An Evaluation Mechanism Based on Ability of Ecosystem Services

Shiyin Zeng

Department of Electrical Engineering, North China Electric Power University, Baoding 71000, China

437682520@qq.com

Keywords: Ecosystem services, Evaluation system, FA, GRA, EWM, FCA

Abstract: With the continuous development of the society, people are suffering from the deterioration of ecology. To alleviate the crisis, we establish an evaluation system based on the ability of the ecosystem services. In order to establish a three-class indicator system with the Ecosystem Service Index (ESI) as the core, we use Factor Analysis (FA) to determine 4 second-class indicators and 15 third-class indicators, as well as the weights of the second-class indicators. Then, we adopt the combined weight model of Grey Relational Analysis (GRA) and Entropy Weight Method (EWM) to compute the weights of 15 third-class indicators. In addition, Fuzzy Cluster Analysis (FCA) is used to measure the ability of the ecosystem services by setting corresponding standards. Above all, the model can be used to make quantitative analysis and qualitative evaluation to assess the overall situation of the ecosystem, which has strong practical guiding significance.

1. Introduction

Ecosystem services refer to life-supporting products and services obtained directly or indirectly through the structure, processes and functions of ecosystems [1]. Arthur Tansley first proposed the concept of ecosystems in 1935, and people began to understand the Earth's ecosystem [2]. In 1970, the Study of Critial Environment Problems (SCEP) proposed the concept of environmental service functions [3]. In 1997, Daily and Costanza re-elaborated the connotation of ecosystem services. Daily defined ecosystem services as the conditions and processes of maintaining the ecosystem environment for human existence from the ecological perspective [4]. And Costanza defined ecosystem services as the benefits that human beings obtain directly or indirectly from ecosystem functions from the economical perspective [5]. In 2001, the United Nations launched the " Millennium Ecosystem Assessment Project" (MA), summarizing ecosystem services as " all benefits that human beings derive from ecosystems" and placing more emphasis on the impact of ecosystem services on human well-being[6]. Based on the relevant literature and research practice at home and abroad, this study first determines the key role played by a perfect evaluation system in the evaluation environment, and then establishes a three-level evaluation system with the Ecosystem Service Index ESI as the core index, in which the combined weight model of Grey Relational Analysis (GRA) and Entropy Weight Method (EWM) is creatively used to calculate the weight of the three-level indexes. Finally, the intuitive criteria are determined by Fuzzy Cluster Analysis (FCA).

2. The Ecosystem Service Index Model

Over the past 50 years, humans have changed these ecosystems more rapidly and extensively than in any comparable period of time in human history. The degradation of ecosystem services is already a significant barrier to achieving the Millennium Development Goals.To support green development, there is an urgent need to improve ecosystem services evaluation approach [7].

In this section, we construct ESI as a measurement indicator, which represents the comprehensive ability of ecosystem to provide services. And the higher the ESI is, the greater ability the ecosystem has to provide services.

2.1 Model Construction by Factor Analysis

After consulting a number of relevant references, 68 indicators are initially identified to measure the capacity of ecosystem services, covering the atmosphere, land, water and other aspects of the ecosystem.

In the model, Factor Analysis is used to reduce the number of major indicators because these indicators may be correlated to some extent, thus affecting the accuracy of the evaluation. So we select 30 ecosystems of different scales all over the world. We first standardize the original data. Then we calculate the correlation coefficient matrix of the original variables, generating an elementary load matrix.

Based on the processes above, we select six major factors and calculate the rotation factor contributions and the cumulative contribution rates. Four main factors among them are selected to be second-class indicators, which can be shown in the Table 1. Finally, reasonable factor explanations are given through factor rotation and factor scores are calculated for comprehensive evaluation.

Table 1. Framework of sustainability indicators

Major factors	Third-class indicators	Abbrev-iation	Explanation
F_1	Water quantity	WQ	It represents the amount of water in a certain area.
	Forest products	FP	It refers to the total amount of all forest-related products.
	Mineral quality	MQ	It denotes the total amount of minerals in a certain area.
	Marine products	MP	It is defined to measure the richness of resources in the ocean.
F_2	Water quality purification	WQP	It is defined to measure the ability of water to purify itself.
	Water conservation	WC	It reflects the ability to manage the natural resources of fresh water.
	Climate regulation	CR	The processes which regulate atmosphere and weather patterns are represented by the indicator.
	Carbon fixation	CF	It represents the conversion process of carbon dioxide to oxygen by living organisms.
	Atmospheric regulation	AR	It refers to the ability to ensure the stability of its own atmospheric composition.
F_3	Biodiversity conservation	BC	It denotes the conservation of species within their natural habitats.
	Soil retention	SR	It refers to the ability of soil to maintain fertility.
	Land reclamation	LR	It represents the process of creating new land from oceans, riverbeds, or lake beds.
F_4	Travel and leisure	TAL	It refers to recreational experiences related to the ecosystem.
	Scientific research and education	SRAE	It indicates the use of ecosystem for school excursions and scientific discovery.
	Artistic creation	AC	It reflects the use of nature as films, paintings, national symbols, architecture, etc.

From the indicators listed in the Tab.1, we can find that results above are similar to the classification of ecosystem services in the references. Combined with Millennium Ecosystem

Assessment [8, 9], we select the second-class indicators and the explanations are as follows:

- F_1: Provisioning Service Index(PSI)

This indicator is used to measure the overall ability of the ecosystem to supply materials, including raw materials for life and production such as food, medicine and energy, etc.

- F_2: Regulation Service Index(RSI)

This indicator is adopted to evaluate the ability of the ecosystem to maintain various cycles and balances of various indicators through a series of physical and chemical processes, including water cycle balance and temperature balance, etc.

- F_3: Maintenance Service Index(MSI)

This indicator is used to evaluate the ability of ecosystem to form the necessary environmental conditions for human survival [10], which includes nutrient circulation to maintain the living environment of life on Earth and biodiversity, etc.

- F_4: Cultural Service Index(CSI)

This indicator makes a judgment on whether the ecosystem can meet the higher level of human spiritual needs, covering all services related to entertainment, science technology and education, etc.

2.2 Weighting Models of Evaluation Indicators

Weighting models are of vital importance to evaluate the contributions of indicators. Therefore, to calculate the weights of 15 third-class indicators, we choose to use the combined weight model of Grey Forecasting Model and Entropy Weight Method.

2.2.1 Weights determined by Grey Relational Analysis

Grey Relational Analysis (GRA) is a method which uses grey correlation degree to measure the correlation degree between factors. Because GRA is common, the processes of the calculation will not be given in this paper. We just show the results in the Table 2.

Table 2. Weights of third-class indicators by GRA

Provisioning Services	**WQ**	**FP**	**MQ**	**MP**
Weight	0.2643	0.2346	0.2704	0.2307

Regulation Services	**WQP**	**WC**	**CR**	**CF**	**AR**
Weight	0.2341	0.2264	0.1749	0.1595	0.2050

Maintenance Services	**BC**	**SWR**	**LR**
Weight	0.3476	0.3115	0.3408

Cultural Services	**TAL**	**SRAE**	**AC**
Weight	0.3370	0.3199	0.3431

2.2.2 Weights determined by Entropy Weight Method

The detailed processes of the weight determination by Entropy Weight Method (EWM) are as follows:

Step 1 Standardize the data

Suppose that K indexes $X_1, X_2, \cdots X_k$ are given and the normalized value for each index is $Y_1, Y_2, \cdots Y_k$. Then we can get that $Y_{ij} = \dfrac{X_{ij} - \min(X_i)}{\max(X_i) - \min(X_i)}$.

Step 2 Compute the information entropy of each index

The information entropy of a group of data can be defined as $E_j = -k\sum_{i=1}^{n} p_{ij} \cdot \ln p_{ij}$, where

$k = 1/\ln n$ and $p_{ij} = Y_{ij} / \sum_{i=1}^{n} Y_{ij}$. If p_{ij} equals to 0, then we obtain that $\lim_{p_{ij}\to 0} p_{ij} \cdot \ln p_{ij} = 0$.

Step 3 Determine the weight of each index

According to the calculation formula of information entropy, the calculated information entropy of each index is $E_1, E_2, \cdots E_k$. We can compute the weight of each index by information entropy, which can be showed as

$$W_i = \frac{1-E_i}{k-\sum E_i}(i = 1, 2, \cdots, k).$$

The actual weights of third-class indicators determined by EWM are showed in the Table 3.

Table 3. Weights of third-class indicators by EWM

Provisioning Services	**WQ**	**FP**	**MQ**	**MP**
Weight	0.2451	0.2475	0.2685	0.2389

Regulation Services	**WQP**	**WC**	**CR**	**CF**	**AR**
Weight	0.3779	0.3116	0.0962	0.0908	0.1235

Maintenance Services	**BC**	**SWR**	**LR**
Weight	0.3458	0.2983	0.3559

Cultural Services	**TAL**	**SRAE**	**AC**
Weight	0.3116	0.3443	0.3441

2.2.3 Combined weights of GRA and EWM [11]

Suppose that the weight determined by GRA is $W_1 = [w_{11} \quad w_{12} \quad \cdots \quad w_{1t}]$,where $0 \le w_i \le 1$ and $\sum_{i=1}^{t} w_{1i} = 1$ for $i = 1, 2, \cdots, t$.

Similarly, we also suppose the weight determined by EWM is $W_2 = [w_{21} \quad w_{22} \quad \cdots \quad w_{2t}]$, where $0 \le w_i \le 1$ and $\sum_{i=1}^{t} w_{1i} = 1$ for $i = 1, 2, \cdots, t$.

Then we get the combined weight

$$W = \alpha W_1 + \beta W_2, \tag{1}$$

Where $0 < W \le 1$ and $\alpha + \beta = 1$.

Since the combined weight is obtained from two weights above respectively, the corresponding expected value of the weight can be computed as follows:

$$\begin{cases} E(w_{1i}) = \sum_{s=1}^{l} w_{1i} & 1 \le i \le m \\ E(w_{2i}) = \sum_{b=l+1}^{l} w_{2i} & 1 \le i \le m \end{cases}. \tag{2}$$

By simplifying the formulas above, the expressions of α and β can be defined as

$$\begin{cases} \alpha = \dfrac{\sum_{i=1}^{n} \alpha_i}{\sum_{i=1}^{n} \alpha_i + \sum_{i=1}^{n} \beta_i} \\ \beta = \dfrac{\sum_{i=1}^{n} \beta_i}{\sum_{i=1}^{n} \alpha_i + \sum_{i=1}^{n} \beta_i} \end{cases} . \tag{3}$$

According to the formulas (2) and (3), we can know that α equals to 0.5 and β equals to 0.5. After substituting the coefficient sum into the formula (1), the combined weight can be defined as

$$W = 0.5 * W_1 + 0.5 * W_2 .$$

Through the combined weight model of GRA and EWM, the actual weights of the three-class indicator system can be shown in the Fig.1.

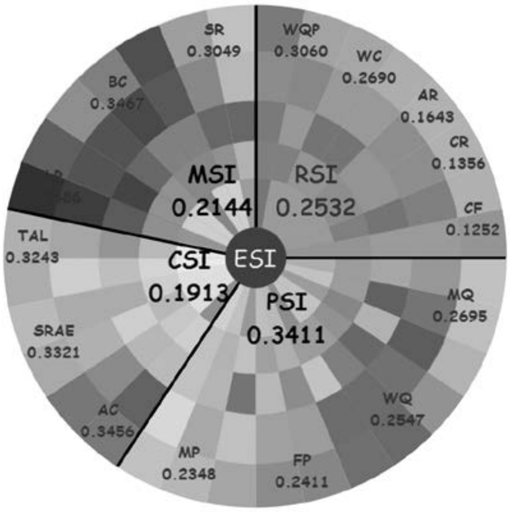

Figure 1. Weights of the three-class indicator system

2.3 Standard Setting Based on K-means Clustering Algorithm

Although we have used FA, GRA and EWM to establish the three-class evaluation system, we still need an appropriate standard to directly evaluate ESI. Therefore, K-means Clustering Algorithm (KA) is adopted for evaluation.

2.3.1 Basic steps of Fuzzy Clustering Analysis

Step1: Standardizing the data

In our model, different data has different properties and dimensions. Here we use the Translation-Standard Deviation Transformation Method, whose detailed processes are as follows:

$$x'_{ij} = \frac{x_{ij} - \overline{x}_j}{s_j} \quad \left(i = 1, 2, \cdots n, j = 1, 2, \cdots n\right).$$

Note that $\overline{x}_j = \frac{1}{n}\sum_{i=1}^{n} X_{ij}, s_j = \left[\frac{1}{n-1}\sum_{i=1}^{n}(x_{ij} - \overline{x}_j)^2\right]^{\frac{1}{2}} \left(j = 1, 2, \cdots m\right)$ and that x_{ij} denotes the observation value of the *j*-th index under the *i*-th classified object.

Step2: Establishing Fuzzy Similarity Matrix

Suppose that the similarity coefficient between x_i and x_j is $r_{ij} = R\left(e_i, e_j\right)$. Then it can be determined by the Angle Cosine Method whose formula can be defined as

$$r_{ij}=\frac{|\sum_{k=1}^{n}x_{ik}\cdot x_{jk}|}{\sqrt{\sum_{k=1}^{m}x_{ik}^2\cdot\sum_{k=1}^{m}x_{jk}^2}},(i,j=1,2,\cdots n).$$

Step3: Clustering

Based on the fuzzy similarity matrix R obtained from the Step 2, we construct a fuzzy equivalent matrix R^*. And by using the Flat Method, we figure out that $t(R)$ is the transitive closure of R and that $t(R)$ equals to R^*. Then, we take a group of λ for $\lambda\in[0,1]$ in descending order and determine the corresponding λ-section matrix, thus classifying these 30 ecosystems.

2.3.2 Results of KA

According to KA above, the setting of evaluation standards of ecosystem service ability are shown in the Fig.2:

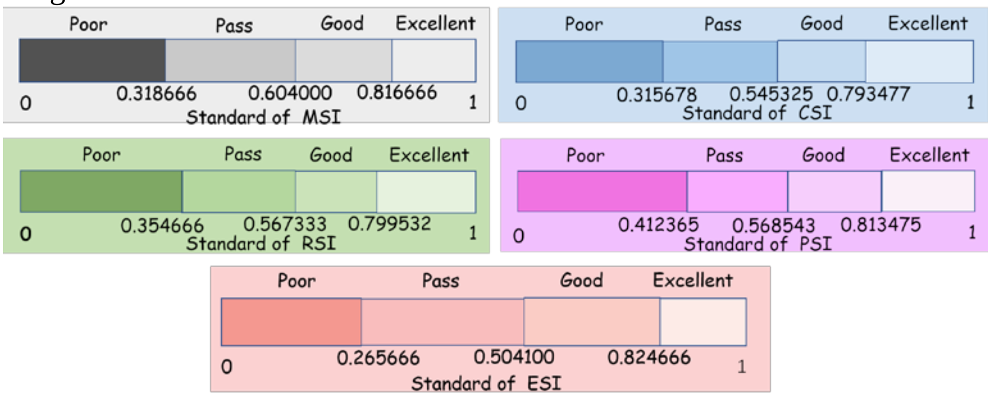

Figure 2. Evaluation standards of ecosystem service ability

3. Conclusion

To alleviate the crisis brought by environmental degradation to mankind, we established an evaluation system based on the ability of the ecosystem services including a three-class indicator system with the Ecosystem Service Index (ESI) as the core and corresponding standards. In conclusion, we can apply this method to practice, which is conducive to make quantitative analysis and qualitative evaluation.

References

[1] Zongming Wang, Bai Zhang, Shiqing Zhang. Study on the change of ecosystem service value in Jilin Province [J]. Journal of Natural Resources, 2014 (01): 55-61.

[2] Tansley A G. The Use and Abuse of Vegetational Concepts and Terms [J]. Ecology, 1935, 16 (3): 284-307.

[3] SCEP. Man's Impact on the Global Environment [M]. Cambridge: MIT Press, 1970.

[4] Daily G C. Nature's services: societal dependence on natural ecosystems [J]. Pacific Conservation Biology, 1997, 6 (2): 220-221.

[5] Costanza R, D'Arge R, Groot R D, et al. The value of the world's ecosystem services and natural capital [J]. Nature, 1997, 387 (15): 253-260.

[6] Lu Ting, Yao Juan. Current Status and Prospects of Ecosystem Service Value Evaluation Research [J]. Agricultural Outlook, 2018, 14 (04): 53-57.

[7] Yang, Q., Liu, G., Casazza, M., Campbell, E., Giannettia, B., Brown, M., December 2018.

Development of a new framework for non-monetary accounting on ecosystem services valuation. Ecosystem Services 34A, 37-54.

[8] Yanni Gao, Linbo Zhang, Kai Li. Study on Index System of Ecosystem Value Accounting [J]. Environmental science research, 2019, 32 (01): 58-65.

[9] De GROOTRS, ALKEMADER, BRAATL, et al. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making [J]. Ecol Complexity, 2010, 7 (3): 260-272.

[10] Huijing Ni, Wenhui Su. Advances in research on effects of nutrient input methods on soil nutrient cycling in forest ecosystems [J]. Journal of ecology, 2019, 01: 1-13.

[11] Xueying Bao, Hailian Li. Research on determination method of combined weight based on grey relational analysis and principal component analysis [J]. Practice and understanding of mathematics, 2016, 46 (09): 129-134.