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Article

Application of Fuzzy Analytic Hierarchy Process to Evaluate Resource Environmental Bear Capacity

Xijuan Shen [1] , Bang-Wen Jeang [2] , Xu Wu [3, *], Yongyi Lu [3, **], Chen Ling [3], Yee-Chaur Lee [4] , and Kun-Chi Chang [4]

[1] School of Architecture and Urban Planning, Suzhou University of Science and Technology, Suzhou 215000, China; SXJ_719@163.com

[2] College of Management, Guangdong University of Science and Technology, Guangdong, 523083, China; 2120385607@qq.com(B.-W.J.)

[3] School of Urban and Environmental Science, Huaiyin Normal University, China;

[4] College of Architecture and Design, Chung Hua University, Taiwan; joeychuc@yahoo.com.tw (Y.-C.L.) ; Keith230@hotmail.com(K.-C.C.)

* Corresponding Author: Email, Tel: * snow01212@163.com, +86-18662981078 (X.W.); ** luyongyi2000@foxmail.com (Y.L.), +8613218316039

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Abstract: Environmental resource is the foundation of the development of the economy in a society. As the contradiction between the economy and the resource is becoming more prominent, the bearing capacity of the environmental resource has received great attention from all sectors of society including the government. In the context of the "double evaluation" proposed by the national land spatial planning, many scholars have been studying the theory and methods of the bearing capacity of the environmental resource. In this study, we suggested the evaluation index, calculating the comprehensive weight at the structure level and the index level to yield the standardized result for the bearing capacity of the environmental resource using the fuzzy analytic hierarchy process.

Keywords: Bearing Capacity, Environmental Resource, Evaluation Index, Fuzzy Analytic Hierarchy Process

1. Introduction

China's spatial planning has gradually entered the stage of "resources management" planning in the period of stabilized urbanization [1,2]. Thus, the focus of spatial planning is shifting to "resource protection". The preparation of the space planning is proposed to carry out "dual evaluation": evaluation of the bearing capacity of environmental resources and the sustainable land-space development. The development of "dual evaluation" enables maintaining and securing regional ecology. According to Resource Scarcity Theory and Growth Pole Theory, human society must pay attention to resource and environment carrying capacity while pursuing economic growth. Resources and environment carrying capacity is an important way to comprehensively measure the coordination between population and resources and environment, as well as the sustainable economic development, which has a certain guiding role in the future regional sustainable development. This paper describes the weighted evaluation index of the bearing capacity of the environmental resource and provides a reference for improving the efficiency of resource utilization and achieving the efficiency of the national land spatial planning.

2. Literature Review

The bearing capacity of environmental resources refers to the ability of the system to be sustained for various social and economic activities of human beings under certain conditions within a certain period in a region [3–5]. It contains the degree of the mutual adaptation between the environmental resource and the types and scope of human economic and social activities. The research on the bearing capacity of the environmental resource mainly reflects the extensibility and the synthesis of the evaluation index system and the Spatio-temporal dynamics of the bearing capacity of environmental resources [6–8].

Bearing capacity is one of the common indicators to describe the degree of economic and social development in restricted areas. The evaluation of the bearing capacity of environmental resources includes that of land resources [1,9–13], water resources [14–16], and environment and disaster. With the background of the comprehensive assessment of the natural and ecological environment, the evaluation of the bearing capacity of environmental resources is the foundation of nationwide land development. It determines the bearing capacity of the land space in different functional orientations such as ecology environmental protection, agricultural production, and urban and rural construction. Resources, environment, society, and economy are closely related to each other. Therefore, we have to consider them for systematic research [17].

The research of the bearing capacity of environmental resources includes macro research of the country, medium research of province and city, micro research of district and county. The research methods include the analytic hierarchy Process (AHP), PS-DR-DP theoretical model, and ecological footprint method. In this paper, the fuzzy analytic hierarchy process is used to evaluate the resources and environment carrying capacity.

3. Method

The fuzzy analytic hierarchy process (FAHP) is based on the combination of an analytic hierarchy process (AHP) and a fuzzy theory [18]. The concept of a membership function replaces the explicit value of traditional AHP, imitating human's way of judgment and comparing the value of two factors under the evaluation framework [19]. The steps of FAHP are different from those of AHP proposed by A. L. Saaty (Saaty, 1980) on two points. (1) AHP constructs a judgment matrix through pairwise comparison of elements, while FAHP constructs a fuzzy consistent judgment matrix through pairwise comparison of elements. (2) The method of calculating the relative importance weight of each element by the fuzzy uniform matrix is different from that by the judgment matrix. FAHP and fuzzy theory are used to generate the weighted factor scores at each level in this study. After each dimension of evaluation and standard weight is combined with the evaluation value at each level, an objective evaluation score is obtained. The steps to obtain the score are as follows.

3.1 Describing issues and establishing hierarchy

First, the problem to be solved for the solution or goal for the decision-maker is determined. The purpose is to establish the integrated evaluation of the bearing capacity of the environmental resource. The hierarchy is based on the analysis of objective issues to determine the factors for all levels of evaluation. Generally, important evaluation factors are chosen to solve objective problems, and a hierarchical structure is established through expert interviews, questionnaires with expert scores, and literature reviews.

3.2 Establishing fuzzy pairwise comparison matrix

The comparison matrix is based on the relative importance of the elements to each other. Fuzzy trigonometric functions are brought into the paired contrast matrix to solve the fuzzy problem and determine the importance of the proportions in each plan [20]. According to Saaty (Saaty, 1980), a comparison scale between 1 and 9 [21,22] is recommended as shown in Table 1. Fuzzy language variables are shown in Figure. 1.

Table 1. Fuzzy Linguistic Variables

Fuzzy numbers	Semantic value	Fuzzy number endpoint
$\tilde{1}$	Equally important	(1,1,3)
$\tilde{2}$	Between equally important and weakly important	(1,2,4)
$\tilde{3}$	Weakly important	(1,3,5)
$\tilde{4}$	Between weakly important and essentially important	(2,4,6)
$\tilde{5}$	Essentially important	(3,5,7)
$\tilde{6}$	Between essentially important and very strongly important	(4,6,8)
$\tilde{7}$	Very strongly important	(5,7,9)
$\tilde{8}$	Between strongly important and absolutely important	(6,8,9)
$\tilde{9}$	Absolutely important	(7,9,9)

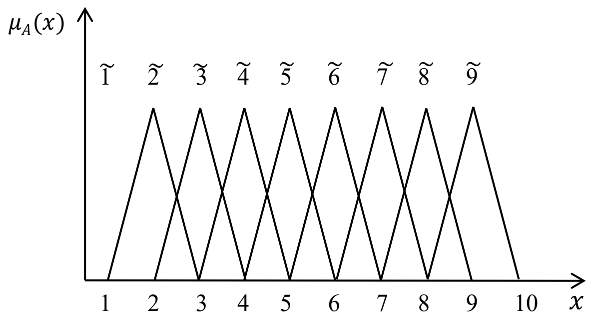

Figure 1. Membership function table of Linguistic Variables.

A pairwise comparison matrix A is obtained between two factors. If there are n factors to be compared in an index system, $n(n-1)/2$ pairwise comparisons are conducted. If the ratio of factor *i* to factor *j* is $\tilde{a}_{ij}$ by the pairwise comparison, the ratio of the factor *j* to the factor *i* is the reciprocal of the original ratio, $1/\ \tilde{a}_{ij}$. In the same way, the lower triangular part of the pairwise comparison matrix A is the inverse of the triangular part as shown in Eq. (1).

$$A = [\tilde{a}_{ij}] = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \frac{1}{\tilde{a}_{12}} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{\tilde{a}_{1n}} & \frac{1}{\tilde{a}_{2n}} & \cdots & 1 \end{bmatrix} \tag{1}$$

According to the questionnaires and evaluation standards, the geometric mean integrates the comparative values from the questionnaires under the same dimension or standard.

$$\tilde{a}_{ij} = \left(\tilde{a}_{ij}^{1} \otimes \tilde{a}_{ij}^{2} \otimes \cdots \otimes \tilde{a}_{ij}^{k}\right)^{\frac{1}{k}}, \tag{2}$$

where $\tilde{a}_{ij}^{k}$ is the fuzzy number in the *i*-th row and *j*-th column in the fuzzy matrix of the k-th expert, $\tilde{a}_{ij}$ is the fuzzy number in the *i*-th row and *j*-th column in the fuzzy matrix after the group decision of experts.

3.4 Calculating fuzzy weight value

The weight value of the element is called the eigenvector. The calculated weight of the triangular fuzzy positive reciprocal matrix adopts the normalization of the geometric mean of column vector values as shown in Eqs. (3) and (4).

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{i1n})^{\frac{1}{n}} \tag{3}$$

$$\widetilde{w}_i = (\tilde{r}_1 \otimes \tilde{r}_2 \otimes \tilde{r}_3 \cdots \otimes \tilde{r}_n)^{-1} \tag{4}$$

where $\tilde{a}_{ij}$ is the fuzzy number in the *i*-th row and *j*-th column of the fuzzy matrix, $\tilde{r}_i$ is the average value of the column vector of the fuzzy number, and $\widetilde{w}_i$ is the fuzzy weight of the *i*-th factor.

3.5 Verifying fuzzy consistency

Buckley proposed the consistency check method of the fuzzy matrix $\tilde{A}$ with traditional AHP, and calculated the matrix of the median value of the fuzzy number. When $A = [a_{ij}]$ passes the requirement of conformity test, that is, C.I. < 0.1, it can be inferred that $\tilde{A} = [\widetilde{a_{ij}}]$ of FAHP has the same consistency.

3.6 Defuzzification value

Based on calculating the fuzzy value, a triangular fuzzy number is provided for each selected factor to be analyzed. However, since the fuzzy number is not an accurate value, the obtained fuzzy number needs to be defuzzified according to a fuzzy sorting method. The problem is solved by the center of gravity method. The key of the method is to find the center of the triangle area, and the representative value is the area center point of the fuzzy number as shown in Eq. (5).

$$BNP = [(U\widetilde{w_i} - L\widetilde{w_i}) + (M\widetilde{w_i} - L\widetilde{w_i})] \div 3 + L\widetilde{w_i}, \ \ \forall i \tag{5}$$

where i is the code of the criterion, $L\widetilde{w_i}$ is the low average score of the weight of the plan criterion i given by the expert group, $M\widetilde{w_i}$ is the median average score of the weight of the plan criterion i given by the expert group, and $U\widetilde{w_i}$ is the high average score of the weight of the plan criterion i given by the expert group.

3.7 Hierarchy series and program sequencing

The value obtained from the structure selection value E is multiplied by the calculated weight W to obtain the total R evaluation value of each level as shown in Eq. (6).

$$R = W \times E \tag{6}$$

The overall evaluation value R of the plan is obtained to sort the plans and judge the pros and cons.

4. Results and Discussion

4.1 Constructing Indicator system

Based on scientific and regional principles, we designed two evaluation aspects of resource abundance and environmental capacity with reference to different evaluation index systems. Each aspect corresponds to three evaluation indexes to construct an integrated evaluation index system for the regional bearing capacity of environmental resources as shown in Figure. 2 [8,23].

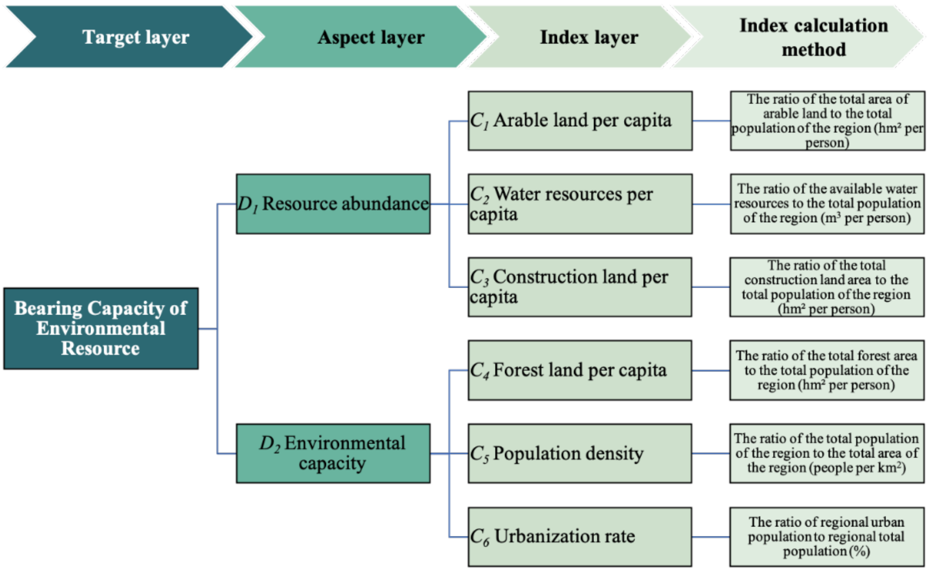

Figure 2. Integrated evaluation index system of bearing capacity of environmental resources.

4.2 Index weight

First, the comprehensive evaluation index system is divided into three levels: target level, dimension level, and index level. The importance of the two indicators is compared and judged, and the determinant of the eigenvector is obtained corresponding to the largest eigenvalue of the calculation matrix. Then, the importance of each plan is determined. The individual survey result is fuzzified, and the final weight value of the importance of the plan is obtained. Then, the optimization and determination of a plan become more user-friendly. Figures 3 and 4 show the weighted results of the factors of various evaluation indexes of the bearing capacity of environmental resources.

According to Figure. 3, the weight of resource abundance (0.579) is larger than that of environmental capacity (0.421). According to Figure. 4, the water resource index per capita has the largest weight (0.211) of all resource abundance factors. In terms of environmental capacity, the forest land index per capita has the largest weight, 0.203. Integrating all the elements and indicators, the order of the weights is, water resources per capita (0.357)> arable land per capita (0.192)> forest land per capita (0.103)> per-capita construction land per capita (0.100)> urbanization rate (0.089)> population density (0.049).

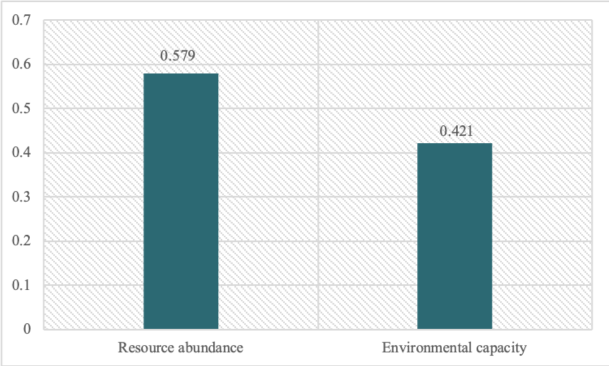

Figure. 3. Aspect layer weighted factor of the evaluation index of the bearing capacity of environmrntal resources.

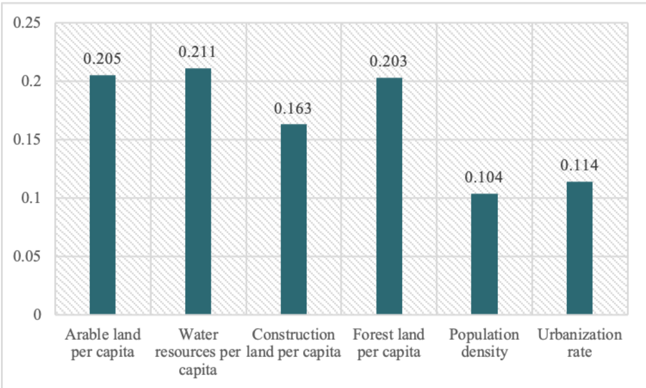

Figure. 4. Index layer weighted factor of the evaluation index of the bearing capacity of environmrntal resources.

5. Conclusions

The results of this study show that the weight of resource abundance (0.579) in the dimension layer is larger than the weight of environmental capacity (0.421), indicating that the importance of resource abundance is greater than that of the environmental capacity in the evaluation of the bearing capacity of environmental resources. When studying the bearing capacity, one should consider the resource endowment. The higher the resource endowment, the greater the carrying capacity of the resource environment. Among the indicators at the index level, the highest weight is water resources per capita, 0.211, followed by arable land per capita (0.205), and forest land per capita (0.203). The water resources index per capita is important for the bearing capacity of environmental resources. The overall improvement of the bearing capacity needs the development and protection of water resources.

According to the analysis, the major influential factors of the bearing capacity include the conditions of resources, natural environment, economy, and society. This means that improving the bearing capacity of environmental resources demands the collective consideration of the three elements. The analysis of the weights of the evaluation index of resources in this study helps the "double evaluation" of land and space planning carried out and provides the basis on efficient planning.

The evaluation methods and indicators of resources and environmental carrying capacity are used to prove practical cases to find the shortcomings and characteristics of resource elements in different regions and explore unique development paths. It has important scientific significance and practical value to promote the development of special resource allocation and environment-sensitive areas.

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