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Construction of rural water ecological civilization index system in China

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Abstract

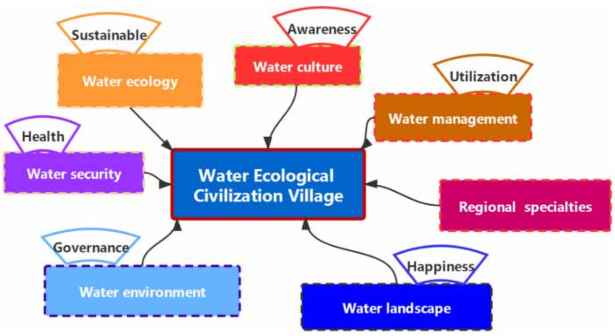
Water ecological civilization is an important component and basic guarantee of ecological civilization. With the comprehensive development of ecological civilization in China, the practice of water ecological civilization village construction has been carried out one after another. The establishment of an evaluation index system of rural water ecological civilization is an important step in the construction of rural water ecological civilization from the theoretical stage to the practical application stage. Based on China's rural water conditions, this study constructed an evaluation index system, including 21 evaluation indicators of seven subsystems: water security, water environment, water ecology, water management, water landscape, water culture, and regional characteristic indicators. The indicator weights are determined by the analytic hierarchy process, a set-pair analysis model is established, and typical rural were selected for instance verification. The results show that the evaluation index system of rural water ecological civilization is reasonable, and the comprehensive evaluation model is also feasible.

Key words: evaluation, index system, rural, set pair analysis, water ecological civilization

Highlights

- Rural area.
- Selected the indicators that affect water ecological civilization.
- Established the index evaluation model of water ecological civilization.

Graphical Abstract



INTRODUCTION

Water resource is an indispensable precious resource for human survival and development, a controlling element of the ecological environment, and an important foundation for sustainable development of society (Zhang 2017). The idea of China's ecological civilization construction is a concrete measure to promote the harmonious coexistence between man and nature, create a good production and living

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ecological environment for the people, and achieve sustainable development (Wang & Chen 2019). Advocating water ecological civilization is an ecological civilization that promotes the protection, restoration, development, and use of water resources on which human beings depend for survival and development, and gradually realizes the harmonious coexistence between man and water, and the common prosperity of all. The construction of an indicator system of rural water ecological civilization construction can provide guidance for in-depth research on rural water ecological civilization, thereby promoting the speeding up of the improvement of rural water ecological civilization in various regions. For supporting the rural revitalization strategies, as well as to further enhance the level of beautiful countryside construction is of great important practical significance.

At present, the construction of China's water ecological civilization is at a development stage, and its research hotspots have shifted from previous theoretical research to a combination of theory and practice. The pilot construction of urban water ecological civilization has basically completed various construction tasks, and has achieved significant results (Yang *et al.* 2019). Ren Junlin (Ren *et al.* 2016) and Liu Haijiao (Liu *et al.* 2013) respectively built an evaluation index system for the construction of a water ecological civilization city from the aspects of water ecology, water management, water engineering, water landscape, etc., and evaluated the degree of urban water ecological civilization. Compared with cities, there are few domestic studies on rural water ecological civilization. Rural areas have the characteristics of poor economic development, inadequate infrastructure, and relatively prominent water environmental pollution. The construction of an index system for water ecological civilization in rural areas is more difficult to quantify and unify than urban. This study aims to build a relatively comprehensive evaluation index system for water ecological civilization construction in rural areas based on China's rural water conditions, to evaluate the state of water ecological civilization in various regions and the problems existing in water ecological civilization construction, to guide various regions to accelerate and improve the construction of water ecological civilization. Thereby promoting water ecological civilization construction in the country and creating a good production and living environment for the people, improve quality of life and happiness indicator.

There are many mathematical models applied to the evaluation of water ecological civilization construction. Each model has its advantages and disadvantages. Commonly used are analytic hierarchy process (Xu *et al.* 2017b; Liu *et al.* 2019), principal component analysis (Ren *et al.* 2016), and matter-element extension method (Deng *et al.* 2015; Xu *et al.* 2017a; Han *et al.* 2019), etc. And data mining technology is also a new efficient method to deal with classification problems (Najafzadeh *et al.* 2018a; Saberi-Movahed *et al.* 2020). However, the subjective judgment of people in the analytic hierarchy process has a great influence on the evaluation results; the principal component analysis method should ensure the contribution ratios of the first few principal components extracted reach a high level and cannot reflect the objective development level; the matter-element extension model has the limitation of being unable to calculate when the measured data exceeds the node area during evaluation. Among the data mining techniques, the Support Vector Machine (SVM) and the Model Tree(MT) method can effectively avoid the artificial subjective influence and uncertainty in the evaluation process, and has strong objectivity (Zahiri & Najafzadeh 2017; Najafzadeh *et al.* (2017, 2018b)). However, in order to make it easier for more audiences to understand and obtain help, choosing an effective and universal method may better enable the research results to be used in practice. The set pair analysis is a systematic analysis method that deals with the problems of determination and uncertainty. And the construction of water ecological civilization as a huge system has certainty and uncertainty. This article combines the analytic hierarchy process and set-pair analysis method to deal with the uncertainty caused by the unreliable pieces of information between the determined evaluation indicator and the standard value of the evaluation indicator. In this way, the comprehensive evaluation grade of rural water ecological civilization construction is obtained, which provides a reference for China's ecological civilization construction.

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METHODS

Construction of comprehensive evaluation index system

Construction principle

In the process of constructing the evaluation index system for water ecological civilization construction in rural areas, we must comprehensively consider rural factors such as the unique natural resource conditions, economic development level, and folk cultural traditions, and focus on rural drinking water safety, rural sewage discharge methods, and farmland non-point source pollution, livestock breeding pollution and other important factors affecting the rural water environment. At the same time, the influence factors caused by rural regional differences cannot be ignored. In summary, this article follows the basic principles of systematic, absolute and relative combination, qualitative and quantitative combination, independence, integration with existing work, policies, regional characteristics, etc., and believes that the comprehensive evaluation of rural water ecological civilization construction should be including seven subsystems of water security, water environment, water ecology, water management, water landscape, water culture and regional characteristics.

Index system

Evaluation of water safety mainly considers the indicators related to the living health of rural residents, includes three indicators: guaranteed rate of domestic water for rural residents, drinking water quality compliance rate, and rural flood prevention and drainage capacity. Rural flood prevention and drainage capacity is qualitative indicators, includes the formulation and implementation of flood control planning, the construction of flood control and drainage projects, and the implementation of flood control responsibility system.

Water environmental indicators reflect the state of water quality of the water ecosystem, that is, the health of the water ecosystem. The status of rural water environment is measured by four general indicators, such as sewage treatment rate, farmland non-point source pollution control, effective water-saving irrigation area rate, and pollution control of livestock breeding. Among them, the sewage treatment rate is composed of two parts: the domestic sewage treatment rate and the industrial sewage compliance rate. For non-industrial rural, only the domestic sewage treatment part needs to be considered. The control of non-point source pollution in rural areas is a qualitative indicator that characterizes the control of non-point source pollution caused by pollutants in agricultural production activities through farmland drainage.

Water ecological index system includes the rural water environment status, environmental governance and restoration indicators, includes four universal indicators such as rural water area ratio, soil erosion control rate, degree of satisfaction of ecological water requirements and connectivity rate of water systems. The rural water area ratio can directly reflect the overall rural water resources. Ecological water demand includes the ecological basic flow and sensitive water demand of river, for lakes and wetlands, appropriate ecological water level requirements should also be proposed. It is necessary to fully consider each influencing factor according to the actual local conditions, qualitative analysis and then quantify the indicator.

The index system of water management reflects the efficient utilization of water resources and the management of water ecosystem through administrative and technical means. Therefore, three indicators includes the proportion of water ecological civilization construction in party and government performance assessment, intact rate of water conservancy facilities, and the implementation of rural river (lake) system were selected to evaluate the construction degree of in rural water management aspects. The proportion of water ecological civilization construction work in the party and government performance evaluation refers to the proportion of water ecological civilization construction work in the local government party and government cadre performance evaluation score standards. The purpose of setting this indicator is to promote the integration of the construction of water ecological civilization into the evaluation of party and government performance, through intensified assessment, the task of water ecological civilization construction will be implemented.

With the improvement of people's living standards, people have higher and higher requirements for the quality of their living environment, and their demand for hydrophilicity is increasing. Therefore, the water landscape index system is an essential part of the evaluation system for the construction of water ecological civilization, includes the hydrophilic landscape construction, bank slope treatment rate, water area and surrounding environment ornamental. Hydrophilic landscape construction is not only an external requirement for protecting water resources, but also an internal requirement for building and protecting water culture. Protecting water sources, saving water resources, and protecting water conservancy landscapes all requires extensive public participation. It is also important to cultivate and improve awareness of the construction and protection of water ecological civilization.

The water culture index system includes three general indicators: water ecological civilization propaganda and education coverage, degree of combination of water engineering and water culture, and degree of awareness of water conservation and behavior (Turner *et al.* 2014).

Each rural area should combine its own regional characteristics and select regional characteristics indicators according to actual conditions. The characteristic indicators of the southern region include the eutrophication index of lakes and reservoirs. Among them, eutrophication refers to the phenomenon of water pollution caused by excessive levels of nitrogen, phosphorus and other plant nutrients in water bodies such as lakes, rivers and reservoirs. The northern area mainly assesses groundwater overexploitation (Table 1).

Classification and evaluation standard determination

With reference to the Evaluation guide for ecological civilization construction, the Standard for flood control GB50201-2014, and the literature research on water ecological civilization construction evaluation. The construction level for rural water ecological civilization is divided into five levels, from high to low, which are excellent, good, medium, qualified and unqualified, and established a comprehensive evaluation standard for rural water ecological civilization.

Indicator weight determination

There must be subjectivity in comprehensive evaluation: the analytic hierarchy process can analyze the subjective problems objectively and uses this to determine the weight of indicators. This method comprehensively considers the opinions of experts and constructs a judgment matrix. The experts agree that the rural water environment is an important factor affecting rural water ecological civilization with relatively heavy weight, followed by water security, water ecology, and water management (Table 2).

Evaluation model construction based on set pair analysis

Set pair analysis is a systematic analysis theory and method, established by Chinese scholar Zhao Keqin (Zhao & Xuan 1996) in 1989 to deal with deterministic and uncertain information. It has been widely used in many subject areas and systematic reviews. The specific steps are as follows.

Step 1: Define the index $x_l (l = 1, 2, \cdots, 21)$ as a set A_l, and the evaluation criteria of the corresponding index s_k (k = 1, 2, 3, 4, 5) as a set B_k; A_l and B_k can form a set pair $H(A_l, B_k)$.

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Table 1 | Comprehensive evaluation index system of rural water ecological civilization construction

Target layer	Criteria layer	No.	Index layer	Indicator properties
Comprehensive evaluation indicator system of rural water ecological civilization construction	Water safety	1	Guaranteed rate of domestic water for rural residents	Quantitative
		2	Drinking water quality compliance rate	Quantitative
		3	Rural flood prevention and drainage capacity	Qualitative
	Water environment	4	Sewage treatment rate	Quantitative
		5	Farmland non-point source pollution control	Qualitative
		6	Efficient water-saving irrigation area ratio	Quantitative
		7	Pollution control of livestock breeding	Qualitative
	Water ecology	8	Rural water area ratio	Quantitative
		9	Soil erosion control rate	Quantitative
		10	Degree of satisfaction of ecological water requirements	Qualitative
		11	Connectivity rate of water systems	Quantitative
	Water management	12	Proportion of water ecological civilization construction in party and government performance assessment	Qualitative
		13	Intact rate of water conservancy facilities	Quantitative
		14	Implementation of rural river (lake) system	Qualitative
	Water landscape	15	Hydrophilic landscape construction	Qualitative
		16	Bank slope treatment rate	Quantitative
		17	Water area and surrounding environment ornamental	Qualitative
	Water culture	18	Water ecological civilization propaganda and education coverage	Quantitative
		19	Degree of integration of water engineering and water culture	Qualitative
		20	Degree of awareness of water conservation and behavior	Qualitative
	Regional characteristics	21	South Eutrophication index	Quantitative
			North Groundwater over-extraction area rate	Quantitative

Step 2: Establish the connection number expression of the 'same-difference-inverse-hierarchy method' $\mu' A_l \sim B_k$ to describe the relationship of set pairs $H(A_l, B_\text{k})$:

$$\mu' A_l \sim B_k = a_l + b_{l,1} I_1 + b_{l,2} I_2 + B_{l,3} I_3 + c_l J \quad (1)$$

In the formula, respectively a_l indicates the 'identity' (the same level) of the index value x_l and the k-th standard s_k of the index. $\text{b}_{l,1}$, $\text{b}_{l,2}$, $\text{b}_{l,3}$ is the 'degree of difference' between the index value and the k-th standard of the index by one, two, or three levels; c_l is the 'opposition' of the index value x_l and the k-th standard s_k of the index. I_1, I_2, I_3 are 'the degree of partial difference 1', 'the degree of partial difference 2', 'the coefficient of partial difference', and J is the 'opposite degree coefficient', its coefficient is specified as -1.

Step 3: The number of comprehensive connections $\mu A_l \sim B_k$ between the evaluation index and the evaluation index level k is:

$$\mu A_l \sim B_k = \sum_{l=1}^{21} \omega_l \mu' A_l \sim B_k = f_1 + f_2 I_1 + f_3 I_2 + f_4 I_3 + f_5 J \quad (2)$$

In the formula, $f_1 = \sum_{l=1}^{21} \omega_l a_l, f_2 = \sum_{l=1}^{21} \omega_l \text{b}_{l1}, f_3 = \sum_{l=1}^{21} \omega_l \text{b}_{l2}, f_4 = \sum_{l=1}^{21} \omega_l \text{b}_{l3}, f_5 = \sum_{l=1}^{21} \omega_l \text{c}_l$; ω_l is the weight of indicator l, f_1, f_2, f_3, f_4, f_5 are the probability that the evaluation sample belongs to the 1st, 2nd, 3rd, 4th, and 5th standards.

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Table 2 | Classifications of indicator and indicator weight

Criteria Layer	Index Layer		Weight	Indicator classification threshold I $(s_1,s_0]$ Excellent	II $(s_2,s_1]$ Good	III $(s_3,s_2]$ Medium	IV $(s_4,s_3]$ Qualified	V $(s_5,s_4]$ Unqualified
Water safety	Guaranteed rate of domestic water for rural residents (%)		0.05	(90,100]	(80,90]	(60,80]	(40,60]	[0,40]
	Drinking water quality compliance rate (%)		0.05	(90,100]	(75,90]	(60,75]	(40,60]	[0,40]
	Rural flood prevention and drainage capacity		0.081	Level levels according to rural protection levels and standards, flood control planning, construction of rural flood control projects, and implementation of flood control responsibility systems				
Water environment	Sewage treatment rate (%)	south	0.105	(90,100]	(80,90]	(60,80]	(40,60]	[0,40]
		north		(95,100]	(90,95]	(80,90]	(70,80]	[0,70]
	Farmland non-point source pollution control		0.058	Level levels according to the amount of fertilizers and pesticides applied during farmland irrigation and other farmland pollution control				
	Efficient water-saving irrigation area ratio (%)		0.046	(50,100]	(50,30]	(20,30]	(10,20]	[0,10]
	Pollution control of livestock breeding		0.052	Level levels according to whether there are livestock and poultry scale farms in the closed area, and whether there are supporting manure treatment and utilization facilities				
Water ecology	Rural water area ratio (%)		0.03	≧12	≧8	≧5	≧3	<3
				≧8	≧5	≧3	≧2	<2
	Soil erosion control rate (%)		0.043	(80,100]	(70,80]	(60,70]	(50,60]	[0,50]
	Degree of satisfaction of ecological water requirements (%)		0.021	(80,100]	(70,80]	(60,70]	(50,60]	[0,50]
	Connectivity rate of water systems (%)		0.078	(90,100]	(80,90]	(70,80]	(60,70]	[0,60]
Water management	Proportion of water ecological civilization construction in party and government performance assessment (%)		0.031	>10	10～8	8～5	5～1	1～0
	Intact rate of water conservancy facilities (%)		0.045	(98,100]	(90,98]	(80,90]	(70,80]	[0,70]
	Implementation of rural river (lake) system		0.076	Level levels according to whether the rural river (lake) long-term system is in place, related systems and measures, and whether the assessment mechanism is in place				
Water landscape	Hydrophilic landscape construction		0.031	Level levels according to the types of hydrophilic landscapes and the construction of safety protection facilities in the study area				
	Bank slope treatment rate (%)		0.042	(90,100]	(75,90]	(60,75]	(40,60]	[0,40]
	Water area and surrounding environment ornamental		0.024	Level levels according to the study area waters and surrounding natural environment and overall landscape effects				
Water culture	Water ecological civilization propaganda and education coverage (%)		0.03	(80,100]	(60,80]	(40,60]	(20,40]	[0,20]
	Degree of integration of water engineering and water culture		0.019	Level levels according to the degree of integration of humanistic feelings and water conservancy projects in the study area				
	Degree of awareness of water conservation and behavior (%)		0.048	(80,100]	(60,80]	(50,60]	(40,50]	[0,40]
Regional characteristics	south	Eutrophication index (%)	0.04	(0,55]	(50,55]	(55,60]	(60,70]	[70,100]
	north	Groundwater over-extraction area rate (%)		0	(0,10]	(10,20]	(20,30]	[30,100]

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Step 4: Use the confidence criterion to evaluate the level of rural water ecological civilization construction, and determine the grade of rural water ecological civilization.

Calculation of the five-element connection degree of set pair

For the case where there is a left limit and right limit of the level standard threshold, the ambiguity of the level standard boundary value is fully considered. For larger and better indicators, the five-element connection degree of set pair (Wu *et al.* 2010) is

$$\mu' A_l \sim B_k = \begin{cases} 1 + 0I_1 + 0I_2 + 0I_3 + 0J & s_1 \le x_l \le s_0 \\ \dfrac{x_l - s_2}{s_1 - s_2} + \dfrac{s_1 - x_l}{s_1 - s_2} I_1 + 0I_2 + 0I_3 + 0J & s_2 \le x_l \le s_1 \\ 0 + \dfrac{x_l - s_3}{s_2 - s_3} I_1 + \dfrac{s_2 - x_l}{s_2 - s_3} I_2 + 0I_3 + 0J & s_3 \le x_l \le s_2 \\ 0 + 0I_1 + \dfrac{x_l - s_4}{s_3 - s_4} I_2 + \dfrac{s_3 - x_l}{s_3 - s_4} I_3 + 0J & s_4 \le x_l \le s_3 \\ 0 + 0I_1 + 0I_2 + \dfrac{x_l - s_5}{s_4 - s_5} I_3 + \dfrac{s_4 - x_l}{s_4 - s_5} J & s_5 \le x_l \le s_4 \end{cases} \quad (3)$$

Among them, $s_0 \ge s_1 \ge s_2 \ge s_3 \ge s_4 \ge s_5$ is the threshold of the evaluation index.

Confidence criteria to determine the grade of rural water ecological civilization

The method for determining the uncertainty component coefficient (I_1, I_2, I_3) of the difference in connection degree has a certain subjectivity. To avoid this subjectivity, a confidence criterion is adopted (Cheng 1997)

$$h_k = \min\left\{\sum_{i=1}^{k} f_i \ge \lambda,\ 1 \le k \le 5\right\} \quad (4)$$

And satisfies $\sum_{i=1}^{k} f_i = 1$, considering the evaluation object h_k belongs to the corresponding k level. In the formula, λ is the confidence degree, and the value usually ranges from [0.50, 0.80]. The larger λ, the more conservative the evaluation that results.

RESULTS AND DISCUSSION

Case study

For verification of the comprehensive evaluation index system for the construction of water ecological civilization in rural areas, four typical Chinese rural areas to evaluate the degree of rural water ecological civilization construction: Zhuquan village, Yinan county, Linyi city, Shandong province; Liyuba village, Xingren city, Qianxinan prefecture, Guizhou province; Qingyuan village, Yongchun county, Quanzhou city, Fujian province; Hongyan village, Gongcheng Yao Autonomous county, Guilin city, Guangxi Zhuang autonomous region, respectively, were selected. According to the constructed indicator system, through field investigation and analysis, the raw data obtained are shown in Table 3.

Calculate the number of five-element connections for each evaluation index according to Equations (3) and (2), respectively, to obtain the comprehensive connection number between the evaluation index and the evaluation index level k, where $\lambda = 0.8$.

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Table 3 | Evaluation index value of rural water ecological civilization construction

Criteria layer	Index layer	Zhuquan village	Liyuba village	Qingyuan village	Hongyan village
Water safety	Guaranteed rate of domestic water for rural residents (%)	100	100	100	100
	Drinking water quality compliance rate (%)	100	100	100	100
	Rural flood prevention and drainage capacity	Excellent	Excellent	Good	Excellent
Water environment	Sewage treatment rate (%)	95	90	75	100
	Farmland non-point source pollution control	Excellent	Excellent	Excellent	Good
	Efficient water-saving irrigation area ratio (%)	3	18	10	21
	Pollution control of livestock breeding	Excellent	Good	Excellent	Excellent
Water ecology	Rural water area ratio (%)	3.28	4.6	10	1
	Soil erosion control rate (%)	100	100	100	100
	Degree of satisfaction of ecological water requirements	Medium	Excellent	Excellent	Excellent
	Connectivity rate of water systems (%)	98	100	100	100
Water management	Proportion of water ecological civilization construction in party and government performance assessment (%)	10	9	10	12
	Intact rate of water conservancy facilities (%)	95	100	85	100
	Implementation of rural river (lake) system	Good	Excellent	Excellent	Excellent
Water landscape	Hydrophilic landscape construction	Excellent	Excellent	Excellent	Excellent
	Bank slope treatment rate (%)	100	100	100	100
	Water area and surrounding environment ornamental	Excellent	Excellent	Excellent	Excellent
Water culture	Water ecological civilization propaganda and education coverage (%)	80	90	100	100
	Degree of integration of water engineering and water culture	Excellent	Good	Excellent	Good
	Degree of awareness of water conservation and behavior (%)	90	95	95	100
Regional characteristics	south Eutrophication index (%)	–	50	57	35
	north Groundwater over-extraction area rate (%)	0	–	–	–

Evaluation result

From Table 4, Zhuquan village, h1 = 0.755 < 0.8, h2 = 0.755 + 0.137 = 0.892 > 0.8, and according to the confidence criterion, it can be judged that the water ecological civilization construction grade of Zhuquan village is good. Similarly, for Liyu village, Qingyuan village, there are h2 = 0.761 + 0.108, 0.707 + 0.120 > 0.8, respectively. The confidence criteria can be used to judge that the water ecological civilization construction grade of Liyu village and Qingyuan village is good; h1 = 0.866 > 0.8, the

Table 4 | Evaluation results

Rural	f_1	f_2	f_3	f_4	f_5	h_k	Water ecological civilization grade
Zhuquan village	0.755	0.137	0.057	0.032	0.032	0.892	Good
Liyuba village	0.761	0.108	0.118	0.015	0.003	0.869	Good
Qingyuan village	0.707	0.120	0.118	0.070	0.000	0.827	Good
Hongyan village	0.866	0.053	0.024	0.046	0.025	0.866	Excellent

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construction level of the water ecological civilization in Hongyan village is excellent. Through the evaluation of the construction of water ecological civilization in Zhuquan village, Liyu village, Qingyuan village and Hongyan village, the evaluation results of the four rural areas are basically consistent with the on-site experience, which shows that the evaluation index system for the establishment of rural water ecological civilization is reasonable. The comprehensive evaluation model is also feasible.

CONCLUSIONS

Considering the nature of the problem, it is unrealistic to establish a set of evaluation index systems for water ecological civilization that is applicable to various regions. In addition to the amount of water resources, the factors affecting the ecological civilization of water also involve national policies and the customs of residents. According to the characteristics of China's rural water ecological civilization, a comprehensive evaluation index system for rural water ecological civilization construction in China's rural areas was established, and a set-pair analysis and evaluation model combined with the analytic hierarchy process was established. And typical rural areas were selected to obtain the results of the evaluation of water ecological civilization. Considering that the evaluation index system for the construction of water ecological civilization is a complex system, and there are problems such as the uncertainty in the implementation of the indicators in the evaluation index system and the rationality of the evaluation criteria for the indicators, the construction of an evaluation index system for water ecological civilization construction in rural areas needs further consideration and improvement.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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