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Evaluation of the Sustainable Utilization Capacity of Water Resources Based on Two Evaluation Methods in the Huangshui River of the Yellow River, China

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Abstract: The study on the sustainable utilization capacity of water resources is of great significance for the realization of sustainable water resources management and development in the water-scarce regions of Northwest China. It provides insights into the potential for sustainable utilization of these resources. To evaluate the sustainable utilization capacity of the Huangshui Basin, a comprehensive evaluation index system was constructed based on three aspects: climate factors, water resources systems, and socio-economic factors. The evaluation was conducted using two methods: the fuzzy comprehensive evaluation model and the ELECTRE III evaluation method. The results indicate that the Huangshui Basin's water resources, as a whole, exhibit a medium sustainable utilization capacity. Climatic factors and socio-economic characteristics are the main factors affecting the sustainable utilization of water resources in the Huangshui Basin. Based on the results, measures such as strengthening the introduction of external water resources, enhancing water resources management, and implementing comprehensive remediation efforts in the basin can improve the level of sustainable use of water resources. The research results can provide a reference for decision-making regarding the evaluation of sustainable utilization capacity of water resources in water-scarce areas and the optimization of water resources management in the Huangshui Basin.

Keywords: Huangshui Basin; water resources; sustainable utilization capacity; evaluation index; fuzzy comprehensive evaluation method; ELECTRE III

1. Introduction

Water is a fundamental and strategic resource that supports the virtuous cycle of river basin ecosystems and sustainable socio-economic development [1, 2]. However, current freshwater resources are extremely limited, with more than 50% of the global population facing water scarcity issues [3]. China, in particular, faces a significant per capita water shortage, with levels less than one-fourth of the global average [4]. Moreover, there are considerable discrepancies in the spatial and temporal distribution of water resources. Against the backdrop of climate warming and the intensification of human activities, water shortages and water environment pollution have impacted the sustainable development of water resources in river basins, and water scarcity has become a bottleneck for the sustainable development of these basins [5, 6].

Water resources sustainability utilization analysis quantifies the degree of sustainable use of water resources in a basin, objectively reflects its water security, and is the basis for water resources planning and management in a basin [7]. In recent years, the Chinese government has placed great emphasis on the management of water resources in river basins, clearly advocating for the 'implementation of the most stringent water resources management system'. It has promulgated a series of water resources management policies to ensure the sustainable development of river basins, making the evaluation of the sustainable utilization capacity of water resources increasingly recognized [8].

Since the concept of sustainable development was introduced in the 1970s, the issue of sustainable utilization of water resources has prompted in-depth research by scholars worldwide. This research has been closely integrated with the carrying capacity of water resources [9], rational allocation, and scientific management [10], in order to support the overarching strategy of sustainable socio-economic development [11, 12]. As human activities and climate change are the primary drivers of sustainable utilization of water resources, scholars are increasingly engaged in research conducted under uncertain environmental conditions, including those related to human activities and climate change [13]. Most of the existing research on water resources sustainable utilization capacity is concentrated at the basin and regional scales [14], urban scale [15], and national scale [16], such as in China's Yangtze River Basin [17], Poyang Lake Basin [18], and Guangdong Province [19]. However, there is a notable absence of research on the sustainable utilization capacity of water resources in the Huangshui Basin of the northwestern region of China.

The evaluation method for sustainable utilization capacity of water resources is central to the assessment process. This process relies on establishing an effective evaluation index system, applying mathematical methods to calculate the weights of these indices [20], and ultimately combining them with relevant evaluation models to quantitatively assess the sustainable utilization capacity of regional water resources [21, 22]. Given the complexity of water resource systems, the evaluation results can be one-sided and uncertain [23]. Consequently, the construction of the indicator system [24] and the selection of appropriate evaluation methods and models are crucial to the assessment of water resources' sustainable utilization capacity [22].

In recent years, scholars worldwide have primarily employed various evaluation methods for sustainable water resources utilization capacity, such as the fuzzy comprehensive evaluation method, hierarchical analysis method [25], ecological footprint method [26], and comprehensive index method. For instance, Tang et al. [27] evaluated the dynamic trend of sustainable water resources utilization in Ningxia using the fuzzy comprehensive evaluation method based on sustainable development theory. Li Bingyao et al. [28] utilized hierarchical analysis to assess the current status of sustainable utilization capacity in Yuhuan County and proposed measures to enhance water resources' sustainable utilization in water-scarce regions. Chen et al. [29] applied an improved ecological footprint model to evaluate the sustainable utilization capacity in the Beijing-Tianjin-Hebei region and conducted an uncertainty analysis of water resources there. Cui [30] used the comprehensive index evaluation method to assess the level of water resources utilization in the Sugri Economic Development Zone.These evaluation methods offer valuable tools for studying sustainable utilization capacity of water resources, each with its strengths and limitations.

Therefore, based on previous research and considering the unique characteristics of the Huangshui Basin, this study employs both the fuzzy comprehensive evaluation method and the ELECTRE III evaluation method. The aim is to construct an evaluation system for the sustainable utilization capacity of water resources in the Huangshui Basin, to explore its current status and the factors influencing its sustainable utilization capacity. The findings aim to provide insights and recommendations for the healthy management and sustainable development of water resources in the basin.

2. Materials and Methods

2.1. Study Area

The Huangshui Basin, located in the northwestern interior of China (98°49′ - 103°26′E, 36°02′ - 38°22′N), is in the eastern part of Qinghai Province, flanked by the east of Tianjun County, Muli Mountain, and the Qilian Mountains to the north. The basin, covering approximately 32,900 square kilometers, features a complex and diverse terrain, including high mountains, river valley plains, and low hills, with a topography that is narrow in the east and wide in the west (Figure 1). It serves as the economic, political, and cultural hub of Qinghai Province and is the primary agricultural production base. The region is densely populated, with its gross industrial and agricultural product accounting

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for over 60% of the province's total, making it a vital pillar for Qinghai's economic development [31, 32].

Cities within the basin, such as Xining City, are not only the political center of the province but also hold significant positions in economic and cultural spheres. The climate of the basin is characterized by typical alpine and arid conditions, with average annual temperatures ranging from 0.6 to 7.9°C, featuring a large diurnal temperature difference and a small seasonal temperature difference. Annual precipitation varies from 300 to 500 mm, while the average annual evaporation rate is as high as 800 to 1500 mm, indicating significant water scarcity. Although the inter-annual variation in precipitation is minimal, the seasonal variation is pronounced, and the distribution of precipitation is highly uneven across regions, leading to water shortages in certain areas during specific seasons.

Currently, the water resources development and utilization rate in the Huangshui Basin has reached 60%, with an average multi-year water shortage of 240 million cubic meters [32]. This high rate of exploitation reflects the dependency on water resources in the basin and also highlights the constraints of water scarcity on regional development. To foster sustainable development in the Huangshui Basin, there is an urgent need for a comprehensive assessment of the sustainable utilization capacity of water resources. This assessment aims to optimize water resource management, enhance water utilization efficiency, and ensure the coordinated development of the regional economy, society, and ecosystem.

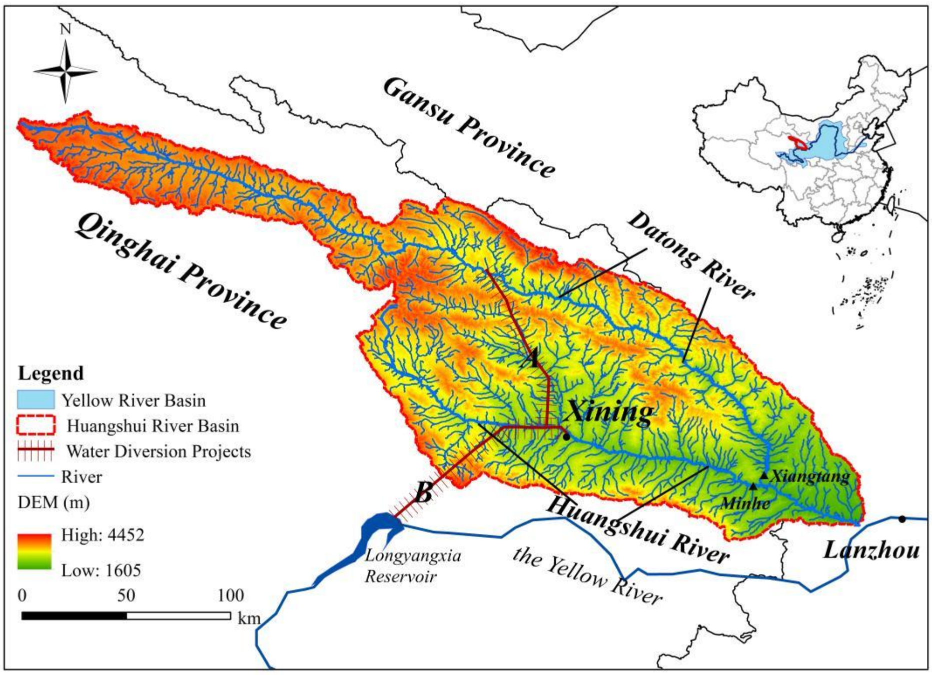

Figure 1. Site of the Huangshui River Basin(ABasin (sion water project from Datong to the Huangshui. B.Diversion water project from the Yellow River to Xining**).**

2.2. Data

The data for the evaluation indexes in this study are sourced from a variety of official publications and reports, including the 'Qinghai Province Water Resources Bulletin', the 'Qinghai Province Statistical Yearbook', and the 'Qinghai Province Environmental Condition Bulletin'. Additionally, we have utilized specialized planning documents such as the 'Huangshui River Basin Comprehensive Planning' (document number Water General Planning [2014] No. 1182), the 'Water

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Resources Configuration Project Planning of Huangshui Main Stream Area of Qinghai Province', and the 'Qinghai Province Second Water Resources Survey and Evaluation Report'.

2.3. Method

2.3.1. Fuzzy Comprehensive Evaluation Method

The specific steps to apply the method are as follows:

(1) Establishment of an Evaluation Index System for Sustainable Utilization Capacity of Resources

Building on previous research related to the sustainable utilization capacity of water resources, this study posits that the basin's water resources system's sustainable utilization capacity is an external manifestation of its natural attributes. This capacity is influenced by external factors such as climate change, water resources development, and utilization. By integrating these considerations with the characteristics of the Huangshui Basin, the main indicators affecting the sustainable utilization capacity of water resources are categorized into three groups: climate factor indicators, water resources system indicators, and socio-economic indicators. The Analytic Hierarchy Process (AHP) is employed to construct a scientifically sound, rational, and operable evaluation index system for the sustainable utilization capacity of water resources. The calculation methods and attributes of each index are detailed in Table 1, which presents the Huangshui River Basin water resources sustainable utilization capacity evaluation index system.

Table 1. Evaluation index system of sustainable utilization capacity of water resources in Huangshui River Basin.

objective	criterion	Indicator	calculation method	Indicators properties
Evaluation of sustainable utilization capacity of water resources	Indicators of climatic factors	Average multi-year precipitation/ mm	Total multi-year rainfall/year	positive
		Concentration of precipitation/ %	Multi-year average ratio of maximum 4 consecutive months of precipitation to annual precipitation	negative
		aridity index	Ratio of annual evaporative capacity to annual precipitation	negative
		Annual Precipitation Extreme Ratio	Ratio of annual evaporative capacity to annual precipitation	negative
	Indicators for water resources systems	water deficit/ %	Ratio of water deficit to total water supply	negative
		Surface water resource development and utilization/ %	Ratio of total water use to total water resources	negative
		Ratio of inter-basin/regional transfers to local water resources/ %	Inter-basin transfers/total water resources	negative
		Water quality compliance rate of water functional areas/ %	Number of water-quality-attainment sections in water functional zones/total number of sections in water functional zones	negative
	Socio-economic indicators	Water resources per capita／ m^3	Total water resources/total population	negative
		water consumption of ten thousand Yuan output value／(m^3/ ten thousand yuan)	Total water consumption/total GDP	negative
		population density / People/ km^2	Total population/basin area	negative
		Per capita GDP/ million yuan	Total GDP/total population	negative
		Average acre-foot water use for irrigated farmland/ m^3	Irrigation water use / irrigated acres of farmland	negative

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Water consumption of 10,000 yuan of industrial output value/(m^3/ million yuan)	Industrial water consumption/million yuan of industrial output value	negative
Centralized urban wastewater treatment rate/ %	Sewage treatment/total sewage discharge	negative

Note: Positive attributes indicate that the larger the value of the evaluation index, the greater the sustainable utilization capacity of the basin's water resources; negative attributes indicate a negative correlation between the evaluation index and the sustainable utilization capacity.

(2) Determination of criteria for grading fuzzy comprehensive evaluation indexes

In this study, the evaluation of the sustainable utilization capacity of water resources is categorized into five distinct levels to reflect varying degrees of sustainability:

Level I: Low sustainable utilization capacity, indicating minimal sustainability in water resource use.

Level II: Moderate sustainable utilization capacity, suggesting a balanced state of water resource use.

Level III: Medium sustainable utilization capacity, denoting a fair level of sustainability in water resource management.

Level IV: Strong sustainable utilization capacity, reflecting a high degree of sustainability and efficient water resource use.

Level V: Very strong sustainable utilization capacity, representing an optimal state of sustainability and resource management.

The grading criteria for each evaluation index, which determine the classification into these levels, are detailed in Table 2

Table 2. Classification standard of evaluation index of sustainable utilization capacity of water resources in Huangshui Basin.

objective	criterion	Indicator	I	II	III	IV	V
Evaluation of sustainable utilization capacity of water resources	Indicators of climatic factors	Average multi-year precipitation/mm	<200	200~400	400~600	600~800	>800
		Concentration of precipitation/ %	>80	70~80	60~70	50~60	<50
		aridity index	>7	3~7	2~3	1~2	<1
		Annual Precipitation Extreme Ratio	>3	2.5~3	2~2.5	1.5~2	<1.5
	Indicators for water resources systems	water deficit/%	>70	50~70	30~50	10~30	<10
		Surface water resource development and utilization/ %	>80	60~80	40~60	20~40	<20
		Ratio of inter-basin/regional transfers to local water resources/ %	>20	15~20	10~15	5~10	<5
		Water quality compliance rate of water functional areas/ %	<40	40~60	60~70	70~90	>90
	Socio-economic indicators	Water resources per capita／m^3	<500	500~1000	1000~1700	1700~3000	>3000
		water consumption of ten thousand Yuan output value／(m^3/million yuan)	>200	170~200	130~170	40~130	<40
		population density / person/ km^2	>500	400~500	260~400	180~260	<180
		Per capita GDP/ million yuan	>8	3.5~8	2.5~3.5	0.5~2.5	<0.5

Average acre-foot water use for irrigated farmland/ m³	>400	320~400	260~320	200~260	<200
Water consumption of 10,000 yuan of industrial output value/(m³/ million yuan)	>100	66~100	40~66	18~40	<18
Centralized urban wastewater treatment rate/ %	<20	20~30	30~50	50~60	>60
Sustainable utilization capacity of indicators	Low sustainable utilization capacity	Lower sustainable utilization capacity	Medium sustainable utilization capacity	Higher sustainable utilization capacity	High sustainable utilization capacity

(1) Evaluation model construction of sustainable utilization capacity of fuzzy integrated water resources

Let the number of evaluation indexes involved in the evaluation of sustainable utilization capacity of water resources be one, there is an evaluation level, and the selected evaluation indexes of sustainable utilization capacity of water resources are expressed in terms of the set of evaluation indexes established can be expressed as follows:

$$U = \{u_1, \cdots u_i, \cdots u_m\} \tag{1}$$

where,u_i is the first evaluation index,$i = 1,2, \cdots m$

As can be seen from Table 2, the evaluation criteria for sustainable utilization capacity of water resources in this study are divided into five levels, then the evaluation set established is:

$$V = \{v_1, v_2, v_3, v_4, v_5\} = \left\{ \begin{matrix} \text{Class I}, & \text{Class II}, \\ \text{Class III}, & \text{Class IV}, & \text{Class V} \end{matrix} \right\}$$

Let the degree of affiliation of the first water resources sustainable utilization capacity evaluation index to the evaluation set be recorded as, the larger the value of the degree of affiliation, the greater the probability that the evaluation index belongs to the evaluation level [33]. This value can be solved by the following affiliation function calculation method:

$$r_{i,j=1} = \begin{cases} 1, & c_i < s_{i,1} \\ \dfrac{s_{i,2} - c_i}{s_{i,2} - s_{i,1}}, & s_{i,1} \le c_i \le s_{i,2} \\ 0, & c_i > s_{i,2} \end{cases} \tag{2}$$

$$r_{i,1<j<n} = \begin{cases} 0, & c_i < s_{i,j-1} \text{或} c_i > s_{i,j+1} \\ \dfrac{c_i - s_{i,j-1}}{s_{i,j} - s_{i,j-1}}, & s_{i,j-1} \le c_i \le s_{i,j} \\ \dfrac{s_{i,j+1} - c_i}{s_{i,j+1} - s_{i,j}}, & s_{i,j} \le c_i \le s_{i,j+1} \end{cases} \tag{3}$$

$$r_{i,j=n} = \begin{cases} 0, & c_i < s_{i,n-1} \\ \dfrac{c_i - s_{i,n-1}}{s_{i,n} - s_{i,n-1}}, & s_{i,n-1} \le c_i \le s_{i,n} \\ 1, & c_i > s_{i,n} \end{cases} \tag{4}$$

In the above formulas (2), (3) and (4):$r_{i,j=1}$、$r_{i,1<j<n}$、$r_{i,j=n}$ respectively, for the 1st level (Class I), intermediate levels (Class II , Class III, Class IV) and the nth level (Class V) corresponding to the affiliation function;c_i is the measured value of the ith evaluation indicator; $s_{i,1}$、$s_{i,2}$、$s_{i,j-1}$、$s_{i,j}$、$s_{i,j+1}$、$s_{i,n-1}$、$s_{i,n}$ are the evaluation level values of the 1st, 2nd, j-1th, jth, j+1th, n-1th, and nth level

of water vulnerability criterion corresponding to the first evaluation indicator. For the evaluation indices where the evaluation grade values are negatively correlated (inversely) with the classification standards, the reciprocal values of the evaluation grade values need to be calculated and substituted to transform the relationships of the evaluation grade values of all evaluation indices into positive correlations, namely $s_{i,1} \le s_{i,2} \le s_{i,j-1} \le s_{i,j} \le s_{i,j+1} \le s_{i,n-1} \le s_{i,n}$.

Based on the affiliation value $r_{i,j}$ calculated by the affiliation function, the fuzzy relationship matrix between the water resources vulnerability evaluation indicators and the evaluation categories is established, which is denoted by R as:

$$R = \begin{bmatrix} r_{1,1} & \cdots & r_{1,n} \\ \vdots & r_{i,j} & \vdots \\ r_{m,1} & \cdots & r_{m,n} \end{bmatrix} \tag{5}$$

(3) Determine the Weights of Evaluation Indicators

Since the importance of each evaluation indicator of water resources vulnerability is implicit in the grading criteria, the grading criteria values are used to determine the weights of the indicators, which are calculated using the following formula:

$$a_i = \frac{s_{i,n-1}/s_{i,1}}{\sum_{i=1}^{m} s_{i,n-1}/s_{i,1}} \tag{6}$$

where,a_i is the weight of the first i evaluation indicator, n is the number of standardized scores; $s_{i,1}$ and $s_{i,n-1}$ are the standardized values of the first evaluation indicator corresponding to level 1 and level n-1, respectively.

Based on the calculated weight values the weight vector can be obtained as:$A = [a_1, \cdots a_i, \cdots a_m]$.

(4) Establishment of a Fuzzy Comprehensive Evaluation Model

According to the fuzzy relationship matrix R and weight vector A the fuzzy comprehensive evaluation model Y can be constructed as follows:

$$Y = A \cdot R = [a_1, \cdots a_i, \cdots a_m] \begin{bmatrix} r_{1,1} & \cdots & r_{1,n} \\ \vdots & r_{i,j} & \vdots \\ r_{m,1} & \cdots & r_{m,n} \end{bmatrix} = [y_1, y_2, \cdots y_n] \tag{7}$$

According to the results obtained from the model Y in the above equation using the principle of maximum affiliation [34] to determine the comprehensive evaluation level, that is, $y_j = max[y_1, y_2, \cdots y_n]$, then the vulnerability category of water resources of the evaluation object is the category j.

2.3.2. ELECTRE III Evaluation Method

ELECTRE (Elimination and Choice Expressing Reality) III is a Multi-Criteria Decision Analysis (MCDA) method that is primarily used to deal with complex decision problems, especially when there are multiple conflicting criteria. The method was proposed by Bernard Roy in the 1970s and belongs to the ELECTRE family of methods. The method introduces preference thresholds, no-difference thresholds, and rejection thresholds to characterize the decision maker's sensitivity and tolerance to different criteria. The core of ELECTRE III is to determine the ranking of advantages and disadvantages by comprehensively evaluating multiple alternatives [35].The specific steps to apply the method are as follows:

1. Construct m evaluation objects n index judgment matrix, this paper has 5 evaluation objects 15 indicators, the Huangshui River Basin based on the evaluation index system data series as program A1 to A5 attribute values:

$$R = (x_{ij})_{mn} (i = 1,2, \dots, m; j = 1,2, \dots) \tag{8}$$

2. The negative threshold is greater than the strict preference threshold. All the above three thresholds are determined by the decision maker and usually take a fixed value, and the veto threshold is usually three times of the prioritization threshold. For any attribute j that satisfies $v_j \ge p_j \ge q_j \ge 0$ no difference threshold q_j:

$$q_j = 0.3p_j \tag{9}$$

strictly dominant thresholds p_j:

$$p_j = \frac{1}{m}[a_{ij\,max} - a_{ij\,min}] \tag{10}$$

veto threshold v_j:

$$v_j = mp_j \tag{11}$$

where, $a_{ij\,max}$、$a_{ij\,min}$ are the maximum and minimum values of the attribute values, respectively.

(1) The formula for performing feasibility calculations is as follows

$$S(i,k) = \begin{cases} C(i,k), & if[36] \\ C(i,k)\prod\frac{1-d_j(i,k)}{1-C(i,k)}, & d_j(i,k) > C(i,k) \end{cases} \tag{12}$$

where, harmony index $C(i,k)$ is the degree of ai better than aj on attribute k, $d_j(i,k)$ is the degree of rejection of a_j level higher than a_k on attribute k, which means that the program a_j is worse than the program a_k.

3. Results

3.1. Evaluation Index Analysis of a Single Index for Sustainable Utilization Capacity of Water Resources

The sustainable utilization capacity of water resources in the Huangshui River Basin, calculated *from* multi-year data series, is detailed in Table 3, which presents the average values and single index evaluation results. As illustrated in Table 3, the evaluation indices for rainfall concentration, the annual precipitation extreme ratio, and the average water consumption level per agricultural mu in the Huangshui River Basin have all reached Level I, indicating a low sustainable utilization capacity. The indices for multi-year average precipitation, water quality of water functional zones, and per capita water resources are categorized at Level II, suggesting a slightly higher but still low sustainable utilization capacity. Furthermore, the drought index, water shortage rate, and GDP per capita have achieved a medium sustainable utilization capacity level.

These findings indicate that climatic factors and socio-economic conditions exert the most significant impact on the sustainable utilization capacity of water resources in the Huangshui River Basin. Additionally, it highlights that there is room for improvement in the water resources system class index to enhance the overall sustainable utilization capacity.

Table 3. Evaluation result of single index of sustainable utilization capacity of water resources in Huangshui River Basin.

objective	criterion	Indicator	Multi-year averages	Level
Evaluation of sustainable utilization capacity of water resources	Indicators of climatic factors	Average multi-year precipitation/ mm	350	II
		Concentration of precipitation/ %	84.2	I
		aridity index	2.57	III
		Annual Precipitation Extreme Ratio	5.3	I
	Indicators for water resources systems	water deficit/ %	34.4	III
		Surface water resource development and utilization/ %	35.2	IV
		Ratio of inter-basin/regional transfers to local water resources/ %	6.7	IV
		Water quality compliance rate of water functional areas/ %	41.7	II
		Water resources per capita／m³	670	II

	water consumption of ten thousand Yuan output value／(m^3/ million yuan)	85	IV
	population density / person/ km^2	196.5	IV
	Per capita GDP/ million yuan	2.01	III
Socio-economic indicators	Average acre-foot water use for irrigated farmland/ m^3	439	I
	Water consumption of 10,000 yuan of industrial output value/(m^3/ million yuan)	32	IV
	Centralized urban wastewater treatment rate/ %	75	V

3.2. Analysis of the Results of the Fuzzy Comprehensive Evaluation of the Sustainable Utilization Capacity of Water Resources

According to table 2 Huangshui basin water resources sustainable utilization capacity evaluation index grading standard in 15 evaluation index and 5 evaluation standard grade standard value, using the affiliation function formula (2), (3) and (4) calculated to get the affiliation value, the establishment of the Huangshui basin water resources sustainable utilization capacity evaluation index and evaluation category fuzzy relationship matrix for:

$$R = \begin{bmatrix} 0.25 & 0.75 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0.665 & 0.335 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0.32 & 0.68 & 0 & 0 \\ 0 & 0 & 0.864 & 0.136 & 0 \\ 0 & 0 & 0.507 & 0.493 & 0 \\ 0.915 & 0.085 & 0 & 0 & 0 \\ 0.66 & 0.34 & 0 & 0 & 0 \\ 0 & 0 & 0.765 & 0.235 & 0 \\ 0 & 0 & 0.273 & 0.727 & 0 \\ 0 & 0 & 0.939 & 0.061 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.795 & 0.205 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

According to formula (6) calculated weight value to the Huangshui Basin water resources sustainable utilization capacity evaluation index weight vector is:

$$A = \begin{pmatrix} 0.0554,0.0222,0.0970,0.0277, \\ 0.0970,0.0554,0.0554,0.0312, \\ 0.0831,0.0693,0.0385,0.2216, \\ 0.0277,0.077,0.0415 \end{pmatrix}$$

Finally, according to formula (7) calculated Huangshui basin water resources sustainable utilization capacity fuzzy comprehensive evaluation model results for: $Y = A \cdot R =$ [0.175,0.168,0.507,0.108,0.042].According to the principle of maximum affiliation can be seen, the above fuzzy comprehensive evaluation results of the maximum affiliation of 0.507, belongs to the third level, so the Huangshui River Basin water resources sustainable utilization capacity for the Ⅲ level, for the medium sustainable utilization capacity level.

Finally, the sustainable utilization capacity of the Huangshui Basin's water resources has been evaluated using a fuzzy comprehensive evaluation model $Y = A \cdot R =$ [0.175,0.168,0.507,0.108,0.042], as calculated by formula (7). According to the principle of maximum membership degree, the evaluation results indicate a maximum membership degree of 0.507. This value corresponds to the third level, signifying that the Huangshui River Basin's water resources have a medium sustainable utilization capacity, classified as Level Ⅲ.

3.3. Results of the ELECTRE III Method of Evaluating the Sustainable Utilization Capacity of Water Resources

In this study, the ELECTRE III method has been employed to evaluate the sustainable utilization of water resources, establishing a total of five evaluation objects: the Huangshui Basin and four standard programs. The entropy weighting method and threshold values were applied to determine the formula for these evaluations. The relationships between the Huangshui Basin and the standard programs are illustrated in Figure 2. The resulting index weights and thresholds derived from this analysis are presented in Table 4.

According to the formula, the five programs have been sorted, and the results are presented in the table. The sorting of the evaluation objects based on the ELECTRE III method is as follows: Ae > Ag > Huangshui River Basin > Af > Ah. The B(Ai) result for the Huangshui River Basin is 0, placing it between the Ag and Af programs. This indicates that the sustainable utilization capacity of the Huangshui River Basin's water resources is classified at the first Level Ⅲ. This classification is consistent with the results from the fuzzy comprehensive evaluation, which also categorizes the capacity as medium sustainable utilization.

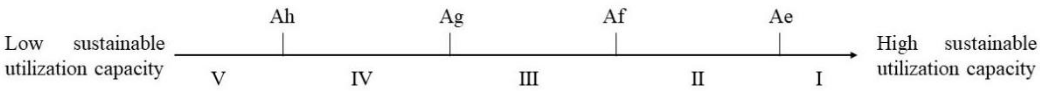

Figure 2. Classification of security grade and standard.

Table 4. Evaluation index weights and thresholds.

Indicator	Weights (w_j)	strictly dominant thresholds(p_j)	no difference threshold(q_j)	veto threshold(v)$_j$
C1	0.0663	760	228	3800
C2	0.0751	-33.16	-9.948	-165.8
C3	0.0555	0.4	0.12	2
C4	0.0569	-0.44	-0.132	-2.2
C5	0.0585	4	1.2	20
C6	0.0612	-4	-1.2	-20
C7	0.0664	-1	-0.3	-5
C8	0.0805	82	24.6	410
C9	0.0802	2900	870	14500
C10	0.0697	0	0	0
C11	0.0716	-80	-24	-400
C12	0.0551	1.1	0.33	5.5
C13	0.0723	-112.2	-33.66	-561
C14	0.0609	2	0.6	10
C15	0.0698	71	21.3	355

Table 5. Evaluation index weights and thresholds.

Indicator	A_1 (Huangshui basin)	A_2 (Ah)	A_3 (Af)	A_4 (Ag)	A_5 (Ae)
B（a_i）	0	-3	-1	1	3
Rank	3	5	4	2	1

4. Discussions

A comparison of the weighting results obtained from the fuzzy evaluation method and the ELECTRE III method reveals significant differences in the indices considered most impact on the sustainable utilization capacity of water resources (Figure 3). In the fuzzy evaluation method, the drought index (C3), water shortage rate (C5), per capita water resources (C9), and water consumption

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per ten thousand yuan of industrial output value (C14) are weighted highly, indicating their substantial influence on sustainability.

Conversely, the ELECTRE III method emphasizes the importance of different indices, such as precipitation concentration (C2), water quality compliance rate in water functional zones (C8), per capita water resources (C9), and population density (C11), in affecting the sustainable utilization capacity.

Integrating the findings from both methods, it is evident that certain indices—precipitation concentration (C2), the degree of drought (C3), water scarcity rate (C5), compliance rate with water quality standards in water functional zones (C8), per capita water resources (C9), and water consumption in irrigated farmland (C13)—have a pronounced impact on the sustainable utilization capacity of water resources. These indices should be prioritized in future water resource management strategies to enhance sustainability.

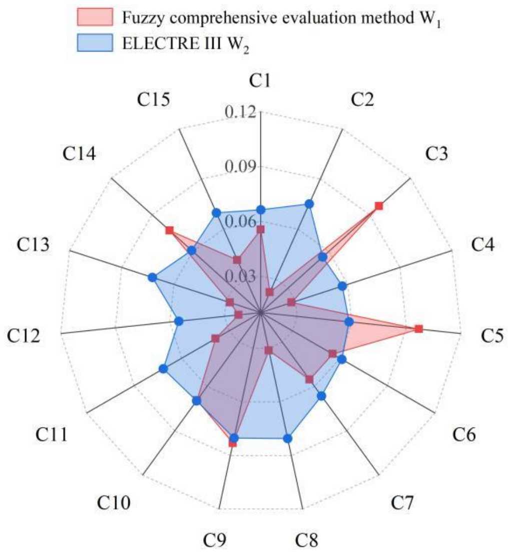

Figure 3. Influence Factor Diagram.

When addressing the critical issues surrounding the sustainable utilization of water resources in the Huangshui Basin, it is essential to concentrate on a set of core indicators. These indicators not only reflect the current state of water resource management but also foresee potential and challenges for future development. Based on a detailed analysis of these indicators, targeted measures and recommendations are proposed to ensure the long-term, stable, and efficient use of water resources in the Huangshui Basin.

Enhance External Water Resource Allocation: Given that climate factors are pivotal in determining water availability, the analysis indicates that the Huangshui Basin's climate-related indicators for sustainable water use are generally lower than the overall evaluation suggests. This implies significant water scarcity, highlighting the need for augmenting external water sources to bolster the basin's total water resources and enhance its sustainable utilization capacity. Initiatives such as accelerating water diversion projects like diversion water from Datong to the Huangshui and diversion water from the Yellow River to Xining are recommended.

Strengthen Water Resource Management: Implement flood early warning systems with automatic rainfall stations in key watersheds for real-time monitoring. Construct and maintain efficient drainage networks, including pipes, collection ponds, and pumping stations, with regular inspections to ensure functionality. Moreover, given the relatively low per capita water resources and irrigation efficiency in the basin, it is crucial to maximize water resource utilization efficiency.

Increase Comprehensive Water Body Remediation: The low water quality standard rate within the Huangshui Basin's water function areas calls for clear management objectives and corresponding measures. Regular monitoring and assessment are needed to uphold water quality standards.

Additionally, managing pollution sources from industrial, agricultural, and domestic sectors can reduce pollutant discharges. Establishing a sewage licensing system will regulate pollutant discharges. Strengthening water ecological protection and implementing ecological restoration projects, such as wetland conservation and river restoration, will help restore the natural purification capacity of water bodies.

5. Conclusions

The evaluation of the sustainable utilization capacity of water resources in the Huangshui Basin has been conducted using both the fuzzy comprehensive evaluation method and the ELECTRE III method. These methods involved constructing an index system, establishing a relationship matrix, determining index weights, and developing a comprehensive evaluation model. Based on the collected data, the evaluation indicates that the Huangshui Basin's water resources have a utilization capacity level of III, which is classified as medium sustainable utilization capacity.

Climatic factors and socio-economic conditions are identified as the primary reasons for the relatively low sustainable utilization capacity in the Huangshui Basin. To improve this, measures such as increasing the introduction of external water resources, enhancing water resource management, and comprehensively renovating surface water bodies are recommended.

Rainfall concentration and average water consumption in agricultural irrigation are the main factors affecting the low sustainable utilization capacity of the Huangshui River Basin's water resources. Other significant factors include multi-year average precipitation, the standard compliance rate of water quality in water functional zones, and per capita water resources. Additionally, the drought index, water scarcity rate, and per capita GDP have a certain degree of impact on the sustainable utilization status.

Due to data limitations within the Huangshui Basin, this paper's evaluation reflects the overall situation in recent years. Future research should focus on long-term, smaller regional scale evaluations to more objectively and accurately reflect the sustainable utilization capacity of water resources within the basin.

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