ISSN: 2688-9323

Research on Evaluation of Ecological Carrying Capacity in Chaohu Area based on TOPSIS Model

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Abstract

This paper constructs an evaluation index system of the ecological carrying capacity for the Chaohu Lake area based on relevant theories and following certain principles. Secondly, the entropy weight method was used to determine each index's weights, and the TOPSIS model calculated the ecological carrying capacity from 2010 to 2020. According to the empirical result, the overall ecological carrying capacity of the Chaohu Lake area is on the rise.

Keywords

Ecological Carrying Capacity; Evaluation Index; Entropy Weight Method; TOPSIS Model.

1. Introduction

Ecological carrying capacity refers to the ability of an ecosystem to self-sustain, self-regulate and restore its own homeostasis. The concept reflects the amount of human social activity that ecosystems can sustain and that ecosystems are influenced by people's value choices, social goals and responses. Carrying capacity was originally introduced into ecology by Park and Burgess (1921), who defined carrying capacity. Over time, academic research on carrying capacity has begun to focus on the entire ecosystem rather than on a single element, a change resulting from the definition of *ecological footprint* by Rees (1990) and Wackernagel (1997). Odum (1996) studied ecosystems and economic systems, analyzed both systems' characteristics using energy value analysis, and further explored the current state of ecological carrying capacity[1]. Hubacek and Giljum (2003) combined the input-output analysis method and ecological footprint model to improve the accounting model of ecological carrying capacity. Brigolin (2008) used an analytical model to study the relationship between cultured shellfish production capacity and ecological carrying capacity concerning the spatial distribution of shellfish density in the permit area[2]. Tairong He et al. (2009) analyzed the impact of urbanization on ecological carrying capacity based on the model of ecological footprint method[3]. Lee (2013) assessed the environmental sustainability and considered the carbon carrying capacity in the process of assessing[4]. Outeiro(2018) used the estuarine bay where mussel farming and artificial fishery practices are conducted as the study area and used ecological modeling with ecological pathway software to calculate the current ecological carrying capacity. [5].

Through reviewing the relevant literature, it can be seen that scholars have conducted more research on ecological carrying capacity, and there are various research methods. However, less literature includes the evaluation model that considers natural, climatic, resource, environmental, and socio-economic factors.

2. Construction of the Indicator System

2.1. Principles for the Construction of the Indicator System

The data in this article comes from Anhui Provincial Statistical Yearbook, China Environmental Statistical Yearbook, Anhui Provincial Statistical Bulletin, and public government websites from

ISSN: 2688-9323

the year 2010–2020. In ecological carrying capacity evaluation, the selection of indicators is significant, related to the reliability and accuracy of the evaluation results. In order that the selected indicators can fully reflect the ecological carrying capacity of the central region, this paper should be based on the following principles: scientific principle, feasibility principle, comprehensiveness principle, and dynamicity principle.

Scientific principle: the selection and processing of indicators should be scientifically based, and a scientific attitude is necessary for selecting indicators and processing data; In addition, both the calculation and definition of indicators need to be supported by scientific principles.

Feasibility principle: the setting of evaluation indicators should be easy to understand and easy to operate, especially to be close to the actual work, especially to choose those indicators that can grasp first-hand information through the actual survey, or through intuition can draw conclusions.

Comprehensiveness principle: ecological carrying capacity is a comprehensive system covering natural, resource, environmental, social, and economic aspects. It is necessary to consider when choosing evaluation indicators that can comprehensively characterize the ecological carrying capacity of the central region.

Dynamicity principle: the condition of wetland resources is changing dynamically, and the condition of the same wetland resources can show significant differences at different times. Furthermore, the environmental pressures reflected by different resource conditions and the response behaviors adopted to alleviate them differ, which requires the evaluation index system to describe the environmental pressure and the response behavior of the wetland, which requires a certain degree of flexibility in the evaluation index system based on the ability to describe objective reality.

2.2. Indicators System

This paper constructs an evaluation index of the ecological carrying capacity for the Chaohu Lake region from four subsystems: ecological resilience, resource carrying capacity, environmental carrying capacity, and socio-economic adjustment capacity. Details of indicators are shown in Table 1.

Table 1. Indicator's system

Subsystems	Indicators
Ecological resilience	Average annual precipitation
	Annual sunshine duration
	forest coverage
resource carrying capacity	per capita water resources
	farmland areas per person
	public green space area per capita
	per capita output of grain
environmental carrying capacity	volumes of industrial wastewater discharged
	industrial so_2 emissions
	industrial fumes emission
	sewage treatment rate
socio-economic adjustment capacity	GDP per capita Engel coefficient of urban households
	Engel coefficient of rural households
	Thousands of people with health technicians

ISSN: 2688-9323

3. TOPSIS Evaluation Model

3.1. Preliminary Analysis

Assuming that the sample size of the study in this paper is m and the number of indicators is n, construct the original evaluation indicator matrix as follows:

$$X_{ij} = \begin{Bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m} & \cdots & x_{mn} \end{Bmatrix} \tag{1}$$

where X_{ij} is the initial value of the jth indicator of the i-th sample.

Data are generally not directly comparable because the units of the collected data are not necessarily the same. Therefore, to make the data comparable and eliminate the effects caused by the difference in the data's magnitude, the data should be dimensionless. In this paper, the data are dimensionless for different data types, and the processing method is normalization. The situation reflected by different index values is different; some index values are larger, the better the situation reflected, and vice versa; some index values are smaller, the better the situation reflected. The formula of normalization is as follows:

$$S_{ij} = \frac{(X_{ij} - \min_{1 \le j \le n} {}_{ij})}{(\max_{1 \le j \le n} X_{ij} - \min_{1 \le j \le n} X_{ij})} \times 0.998 + 0.002 \tag{2}$$

3.2. Weights Calculation

Although there are more methods to determine index weights in academia, the entropy weighting method has been widely recognized for its objectivity and comprehensiveness. The entropy weight method is a method to determine indicator weights objectively, and its calculation of weights is based on the size of the information reflected by the indicators. The entropy value is used to measure uncertain things. The more information reflected by the indicator will reduce the uncertainty of things, then the entropy will be smaller, which will have a certain impact on the system's structure and make it more unbalanced; the smaller the entropy value will make the difference coefficient bigger. Naturally, the indicator's weight will be heavier, and vice versa is also this reason. The process of calculation is as follows:

Firstly, the weight of indicator j in sample i is calculated by the following formula:

$$Y_{ij} = \frac{S_{ij}}{\sum_{i=1}^{m} S_{ij}} \tag{3}$$

Secondly, the information entropy of the jth indicator is calculated by the following formula:

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{m} Y_{ij} \times \ln Y_{ij} \tag{4}$$

Thirdly, the entropy redundancy of the jth indicator is calculated by the following formula:

$$d_j = 1 - e_j \tag{5}$$

Finally, calculate the weight of the jth indicator with the following formula:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6}$$

Based on the above steps, the weights of each indicator within the index system can be derived.

3.3. TOPSIS Analysis

TOPSIS method is a comprehensive evaluation method proposed by Hwang and Yoon, which is similar to the algorithm of merit search. Firstly, the original evaluation matrix is determined. The data is dimensionless to derive the normative matrix. The weighting matrix is derived by combining the index weights. The positive ideal best solution and the negative ideal worst solution are found based on the existing solutions. The distance between the evaluation object and these two solutions is calculated separately. The distance between the object and these two solutions is calculated, and finally, the closeness to the positive ideal solution is used as the evaluation basis. The calculation process of the TOPSIS method is as follows:

Firstly, the vector norm method is used to find the normed decision matrix:

$$Y = \{y_{ij}\} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{7}$$

Secondly, calculate the weighted norm matrix:

$$Z = \{z_{ij}\} = w_j \times y_{ij} \tag{8}$$

Thirdly, determine the ideal solution z_j^* and the negative ideal solution z_j^0:

$$z_j^* = \max_i z_{ij} \tag{9}$$

$$z_j^0 = \min_i z_{ij} \tag{10}$$

Fourthly, calculate the distance d_i^* from each solution to the ideal solution and the distance d_i^0 to the negative ideal solution:

$$d_i^* = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_j^*)^2} \tag{11}$$

$$d_i^0 = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_j^0)^2} \tag{12}$$

Finally, calculate the closeness of each scenario to the ideal solution C_i^*:

$$C_i^* = \frac{d_i^0}{d_i^0 + d_i^*} \tag{13}$$

ISSN: 2688-9323

Based on the closeness of each scheme, the order of merit of each scheme can be judged. The larger the value is, the greater the ecological carrying capacity and the smaller the value is, the smaller the ecological carrying capacity.

4. Empirical Analysis

This paper determines the weights of each index under the indicator system by the entropy weight method and derives the closeness of each central province each year according to the TOPSIS model to characterize the ecological carrying capacity score MatLab, as seen in table 2.

Table 2. Ecological carrying capacity score

Year	Ecological carrying capacity score
2010	0.2122
2011	0.2150
2012	0.2207
2013	0.2319
2014	0.2642
2015	0.2761
2016	0.2847
2017	0.3014
2018	0.3079
2019	0.3125
2020	0.3211

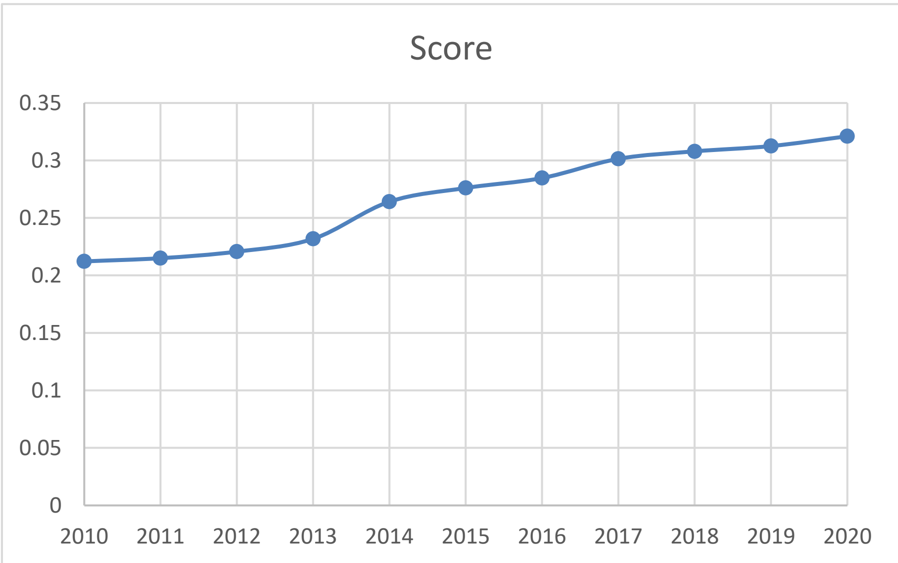

Figure 1. Ecological carrying capacity score

From Table 2 and Figure 1, it can be seen that the overall ecological carrying capacity of the Chaohu Lake area is on the rise. The score in 2010 is the lowest, and 2020 is the highest. Chaohu area attaches great importance to ecological, environmental protection, upholds the critical concept that green water and green mountains are the silver mountain of gold, and advocates the harmonious coexistence of man and nature. In recent years, the government has raised awareness of wetland protection, optimizing land use, establishing nature reserves and wetland parks, and rationalizing water resources.

5. Conclusion

This paper firstly establishes the evaluation index system of the ecological carrying capacity in the central region. It calculates the ecological carrying capacity and the scores of each subsystem of each central province from 2010 to 2020 by combining the entropy weight method and the TOPSIS model. According to the empirical results, the overall ecological carrying capacity of the Chaohu Lake area is on the rise.

In determining the index weights, the entropy method used in this paper can objectively reflect the relative importance of different indexes but omits subjective factors, which should be combined with subjective methods in future research to improve the accuracy of index weights.

Acknowledgments

This work is supported by Anhui Philosophy and Social Science Planning Project (AHSKQ2021 D176).

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