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Ecosystem governance of rural water ecosystem services under sustainable utilization

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ABSTRACT

Water resources not only threaten the physical health of rural residents but also affect their drinking water needs, causing certain damage to the rural water ecosystem services (WES) and threatening the coordinated development of the natural ecological environment. In response to issues such as outdated personnel awareness, severe WES waste, and low resource utilization in current WES governance, this article optimized and monitored relevant governance methods for the rural WES environment to improve the sustainable utilization of WES. This article analyzed the main types of WES and studied the monitoring and governance methods of WES governance. This article used the projection pursuit model to evaluate the governance methods of WES comprehensively and proposed corresponding strategies for optimal utilization to improve the utilization rate of WES. The WES utilization rate and rural sewage treatment capacity after optimization measures were higher than those before optimization measures. The utilization rate of WES after the optimization strategy was 15.4% higher than before, and the rural pollution treatment capacity was 17.8% higher than before the optimization strategy. Improving investment in water pollution technology and environmental infrastructure in rural areas is important and positive in improving rural WES governance and sustainable utilization.

Key words: ecosystem governance, projection pursuit model, sustainable utilization, water resources

HIGHLIGHTS

- WES environmental governance methods in rural areas to improve the sustainable use of WES are monitored and optimized.
- This paper analyzes the main types of WES.
- The monitoring methods and governance methods of WES governance are studied.
- In this paper, the projection pursuit model was used to comprehensively evaluate WES governance methods.
- Corresponding optimal utilization strategies were proposed to improve the utilization of WES.

1. INTRODUCTION

Water ecosystem services (WES) is an important material for human survival and development, but in recent years, there have been varying degrees of water environmental problems in both urban and rural areas (Liu *et al.* 2023; Yu & Zhou 2023). In rural areas, the situation of water pollution control is not optimistic due to insufficient sewage treatment equipment and capacity. In rural areas, a good water environment can promote the construction of ecologically livable rural areas, laying a solid foundation for people's production and living, as well as the healthy and sustainable development of rural economy and society (Nong *et al.* 2023; Wu *et al.* 2023). However, if a poor water environment occurs, it would have adverse effects on the development of agriculture. Therefore, the governance of the rural WES environment has important practical significance for the sustainable utilization of WES.

Many scholars have analyzed and studied WES (Qiu *et al.* 2023; Sang *et al.* 2023; Yuan *et al.* 2023). The governance and management of WES require a lot of technical and policy support, and WES pollution can also bring certain harm to various aspects. Sheffield *et al.* (2018) reviewed the data requirements for regional WES management that may further develop its resources and mitigate the impact of hydrological disasters, as well as the role that satellite remote sensing can play in filling gaps and strengthening WES management. Li *et al.* (2018) used a comprehensive ecological hydrological model and combined it with systematic observations to analyze the hydrological cycle of the Heihe River Basin in a typical arid region. Neal (2020) found that the water sector plays an important role in immediate response to emergencies, as well as in the recovery and reconstruction stages, and revealed the importance of water in addressing health, food, transportation, environmental, and economic crises. Sit *et al.* (2020) conducted a systematic review of the literature to identify existing studies that incorporate deep learning methods in the water sector in WES monitoring, management, governance, and communication. Li & Hui (2018) briefly introduced the current status of WES research at the national and research levels, highlighting its role in addressing flood and water scarcity issues, improving WES management in inland plains, and supporting national sustainable development. Cravero *et al.* (2018) proposed a solution to the big data management problem of WES, which combines the growing demand for water, climate, and hydrological disparities, prompting decision-makers and WES managers to find effective strategies for managing WES. Velempini *et al.* (2018) studied the challenges of the local management of existing traditional small-scale WES through community participation research based on emerging methods of community adaptation and studied the constantly changing local institutional arrangements during colonial and postcolonial periods. Hall *et al.* (2020) used multi-objective optimization tools to explore the tradeoffs between these risk indicators and alternative plan costs and used sensitivity analysis to determine plans and other performance goals that can achieve tolerable risk objectives robustly. The studies all illustrate the content of WES governance and utilization, but there are still issues such as imperfect systems in the protection and sustainable development of the WES environment.

To analyze the monitoring effect and utilization rate of the rural WES environment, this article evaluates the comprehensive effect of WES environmental monitoring using a projection pursuit model. Through experiments, the data reliability, sample collection efficiency, and monitoring quality under WES environmental monitoring were analyzed. Through experimental analysis, it was found that monitoring the WES environment can not only improve the quality of the WES environment but also improve the utilization rate of WES, improve rural sewage treatment technology, and enhance rural sewage treatment capacity.

2. MAIN TYPES OF RURAL WES ENVIRONMENTAL POLLUTION

2.1. Main factors causing rural WES pollution

2.1.1. Domestic pollution and source pollution

At present, rural domestic sewage has not been effectively treated, while the discharge of rural domestic sewage is on the rise. Most rural domestic sewage is directly discharged into rivers and lakes, which has a great impact on the rural water environment (Saadatpour 2020; Xu *et al.* 2022a). The collection and treatment facilities for rural domestic sewage and garbage are severely lacking. Most of the domestic sewage is directly discharged into the water, and farmers have the habit of pouring garbage into the water, resulting in a large amount of domestic garbage being randomly piled up and thrown everywhere, and the phenomenon of 'dirty, messy, and poor' is very prominent (Davide 2021; Huang 2022). In addition, the burning and composting of straw have also caused serious pollution in rural WES.

2.1.2. Water environment pollution caused by agricultural activities

The widespread use of pesticides and fertilizers is an important factor in eutrophication in the Great Lakes region and rivers. In recent years, with the reduction of arable land, farmers often use more fertilizers and insecticides to increase soil yield. Pesticide residues include a portion of soil, water, and air loss, which ultimately enter the water through precipitation and runoff, causing long-term and potential environmental problems to the WES environmental system.

2.1.3. Pollution from livestock and poultry waste

With the large-scale development of livestock and poultry industry, the discharge of poultry excrement is increasing day by day and has become a major source of pollution in agricultural production. In rural areas, some intensive livestock and poultry breeders, in order to save costs, mostly do not set up biogas digesters to directly discharge livestock and poultry manure, slaughterhouse wastewater, waste, etc., into the water. In addition, with the development of aquaculture, the scale of aquaculture continues to expand, and a large amount of bait is invested in the aquaculture industry, causing serious eutrophication problems.

2.1.4. Insufficient sewage treatment capacity

At present, there are significant deficiencies in infrastructure construction, overall treatment planning, and technical personnel for rural sewage treatment. In areas with rapid economic development, although corresponding water pollution control facilities are already in place, they often cannot operate normally due to reasons such as funding and talent. In some economically underdeveloped areas, production and household waste is dumped on-site into rural ditches and rivers, and domestic sewage, livestock, and poultry breeding sewage, etc., are also directly discharged into the water. People's environmental awareness is weak, and the phenomenon of valuing the economy over environmental protection is still common.

2.2. Main proportion of WES pollution types

The main types of WES pollution mentioned in the above description include domestic pollution sources, fertilizers and pesticides, livestock and poultry, and pollution treatment capabilities. So, this article investigated the main distribution types of WES environmental pollution in four rural areas (R1, R2, R3, R4, and R5), and the specific survey results are shown in Table 1.

According to the data in Table 1, it can be seen that R1 has the highest proportion of domestic pollution sources, and R4 has the highest proportion of fertilizers and pesticides. The highest proportion of livestock and poultry is in R1, and the highest proportion of pollution treatment capacity is in R4. From a comprehensive perspective, the relationship is as follows: pollution treatment capacity > domestic pollution sources > fertilizers and pesticides > livestock and poultry. The above ranking indicates that water pollution treatment capacity is the main cause of WES environmental pollution. Due to outdated water pollution treatment equipment in rural areas and insufficient funding for environmental infrastructure, WES is unable to receive timely treatment after pollution, leading to increased environmental pollution in WES. In addition, rural residents have the weak awareness of WES protection, and all household waste and aquaculture wastewater would be discharged into rivers, seriously polluting WES.

3. MONITORING AND GOVERNANCE OF RURAL WES

3.1. Main deficiencies in rural WES ecosystem governance

The implementation of measures such as effectively improving WES management level and developing water conservancy projects is the overall performance of rural WES planning (Yang *et al.* 2021). The following deficiencies have been exposed in rural WES ecosystem governance (Yang *et al.* 2023).

The first is the insufficient investment of funds. Rural areas are relatively underfunded, and the burden of increased investment is increasing. In addition, the low-income level of farmers makes it difficult to increase the cost of wastewater treatment. Therefore, insufficient investment is also one of the reasons for the inadequate rural environmental policies of WES.

The second is that the technology and methods are not mature. In rural areas, the technology of sewage treatment cannot be updated promptly. On the one hand, the purchase of new technologies requires a large amount of money, and on the other hand, the application of new technologies also requires skilled personnel, which would cause certain financial pressure on townships. Moreover, it is uncertain whether the application of new technologies can produce significant results; therefore, in many rural areas, the speed of technological updates is relatively slow.

Thirdly, there is insufficient ideological awareness. Villagers do not pay enough attention to WES ecosystem governance, have insufficient understanding of WES protection, and have insufficient implementation of WES rural environmental management. One of the reasons for insufficient water pollution control is that villagers have a superficial understanding of WES protection and environmental management issues, and lack attention to the ideology of WES ecosystem governance.

Fourthly, the management mechanism is not perfect. The tension between WES and economic and social development is becoming increasingly severe due to the contradiction between the large population and the uneven distribution of WES in time and space (Fang *et al.* 2019). When environmental issues occur, differences may arise between different institutions and

Table 1 | Main distribution types of water resource environmental pollution in four rural areas

	Domestic pollution sources	Fertilizer and pesticide	Livestock and poultry	Pollution treatment capacity
R1	0.28	0.15	0.13	0.44
R2	0.27	0.17	0.10	0.46
R3	0.25	0.14	0.12	0.49
R4	0.23	0.18	0.07	0.52
R5	0.25	0.16	0.12	0.49
Average value	0.26	0.16	0.11	0.48

departments, which not only resolve quickly and promptly but also greatly reduce the work efficiency of different departments, leading to the inability to implement rural water pollution control measures normally. In addition, insufficient financial security and a sound financial security system have resulted in a relatively backward ecological foundation in rural areas compared to cities.

Fifthly, the enthusiasm for public participation is not high. Due to the lack of legal guarantees, people are unable to effectively participate in the cooperation between the government and relevant departments, which greatly reduces people's enthusiasm. Those who want to join would definitely be involved. Due to the imperfect participation mechanism, it is difficult for various entities in society to efficiently and reasonably participate in sewage treatment work. The communication and connections between various subjects are not smooth, and there is a lack of platforms for using various connections and exchanges, and a mechanism for establishing connections and exchanges has not been established.

3.2. Monitoring of the rural WES environment

The monitoring of rural WES environment defects can be controlled from three aspects, as shown in Figure 1.

3.2.1. Quality control during the preparation phase

The first is to configure and reasonably optimize various resources, such as rural water environment monitoring instruments and equipment, sampling equipment, and experimental water, to ensure efficient and orderly follow-up work. The second is to choose detection methods that are suitable for different rural aquatic environments. The testing methods include environmental testing of rural surface water, ecological monitoring of rural groundwater, and water and sediment monitoring (Ma *et al.* 2023). It can choose from water temperature measurement methods, glass electrode detection methods, and barium

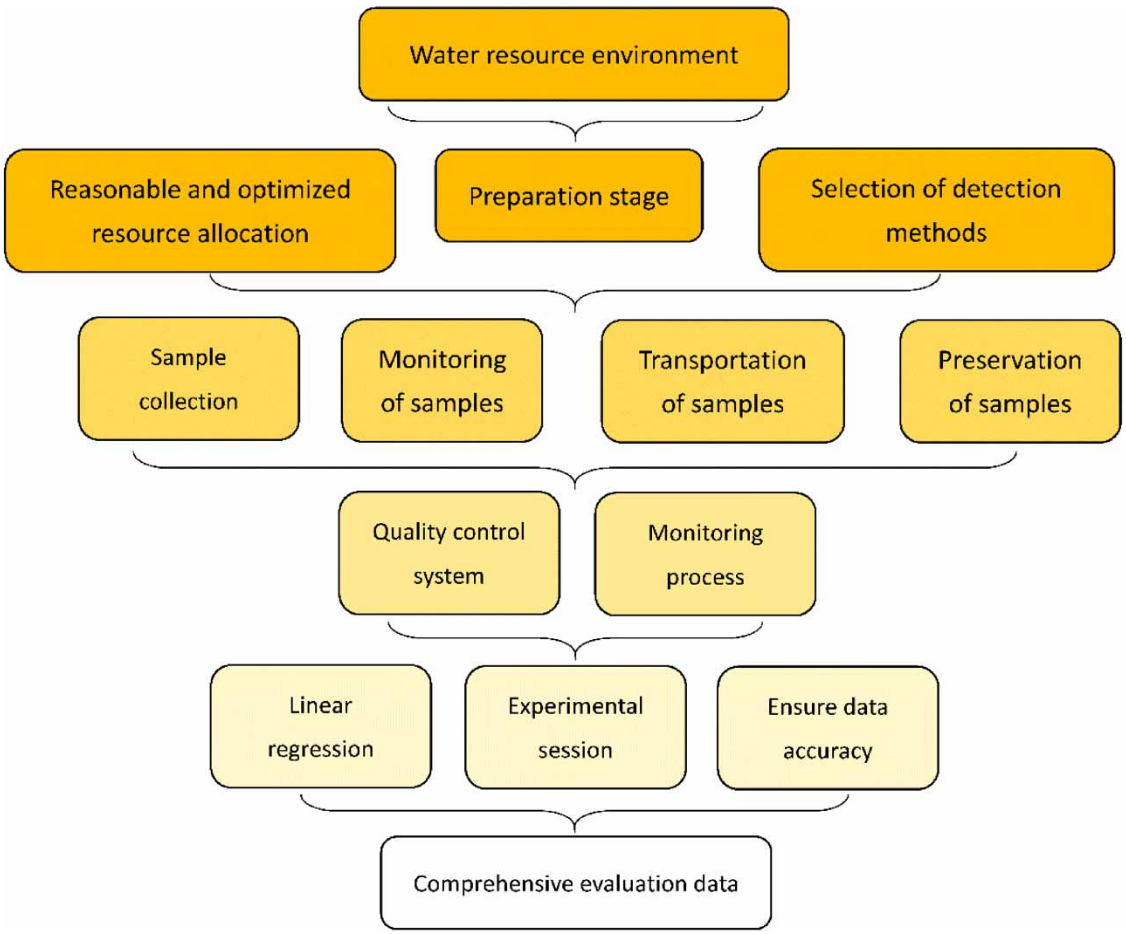

Figure 1 | Monitoring of the rural WES environment.

sulfate weight measurement methods. Based on the characteristics of the rural aquatic environment, appropriate monitoring methods can be selected to maximize monitoring quality, ensure effective participation and leadership, and further utilize and protect the water environment in rural areas (Barry & Coombes 2018; Gao *et al.* 2023). When monitoring rural water bodies in a certain area, it is necessary to first sample them and then transport, preserve, and monitor them.

3.2.2. Quality control during the monitoring process

The first is to collect and monitor samples by relevant national regulations and the special requirements of rural water environment monitoring and develop a scientific and reasonable quality control system to ensure the quality of all stages of sample collection. The second is to standardize the use of sampling equipment and strictly control the frequency and time of sampling.

3.2.3. Quality control of the experimental phase

The first is to select reasonable experimental analysis methods based on different types of water samples to ensure the accuracy of monitoring data. The same detection and quality control methods can be used for samples with the same water quality. When testing non-technical water quality indicators, it is necessary to choose the same testing instruments and sampling methods to obtain the most reliable data. The second issue is that the process of drawing calibration curves is influenced by various factors. To ensure the accuracy of measurements, linear regression methods can be used. The third is to comprehensively evaluate the test results and review the test results, including sampling review, original record review, and result report review. Through three-level auditing, monitoring data of the rural WES environment can be controlled at different levels to maximize the accuracy of monitoring results.

3.3. Experiment of WES environmental monitoring

In response to the WES environmental monitoring method mentioned in the above description, this article needs to conduct an experimental analysis to verify the feasibility of this method. Therefore, this article investigated the data reliability, sample collection efficiency, and monitoring quality of the WES environment in a certain rural area under monitoring. The survey lasted for a total of 15 days, and the peak values of these three indicators were all 1. The specific survey results are shown in Figure 2.

As shown in Figure 2, the data reliability, sample collection efficiency, and monitoring quality of the WES environment in this rural area gradually improve with the increase of monitoring time, and the data reliability has been improved by 0.35 throughout the entire process. The sample collection efficiency improved by 0.18 throughout the entire process, whereas the monitoring quality improved by 0.38 throughout the entire process. From this, it can be seen that monitoring the rural WES environment can effectively improve the accuracy of monitoring data to prevent WES from exceeding the maximum bearing capacity. At the same time, it can also reduce the pollution situation of the WES environment, and the increase in the collection rate of water quality samples under monitoring helps the monitoring system to analyze the status of the

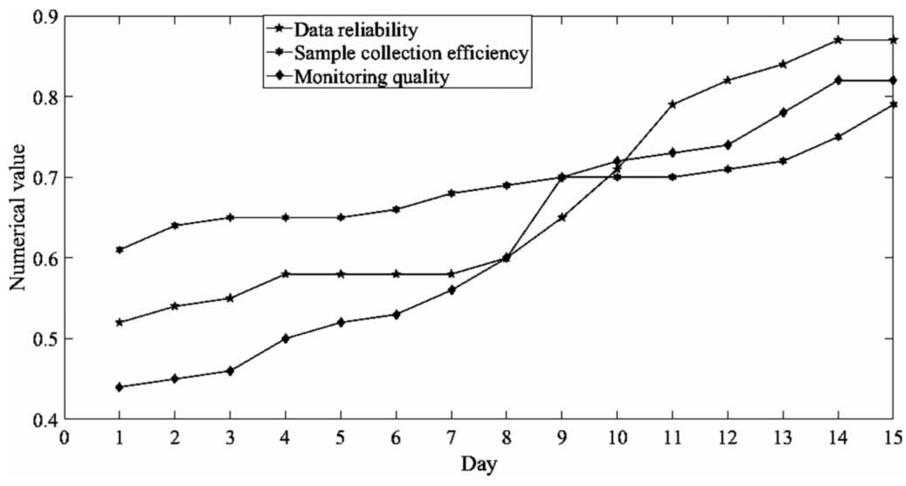

Figure 2 | Experimental analysis of water resource environmental monitoring.

WES environment promptly. Corresponding improvements can be made based on its environmental conditions to improve the monitoring quality of WES.

4. GOVERNANCE AND EVALUATION OF THE RURAL WES ENVIRONMENT

4.1. Governance methods for the rural WES environment

In response to the deficiencies in the rural WES environment, the governance approach should be optimized from the following aspects.

4.1.1. Waste resource treatment

For the comprehensive utilization of livestock and poultry manure, methods such as the dry-wet method and the biogas method are used. Dead poultry and livestock are centrally disposed of by professional harmless disposal centers; crop straw can be comprehensively utilized through various means such as fertilizers, feed, fuel, base materials, and raw materials. Market-oriented recycling, disposal, and reuse mechanisms can be explored for agricultural film and pesticide packaging materials. Research and formulate prices for biogas and straw power generation enterprises and support policies for organic fertilizer enterprises, so that they have the same competitive advantage as similar products in the market (Liu *et al.* 2022; Xu *et al.* 2022b).

4.1.2. Promoting water pollution treatment technology

With the advancement of wastewater treatment technology, the treatment methods for wastewater are becoming more diverse and convenient (Huang & Rudolph 2021; Lenggana 2022). On the basis of national investment and social capital replenishment, it should accelerate the construction of rural sewage discharge and treatment systems. It should do a good job in WES recycling and promote the efficient and economical use of WES (Shirai *et al.* 2018). Based on the resources and environmental conditions in rural areas, it would vigorously develop and promote practical, locally tailored, and low-cost sewage treatment processes. Ecological technology can be used to treat wastewater, and currently more mature methods include soil method, oxidation pond method, and wetland method. The land treatment system is the process of passing sewage through a soil biological system to remove nutrients from the sewage. The effluent quality reaches or exceeds the conventional tertiary treatment effluent quality, and there is no problem with sludge treatment. The three soil treatment methods of slow irrigation, rapid irrigation, and slope runoff have good removal effects on total phosphorus and total nitrogen under a certain pollutant load (Li *et al.* 2021).

4.1.3. Improving relevant environmental regulations

It would need to improve environmental laws and regulations related to rural economic development, establish environmental monitoring mechanisms, regularly monitor water environment conditions, and promote environmental work. Firstly, it is necessary to improve local laws on rural environmental resource protection, as well as rural environmental protection laws and supervision and management systems. It would need to expand the scope of the rural WES protection legal system, narrow the legal gap, and establish a rural accountability mechanism. All polluters can comply with the rules and take responsibility. It would need to establish a sound environmental supervision mechanism, strengthen environmental law enforcement, and provide legal support for solving WES pollution problems. Secondly, it is necessary to improve the rural environmental management system, increase investment in financial and human resources for rural environmental protection, use special working mechanisms, and invest in special funds for rural environmental protection. A supervision mechanism can be used to ensure the full utilization of resources and the fulfillment of people's duties, thereby promoting the concerted efforts and perseverance of the rural masses to effectively manage and prevent the rural water environment.

4.1.4. Strengthening the construction of rural environmental facilities

Although some rural areas have invested a large amount of manpower and resources in building garbage houses and public toilets, due to improper use and no one managing them, these facilities have become decorations in just 1 or 2 years, causing huge waste and having a negative impact on farmers. Therefore, the county government, streets (towns), and village committees should develop a complete set of operation and management plans at the beginning of the construction of rural environmental facilities. The natural resource endowment, economic development level, degree of industrialization, and technological progress have greatly promoted the utilization rate of WES (Zou & Cong 2021). Therefore, it is necessary to strengthen investment in rural infrastructure to improve the living standards of rural society. In addition, the government should establish a long-term management mechanism for waste disposal and promote the household waste disposal method of 'village cleaning, village collection, town transportation, and county disposal'. For domestic sewage, artificial wetlands, oxidation ponds, and stabilization ponds can also be used and combined with existing natural environments for treatment.

4.2. Application of the projection pursuit model in WES ecosystem governance evaluation

WES safety evaluation is related to the effectiveness of water resource environment governance. Therefore, this article evaluates WES ecosystem governance through a projection pursuit model, which includes data preprocessing, analysis, and optimization of projection index functions. Firstly, data preprocessing on WES ecosystem governance, as shown in Equations (1) and (2), is performed.

$$A = \{a(i, j)|i = 1,\ 2,\ \ldots,\ n; j = 1,\ 2,\ \ldots,\ m\} \tag{1}$$

$$a(i, j) = \frac{a(i, j) - a_{\min}(j)}{a_{\max}(j) - a_{\min}(j)} \tag{2}$$

where A is the evaluation dataset for WES, $a(i, j)$ is the jth evaluation indicator value for WES ecosystem governance in the ith year, $a_{\max}(j)$ and $a_{\min}(j)$ are the maximum and minimum values of WES environmental evaluation indicators, and n and m are the evaluation duration and number of evaluation indicators. Based on the data processing results, the projection index function for WES ecosystem governance is analyzed as follows:

$$G(i) = \sum_{j=1}^{m} t(j)a(i, j) \tag{3}$$

$$Q(t) = S_G R_G \tag{4}$$

where $t(j)$ is the projection direction value of Equation (2), and $G(i)$ is the one-dimensional projection value. $Q(t)$ is the projection index function, R_G is the local density value of $G(i)$, and S_G is the projection standard deviation of Equation (3). The optimal functional solution for WES ecosystem governance can ultimately be obtained as follows:

$$O = \mathrm{Max}(Q(t) = S_G R_G) \tag{5}$$

s.t.

$$\sum_{j=1}^{m} G^2(j) = 1 \quad G \in [0,\ 1] \tag{6}$$

where O is the optimal functional solution for WES ecosystem governance.

Based on the above optimal function solution and projection index function, the optimal function solution and projection index value of WES ecosystem governance are calculated to determine the effectiveness of WES ecosystem governance. This article investigates the changes in the optimal function solution and the projection index value of three water bodies over time. This article surveyed for a total of 15 days, and the specific survey results are shown in Table 2.

According to the data described in Table 2, it can be seen that the optimal function solutions and projection index values of these three water bodies continue to increase with the increase of treatment time, and the comprehensive treatment effect is also gradually improving. During the entire investigation process, the comprehensive management effect of the three water bodies improved by 0.48. After monitoring rural WES, the optimal solution growth of WES governance indicates that WES ecosystem governance can effectively improve the comprehensive evaluation value of the WES environment. It can also effectively improve the distribution of microbial communities in water bodies, avoid excessive eutrophication of water bodies, and cause serious pollution to the WES environment. In addition, the governance of the WES environment can also improve the utilization rate of rural WES and reduce the loss of WES.

Table 2 | Optimal function solutions and changes in projection index values for different water bodies

	Optimal function solution	Projection indicator value	Comprehensive governance effect
1	0.57	0.51	0.41
2	0.60	0.57	0.45
3	0.63	0.57	0.47
4	0.65	0.58	0.49
5	0.65	0.61	0.57
6	0.66	0.63	0.57
7	0.67	0.66	0.63
8	0.72	0.71	0.65
9	0.82	0.71	0.66
10	0.84	0.73	0.70
11	0.84	0.76	0.73
12	0.88	0.76	0.77
13	0.89	0.77	0.78
14	0.91	0.78	0.88
15	0.92	0.82	0.89

5. UTILIZATION ISSUES AND OPTIMIZATION STRATEGIES FOR SUSTAINABLE UTILIZATION OF RURAL WES

5.1. Relevant factors affecting the development and utilization of rural WES

In the process of rural WES development and utilization, the main factors affecting utilization efficiency include WES shortage, severe water pollution, unreasonable water use structure, and low WES utilization rate.

5.1.1. WES shortage

WES is widely used in cities and is contaminated from various sources; therefore, it is also contaminated in rural areas. On the other hand, the water required for expanding irrigation far exceeds the available WES. The overexploitation of WES in rural areas has not only caused a crisis of agricultural water use that heavily depends on groundwater but also caused a crisis of domestic and industrial water use.

5.1.2. Severe water pollution

There are many reasons for rural water pollution. Among them, the problem of water pollution is particularly serious and has a trend of rapid deterioration. It is mainly manifested in the eutrophication of surface water and the gradual deterioration of groundwater quality. In addition, with the widespread use of pesticides and other chemicals, groundwater in many areas is not suitable for drinking, which has had a significant impact on people's physical health and the healthy development of rural economy. This is not only due to the inherent reasons of rural areas but also due to the damage caused by external factors to rural areas.

5.1.3. Unreasonable water use structure

People lack the awareness of the use of WES, believing that it is inexhaustible and has formed a subtle concept, especially for farmers. They pay more attention to tangible economic benefits while ignoring potential environmental hazards. They believe that only factories emitting toxic substances are truly polluting, while drainage practices such as aquaculture and slaughterhouses are not considered pollution. People's sense of crisis and environmental awareness toward the environment is still weak, or even non-existent. Moreover, in order to stimulate the economy, it is also a common phenomenon for the government to blindly requisition farmland and accept the heavily polluting enterprises that the city has transferred to them.

5.1.4. Low WES utilization

The management of rural WES is a relatively weak link. Nowadays, in rural areas, water fees are charged based on surface water volume. Due to the lack of measurement and fee collection of groundwater, large-scale development and utilization of underground water resources have been achieved, and this situation would continue for a considerable period, resulting in greater resource waste. The current system makes the management of WES very difficult because of rural areas, WES does not have a unified plan, and the management of irrigation systems for planting water is relatively backward. The allocation of time and space is also relatively unreasonable, with insufficient management equipment and lack of high-quality management personnel. At present, water prices in rural areas are generally low, even free, leading to a weak awareness of water-saving among farmers. The development of the agricultural water-saving industry is not stable, the construction progress of water conservancy facilities is relatively slow, the irrigation volume is large, and the distribution of WES is uneven.

5.2. Strategies to improve the WES utilization rate

5.2.1. Designated rural water supply and demand plan

Based on the principles of sustainable development, supply and demand coordination, and reasonable and effective utilization of WES, the development status of rural water supply systems and WES development planning can be analyzed to ensure sufficient water supply. It is necessary to promote the importance of water-saving in rural areas, enhance farmers' awareness of water-saving, and make the development of water-saving in rural areas a goal of struggle. Economic leverage can be used to motivate rural areas to save water, increase investment in water-saving technologies in rural production processes, and actively promote effective measures, production methods, and experiences for water conservation. On this basis, the optimization of agricultural production structure and layout can be carried out based on the actual situation of WES zoning, research on drought-resistant and high-yield crops can be carried out, and new non-engineering water-saving technologies such as transpiration resistance and water retention agents can be actively promoted. It can vigorously develop sprinkler irrigation, drip irrigation, and infiltration irrigation, implement ditch lining and film covering, and promote the construction of water conservancy projects. In addition, WES planning and management should be strengthened, irrigation processes should be improved, and the WES utilization rate should be increased (Dong *et al.* 2019).

5.2.2. Introduction of computer technology

Rural governments should introduce advanced information technology into WES sustainable utilization, establish a reliable WES information management system, and create a favorable information environment for sustainable water use. WES protection and other elements can be integrated into the WES information management system, utilizing big data and Internet of Things technology to achieve accurate data management and security and achieving sustainable water use. Monitoring stations near rural rivers are established. On this basis, historical WES data such as rainfall and runoff can be combined to establish multi-source data such as watershed water quantity, water quality, and hydrology, providing a scientific basis for rural WES management and WES optimization configuration. In addition, with the economic development of neighboring cities, the efficiency of water resource utilization in cities may improve (Xie *et al.* 2021). On this basis, geographic information system technology can be introduced to establish a rural WES management system, visually manage rural WES, and lay the foundation for the sustainable utilization of WES (Yin *et al.* 2023).

5.3. Experiment of the utilization rate under WES utilization strategies

The main purpose of the optimization measures proposed in the previous text is to improve the utilization rate of WES and rural sewage treatment capacity. An analysis was conducted on the utilization rate of WES and rural sewage treatment capacity before and after the optimization measures. A total of five rural areas were surveyed, and the specific survey results are shown in Table 3.

According to the data in Table 3, it can be seen that the WES utilization rate and rural sewage treatment capacity after the optimization strategy are higher than those before the optimization strategy. The utilization rate of WES after the optimization strategy is 15.4% higher than before, and the rural pollution treatment capacity is 17.8% higher than before the optimization strategy. After the implementation of optimization measures, the utilization rate of WES in rural areas gradually increases, and new technologies can be used for the pollution treatment of domestic sewage and livestock pollutants to reduce domestic pollution and livestock pesticide pollution. Computer technology can also monitor water quality near water bodies, thereby regulating the behavior of villagers and reducing their damage and pollution to the WES environment.

Table 3 | Analysis of water resource utilization rate and sewage treatment capacity before and after optimization measures

	Water resource utilization rate		Sewage treatment capacity	
	Before optimizing countermeasures (%)	After optimizing the countermeasures (%)	Before optimizing countermeasures (%)	After optimizing the countermeasures (%)
R1	67.5	80.4	52.4	67.8
R2	69.1	82.6	54.6	69.4
R3	65.4	83.4	55.7	70.6
R4	66.3	85.6	51.2	73.4
R5	70.5	84.2	50.9	72.7
Average value	67.8	83.2	53.0	70.8

In addition, after the implementation of WES protection measures, more advanced green technologies can be utilized to store and detect WES. This can greatly improve the protection effect of the WES environment by conducting water quality remediation before the occurrence of WES environmental damage.

Understanding the impact of watershed water use on lake nutrition can help prevent lake eutrophication and promote the sustainable management of WES (Peng *et al.* 2020). Based on the rural water supply and demand ratio under WES environmental monitoring to evaluate WES availability, this article conducted a survey and analysis of water supply and demand in the five rural areas mentioned above. This article takes the monthly average water supply and demand of all villagers in these five rural households and investigates a total of 10 months. The specific survey results are shown in Table 4.

According to Table 4, it can be seen that in the five surveyed rural areas, the water supply in the first 3 months was less than the water consumption, resulting in a shortage of rural water resources. Starting from the fourth month, the water supply gradually exceeds the water consumption, indicating that the WES environment is gradually improving and villagers have water-saving awareness. In the case of abundant WES, the change in the water consumption of villagers is still very small. These data all indicate that under WES environmental monitoring, the utilization rate of WES is gradually increasing.

In order to study the water resource management and reasonable performance of the water use structure of rural WES, this article also analyzes the waste treatment rate, rationality of water use structure, and water-saving awareness of villagers in rural areas. The peak values of these three indicators are all 1, and those above 0.75 are considered qualified. The specific investigation results are shown in Table 5.

According to the data in Table 5, it can be seen that the overall waste treatment rate, rationality of water use structure, and water-saving awareness of villagers in the surveyed rural areas have all reached a qualified state. This indicates that under the

Table 4 | Analysis of monthly average water supply and demand among villagers

	Water supply (10^3 m^3)	Water consumption (10^3 m^3)	Supply-demand ratio
1	4.45	5.70	0.78
2	4.08	4.80	0.85
3	4.98	5.30	0.94
4	6.21	5.40	1.15
5	6.94	5.60	1.24
6	8.70	6.40	1.36
7	9.65	6.70	1.44
8	9.00	6.00	1.50
9	9.85	5.90	1.67
10	9.79	5.50	1.78
Comprehensive value	7.37	5.73	1.27

Table 5 | Reasonable performance analysis of water resource management and water use structure of WES

	Waste treatment rate	Rationality of water use structure	Villagers' awareness of water conservation
R1	0.72	0.73	0.75
R2	0.80	0.78	0.74
R3	0.90	0.78	0.89
R4	0.85	0.82	0.74
R5	0.77	0.87	0.86

WES governance in rural areas, there is not only a better treatment method for daily generated waste, but it can also make the traditional water use structure more reasonable. On this basis, villagers' water-saving awareness has also made a qualitative leap.

6. CONCLUSIONS

At present, the coexistence of scarcity and waste in rural WES has become a bottleneck restricting rural economic development and improving farmers' lives and has also had adverse effects on water-saving society and the construction of a new socialist countryside. Therefore, it is necessary and urgent to increase attention to rural WES. To achieve the sustainable utilization of rural WES and governance of the WES environment, legal measures should be taken to strengthen people's water-saving awareness and vigorously support the water-saving economy. It is possible to develop WES reasonably, increase investment in environmental protection projects, and increase efforts in pollution control. This can promote the sustainable development of WES and promote healthy socio-economic development. The research on rural WES ecosystem governance and sustainable utilization in this article can play a certain role in improving the effectiveness of WES management in the future, but further research is needed to analyze the environmental problems and causes of WES. In future development, it is still necessary for all parties to collaborate and jointly maintain the governance of the WES environment.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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