subsystem weight by analytical hierarchy process.

| SN | Response subsystem indicators | Indicator weight |
|---|---|---|
| R1 | Standard discharge rate of industrial wastewater (%) | 0.1578 |
| R2 | Urban sewage treatment rate (%) | 0.1578 |
| R3 | Rate of soil erosion control (%) | 0.2978 |
| R4 | Proportion of water funds total investment accounting for GDP (%) | 0.2978 |
| R5 | Recycling rate of industrial consumption (%) | 0.0888 |

below sub-healthy. In 2008, for example, for all indicator values in three systems, among which water use amount per 10,000 Yuan GDP, water consumption per capita, urbanization rate, urban Engel coefficient, per capita GDP, per Capita Arable Land area, and urban sewage treatment rate are in a morbid state, the proportion of daily mean water level lower than 13 m, proportion of natural reserve areas accounting for national territorial area, eutrophication rated value in April-September, the per capita net income of farmers, standard discharge rate of industrial wastewater, and recycling rate of industrial consumption are in slightly morbid state, applying quantity of agricultural fertilizer, droughts affected area rate, density of population, use of pesticides, water resources per capita, per capita food in sub-healthy state, flood-affected area rate, the proportion of daily mean water level lower than 9 m, mean value of mean

Table 10. Computation result of evaluating standard indicator system by TOPSIS method.

| Systems | | Very healthy | healthy | Sub-healthy | Slightly morbid | Morbid |
|---|---|---|---|---|---|---|
| Pressure system | $C$ | 1 | 0.8921 | 0.7714 | 0.6241 | 0 |
| | $D^{*}$ | 0 | 0.0375 | 0.0815 | 0.1419 | 0.3419 |
| | $D^{-}$ | 0.3419 | 0.3100 | 0.2750 | 0.2355 | 0 |
| State system | $C$ | 1 | 0.6332 | 0.4280 | 0.2430 | 0 |
| | $D^{*}$ | 0 | 0.1324 | 0.2069 | 0.2699 | 0.3466 |
| | $D^{-}$ | 0.3466 | 0.2287 | 0.1548 | 0.0866 | 0 |
| Response system | $C$ | 1 | 0.7318 | 0.5083 | 0.2755 | 0 |
| | $D^{*}$ | 0 | 0.1288 | 0.2362 | 0.3480 | 0.4751 |
| | $D^{-}$ | 0.4751 | 0.3515 | 0.2442 | 0.1323 | 0 |

Table 11. Computation results by TOPSIS method in 2008-13.

| Systems | | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|
| Pressure system | $C$ | 0.4538 | 0.5035 | 0.5554 | 0.5595 | 0.5597 | 0.6189 |
| | $D^{*}$ | 0.2393 | 0.2026 | 0.1630 | 0.1627 | 0.1630 | 0.1403 |
| | $D^{-}$ | 0.1988 | 0.2054 | 0.2036 | 0.2066 | 0.2072 | 0.2278 |
| State system | $C$ | 0.4584 | 0.4759 | 0.4725 | 0.4950 | 0.5153 | 0.5303 |
| | $D^{*}$ | 0.2187 | 0.2099 | 0.2097 | 0.1973 | 0.1870 | 0.1804 |
| | $D^{-}$ | 0.1851 | 0.1906 | 0.1878 | 0.1933 | 0.1988 | 0.2037 |
| Response system | $C$ | 0.6603 | 0.5741 | 0.5882 | 0.5576 | 0.6182 | 0.5799 |
| | $D^{*}$ | 0.1902 | 0.2191 | 0.2155 | 0.2400 | 0.2024 | 0.2356 |
| | $D^{-}$ | 0.3697 | 0.2954 | 0.3078 | 0.3025 | 0.3278 | 0.3253 |

Table 12. TOPSIS method evaluation results based on analytical hierarchy process weighting.

| Evaluation result | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|
| Pressure system | Slightly morbid | Slightly morbid | Slightly morbid | Slightly morbid | Slightly morbid | Slightly morbid |
| State system | Sub-healthy | Sub-healthy | Sub-healthy | Sub-healthy | Sub-healthy | Sub-healthy |
| Response system | Healthy | Sub-healthy | Sub-healthy | Sub-healthy | Sub-healthy | Sub-healthy |
| Total | Sub-healthy | Sub-healthy | Sub-healthy | Sub-healthy | Sub-healthy | Sub-healthy |

water level 1-10 June, the proportion of water level lower than 13 m in October, number of birds, rate of soil erosion control in healthy state, rate of polluted rivers, oncomelania hupensis area, woodland coverage rate, the probability with monthly average water level at 10-19 m in Xingzi station, water quality in dry season, water quality in wet season, and proportion of water funds total investment accounting for GDP are in healthy state. Based on the above analysis, the ecological health of Poyang Lake in 2008 is in a healthy state, and the results obtained by the evaluation methods used in this paper are reasonable.

## Conclusions

Much is involved in a health evaluation of wetland ecosystems. To make ecological-economic-social elements better combined in evaluation, this paper adopts the "Pressure-State-Response" (PSR) model to structure a set of indicator systems of health evaluation on the Poyang Lake ecosystem wetland which is complete of strong operability. The weight values of subsystem indicators are determined through separate evaluations of pressure, state, response of ecosystem of Poyang Lake wetland, and analysis on the interaction between the three adopting analytical hierarchy processes, and the consistency check is passed. Substitute the weight value into the TOPSIS model, calculate the Euclidean distance between programs and the ideal alternative. Through a comparison between the approach degree of ideal alternatives in 2008-13 and that of 5 evaluation grades and ideal alternatives, the health states in 2008-13 are finally determined as: sub-healthy, sub-healthy, sub-healthy, sub-healthy, sub-healthy, and sub-healthy.

According to analysis of results of the evaluation, the natural habitat of Poyang Lake wetland is largely affected by human disturbances such as urbanization, tourism development, operation of the Three Gorges Project, and pollution of surrounding lake regions. At present it is the lack of sufficient and reasonable management and protection that results in Poyang Lake wetland's inability to maintain its normal state or play its normal ecological role. To solve these problems, it is difficult to completely recover the damaged wetland ecological environment of Poyang Lake naturally. Artificial means and measures must be taken to promote the recovery and reconstruction of the wetland ecosystem. In order to improve the health level of Poyang Lake wetland ecosystem, the following regulation countermeasures are put forward:

(1) Bring water pollution under control and improve assurance rate of water resources. Effective purification of the water inflowing into the lake can effectively control the amount of pollutants into the lake, thus improving the water environment quality of Poyang Lake water gradually.

(2) Restore natural wetland. To solve the serious problems for Poyang Lake wetland caused by human interference, it is suggested to reduce human disturbance, take appropriate recovery mode to regions with the value of restoration, and restore the structure and function of the natural ecosystem of the wetlands.

(3) Increase investment in environmental protection and enhance ecosystem management. Increase funding of wetland protection, and strengthen scientific research in wetland restoration. In aspects of wetland management, further straighten out the management relations, perfect related laws and regulations, comprehensively improve law enforcement, strengthen wetland ecological protection publicity and education, and raise environmental awareness and public participation enthusiasm.

This paper specifically discusses the health of the ecosystem of Poyang Lake wetland, providing referable examples for health evaluation on wetland ecosystem and protection and recovery work. However, due to a variety of reasons, there are still some inadequacies in this study. To continuously deepen the study on Poyang Lake wetland ecosystem health, perfect the indicator system, combining with the actual issue of the study object, the author believes that further discussion on aspects of indicator system of wetland ecosystem health evaluation, health test, and research method, analysis on influencing factors of health of wetland ecosystem, etc., shall be made.

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