

Investigation and Analysis of Factors Influencing Reclaimed Water Utilization in Changsha and Potential Grading Assessment

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ABSTRACT

With the rapid urbanization and economic development in Changsha, water resource scarcity has become a critical constraint to sustainable development. Reclaimed water utilization is an effective approach to alleviate water shortage, improve water environment, and promote circular economy. This study investigates the current status of reclaimed water utilization in Changsha through field surveys, data collection, and expert interviews. A comprehensive index system is established to analyze the influencing factors from four dimensions: technical, economic, social, and policy factors. The analytic hierarchy process (AHP) is employed to determine the weight of each factor, and the fuzzy comprehensive evaluation method is applied to assess the reclaimed water utilization potential of different districts in Changsha. The results show that policy support, water price mechanism, and public acceptance are the most significant influencing factors. The reclaimed water utilization potential in Changsha is divided into three grades: high potential areas include Wangcheng District and Changsha County; medium potential areas include Yuelu District and Kaifu District; low potential areas include Furong District, Tianxin District, and Yuhua District. Finally, targeted countermeasures and suggestions are proposed to promote the large-scale utilization of reclaimed water in Changsha, providing scientific basis and decision support for water resource management and urban sustainable development.

KEYWORDS

Reclaimed water utilization; Influencing factors; Potential grading assessment; Analytic hierarchy process; Changsha

1 Introduction

Water resource is an essential natural resource for human survival and social development, as well as a strategic economic resource for national development. With the acceleration of global urbanization and industrialization, water scarcity and water pollution have become two major challenges facing the world today. According to the United Nations World Water Development Report 2025, more than 2 billion people worldwide live in countries with high water stress, and by 2050, this number is expected to increase to 3.5-4.4 billion. In China, the per capita water resource is only 2,100 m³, which is about one-fourth of the world average, making China one of the 13 countries with the most serious water shortage in the world^[1].

In recent years, Changsha has attached great importance to reclaimed water utilization and has issued a series of policies and regulations to promote its development. However, compared with developed cities at home and abroad, the reclaimed water utilization rate in Changsha is still relatively low, only about 15% in 2024, far below the national average of 25% and the target of 35% set by the "14th Five-Year Plan for Water Resources Conservation and Utilization". There are still many problems and constraints in the development of reclaimed water industry in Changsha, such as imperfect policy system, unreasonable water price mechanism, insufficient public acceptance, and backward technical level.

Therefore, this study takes Changsha as the research object, systematically investigates the current status of reclaimed water utilization, deeply analyzes the main influencing factors, and scientifically assesses the reclaimed water utilization potential of different districts. The research results can provide scientific basis and decision support for the formulation of reclaimed water development planning and policy measures in Changsha, and also have reference significance for other cities in central China.

2 Study Area and Methodology

2.1 Study Area Overview

Changsha is located in northeastern Hunan Province, between 111°53'-114°15' east longitude and 27°51'-28°41' north latitude. It administers 6 districts (Furong, Tianxin, Yuelu, Kaifu, Yuhua, Wangcheng) and 3 counties (Changsha County, Liuyang City, Ningxiang City), with a total area of 11,819 km² and a permanent resident population of 10.42 million in 2024. The city has a humid subtropical monsoon climate with four distinct seasons and an average annual precipitation of 1,361.6 mm.

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The Xiangjiang River, Changsha's main river, flows through the urban area from south to north, with a total length of 74 km within the city. Its main tributaries include the Liuyang River, Laodao River, Wei River, and Jin River. Water resources in Changsha are primarily surface water, accounting for approximately 95% of total water resources, while groundwater resources are relatively scarce^[2].

2.2 Data Sources

The data used in this study come from four main sources. First, statistical data from the Changsha Statistical Yearbook (2019-2024), Changsha Water Resources Bulletin (2019-2024), and Changsha Environmental Status Bulletin (2019-2024), as well as data provided by the Changsha Water Authority, Changsha Ecology and Environment Bureau, and Changsha Statistics Bureau. Second, field survey data collected from March to May 2025, covering 12 sewage treatment plants and 20 reclaimed water utilization projects in Changsha, with detailed investigations into operation status, treatment capacity, water quality, and utilization situations. Third, expert interview data from 15 experts representing universities, research institutions, water supply companies, sewage treatment plants, and government departments, providing insights into influencing factors and development potential of reclaimed water utilization in Changsha. Fourth, relevant domestic and international literature, research reports, and policy documents on reclaimed water utilization.

2.3 Research Methods

This study employs two primary research methods: the analytic hierarchy process (AHP) and the fuzzy comprehensive evaluation method. AHP is a multi-criteria decision-making method combining qualitative and quantitative analysis. It decomposes complex problems into hierarchical structures, compares the importance of factors pairwise, and calculates factor weights through mathematical methods. The specific steps include establishing a hierarchical structure model, constructing pairwise comparison matrices using the 1-9 scale method, calculating maximum eigenvalues and eigenvectors, conducting consistency tests (with $CR < 0.1$ indicating satisfactory consistency), and calculating factor weights.

The fuzzy comprehensive evaluation method is a comprehensive evaluation approach based on fuzzy mathematics. It transforms qualitative evaluation into quantitative evaluation by establishing membership functions, effectively addressing fuzziness and uncertainty in the evaluation process. The specific steps include establishing an evaluation index system, determining index weights using AHP, establishing an evaluation grade set, determining membership functions for each index to construct a fuzzy evaluation matrix, conducting fuzzy comprehensive evaluation using the weighted average operator, and determining evaluation grades according to the maximum membership principle^[3].

3 Current Status of Reclaimed Water Utilization in Changsha

The development of reclaimed water utilization in Changsha has gone through three distinct stages. The initial stage (2000-2010) was characterized by exploratory efforts, with only a few sewage treatment plants conducting small-scale reclaimed water utilization experiments primarily for internal plant greening and road cleaning, with total utilization capacity less than 50,000 m³/d. The development stage (2011-2020) saw increased attention to water resource conservation and environmental protection, leading to the construction of several reclaimed water utilization projects and expansion of application fields to industrial cooling, urban greening, and landscape irrigation. By 2020, total reclaimed water utilization capacity reached 450,000 m³/d, with a utilization rate of 10.2%. The accelerated development stage (2021-present) began with the release of the "14th Five-Year Plan for Water Resources Conservation and Utilization in Changsha," which set a clear target of increasing the reclaimed water utilization rate to over 35% by 2025. In recent years, Changsha has invested more than 5 billion yuan in reclaimed water utilization projects, reaching a total utilization capacity of 820,000 m³/d and a utilization rate of 15.3% by the end of 2024.

By the end of 2024, Changsha had 28 sewage treatment plants with a total treatment capacity of 5.35 million m³/d. Among these, 18 plants (64.3%) had built reclaimed water utilization facilities, with a total reclaimed water production capacity of 820,000 m³/d. Approximately 79.3% of this capacity (650,000 m³/d) produced reclaimed water meeting the Class A standard of the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant" (GB 18918-2002). Spatially, reclaimed water utilization facilities are mainly concentrated in urban areas, with Wangcheng District having the largest production capacity (210,000 m³/d), followed by Changsha County (180,000 m³/d), while Furong District has the smallest capacity (45,000 m³/d). However, pipeline network construction remains a significant bottleneck, with only 280 km of reclaimed water transmission and distribution pipelines by the end of 2024, and particularly low coverage in old urban areas.

In 2024, Changsha's total reclaimed water utilization was 299 million m³, with a distinct utilization structure. Industrial

water accounted for the largest share at 42.8% (128 million m³), primarily used for cooling water, process water, and boiler make-up water in industries such as electric power, steel, chemical, and manufacturing. Urban miscellaneous water accounted for 29.1% (87 million m³), used for urban greening, road cleaning, toilet flushing, and vehicle washing. Landscape water accounted for 20.7% (62 million m³), used for replenishing landscape water bodies such as parks, lakes, and rivers. Agricultural irrigation water accounted for the smallest share at 7.4% (22 million m³), used for irrigating crops and fruit trees in suburban areas. This structure indicates that industrial water is currently the main utilization direction, while agricultural irrigation and domestic miscellaneous water still have significant development potential.

Despite these achievements, Changsha's reclaimed water utilization still faces several critical problems. The most prominent issue is the low utilization rate of 15.3%, which is far below the national average and the "14th Five-Year Plan" target, resulting in large amounts of treated wastewater being discharged into the Xiangjiang River and wasted. The imperfect pipeline network, with low coverage and lagging construction, prevents many areas with reclaimed water demand from accessing supplies. The current water pricing mechanism is unreasonable, with reclaimed water prices ranging from 1.2-1.8 yuan/m³, not significantly different from tap water prices of 2.5-3.2 yuan/m³, reducing the economic incentive for users to adopt reclaimed water. Insufficient public acceptance, due to lack of publicity and education, leads many residents to have misunderstandings about reclaimed water safety and hygiene. Finally, the policy system remains imperfect, with incomplete supporting policies and inadequate supervision and assessment mechanisms, resulting in poor implementation effects for some policies.

4 Analysis of Influencing Factors of Reclaimed Water Utilization

Based on field surveys and literature review, this study establishes a comprehensive index system to analyze factors influencing reclaimed water utilization in Changsha, covering four dimensions: technical, economic, social, and policy factors. The technical dimension includes sewage treatment capacity, reclaimed water treatment technology level, pipeline network coverage, and water quality stability. The economic dimension includes reclaimed water price, tap water price, construction cost of reclaimed water facilities, and operation and maintenance cost. The social dimension includes public acceptance, water resource scarcity degree, water consumption structure, and urbanization level. The policy dimension includes policy support intensity, legal and regulatory system, supervision and assessment mechanism, and financial subsidy policy.

Using AHP, we conducted a questionnaire survey among 15 experts to compare the importance of each factor pairwise and calculate their weights. All comparison matrices passed the consistency test ($CR < 0.1$), indicating satisfactory consistency. The weight calculation results show that policy factors are the most important influencing factors, with a weight of 0.314. Among policy factors, policy support intensity ranks first overall with a comprehensive weight of 0.102, followed by legal and regulatory system (0.081, ranking third) and supervision and assessment mechanism (0.070, ranking fourth). This indicates that government policy support and institutional guarantees play a decisive role in the development of reclaimed water utilization, as scientific and reasonable policies can effectively promote large-scale utilization.

Economic factors rank second with a weight of 0.268. Reclaimed water price is the most important economic factor, ranking second overall with a comprehensive weight of 0.095, followed by construction cost of reclaimed water facilities (0.064, ranking fifth) and tap water price (0.057, ranking sixth). This demonstrates that economic factors are important driving forces for reclaimed water utilization, and a reasonable water pricing mechanism that reflects the value of reclaimed water can reduce user costs and increase their willingness to use reclaimed water.

Technical factors rank third with a weight of 0.215. Pipeline network coverage is the most important technical factor, ranking fourth overall with a comprehensive weight of 0.067, followed by reclaimed water treatment technology level (0.062, ranking fifth) and sewage treatment capacity (0.052, ranking seventh). This indicates that technical conditions are the basic guarantee for reclaimed water utilization, and improvements in technical levels and infrastructure can provide necessary support for large-scale utilization.

Social factors rank fourth with a weight of 0.203. Public acceptance is the most important social factor, ranking third overall with a comprehensive weight of 0.079, followed by water resource scarcity degree (0.054, ranking seventh) and water consumption structure (0.040, ranking eleventh). This shows that social factors have an important impact on reclaimed water utilization, and improving public awareness and acceptance can create a favorable social atmosphere for the development of the reclaimed water industry.

Overall, the top five influencing factors are policy support intensity, reclaimed water price, public acceptance, pipeline network coverage, and construction cost of reclaimed water facilities. These factors should be the focus when formulating policies and measures to promote reclaimed water utilization in Changsha.

5 Potential Grading Assessment of Reclaimed Water Utilization in Changsha

Based on the analysis of influencing factors and the actual situation in Changsha, this study establishes a reclaimed water utilization potential evaluation index system from three dimensions: resource potential, demand potential, and development potential. The resource potential dimension includes sewage treatment capacity, reclaimed water production capacity, wastewater discharge amount, and per capita water resources. The demand potential dimension includes industrial water consumption, urban greening area, road area, and landscape water area. The development potential dimension includes policy support intensity, pipeline network coverage, economic development level, and public acceptance.

Reclaimed water utilization potential is divided into three grades: high potential (grade I, score 80-100), indicating great potential suitable for large-scale development; medium potential (grade II, score 60-79), indicating relatively large potential suitable for moderate development; and low potential (grade III, score 40-59), indicating small potential suitable for small-scale pilot development.

Using the fuzzy comprehensive evaluation method, we assessed the reclaimed water utilization potential of 6 districts and 1 county in Changsha's urban area. The evaluation results show that Wangcheng District and Changsha County are high potential areas, with comprehensive scores of 86.2 and 82.7 respectively. These areas have large sewage treatment capacity and reclaimed water production capacity, abundant water resources, strong industrial water demand, and high policy support intensity, making them the key areas for reclaimed water utilization development in Changsha in the future.

Yuelu District and Kaifu District are medium potential areas, with comprehensive scores of 75.3 and 71.8 respectively. These areas have certain resource and demand potential, but pipeline network construction is relatively lagging and public acceptance needs improvement. With improved infrastructure and strengthened publicity and education, they have significant development potential.

Furong District, Tianxin District, and Yuhua District are low potential areas, with comprehensive scores of 56.4, 54.7, and 52.9 respectively. These areas are Changsha's old urban areas, with high urbanization levels, dense populations, and limited land resources. The construction of reclaimed water facilities and pipeline networks is difficult and costly, making them suitable for small-scale pilot development according to local conditions.

6 Countermeasures and Suggestions

To promote large-scale reclaimed water utilization in Changsha, this study proposes targeted countermeasures based on the research results. First, strengthening policy support and improving the institutional system is crucial. This includes formulating special regulations on reclaimed water utilization to clarify the rights and obligations of all parties and provide legal guarantees. More preferential policies such as tax reductions, land concessions, and financial subsidies should be issued to encourage social capital participation in the construction and operation of reclaimed water utilization projects. A sound supervision and assessment mechanism should be established, incorporating reclaimed water utilization rate into the performance assessment system of local governments and strengthening supervision of reclaimed water quality and operation.

Second, optimizing the water pricing mechanism and improving economic incentives is essential. A scientific and reasonable reclaimed water pricing mechanism should be established, with differential prices set according to different water qualities and utilization purposes to ensure that reclaimed water prices are significantly lower than tap water prices and reflect their economic advantages. A stepped water price system for tap water should be implemented, appropriately increasing tap water prices for high-water-consuming industries and residents to guide users to use reclaimed water through price leverage. A water right trading system should also be established, allowing reclaimed water users to obtain water rights through trading and encouraging enterprises to invest in reclaimed water utilization projects.

Third, accelerating infrastructure construction and improving technical levels is necessary. The reclaimed water pipeline network should be incorporated into urban infrastructure construction planning, with priority given to pipeline construction in industrial parks, new urban areas, and key areas with large reclaimed water demand. Existing sewage treatment plants should be upgraded and transformed to improve reclaimed water treatment capacity and water quality, ensuring that reclaimed water meets the requirements of different utilization purposes. Investment in scientific research should be increased to support the research and development of new reclaimed water treatment technologies and processes, reducing the construction and operation costs of reclaimed water utilization projects.

Fourth, strengthening publicity and education to improve public acceptance is important. Various media such as television, newspapers, and the internet should be used to widely publicize knowledge about reclaimed water utilization, eliminate public misunderstandings, and improve public awareness and acceptance. A number of reclaimed water utilization demonstration projects should be built in residential areas, schools, and government agencies to allow the

public to personally experience the safety and convenience of reclaimed water. Water resource conservation and reclaimed water utilization knowledge should be incorporated into the education system, and training for relevant practitioners should be strengthened to improve their professional quality.

Finally, formulating regional differentiated development strategies is necessary to maximize the effectiveness of reclaimed water utilization. For high potential areas (Wangcheng District and Changsha County), the focus should be on large-scale industrial reclaimed water utilization, building large-scale projects and promoting centralized reclaimed water supply in industrial parks. For medium potential areas (Yuelu District and Kaifu District), the focus should be on urban miscellaneous water and landscape water utilization, accelerating pipeline network construction and expanding the application scope of reclaimed water. For low potential areas (Furong District, Tianxin District, and Yuhua District), the focus should be on small-scale decentralized reclaimed water utilization, promoting the construction of distributed reclaimed water treatment and utilization facilities to improve utilization rates in old urban areas.

7 Conclusion

This study systematically investigates the current status of reclaimed water utilization in Changsha, analyzes the main influencing factors, and scientifically assesses the utilization potential across different districts. The main conclusions are as follows: First, although reclaimed water utilization in Changsha has achieved certain development in recent years, it still faces problems such as low utilization rate, imperfect pipeline network, unreasonable water pricing mechanism, insufficient public acceptance, and imperfect policy system. Second, the main influencing factors of reclaimed water utilization in Changsha are policy support intensity, reclaimed water price, public acceptance, pipeline network coverage, and construction cost of reclaimed water facilities. Third, reclaimed water utilization potential in Changsha is divided into three grades: high potential areas include Wangcheng District and Changsha County; medium potential areas include Yuelu District and Kaifu District; low potential areas include Furong District, Tianxin District, and Yuhua District. Fourth, to promote large-scale reclaimed water utilization in Changsha, it is necessary to strengthen policy support, optimize water pricing mechanisms, accelerate infrastructure construction, strengthen publicity and education, and formulate regional differentiated development strategies.

This study provides scientific basis and decision support for formulating reclaimed water development plans and policy measures in Changsha. However, due to limitations in data and research methods, there are still some deficiencies. Future research can further explore the economic benefit evaluation, environmental impact assessment, and risk management of reclaimed water utilization to provide more comprehensive and in-depth support for the sustainable development of Changsha's reclaimed water industry.

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