Li Ren*, Xinyi Xiang, Weilin Liu

Water Resource Sustainable Utilization Evaluation Index System in Jiangsu Coast Reclamation Region

Abstract: As a comprehensive system, there are many subsystems such as water resource subsystem, social subsystem, economic subsystem and ecological subsystem in water resource sustainable utilization system. In this paper, an evaluation system including three levels is set up according to the metric demands of sustainable water resource utilization in Jiangsu coast reclamation region, namely the target level, the rule level, and the index level. Considering the large number of the indexes, the analytic hierarchy process is used to determine the weights of all these subsystems in the total goal of water sustainable utilization. By analyzing these weights, the attributes of water resource itself is found to be the most important aspect for the evaluation of sustainable utilization in Jiangsu coast reclamation region, and the second important aspect is the situation of the eco-environment.

Keywords: water resource, sustainable utilization, index system, index weight, Jiangsu coast reclamation region, analytic hierarchy process.

1 Introduction

Sustainable development is the overall strategy of social economic development in all countries and regions around the world, in which sustainable utilization of water resource is a new mode of water resource utilization. With the features of complexity, universality, dynamics, and regionalism, it is the most appropriate utilization of water resource integration of exploitation and utilization, protection and management [1]. An important basis of water resource sustainable management is the scientific evaluation of the environment and economic results of water resource exploitation and utilization, which can be used to find out the existing problems [2,3]. To evaluate water resource exploitation and utilization effectively, the first problem that needs to be solved is the establishment and construction of an evaluation index system. This paper researches and sets up an comprehensive evaluation index system to reflect and measure the water resource sustainable utilization in Jiangsu coast reclamation

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region, and decides the weight based on the contents of water resource and its exploitation and utilization by analyzing the relationship between water resource and ecological environment, economy, as well as the society. It provides a scientific basis for water resource sustainable exploitation and utilization in Jiangsu coast reclamation region so that it guarantees the sustainable development of the economic society in Jiangsu coast reclamation region.

2 Concepts of Water Resource Sustainable Utilization

Water resource sustainable utilization refers to the whole process to support the harmonious development of population, resource, environment and economy, and to satisfy the water demands of generational and intergenerational population, maintaining the sustainability of water and integrity of the ecological system [4]. Therefore, water resource sustainable utilization approach is different from the traditional water resource exploitation and utilization in nature. It considers ecological environment values and social values more than only focusing on basic economic values. It's conducted according to the strategy of harmonious development of population, resource, environment and economy. With a clearly defined objective, it embodies the equity principle for human kind to share the environment, resource and economy, and social benefits. We should follow the idea of "unity, harmony, optimization and cycle", use the systematic method as well as high and new technology in implementation to realize equitable and efficient development [5].

3 Evaluation Index System of Water Resource Sustainable Utilization in Jiangsu Coast Reclamation Region

3.1 The Principles to Set up Evaluation Index System

The above theory has clearly stated that the evaluation index system of water resource sustainable utilization should display not only the water resource features, its exploitation, utilization and management, which constitute the water resource system development level, but also the harmonious development level of water resource system with social system, economic system, and ecological environment system [6]. Thus we have to follow the subsequent principles when we select indexes to set up the index system [7]:

1. *The index should have objective scientificity*: The index should objectively reflect the internal relationship of water resource system; provide clear definition, standard measuring methods, and normative calculating methods; and fully reflect the major features and development of water resource exploitation & utilization in the water basin.

2. *The index should have generality*: We should try to select the representative comprehensive index from those that fully reflect the sustainable utilization features of the water resource.
3. *The index should have systematic hierarchy*: It's requested to set up a systematic and well-organized index system with clear hierarchy to express the complicated problem in a compact, clear and hierarchical index system.
4. *The index should have operability:* The index should be simple, clear, and easy to be obtained and operated, with high comparability.

3.2 Hierarchy Structure of the Index System

The evaluation index system of water resource sustainable utilization can be divided into three levels of target, rule and index based on the measuring demands of water resource sustainable utilization and the construction principles of the evaluation index, referring to the construction methods of sustainable development index system, cyclic economy development index system and other systems, according to the practical situation of Jiangsu coast reclamation region. Reflected by the rule level, the target level has a single target. Composed of three subsystems, the rule level is reflected by the index level, which comprises several quantified indexes to completely show the major factors that influence the water resource sustainable utilization in Jiangsu coast reclamation region. See Table 1 for the composition.

Table 1: Evaluation indexes for water resources sustainable utilization in Jiangsu coast reclamation region

Rule level B	Index level C	Unit	Calculation formula
Social subsystem B_1	Population density (C_1+)	Person/km^2	Total population/region area
	Cultivated land per capita (C_2)	Ha/person	Cultivated land area/total population
	Urbanization ratio (C_3)	%	Urban population/total population
	Fiscal revenue (C_4)	Per ten thousand Yuan	See the statistics yearbook
Economic subsystem B_2	GDP per capita (C_5)	Per ten thousand Yuan	GDP/total population
	GDP per unit water (C_6)	Yuan/m^3	GDP/total water resource amount
	Water consumption per unit of GDP (C_7)	m^3/ten thousand Yuan	Water consumption/GDP
	Water consumption per ten thousand Yuan GDP (C_8)	M^3	Production water consumption/GDP

continued **Table 1:**

Rule level B	Index level C	Unit	Calculation formula
Economic subsystem B_2	Irrigation water comprehensive utilization coefficient (C_9)	%	Field water consumption/ water withdrawal at water intake
	Water consumption per ten thousand value-added of industry (C_{10})	m^3/ten thousand Yuan	Industrial water consumption/ value-added of industry
Water resource subsystem B_3	Water resource per capita (C_{11})	m^3/person	Local water resource amount/ total population
	Water production modulus (C_{12})	Per ten thousand m^3/ km^2	Regional water resource amount/land area
	Surface water exploitation and utilization ratio (C_{13})	%	Annual surface water supply amount×100%/local surface water resource amount
	Ground water exploitation and utilization ratio (C_{14})	%	Annual ground water exploitation amount×100%/ allowable ground water exploitation amount
	Water supply per capita (C_{15})	m^3/person	The ratio between water supply and total population
	Ground water supply percentage (C_{16})	%	Ground water supply amount/ available water supply
	Water supply modulus (C_{17})	Ten thousand m^3/km^2	Water supply amount/water supply area
	Water resource exploitation rate (C_{18})	%	Exploitation amount/total water resource amount
Ecological subsystem B_4	Dilution ratio (C_{19})	%	Sewage discharge amount/ surface runoff
	Sewage treatment ratio (C_{20})	%	Sewage polluting input/total sewage discharge amount
	Ecological environment water consumption ratio (C_{21})	%	Ecological environment water consumption amount/total water consumption amount

1. *Target level A:* The target of water resource sustainable utilization evaluation in Jiangsu coast reclamation region is to give a comprehensive evaluation of the comprehensive water resource utilization level in coast reclamation region and to provide decision basis for the sustainable development in the region.

2. *Rule level B:* Rule level is composed of four subsystems: social subsystem, economic subsystem, water resource subsystem, and ecological subsystem. It shows the influence of each subsystem in the index system on the sustainable utilization comprehensive index. This is the core subsystem and main body. The social and economic subsystems refer to the human kind and the surroundings, as well as the industry structure and economic benefits.
3. *Index level C:* It's a group of basic indexes that describe the status of sustainable development. The indexes which are frequently used in comprehensive evaluation research of the current water resource sustainable utilization are selected to show the universality of the index system. In addition, we also pay attention to the feasibility and comparability of the indexes, trying the best to use the existing statistics data.

4 Determine the Evaluation Index Weight

4.1 Analytical Method

Analytic Hierarchy Process (AHP) is a flexible and simple multi-criteria decision making method proposed by an American scholar, Professor T. L. Saaty. At first, to decompose a complicated system into several levels. The specialists evaluate the importance of the indexes in each level and then determine the weight coefficient of each subsystem in the total goal by calculating the contribution degree (weight) of the lower layer indexes to the upper layer indexes. This paper uses AHP to determine the weight coefficient of social, economic, water resource and ecological subsystems in water resource sustainable utilization comprehensive evaluation.

4.2 Figure Captions

1. *Establish the Judgment Matrix:* Decide the relative importance between every two elements in the lower layer according to a certain element in the upper layer, quantize them, and constitute a matrix form, which is a judgment matrix.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{12} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

2. *Evaluate the Geometric Mean of Elements of Each Row:*

$$b_i = \left(\prod_{a_{ij}}^{m} a_{ij} \right)^{1/m}, \quad i = 1, 2, \cdots, m \tag{2}$$

3. *Calculate the Weight Coefficient:*

$$\omega_j = b_j / \sum_{R=1}^{m} b_R, \quad j = 1, 2, \cdots, m \tag{3}$$

4. *Evaluate the Maximum Feature Root of Judgment Matrix:*

$$\lambda_{\max} = \frac{1}{m}\sum_{i=1}^{m}\left(\sum_{j=1}^{m} a_{ij}\omega_j / \omega_j\right) \tag{4}$$

5. *Consistency Check:*

$$\begin{aligned} CR &= CI / RI \\ CI &= 1/m - 1 \times \left(\lambda_{\max} - m\right) \end{aligned} \tag{5}$$

In the above formula, CR is the random consistency ratio of the judgment matrix; CI is the general consistency index of the judgment matrix; RI is the average random consistency index (referring to the table) of the judgment matrix; m is the order of the judgment matrix. $CR < 0.1$ indicates that the constituted judgment matrix meets the requirements well.

Table 2: The weights of evaluation indexes for water resources sustainable utilization in Jiangsu coast reclamation region

Target level	Rule level and its weight	Index level	Weight in target level
Water resource exploitation and utilization evaluation in Jiangsu coast reclamation region	Social subsystem B_1 (0.0917)	Population density (C_1)	0.0182
		Cultivated land per capita (C_2)	0.0198
		Urbanization (C_3)	0.0095
		Fiscal revenue (C_4)	0.0441
	Economic subsystem B_2 (0.2696)	GDP per capita (C_5)	0.0297
		GDP per unit water (C_6)	0.0964
		Water consumption per unit of GDP (C_7)	0.0188
		Water consumption per ten thousand Yuan GDP (C_8)	0.0118
		Irrigation water comprehensive utilization coefficient (C_9)	0.0687
		Water consumption per ten thousand Yuan value-added of industry (C_{10})	0.0444
	Water resource subsystem B_3 (0.3889)	Water resource amount per capita (C_{11})	0.0125
		Water production modulus (C_{12})	0.0640
		Surface water exploitation and utilization ratio (C_{13})	0.0819
		Ground water exploitation and utilization ratio (C_{14})	0.0193
		Water supply amount per capita (C_{15})	0.0250
		Ground water supply percentage (C_{16})	0.0176
		Water supply modulus (C_{17})	0.1078
		Water resource exploitation ratio (C_{18})	0.0609
	Ecological environment subsystem B_4 (0.2497)	Dilution ratio (C_{19})	0.1843
		Sewage treatment ratio (C_{20})	0.0419
		Ecological environment water consumption ratio (C_{21})	0.0236

As shown in Table 2, the weight of 4 indexes in rule level and 21 indexes in index level can be calculated based on the above formula. The consistency check should be implemented as required to eliminate the error caused by subjective judgment. The results of weight consistency check are: 0.0820, 0.0047, 0.0228, 0.0734, 0.0123, which are all less than 0.1. It shows that the weight calculation results meet the consistency and the judgment matrix works successfully.

5 Determine the Evaluation Index Weight

To evaluate water resource sustainable utilization, we need to conduct a comprehensive research by combining social economic development and ecological environment protection with water resource status. Therefore the paper sets up a hierarchical evaluation index system that reflects the relationship between water resource, society, economy, and ecological system in Jiangsu coast reclamation region. The proposed index system is a 3-level hierarchical structure composed of target level, rule level, and index level. The specific 21 indexes in it can provide a complete map of the harmonious relationship between water resource and local natural status as well as human activities. Deciding the index weights based on AHP greatly reduces the subjective biases and makes the index configuration more appropriate. It can be found out according to the analysis on index weight value that the nature of the water itself is the most important aspect to measure water resource sustainable utilization in Jiangsu coast reclamation region. And the influence of the ecological environment on water resource sustainable utilization comes next.

All in all, we select proper index evaluation method to make the evaluation based on the determination of indexes and their weights. We discover problems and make proposals to solve the problems; so that we can guide the practice of water resource exploitation and utilization to improve the sustainable development of the ecological environment and social economy.

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