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Selection and evaluation of rural wastewater treatment technology in arid regions of Northwest China

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ABSTRACT

The arid regions of Northwest China (ARNC) are characterized by water shortage, drought, and sandstorms. This study aims to propose an effective technical plan for rural sewage in the arid area of Northwest China for reference. This study adopted the analytic hierarchy process method to calculate various parameters of ARNC wastewater treatment. By optimizing the preliminary indicator group of ARNC rural sewage treatment indicators, the optimized standard layer and indicator layer are obtained, and the weights of indicators at all levels are analyzed to obtain the results. Fuzzy comprehensive evaluation combined with the weighted summation method was used to determine the applicability of technology choices, and establish a review set and evaluation matrix. Studies have shown that the most suitable technical solutions for concentrated areas, scattered areas, and water source areas in the arid area of Northwest China are as follows: (1) sequential batch reactor (SBR) activity treatment + constructed wetland technology (CWT), (2) soil infiltration technology (SIT) + constructed wetland technology (CWT), (3) constructed wetland technology (CWT) + oxidation tank technology (OTT). Constructed wetland technology is very effective in all three areas, showing its adaptability and superiority to the environment. The research results provide a certain reference basis for decision makers of wastewater treatment technology in arid regions.

Keywords: Wastewater treatment; Combination model; Rural; Arid areas

1. Introduction

Rural areas have developed in recent years. However, due to the relatively high population in rural areas and the economic aspect that still lags behind urban areas, there is no reasonable treatment method for the large amount of sewage generated in rural areas. Due to the lack of supporting sewage treatment technology in rural areas, only simple processes such as septic tanks are generally adopted, which does not meet the discharge standards after treatment, which has an impact on the environment [1]. In terms of the impact caused by sewage discharge, rural sewage has a large area and is currently one of the main sources of water pollution. 80% of my country's sewage will come from villages and towns, so sewage treatment must be treated from the source [2]. The efficiency of wastewater treatment in rural areas is low, and the treatment efficiency in China is about 20% [3]. Rural sewage treatment has affected the sustainable development of the region. At the same time,

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different regional topography and landforms have made it difficult for rural sewage treatment [4]. For example, in the arid areas of Northwest China, due to lack of water resources, dry weather and high winds, natural factors have become more obstructive to rural sewage treatment. Water environment issues have become increasingly prominent issues in global sustainable development. Therefore, it is imminent to realize the sustainable management, optimization and technology selection of rural sewage [5]. With such problems, we need to evaluate the selection and applicability of arid regions of Northwest China (ARNC's) rural sewage technology.

The northwestern region is vast and sparsely populated, and the population of dispersed villages is relatively high. When dealing with small dispersed areas, the combination of sequential batch reactor technology (SBR) and constructed wetland technology will cause the entire system to fail to achieve the best operating results due to rainfall. At the same time, high-intensity precipitation increases operational difficulties [6]. Studies have shown that the average phosphorus removal efficiency of the sand filter in the septic tank + sand filter combination technology is 53.8%, but it will gradually decrease until it is blocked. The phosphorus adsorption capacity of the clogged sand before and after the sand filter is much higher than that of the new sand, but the combination method needs to consider the maintenance frequency [7]. The study found that the technical methods of sewage treatment for different regions cannot rely on technical design alone, and the commissioning and engineering maintenance of professional companies are equally important. At the same time, financial resources and long-term maintenance are important factors to ensure long-term operation [8]. Simply constructed wetlands can no longer satisfy the current rural sewage treatment. In order to achieve a higher total N removal rate and more complex sewage removal, new types of constructed wetlands such as free water (FWS) CWs and multi-level CWs have gradually developed, and all types of hybrid constructed wetlands are more effective than single constructed wetlands in total N removal [9]. The total N and total P removal rates of the new integrated device inverted A^2/O-MBR process are close to 69% and 89%, respectively. When the dissolved oxygen is 3.0 mg/L, the removal rate of NH_4^+–N, total N and total P can reach 96%, 70% and 88%. The combined process greatly enhances the removal effect of N and P, and the device is small in size. Easy to install and meet the needs of regional sewage treatment in rural areas [10]. The study found that in the case of N and P removal in different seasons, decentralized rural sewage treatment can use anaerobic sewage tanks, adsorption biological filter systems and up-flow constructed wetland combined processes, which have high performance and low maintenance funds [11]. Shen et al. [12] evaluated four combined processes in the Taihu Lake Basin. Constructed wetlands are often used for advanced water quality treatment. Based on the poor effect of ecological ponds, the integrated flow wetland process and the vertical flow wetland process have a high level of pollutant removal. Some countries have begun to implement combined treatment technologies with constructed wetlands as the main body. Among the combined technologies, eight types of sewer overflow-constructed wetland treatment technologies have been identified. These technologies are advanced and widely applicable [13]. Among the combined technology treatments, the constructed wetland treatment technology has relatively excellent removal effects on chemical oxygen demand (COD), TN, TP and NH_4^+–N [14]. Combination technology to treat sewage can be used in accordance with local conditions and targeted use in China's rural sewage treatment. Sewage treatment technology in rural areas of China should be based on the local economy, population distribution, and environmental benefits as the criteria, showing a certain degree of applicability and feasibility. The combined technology has a better removal rate and up to standard water quality when treating rural sewage, and the efficiency is high [15]. Everything has two sides. The choice of technology can only adapt to the environment and make up for shortcomings as much as possible, and cannot be completely immune to geographic factors and extreme climatic conditions.

The rural areas in the northwestern region are relatively scattered. Although there are concentrated large-scale villages, due to geographical factors, such as water shortage, drought, high temperature, treatment technologies need to complement each other and combine with each other. For the feasibility selection of various technologies, evaluation of various indicators of different technologies through models, optimization and selection is a reasonable, effective and intuitive method. Wang et al. found in the research on optimization model of rural domestic sewage treatment that the biological-ecological combination technology, with constructed wetlands as the main body, has a better effect on removing P and higher efficiency [16]. Studies have shown that a new type of wastewater treatment technology sustainability assessment uses analytic hierarchy process (AHP) to find four important indicators: annual total equivalent cost, carbon emission intensity, eutrophication potential and resilience. When choosing different technology options, sustainability and economic costs are relatively important factors [17]. For the evaluation system of sewage treatment technology, Shen et al. [12] applied four processes in the Taihu Lake Basin: vertical flow wetland-ecological pond-surface flow wetland-horizontal flow wetland, vertical flow wetland-horizontal flow wetland, ecological pond-horizontal flow wetland-surface flow wetland, ecological ditch-ecological pond are evaluated, using AHP method, entropy weight method to calculate indicator weight, using enrichment evaluation preference ranking organization method (PROMETHEE) to rank processing technology. Studies have used the life cycle method to evaluate wastewater treatment facilities (WWTF). Calculate and evaluate the indicators under the three standard levels, including economic performance, then use fuzzy logic analysis to identify them, and finally select wastewater treatment technology with the help of the global sustainable development indicator to achieve the principle of sustainable development [18]. The selection of the best combination technology can also be evaluated through the AHP method, combined with the entropy weight method to calculate the weight, and evaluated through the statistical method [12]. The AHP method can be combined with fuzzy set theory (FST), and the results are more convincing [19]. Interestingly, multi-level, multi-level comprehensive analysis of environmental or economic related issues is very useful [17]. Such as the combination of different models and methods of OFW + AHP + FST [12]. Studies have shown that the AHP method is usually suitable for combining with other models and methods to evaluate the importance of indicators under different environmental factors [20,21]. There are studies that combine AHP with other methods to evaluate the governance model and select technology, and it is of great significance to deal with extreme weather and cold conditions in areas where it is difficult to choose a treatment method [22].

According to the specific regional characteristics of ARNC, this paper adopted the AHP + FCE method. The AHP method combines the data obtained by experts in related fields and quantitative calculation, and can use the formula to quantify the subjectivity, but the judgment is mostly based on experience and literature support, so the corresponding paired evaluation method is needed to make up for the deficiency. Combined with fuzzy comprehensive evaluation (FCE), FCE can be used to effectively reduce the subjectivity of evaluation, that is, the "experience and literature" mentioned in AHP. AHP + FCE allows both quantification and subjectivity issues to be well resolved. Through the acute calculation and analysis of ARNC's rural sewage indicators, it provided a certain reference for sewage treatment in drought, water shortage, and sandy areas. In this study, the weights of 3 indicators at the criterion level and optimization indicator were calculated and ranked comprehensively. And then we through the establishment of evaluation set classification. Finally, the membership degree and fuzzy degree of each technology selection of the combined technology were analyzed, and the weighted summation was performed to obtain the combination of the highest and the secondary technology, and the feasibility of each technology can be judged simplified and convenient for selection. This study provided a reference for the combination of rural sewage treatment technologies in arid areas.

2. Methods

2.1. Establish an indicator model

First of all, the evaluation indicator was established. This research constructed the hierarchy of "target-selectivity-indicator". 40 preliminary indicators were optimized and selected from three levels of economic, technical and environmental by means of check and field investigation. The construction of the indicator system needed to conform to the eight principles of scientificity, practicality, measurability, comparability, simplicity, systematicness, dynamics and operability. For rural and remote areas in the northwest, the construction and operation of various process facilities required a lot of capital. The economic benefit indicator reflected the investment situation and also reflects the rationality of operation and management. Technical performance indicators could essentially be divided into technical maturity and whether the effluent quality meets the standard. For different regions, the scope of its facility service needed to investigate and analyze the removal effect of sewage, and consider COD, biochemical oxygen demand (BOD_5), ammonia nitrogen and other indicators to reflect the technical efficiency and facilitate the adjustment of parameters to improve the method. Environmental impact was an important part of the mix of different technology options. In terms of sewage treatment, it was necessary to consider both the impact of the regional environment on the choice of technology and the impact of technology on the village. The environment was closely related to whether the decision-makers choose and match the process is reasonable or not in practical application. Due to the different nature of China's geography and conditions, the choice of governance technology was different, the preliminary indicators are shown in Table 1.

2.2. Optimization of indicators system

Used AHP to optimize the evaluation indicator, the 40 index in the preliminary system were screened and optimized, and finally the 15 most important (C_1–C_{15}) evaluation indicators were obtained. When selecting and optimizing the evaluation indicators of rural sewage treatment technology in the northwest region, it is necessary to ensure the availability of the indicators and easy quantitative analysis. And whether the indicators are effective and reasonable for the region. Following the 8 principles mentioned above, the selection of indicators should ensure that the definition is accurate, there are actual data sources that can accurately reflect the actual operating conditions, and the sewage treatment technology can be evaluated scientifically and reasonably. When selecting and optimizing the evaluation indicators of rural sewage treatment technology in the northwest region, it is necessary to ensure the availability of the indicators and easy quantitative analysis. And whether the indicators are effective and reasonable for the region. Following the 8 principles mentioned above, the selection of indicators should ensure that the definition is accurate, there are actual data sources that can accurately reflect the actual operating conditions, and the sewage treatment technology can be evaluated scientifically and reasonably. The indicator system followed the principles of scientificity, practicality, and simplicity [23]. The results are express in Table 2. Based on the weight of the indicators, an AHP model was established. In the single-level ranking method, the matrix and eigenvectors are used to normalize the weights of the indicators. Used formula calculations (1)–(3):

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(XW)_i}{W_i} \tag{1}$$

$$C_I = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

$$C_R = \frac{C_I}{R_I} \tag{3}$$

According to the AHP method, established a model and perform calculations. Then, Python, WPS and Excel software were used to simulate, built the corresponding model. The indicator system established is shown in Fig. 1. R_I value is shown in Table 3.

Table 1
Comprehensive evaluation indicator of rural sewage treatment model

Target layer	Criterion layer	Indicator layer	
Rural sewage treatment model	Economic benefit	1. Local funds	8. Unit construction area
		2. Operating costs	9. Land cost
		3. Unit investment	10. Equipment maintenance
		4. Unit energy consumption	11. Economic benefit
		5. Construction area	12. Process complexity
		6. Consumption	13. Equipment prices
		7. Reasonable scale	14. Transportation cost
	Technical performance	15. Total sewage treatment	23. Total N removal rate
		16. COD removal rate	24. Total P removal rate
		17. BOD_5 removal rate	25. Total dissolved solids removal rate
		18. SS removal rate	26. Stability of effluent compliance rate
		19. NH_4^+–N removal rate	27. Pathogenic microorganism removal rate
		20. pH compliance rate	28. Process operation stability
		21. Water color	29. Difficulty of management and operation
		22. Process simplicity	30. Sludge treatment
	Environmental impact	31. Noise impact level	36. Temperature influence
		32. SO_2 production	37. Available water
		33. NO_x production	38. Regional water volume
		34. CO_2 production	39. Impact on local residents
		35. H_2S production	40. Ecological balance

Annotation: Biochemical oxygen demand (BOD_5), Hydrogen ion concentration (pH), Sulfur dioxide (SO_2), Nitrogen oxides (NO_x), Carbon (CO_2), Hydrogen sulfide (H_2S)

Table 2
ARNC rural sewage treatment comprehensive evaluation indicator system optimization results

Target layer	Criterion layer	Indicator layer
Rural wastewater treatment technology in ARNC (A)	Economic benefit (B_1)	Local funds (C_1)
		Operating costs (C_2)
		Equipment maintenance (C_3)
		Transportation cost (C_4)
	Technical performance (B_2)	COD removal rate (C_5)
		BOD_5 removal rate (C_6)
		NH_4^+–N removal rate (C_7)
		SS removal rate (C_8)
		Total N removal rate (C_9)
		Total P removal rate (C_{10})
	Environmental impact (B_3)	Available water (C_{11})
		CO_2 production (C_{12})
		Regional water volume (C_{13})
		Impact on local residents (C_{14})
		Ecological balance (C_{15})

Table 3
Average random consensus indicator R_I

n	1	2	3	4	5	6	7	8	9	10
R_I	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.3. Reference situation of technical indicators of sewage treatment in Northwest China today

The selection of wastewater treatment technology needs to be based on a series of indicators such as water consumption, local wastewater quality, wastewater treatment efficiency, and cost. The reference values of each indicator are shown in Tables 4–6 [24–26]. Upgrading wastewater treatment plants and using combined processes can greatly improve effluent quality and efficiency are shown in Table 7 [26].

2.4. Establishment of evaluation model

The establishment of an evaluation model requires the establishment of an evaluation indicator system. The factors of the evaluation system were divided into quantitative indicators and qualitative indicators. So we assumed the total set T and its subsets t_1, t_2, t_3, t_4, …, t_n. The AHP method was used to determine the weight set I of the evaluation indicator system.

2.5. FCE method to calculate the evaluation grade

The FCE method indicates the level of factors through a set of hypothetical annotations. In this study, five levels of evaluation were passed, it is supposed that P = {worst, worse, average, better, good}. Through the rating result, a standardized evaluation value R_L was obtained. The maximum value of final M was the final selection model result Eq. (4):

$$M = R_{kL} \times W = \begin{pmatrix} R_{11} & R_{12} & " & R_{1n} \\ R_{21} & R_{22} & " & R_{2n} \\ " & " & " & " \\ R_{k1} & R_{k2} & " & R_{kn} \end{pmatrix} + \begin{pmatrix} W_1 \\ W_2 \\ " \\ W_n \end{pmatrix} = \begin{pmatrix} M_1 \\ M_2 \\ " \\ M_k \end{pmatrix} \quad (4)$$

where W represents the weight value; R_{kL} is the result of the Lth index in the kth model.

2.6. Comprehensive calculation

Membership is also called membership function, which is a concept in fuzzy evaluation function. In the evaluation of membership degree, the positive trend shows an increasing positive trend, and the negative trend shows a decreasing positive trend.

The calculation of $h(I)$: $0 < I \leq 1$, $h(I) = 1$; $I > 1$, $h(I) = e-(I-1)$. Ii = Si/Ci (positive indicators); Ii = Ci/Si (negative indicators).

In the comprehensive evaluation, we sorted the membership degrees of different indicators at all levels and calculate the fuzzy measure of each indicator. The calculation formula of the fuzzy integral evaluation model is Eq. (5).

$$\int \mathrm{xh}(x_i) * g(\cdot) = \sum_{i=1}^{n} \left[h(x_i) \cdot H(x_i) \right] \quad (5)$$

2.7. Use the AHP method to select the optimal technology combination by weighted summation

The weighted summation of the weights of 15 indicators in the indicator layer was used to obtain the comprehensive score of each technology, and the optimal solution was selected. (√ indicates the advantage of the technology, × indicates no such advantage).

3. Results

3.1. Evaluation of criterion layer

According to the judgment matrix constructed by the AHP method, we can think that when $C_R < 0.1$, the weight of the indicator factor according to the nine-scale matrix A-B W_i conforms to the expected result.

$$\text{Matrix } A\text{-}B \quad \begin{matrix} & B_1 & B_2 & B_3 \\ B_1 & 1 & 2 & 3/2 \\ B_2 & 1/2 & 1 & 1/2 \\ B_3 & 2/3 & 2 & 1 \end{matrix} \quad (6)$$

Table 5
Influent water quality index in Northwest China

No.	Project	
1	COD_{Cr} (mg/L)	420
2	BOD_5 (mg/L)	136
3	SS (mg/L)	215
4	NH_3–N (mg/L)	65
5	TN (mg/L)	73
6	TP (mg/L)	6.9
7	Temperature (°C)	9

Table 4
Reference for rural water consumption in Northwest China

Domestic water and equipment conditions	Water consumption per capita (L/d)
No basic water supply, water facilities	10–25
There are water supply facilities, but the water supply facilities are not perfect	25–45
Equipped with tap water supply and washing machine	40–70
Fully equipped with water	65–90

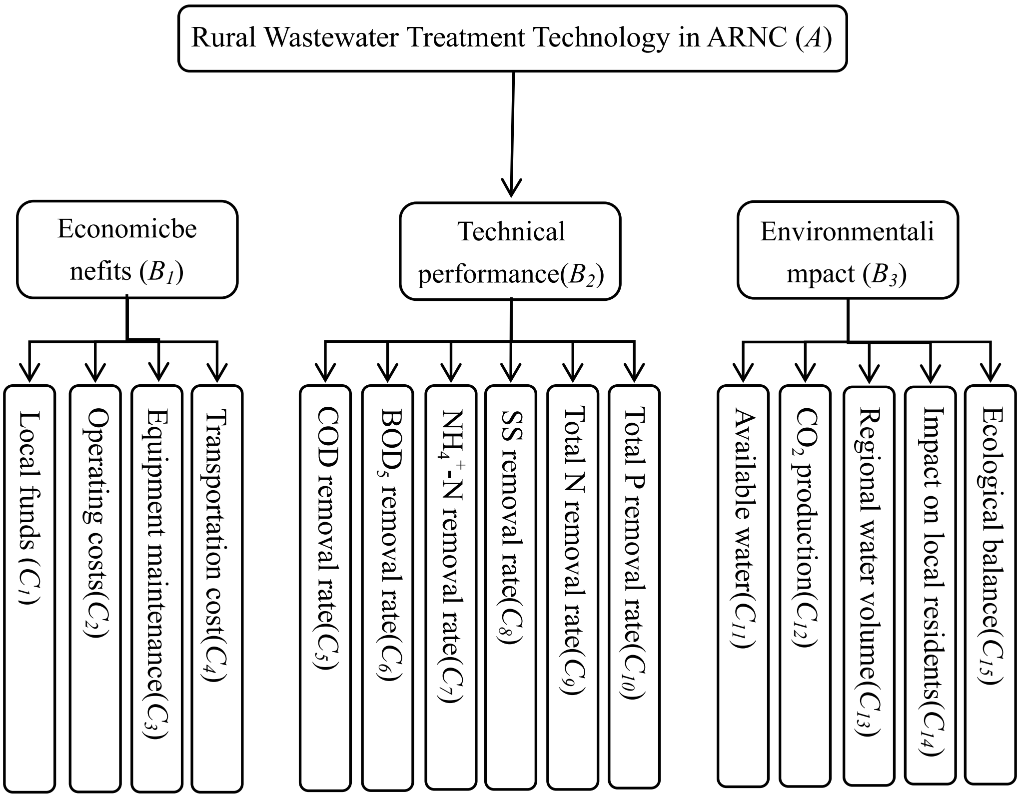

Fig. 1. ARNC rural sewage treatment technology evaluation indicator system.

Table 6
The proportion of discharge standards implemented by urban sewage treatment plants in my country

Emission Standards	Tier 1 A Standard	Tier 1 B Standard	Secondary standard	Other
Proportion	33%	39%	14%	14%

Table 7
Influent and effluent effects and treatment efficiency after renovation

Parameter	COD_{Cr}	BOD_5	TP	SS	TN	NH_4^+–N	Temperature
Influent (new) (mg/L)	400	200	6	200	70	60	12°C–25°C
Effluent (new) (mg/L)	30	6	0.3	5	15	1.5(2.5)	12°C–25°C
Processing rate (%)	93	97	95	98	79	98	
Effluent (old) (mg/L)	60	20	1	20	20	8	12°C–25°C

$$\text{Relative importance weight } W_i = \begin{bmatrix} 0.4546 \\ 0.1986 \\ 0.3469 \end{bmatrix} \quad (7)$$

For ARNC criterion layer indicator B_1–B_3 calculation, the weights W_i in the criterion layer are 0.4546, 0.1986, 0.3469, respectively, as shown in Table 8. We use the formula $AW_i/W_i = \lambda_{\max}$ to calculate $\lambda_{\max} = 3.0183$.

Regarding $C_I = \frac{\lambda_{\max} - n}{n-1} = 0.0092$, Table 3 expressed that $n = 3$, $R_I = 0.58$. For the random consistency test of the matrix A-B, the calculation result of the formula $C_R = \frac{C_I}{R_I} = 0.0158$ (<0.1) indicates that met the requirements principle.

3.2. Economic benefit indicator (B_1)

The above-method was used to construct the index matrix B_1–C. The nine-scale matrix B_1–C was calculated and check the consistency. According to the judgment matrix constructed by the AHP method, it can be considered that when $C_R < 0.1$, the weight of the indicator factor according to the nine-scale matrix B_1–C W_i conforms to the expected result in Table 9.

Regarding $C_I = \frac{\lambda_{max} - n}{n-1} = 0.0775$, when n = 4, R_I = 0.90. For the random consistency test of the matrix B_1–C, the calculation result of the formula $C_R = \frac{C_I}{R_I} = 0.0861$ (<0.1) indicates that met the requirements principle.

3.3. Technical performance indicator (B_2)

The above-method was used to construct the index matrix B_2–C. The nine-scale matrix B_2–C was calculated and check the consistency. According to the judgment matrix constructed by the AHP method, it can be considered that when C_R < 0.1, the weight of the indicator factor according to the nine-scale matrix B_2–C W_i conforms to the expected result. The results are shown in Table 10.

Regarding $C_I = \frac{\lambda_{max} - n}{n-1} = 0.0867$, when n = 6, R_I = 1.24. For the random consistency test of the matrix B_2–C, the calculation result of the formula $C_R = \frac{C_I}{R_I} = 0.0699$ (<0.1) indicates that met the requirements principle.

3.4. Environmental impact indicator (B_3)

The above-method was used to construct the index matrix B_3–C. The nine-scale matrix B_3–C was calculated and check the consistency. According to the judgment matrix constructed by the AHP method, it can be considered that when C_R < 0.1, the weight of the indicator factor according to the nine-scale matrix B_3–C W_i conforms to the expected result. The results are shown in Table 11.

Regarding $C_I = \frac{\lambda_{max} - n}{n-1} = 0.10627$, when n = 5, R_I = 1.12. For the random consistency test of the matrix B_2–C, the calculation result of the formula $C_R = \frac{C_I}{R_I} = 0.0948$ (<0.1) indicates that met the requirements principle.

Table 8
Summary of the results of the nine-scale matrix judgment at the criterion layer (Matrix *A-B*)

A-B	B_1	B_2	B_3	W_i
B_1	1	2	3/2	0.4546
B_2	1/2	1	1/2	0.1986
B_3	2/3	2	1	0.3469

Table 9
Summary of the results of the nine-scale matrix of the economic benefit layer (Matrix B_1–C)

B_1–C	C_1	C_2	C_3	C_4	W_i
C_1	1	1/2	1/3	2/3	0.1245
C_2	2	1	3	4	0.4772
C_3	3	1/3	1	2	0.2564
C_4	3/2	1/4	1/2	1	0.1419

3.5. Comprehensive weight result

After sorting through the level list, we comprehensively sorted the various indicators of ARNC rural sewage treatment technology, determine the comprehensive weight and rank of each evaluation indicator. The results are shown in Table 12. The distribution diagram of the calculation results of the indicator layer is shown in Fig. 2.

3.6. Evaluation criteria of indicators

We divide the indicators into two categories. The evaluation criteria of ARNC's rural sewage treatment technology are divided into quantitative indicators and qualitative indicators. The optimization evaluation indicators obtained by the optimization of the AHP method are divided into five categories. The qualitative and quantitative evaluation results of the indicators are shown in Table 13.

3.7. Establishment of ARNC rural wastewater treatment technology evaluation model

Based on the above ARNC indicator evaluation standards, an applicability evaluation system is established. The indicators are divided into two categories, and the classification results are shown in Table 14. According to different levels of indicators, a set U and each subset u_1, u_2, u_3 are established, and a 15-item level set W is established.

U = {Economic benefits (u_1), Technical performance (u_2), Environmental impact (u_3)},

u_1 = {Local funds (u_{11}), Operating costs (u_{12}), Equipment maintenance (u_{13}), Transportation cost (u_{14})},

u_2 = {COD removal rate (u_{21}), BOD_5 (u_{22}), NH_4^+–N (u_{23}), SS (u_{24}), Total N (u_{25}), Total P (u_{26})},

Table 10
Summary table of the results of the nine-scale matrix of the technical performance layer (Matrix B_2–C)

B_2–C	C_5	C_6	C_7	C_8	C_9	C_{10}	W_i
C_5	1	1	2	2	3	3/2	0.2376
C_6	1	1	2	2	3	1/2	0.1978
C_7	1/2	1/2	1	2	4	1	0.1647
C_8	1/2	1/2	1/2	1	3	1/2	0.1110
C_9	1/3	1/3	1/4	1/3	1	1/3	0.0560
C_{10}	2/3	2	1	2	3	2	0.2329

Table 11
Summary of the results of the nine-scale matrix of the environmental impact layer (Matrix B_3–C)

B_3–C	C_{12}	C_{13}	C_{14}	C_{15}	W_i
C_{11}	1	3	4/5	3	0.3397
C_{12}	1/3	1	2	3	0.2289
C_{13}	5/4	1/2	1	4	0.2393
C_{14}	1/4	1/2	1/2	3	0.1241
C_{15}	1/3	1/3	1/4	1	0.0680

Table 12
Comprehensive weight table of indicator system

Target layer	Criterion layer	Weights	Indicator layer	Weights	Comprehensive weight
Rural wastewater treatment technology in ARNC (A)	Economic benefits (B_1)	0.4546	Local funds (C_1)	0.1245	0.0415
			Operating costs (C_2)	0.4772	0.1591
			Equipment maintenance (C_3)	0.2564	0.0855
			Transportation cost (C_4)	0.1419	0.0473
	Technical performance (B_2)	0.1986	COD removal rate (C_5)	0.2376	0.0792
			BOD_5 removal rate (C_6)	0.1978	0.0659
			NH_4^+–N removal rate (C_7)	0.1647	0.0549
			SS removal rate (C_8)	0.1110	0.0370
			Total N removal rate (C_9)	0.0560	0.0187
			Total P removal rate (C_{10})	0.2329	0.0776
	Environmental impact (B_3)	0.3469	Available water (C_{11})	0.3397	0.1132
			CO_2 production (C_{12})	0.2289	0.0763
			Regional water volume (C_{13})	0.2393	0.0798
			Impact on local residents (C_{14})	0.1241	0.0414
			Ecological balance (C_{15})	0.0680	0.0227

Table 13
Indicator evaluation standard for rural domestic sewage treatment model.

Evaluation indicator	Rating				
	0.2	0.4	0.6	0.8	1.0
COD removal (%)	Worst (<60)	Worse (60–70)	Average (70–80)	Better (80–90)	Good (>90)
BOD_5 removal (%)	Worst (<60)	Worse (60–70)	Average (70–80)	Better (80–90)	Good (>90)
NH_4^+–N removal (%)	Worst (<60)	Worse (60–70)	Average (70–80)	Better (80–90)	Good (>90)
SS removal (%)	Worst (<60)	Worse (60–70)	Average (70–80)	Better (80–90)	Good (>90)
Total N removal rate	Worst (<60)	Worse (60–70)	Average (70–80)	Better (80–90)	Good (>90)
Total P removal rate	Worst (<60)	Worse (60–70)	Average (70–80)	Better (80–90)	Good (>90)
Available water	Rarely	Less	Average	More	Mickle
CO_2 production	Rarely	Less	Average	More	Mickle
Regional water volume	Rarely	Less	Average	More	Mickle
Impact on local residents	Serious	Obviously	Influential	Slightly	No
Ecological balance	Imbalance	Unstable	Average	Relatively stable	Stability

u_3 = {Available water (u_{31}), CO_2 production (u_{32}), Regional water volume (u_{33}), Impact on local residents (u_{34}), Ecological balance (u_{35})}.

W = {0.0415, 0.1591, 0.0855, 0.0473, 0.0792, 0.0659, 0.0549, 0.0370, 0.0187, 0.0776, 0.1132, 0.0763, 0.0798, 0.0414, 0.0227}.

3.8. FCE calculation evaluation

We get the values of various indicators through FCE. The evaluation standard R_L of the evaluation index is determined by the score of the indicator. Eqs. (4) and (5) are used to calculate and determine the final results and the corresponding fuzzy measure. The calculation results obtained by fuzzy measure are shown in Table 15.

3.8.1. Indicator layer evaluation value result

In the evaluation integral model, the evaluation value of B_1 indicator (economic benefit) calculates the four indicator levels of C_1–C_4, and their membership degrees are 0.938, 0.919, 0.975 and 0.988, respectively, and the order of membership degrees is $C_4 > C_3 > C_1 > C_2$. The corresponding fuzzy metrics are 0.325, 0.309, 0.270, 0.264. The evaluation value L_1^1 = 0.956 was calculated. The same can be calculated L_1^2 = 0.947, L_1^3 = 0.971, L_1^4 = 0.988.

3.8.2. Criterion layer evaluation value result

Like above-method, the membership degree is calculated for the indicator evaluation standard of the criterion layer, and the comprehensive evaluation value L_0^1 = 5.177, L_0^2 = 4.391,

Table 14
ARNC rural sewage treatment technology applicability evaluation system

Classification	Various indicators
Qualitative indicators	Process applicability (C_9); Stability of effluent reaching standard (C_{10}); Ease of management and operation (C_{11}); Malodorous gas influence (C_{12}); Noise level (C_{13}); Regional environmental temperature influence (C_{14}); Impact on local residents (C_{15})
Quantitative indicators	Local funds and Unit investment (C_1); Operating costs (C_2); Construction area and Service population ratio (C_3); Sewage water volume (C_4); COD removal rate (C_5); BOD_5 removal rate (C_6); NH_4^+–N removal rate (C_7); SS removal rate (C_8)

L_0^3 = 5.035 was calculated according to the fuzzy comprehensive evaluation method.

3.9. Judge the pros and cons of the technology through weighted sum calculation

Establishing models through AHP and FCE methods and calculating the weight results, we use the indicators for the existence of various technologies to comprehensively judge their pros and cons. ARNC rural sewage treatment technology is applied in three treatment areas.

The indicator codes are as follows: local funds (C_1), operating costs (C_2), equipment maintenance (C_3), transportation cost (C_4), COD (C_5), BOD_5 (C_6), NH_4^+–N (C_7), SS (C_8), total N (C_9), total P (C_{10}), available water (C_{11}), CO_2 production (C_{12}), regional water volume (C_{13}), impact on local residents (C_{14}), and ecological balance (C_{15}). Through on-site inspections and expert evaluations, the three governance areas and related processing technologies are weighted and sorted, and more preferred items are obtained.

3.9.1. Calculation results of centralized governance regional superiority technology

In the centralized treatment area, the common methods are sequential batch reactor activity (SBR) treatment method, biological contact oxidation (BCO) method, membrane bioreactor (MBR) method, constructed rapid infiltration (CRI) system and constructed wetland technology (CWT). The codes are G_1, G_2, G_3, G_4, G_5. The results are shown in Table 16. The AHP comprehensive evaluation of G_1 = 0.9010 is the highest, G_5 = 0.7232 is secondary, G_2 = 0.6082, G_3 = 0.5686, G_4 = 0.7080. $G_1 > G_5 > G_4 > G_2 > G_3$. The FCE comprehensive evaluation of G_5 = 3.155 is the highest, G_1 = 3.136 is secondary. Therefore, SBR technology + CWT is the best choice for centralized treatment areas.

3.9.2. Calculation results of regional superiority technology for decentralized governance

In decentralized treatment areas, the most applicable technologies are constructed wetland technology (CWT),

Table 15
Fuzzy measurement results of criterion level and indicator level

Criterion layer	Indicator layer	Fuzzy measure
Economic benefits B_1		0.519
	Local funds (C_1)	0.270
	Operating costs (C_2)	0.264
	Equipment maintenance (C_3)	0.309
	Transportation cost (C_4)	0.325
Technical performance B_2		0.237
	COD removal rate (C_5)	0.144
	BOD_5 removal rate (C_6)	0.103
	NH_4^+–N removal rate (C_7)	0.141
	SS removal rate (C_8)	0.168
	Total N removal rate (C_9)	0.213
	Total P removal rate (C_{10})	0.225
Environmental impact B_3		0.488
	Available water (C_{11})	0.399
	CO_2 production (C_{12})	0.294
	Regional water volume (C_{13})	0.427
	Impact on local residents (C_{14})	0.148
	Ecological balance (C_{15})	0.431

Table 16
Calculation results of centralized governance regional superiority technology

Evaluation indicator	AHP	FCE	Governance technology				
			G_1	G_2	G_3	G_4	G_5
C_1	0.0415	0.270	√	×	×	×	√
C_2	0.1591	0.264	√	×	√	√	×
C_3	0.0855	0.309	√	√	×	×	√
C_4	0.0473	0.325	√	×	×	×	√
C_5	0.0792	0.144	√	√	√	√	√
C_6	0.0659	0.103	√	√	√	√	√
C_7	0.0549	0.141	√	√	√	√	√
C_8	0.0370	0.168	√	√	√	√	√
C_9	0.0187	0.213	√	√	√	√	√
C_{10}	0.0776	0.225	√	√	√	√	√
C_{11}	0.1132	0.399	√	√	×	√	√
C_{12}	0.0763	0.294	×	√	√	×	×
C_{13}	0.0798	0.427	√	×	×	√	√
C_{14}	0.0414	0.148	√	×	×	×	×
C_{15}	0.0227	0.431	×	×	×	√	√
Calculation results	AHP		0.9010	0.6082	0.5686	0.7080	0.7232
		FCE	3.136	1.996	1.552	2.515	3.155

soil infiltration technology (SIT), stabilization tank technology (STT) and septic tank technology (ST), and the codes are G_6, G_7, G_8, and G_9 respectively. The results are expressed in Table 17. After weighting, the AHP comprehensive results were G_7 = 0.8731, followed by G_6 = 0.6759, G_8 = 0.5891, G_9 = 0.4820. $G_7 > G_6 > G_8 > G_9$. The FCE comprehensive evaluation of G_7 = 3.404 is the highest, G_6 = 2.83 is secondary. Therefore, SIT + CWT is preferred.

3.9.3. Calculation results of regional superiority technology for water source treatment

In the water source treatment area, we choose to use more treatment technologies, namely CWT, STT, oxidation tank technology (OTT) and stabilization pond technology (SPT) which are G_{10}, G_{11}, G_{12}, and G_{13} respectively. The results are shown in Table 18. After weighting results, G_{10} = 0.8730 is the highest, G_{12} = 0.6363 is secondary, G_{11} = 0.5793, G_{13} = 0.6180. $G_{10} > G_{12} > G_{13} > G_{11}$. The FCE comprehensive evaluation of G_{10} = 3.282 is the highest, G_{12} = 2.386 is secondary. Therefore, CWT + OTT is preferred.

In the results of AHP and FCE, the technologies with the first and second scores were different, and the scores of the two optimal processes were slightly not the same, but the overall results tend to be consistent, indicating that the weighted sum method of AHP + FCE was feasible for technology selection.

3.10. Important weights and relative important weights

The economic benefit weight at the criterion level is the highest, as shown in Table 12, so they are given priority. Therefore, in actual investigations and indicator evaluations, economic benefits are more important than environmental impacts than technical performance. Due to the drought and severe water shortage in the northwest, the weight of water consumption is relatively high. When selecting treatment technologies, the priority is higher. However, due to the climatic conditions in the northwest, such as the impact of wind and sand, equipment maintenance is a secondary consideration. It can be clearly seen from Fig. 2 that the weights of the five relatively important indicators are 0.1591, 0.1132, 0.0855, 0.0798, and 0.0792, including operating costs (C_2), available water (C_{11}), equipment maintenance (C_3), regional water volume (C_{13}) and COD removal rate (C_5) which are important indicators to evaluate the applicability of ARNC rural sewage treatment technology. Therefore, the five indicators can give a certain direction to the preferences of decision makers.

4. Discussion

The purpose of wastewater treatment is to remove pollutants from the water and reduce the risk of their migration, transformation and harmful effects in the environment [27]. ARNC rural sewage treatment technology used the results obtained by AHP + FCE + weighted summation, which had a certain reference for the technical applicability of the three regions. Through data and charts, we can clearly understand the impact of various indicators on the technology. The combination of different models can make up for each other's inaccuracy and singularity, transform human subjectivity into data support, and make the results more convincing [28].

For the complex process design and coking wastewater (CW), the analytic hierarchy process (AHP) was used for inclusive evaluation and ranking [29]. There were studies based on the AHP method, used the Delphi method (DM)

Table 17
Calculation results of regional superiority technology for decentralized governance

Evaluation indicator	AHP	FCE	Governance technology			
			G_6	G_7	G_8	G_9
C_1	0.0415	0.270	√	√	√	√
C_2	0.1591	0.264	×	√	×	√
C_3	0.0855	0.309	√	×	×	√
C_4	0.0473	0.325	×	√	×	×
C_5	0.0792	0.144	√	√	√	√
C_6	0.0659	0.103	√	√	√	×
C_7	0.0549	0.141	√	√	√	×
C_8	0.0370	0.168	√	√	√	√
C_9	0.0187	0.213	√	√	×	×
C_{10}	0.0776	0.225	√	√	×	×
C_{11}	0.1132	0.399	√	√	√	×
C_{12}	0.0763	0.294	×	√	√	×
C_{13}	0.0798	0.427	√	√	√	√
C_{14}	0.0414	0.148	×	×	√	×
C_{15}	0.0227	0.431	√	√	×	×
Calculation results	AHP		0.6759	0.8731	0.5891	0.4820
		FCE	2.83	3.404	2.094	1.582

Table 18
Calculation results of regional superiority technology for water source treatment

Evaluation indicator	AHP	FCE	Governance technology			
			G_{10}	G_{11}	G_{12}	G_{13}
C_1	0.0415	0.270	×	√	√	√
C_2	0.1591	0.264	√	√	√	√
C_3	0.0855	0.309	×	×	×	×
C_4	0.0473	0.325	√	×	×	×
C_5	0.0792	0.144	√	√	√	√
C_6	0.0659	0.103	√	√	√	√
C_7	0.0549	0.141	√	√	√	√
C_8	0.0370	0.168	√	×	√	×
C_9	0.0187	0.213	√	×	√	√
C_{10}	0.0776	0.225	√	×	√	√
C_{11}	0.1132	0.399	√	×	×	×
C_{12}	0.0763	0.294	√	√	×	×
C_{13}	0.0798	0.427	√	√	√	√
C_{14}	0.0414	0.148	√	×	×	√
C_{15}	0.0227	0.431	√	√	√	×
Calculation results	AHP		0.8730	0.5793	0.6363	0.6180
		FCE	3.282	2.074	2.386	1.935

and the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method to select the process [30]. Although the DM + VIKOR method was easy to obtain selective results, it was susceptible to subjective factors. Compared with the pure mathematical method of FCE and weighted summation in this study, the credibility and support strength were reduced.

The advantages of combined processes for water treatment have become increasingly apparent [31]. SBR technology treats sewage through water inlet, aeration, precipitation, water outlet and standing. The advantages were simplicity, low capital consumption, and good effect of removing N and P. The treatment of rural sewage in China needed to follow the principles of low cost, reasonable

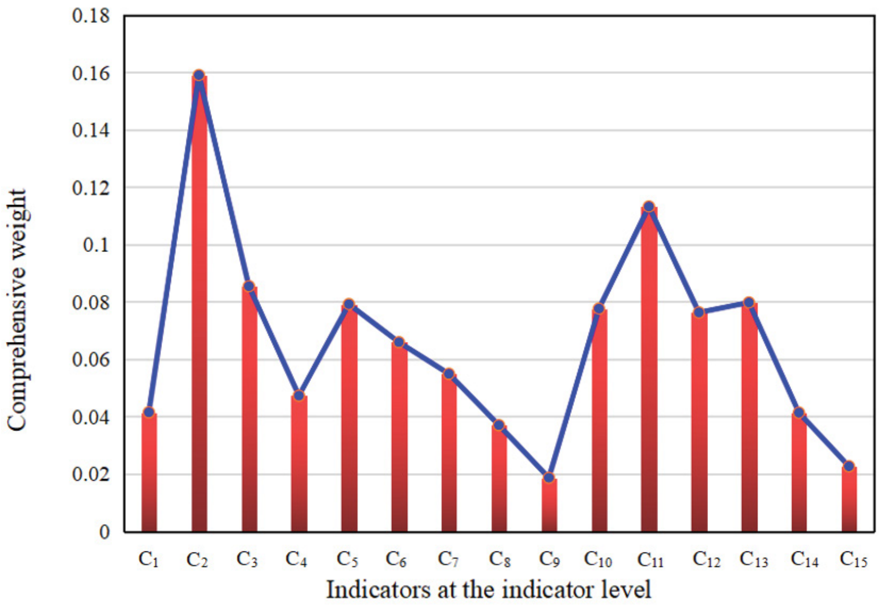

Fig. 2. Indicator layer weight result (Local funds (C_1), operating costs (C_2), equipment maintenance (C_3), transportation cost (C_4), COD removal rate (C_5), BOD_5 removal rate (C_6), NH_4^+–N removal rate (C_7), SS removal rate (C_8), total N removal rate (C_9), total *P* removal rate (C_{10}), available water (C_{11}), CO_2 production (C_{12}), regional water volume (C_{13}), impact on local residents (C_{14}), ecological balance (C_{15})).

planning, easy operation and capital flow [32]. When adopted a combined process, multiple factors need to be considered. CWT technology can make up for the environmental and ecological balance brought by SBR technology [33]. According to the above calculation results, when the centralized area treatment technology was selected, the SBR weighted summation result was the highest 0.9010, and the CWT summation result was the second, which was 0.7232. The two meet more evaluation indicators in the centralized area sewage treatment technology selection, so they were in the centralized area. SBR + CWT combined treatment process was more appropriate in the selection of regional sewage treatment technology. The process satisfies the financial issues, and SBR had better sewage treatment results, and it was also suitable for automated management in terms of weak management [34].

Dispersed regional governance is uncertain about geographical factors, uneven climatic conditions, and sewage treatment in sparsely populated rural areas is better. The drought and water shortage conditions in the Northwest have relatively little impact on the governance of scattered areas [35]. The soil infiltration technology is suitable for sewage treatment in scattered areas through the tension and filtration between soil-microbes-plants, and the effluent quality is good [36]. According to the above calculation results, when the decentralized area treatment technology was selected, the SIT weighted summation result was the highest 0.8731, and the CWT summation result was the second, which was 0.6759. The results showed that the decentralized governance model of SIT + CWT combined technology was feasible in scattered rural areas. Compared with the combined technology of this study, the MBR technology would be restricted by N, and the energy consumption was much higher than other treatment processes [37,38]. MBR construction funds consumed less, but the relative equipment cost was high, and the management cost was higher, and it was not suitable for rural sewage treatment in the ARNC area [39].

Constructed wetland technology simulates a structure similar to a natural wetland through soil seepage, which can restore and purify the natural environment [40]. Constructed wetland requires low construction cost, obvious effect, fewer operators had the advantages of low resource consumption due to self-repair cycle [41]. According to the above calculation results, when the water source treatment technology was selected, the CWT weighted summation result was the highest, which is 0.8730, and the OTT summation result was the second, which was 0.6363. Both met more evaluation indicators in the selection of sewage treatment technology in the water source treatment area, and the CWT + OTT combined treatment process had a better effect in the selection of sewage treatment technology in this area. Constructed wetlands also had the characteristics of being able to generate landscapes, which would promote ARNC rural areas to a certain extent. Constructed wetlands could also have mechanisms such as adsorption and filtration, and adsorption also played an important role in sewage treatment [42–44]. Constructed wetland was a nearly unpowered sewage treatment program, suitable for sewage treatment in the water source area [45,46].

This research analyzes ARNC's rural sewage treatment technology, based on the geographical environment, and provides certain decision-making plans for the governance of concentrated areas, scattered areas, and water source areas. From the choice of three regional treatment technologies, we can find that CWT technology can cope with different environmental conditions well. In order to deal with special areas and extreme weather, the research can consider the rational choice of rural sewage treatment technology in various aspects according to local conditions and demand.

5. Conclusions

Based on the correlation between drought and climatic conditions in Northwest China, this research provides selective treatment technologies for the concentration and dispersion of rural sewage, and the regional treatment of water source areas. We can use the AHP + FCE + weighted sum method to select the best technology. We can use AHP to calculate the comprehensive weight of the criterion layer and the index layer, analyze the important indicators and the relative important indicators, and determine the evaluation criteria. The optimized weighting results show that centralized regional governance uses SBR + CWT combined technology, decentralized regional governance uses SIT + CWT combined technology, and water source regional governance uses CWT + OTT combined technology. The three areas all involve CWT technology, indicating that it has a certain degree of adaptability and effectiveness. Through the evaluation of ARNC rural sewage treatment technology, this article provides a new combination of options for rural sewage treatment in arid environment areas, and provides a certain reference value for decision-makers.

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