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Original Research

Comprehensive Assessment of Marine Ecological Environment Based on Entropy Weight Model

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Abstract

In order to overcome the defects of stronger subjectivity of common assessment methods of marine ecological environmental assessment, the entropy weight model was introduced. In the comprehensive assessment, because of different influence degrees of each index to the comprehensive assessment results, different improved measures can be adopted to increase policy ability. As Shannon information entropy has the advantages of objectivity and adaptability in determining weight value, it was applied to determine the weight value of each index in the comprehensive assessment model. Then the optimal and worst indexes were selected based on a double base point model. Through comparing the distance between the scheme point and double base points, the result of comprehensive assessment can be obtained. Then the model was employed to assess the ecological environment of a bay of China. Application results show the efficiency of this method.

Keywords: marine ecological environment, entropy, Shannon information entropy, double base point; assessment model

Introduction

With the continuous development of marine economy, increasing deteriorative marine ecological environmental problems become a serious barrier for sustainable development of humans and the economy [1-4]. From then, the concept of development starts to be reflected gradually. Marine ecological environments also are being given more and more attention [5-8]. Therefore, how to protect marine environments effectively turns into an important and difficult problem people have to face [9-13]. In order to reflect the status of marine ecology and environments effectively, marine environmental monitoring has to come into effect. And an appropriate method should be employed to analyze and evaluate the data acquired through marine environmental monitoring. Then, through analysis and assessment, the status of the marine ecological environment can be shown. It offers a necessary and valuable reference for sustainable development of humans and the economy. And improved measures based on the result of comprehensive assessment can be adopted to manage and protect marine ecological environments.

Today common methods and models are applied to evaluate marine ecological environments. But most methods rely on stronger subjectivity and experiences in determining weight value. The objectivity and accuracy of weight value didn't avoid to be influenced. Thus, assessment results from different researchers are always full of uncertainty. Therefore, we have to find an effective comprehensive method for the assessment of marine ecological environments, which has the characteristics of objectivity, simple operation, and little interference.

Here, the entropy method was employed in the assessment of marine ecological environments. And Shannon information entropy, which is an objective and applicable method for the determination of weight value [14-16], was introduced into the comprehensive assessment. It can calculate weight value of each index more effectively in the comprehensive assessment of marine ecological environments. In the application of Shannon information entropy

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method, the greater entropy weight indicates greater variation extent of relevant index, provides much more information, and has a greater effect. So, weight value of the corresponding index also should be bigger. In contrast, for the smaller entropy weight which has little effect, its weight value should be smaller.

The structure of this paper is as follows: we first briefly introduce the importance of marine ecological environmental assessment and clearly point out the advantages of the method employed. Then the comprehensive assessment model of a marine ecological environment based on entropy method was introduced. In the following part, we focus on the application of the model in practice. Finally, through the application in the assessment of marine ecological environment, we show the effectiveness and feasibility of the method.

Entropy Weight Model and Double Base Method

Entropy, which used to be a thermodynamic concept, was introduced into information theory in 1948 by C. E. Shannon, who put forward the concept of information entropy to measure the level of system chaos or disorder. The double base point method can be employed to solve the problems of assessment and rank for a multi-index scheme [14, 17, 18]. In the assessment, a set of optimal index data selected based on the characters and data of index were seen as an ideal point. A set of worst index data selected based on the characters and data of index were viewed as the anti-ideal point. So, double base points refer to ideal point and anti-ideal point. Then, through comparing the distance between scheme point and double base points, the advantages and disadvantages of assessment scheme were acquired [18].

Data Standardization

Suppose the research plan is x_{ij} (i=1, 2,..., n; j=1, 2,..., m). It denotes that there are i samples and j indexes in the research plan. Based on appraisal target characteristics, the indexes are divided into the benefit type, cost type, and stationary indexes. The benefit-type indexes are the indexes whose values are the bigger the better. The cost-type indexes refer to the indexes whose values are the smaller the better. The stationary-type indexes are the indexes whose values are constant.

For the-benefit type indexes, standardization is as follows:

$$y_{ij}=\frac{x_{ij}-\min x_{ij}}{\max x_{ij}-\min x_{ij}} \tag{1}$$

For the cost-type indexes, standardization is:

$$y_{ij}=\frac{\max x_{ij}-x_{ij}}{\max x_{ij}-\min x_{ij}} \tag{2}$$

...where, $\max x_{ij}$ and $\min x_{ij}$ are the maximum and minimum values in the index j, respectively.

For the stationary factors, the standardization is:

$$y_{ij}=1-\frac{x_{ij}-x_{ij}^{*}}{\max\left|x_{ij}-x_{ij}^{*}\right|} \tag{3}$$

...where, x_{ij}^{*} is the best stable value in index j.

After the standardized processing, the standard matrix $y=(y_{ij})_{n\times m}$ can be obtained.

Determination of Entropy Weight

Suppose the weight vector of m targets is:

$$w=(w_1,w_2,\cdots,w_m),0\le w_j\le 1 \tag{4}$$

In order to determine weight values effectively, Shannon information entropy is introduced:

$$H=-\sum_{J=1}^{M} w_j \ln w_j \tag{5}$$

Through the equation of information entropy, it can bring to our knowledge a double-plan question. It should be transferred to a single objective mathematics model to make calculation easy. Then the established single objective mathematics model is as follows:

$$\min u\sum_{i=1}^{n} w_j(1-y_{ij})+(1-u)\sum_{j=1}^{m} w_j \ln w_j \tag{6}$$

Where, u is the equilibrium coefficient between two goals and $0 < u < 1$.

Then the Lagrangian function was employed to solve this model. Establishing the Lagrangian function based on (5) is as follows:

$$\begin{aligned}L(w,\lambda)&=u\sum_{i=1}^{n}\sum_{j=1}^{m} w_j(1-y_{ij})+\\&(1-u)\sum_{j=1}^{m} w_j\ln w_j-\lambda(\sum_{j=1}^{m} w_j-1)\end{aligned} \tag{7}$$

After solving (7) based on necessary conditions of extreme value existence, the weight model can be obtained:

$$w_j=\frac{\exp\{-[1+u\sum_{i=1}^{n}(1-y_{ij})/(1-u)]\}}{\sum_{j=1}^{m}\exp\{-[1+u\sum_{i=1}^{n}(1-y_{ij})/(1-u)]\}} \tag{8}$$

Double Base Point Model

Suppose d_i^+ is the distance between the scheme point and the ideal point, and d_i^- is the distance between the scheme point and anti-ideal point. According to the expression of Hamming distance, d_i^+ and d_i^- can be solved as follows:

$$d_i^+=\sum_{j=1}^{m} w_j(y_{ij}-y_{+j})^{\frac{1}{2}}=\sum_{j=1}^{m} w_j(1-y_{ij}) \tag{9}$$

Table 1. Comprehensive assessment indexes and monitoring points of Dalian Bay.

Assessment index	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Suspended matter (mg/L)	6	7	7.7	6.4	6.3	6.1
Petroleum (mg/L)	0.0205	0.036	0.0205	0.018	0.0095	0.0105
Inorganic nitrogen (mg/L)	0.4795	0.465	0.4065	0.04685	0.195	0.06625
Active phosphate (mg/L)	0.0119	0.2515	0.02515	0.01	0.0077	0.0021
Dissolved oxygen (mg/L)	10.2	9.85	9.76	9.81	9.78	9.92
Salinity (mg/L)	31.5	31.3	31.3	31.5	31.4	31.6
Cu (ug/L)	32.1	45.7	36.2	27.8	22.6	32.3
Pb (ug/L)	39.5	42.1	37.1	39.8	42.5	47.8
Zn (ug/L)	103.5	87.5	92.3	83	121.5	78.5
Cd (ug/L)	0.61	0.87	0.96	1.32	0.81	0.77
Organic carbon (ug/L)	2400	3300	2100	2600	1700	1600
Sulfide (ug/L)	874	550	969	1349	448	525
Diversity index of phytoplankton	2.46	2.24	1.99	2.42	2.48	1.47
Diversity index of zooplankton	3.16	2.68	2.42	2.33	2.72	1.98
Diversity index of benthos	0.996	1.192	2570	3.348	3.1699	3.736
Total bacteria (ind/L)	23000	17000	14000	20000	16000	13000
Organism residue	0.234	0.205	0.147	0.356	0.127	0.109

$$d_i^- = \sum_{j=1}^{m} w_j (y_{ij} - y_{-j})^{\frac{1}{2}} = \sum_{j=1}^{m} w_j y_{ij} \quad (10)$$

...where y_{+j} is maximum value of index j among n assessment samples.

$$y_{+j} = \max(y_{1j}, y_{2j}, \cdots, y_{nj}) \quad (11)$$

In contrast, y_{-j} is the minimal value of index j among n assessment samples.

$$y_{-j} = \min(y_{1j}, y_{2j}, \cdots, y_{nj}) \quad (12)$$

In order to compare the distance between the scheme point and double base points, we can define:

$$T_i = d_i^+ / d_i^- \quad (13)$$

...where T_i is the relative quality level of scheme i.

Comprehensive Assessment of Marine Ecological Environment

In order to show the possibility and effectiveness of the method proposed, the comprehensive assessment model was employed to evaluate the marine ecological environment of Dalian Bay [19]. The monitoring points and data are the same as [19]. The comprehensive assessment indexes and monitoring points of Dalian Bay are shown in Table 1.

Table 2. Weight value of each index.

Assessment index	Weight value
Suspended matter (mg/L)	0.0816
Petroleum (mg/L)	0.0716
Inorganic nitrogen (mg/L)	0.0264
Active phosphate (mg/L)	0.1954
Dissolved oxygen (mg/L)	0.0089
Salinity (mg/L)	0.0445
Cu (ug/L)	0.0454
Pb (ug/L)	0.0553
Zn (ug/L)	0.0697
Cd (ug/L)	0.0600
Organic carbon (ug/L)	0.0177
Sulfide (ug/L)	0.0375
Diversity index of phytoplankton	0.1055
Diversity index of zooplankton	0.0236
Diversity index of benthos	0.0429
Total bacteria (ind/L)	0.0071
Organism residue	0.0767

Table 3. Relative quality level.

T_i	T_1	T_2	T_3	T_4	T_5	T_6
Value	0.5603	0.6626	0.2275	1.4341	0.0526	0.3341

So the policy-making matrix is:

$$x_{6\times17}=\begin{Bmatrix} 6 & 0.0205 & 0.4795 & 0.0119 & 10.2 & 31.5 & 32.1 & 39.5 & 103.5 & 0.61 & 2400 & 874 & 2.46 & 3.16 & 0.996 & 23000 & 0.234 \\ 7 & 0.036 & 0.465 & 0.2515 & 9.85 & 31.3 & 45.7 & 42.1 & 87.5 & 0.87 & 3300 & 550 & 2.24 & 2.68 & 1.192 & 17000 & 0.205 \\ 7.7 & 0.0205 & 0.4065 & 0.02515 & 9.76 & 31.3 & 36.2 & 37.1 & 92.3 & 0.96 & 2100 & 969 & 1.99 & 2.42 & 2570 & 14000 & 0.147 \\ 6.4 & 0.018 & 0.04685 & 0.01 & 9.81 & 31.5 & 27.8 & 39.8 & 83 & 1.32 & 2600 & 1349 & 2.42 & 2.33 & 3.348 & 20000 & 0.356 \\ 6.3 & 0.0095 & 0.195 & 0.0077 & 9.78 & 31.4 & 22.6 & 42.5 & 121.5 & 0.81 & 1700 & 448 & 2.48 & 2.72 & 3.1699 & 16000 & 0.127 \\ 6.1 & 0.0105 & 0.06625 & 0.0021 & 9.92 & 31.6 & 32.3 & 47.8 & 78.5 & 0.77 & 1600 & 525 & 1.47 & 1.98 & 3.736 & 13000 & 0.109 \end{Bmatrix}$$

Then the standard matrix $y=(y_{ij})_{6\times17}$ can be determined based on equations (1-3):

$$y_{6\times17}=\begin{Bmatrix} 1 & 0.5849 & 0 & 0.9607 & 1 & 0.3333 & 0.5887 & 0.7757 & 0.4186 & 1 & 0.4706 & 0.5272 & 0.9802 & 1 & 0 & 0 & 0.4939 \\ 0.4118 & 0 & 0.0335 & 0 & 0.2045 & 1 & 0 & 0.5327 & 0.7907 & 0.6338 & 1 & 0.8868 & 0.7624 & 0.4068 & 0.0715 & 0.4 & 0.6113 \\ 0 & 0.5849 & 0.1687 & 0.9076 & 0 & 1 & 0.4113 & 1 & 0.6791 & 0.5070 & 0.2941 & 0.4218 & 0.5149 & 0.3729 & 0.5745 & 0.1 & 0.8462 \\ 0.7647 & 0.6792 & 1 & 0.9683 & 0.1136 & 0.3333 & 0.7749 & 0.7477 & 0.8953 & 0 & 0.5882 & 0 & 0.9406 & 0.2966 & 0.8584 & 0.7 & 0 \\ 0.8235 & 1 & 0.6576 & 0.9775 & 0.0455 & 0.6667 & 1 & 0.4953 & 0 & 0.7183 & 0.0588 & 1 & 1 & 0.6271 & 0.7934 & 0.3 & 0.9271 \\ 0.9412 & 0.9623 & 0.9552 & 1 & 0.3636 & 0 & 0.5801 & 0 & 1 & 0.7746 & 0 & 0.9145 & 0 & 0 & 1 & 0 & 1 \end{Bmatrix}$$

Here, suppose u=0.5, according to equation (8), the weight vector of m targets can be obtained. The weight value of each index is shown in Table 2.

So the distances between scheme point and double base points can be determined according to equations (9-13). Relative quality level of the scheme i T_i was shown in Table 3.

Obviously, we can obtain the result of comprehensive assessment of the marine ecological environment of Dalian Bay according to the table above. The result of comprehensive assessment was shown in Table 4.

Calculation and analysis above indicated that the quality of marine ecological environments near the shore was obviously better than far offshore. Based on the above-mentioned factors, we could realize that the coast of Dalian Bay had been seriously polluted. And the assessment result matched the actual situation. In these assessment indexes, biological index was the most important influence factor, which indicated water exchange ability was poor. Emission of industrial waste water causing water body eutrophication became the problem Dalian had to be eager to solve. So, in order to protect marine ecological environments in this sea area, some effective measurements must be adopted to control the emission of pollutants.

Table 4. Result of comprehensive assessment.

Monitoring point	Order of quality
No. 1	4th
No. 2	5th
No. 3	2nd
No. 4	6th
No. 5	1st
No. 6	3th

Conclusions

The assessment of a marine ecological environment has important significance in theory and practice. And it is also an important basic for realizing the status of marine ecological environments. In order to overcome the disadvantages of stronger subjectivity for existing evaluation methods, the entropy method was employed to evaluate objectively and effectively the status of marine ecological environments. In this method, based on different influence degrees of each index to comprehensive assessment offered, the different measurements can be adopted. Then the feasibility and practicability of policy can be improved. The study provides an effective method for the assessment of marine ecological environments and other fields.

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