Research on the influencing factors of reclaimed wastewater reuse and countermeasure in China

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Abstract. Reclaimed water is regarded as the “Second water source” of the city, which plays an important role in alleviating the shortage of urban water resources and water pollution. By summarizing the current situation of reclaimed wastewater reuse in China, probing into the problems existing in the utilization of reclaimed water, some restrictive factors such as laws and regulations in reclaimed wastewater, water price system, water quality problems, and public participation were analyzed in this paper. Some suggestions in reclaimed wastewater reuse were put forward in this article.

1. Introduction

With the global urbanization expansion and the high-speed development of the relevant industry, the human consumption of water is increasing day by day. Since the beginning of the 20th century, the consumption of water has increased nearly 8 times, and water shortage has become a common phenomenon in most countries. Due to the uneven spatial and temporal distribution of water resources, special national conditions, water conditions and economic development requirements, the problems of water resources and water environment in China are becoming more and more complicated, and the national water safety situation is getting more serious. In the process of implementing the most strict water resources management system, with the water consumption approaching the total water consumption control index in some areas, it has become an inevitable choice for these areas to open up sources and reduce consumption [1]. Reclaimed water development and utilization can replace conventional water resources, improve the recycling efficiency of water resources, and which plays a positive role in alleviating the contradiction between supply and demand of water resources. Promoting the utilization of reclaimed water not only opens up the “Second water source” of urban water use, but also is one of the important contents of water-saving social construction. Meanwhile, it can effectively reduce the pressure caused by pollutant emissions on the ecological environment.

In April 2015, “Focusing on cities in water-scarce and water-polluted areas, improve the reuse facilities of reclaimed water” was proposed by Water Pollution Prevention and Control Action Plan in China [2]. By 2020, “Incorporating reclaimed water into the unified allocation system of water resources” has become an important measure for the Ministry of Water Resources to promote national water conservation and implement the “water conservation first policy” in the new era. It can be seen that the utilization of unconventional water resources such as reclaimed water plays an important role. However, the proportion of reclaimed water utilization in China accounts for less than 1.5% of the...
total water supply, which is still far behind the planned target [3]. Therefore, it is necessary to study the status quo of reclaimed water utilization in China, analyze the influencing factors and problems of reclaimed water utilization, and put forward suggestions to improve the utilization rate of reclaimed water, so as to improve the scale and efficiency of reclaimed water utilization and break the bottleneck that restricts the development and utilization of reclaimed water.

2. Status of reclaimed water utilization

According to the China Water Resources Bulletin from 2009 to 2019, the reclaimed water utilization in China has shown a rapid growth trend in the past 11 years, from 2.15 billion m³ in 2009 to 11.61 billion m³ in 2019 (Table 1 and Figure 1) [4], an increase of nearly 6 times. Regarding the construction of reclaimed water treatment facilities, there has been rapid growth in recent years. As presented in Figure 2, through the investment in fixed assets for urban sewage treatment and reclaimed water utilization in the past 11 years, it can be seen that since 2009, fixed asset investment in this area has grown rapidly. Fixed asset investment in urban sewage treatment and reclaimed water utilization in China has increased from 41.86 billion yuan in 2009 to 80.37 billion yuan by 2019. The daily production capacity of reclaimed water increased nearly 3.5 times from 10.34 million m³ in 2009 to 44.29 million m³ in 2019. The length of the reclaimed water pipeline has increased from 2250 km in 2009 to 12140 km in 2019, an increase of nearly 5.4 times [5]. In this paper, reclaimed water investment facilities construction data are from the 2019 China Urban and Rural Construction Statistical Yearbook [5].

| Year | Number of Sewage Treatment | Treatment capacity of municipal sewage treatment plant / million m³/d | Urban sewage treatment rate /% | Production capacity of reclaimed water /m³/d | Reclaimed water utilization / billion m³ |
|------|---------------------------|-------------------------------------------------|-------------------------------|-------------------------------------------|----------------------------------------|
| 2009 | 1214                      | 90.52                                           | 75.25                         | 1034                                      | 2.15                                   |
| 2010 | 1444                      | 104.36                                          | 82.31                         | 1082                                      | 2.83                                   |
| 2011 | 1588                      | 113.03                                          | 83.63                         | 1389                                      | 3.32                                   |
| 2012 | 1670                      | 117.33                                          | 87.3                          | 1453                                      | 4.43                                   |
| 2013 | 1736                      | 124.54                                          | 89.34                         | 1761                                      | 4.82                                   |
| 2014 | 1807                      | 130.87                                          | 90.18                         | 2065                                      | 4.65                                   |
| 2015 | 1943                      | 140.28                                          | 91.9                          | 2317                                      | 5.26                                   |
| 2016 | 2039                      | 149.10                                          | 93.44                         | 2762                                      | 5.92                                   |
| 2017 | 2209                      | 157.43                                          | 94.54                         | 3588                                      | 7.13                                   |
| 2018 | 2321                      | 168.80                                          | 95.49                         | 3578                                      | 8.55                                   |
| 2019 | 2471                      | 178.63                                          | 96.81                         | 4429                                      | 11.61                                  |

At present, investment in the utilization of reclaimed water in various parts of China is extremely unbalanced, of which Beijing has the most investment. Taking 2019 as an example, Beijing invested nearly 1.42 billion yuan in reclaimed water utilization, accounting for 29.5% of the investment in reclaimed water utilization in China. Other provinces and cities invested less, among them, 11 provinces such as Hubei and Liaoning have no investment in fixed assets of reclaimed water [4]. From this point of view, although the construction of reclaimed water facilities in China has developed rapidly, the investment in various regions is extremely uneven, and some provinces and cities are not enthusiastic about investment and construction.
3. Analysis of influencing factors of reclaimed water

This study investigated the development, utilization and investment of reclaimed water, and construction of sewage treatment facilities in China in the recent 11 years, and conducted correlation
analysis. According to the correlation analysis of factors affecting the development and utilization of reclaimed water (Figure 3), the annual reclaimed water utilization has an obvious positive correlation with the fixed asset investment of the whole society ($r=0.882$, $p<0.01$), and is positively correlated with the production capacity of reclaimed water and the total amount of sewage treatment ($r>0.86$, $P<0.05$). The production capacity of reclaimed water has an obvious positive correlation with Gross Domestic Product (GDP), fixed asset investment of the whole society, financial revenue, pipeline length and the construction of municipal public facilities ($r=0.91$, $p<0.01$). The total amount of sewage treatment has positive correlation with the production capacity of reclaimed water, pipelines length, the construction of municipal public facilities, financial revenue and GDP ($r>0.94$, $p<0.01$).

![Figure 3. RDA on influencing factors of reclaimed water development and utilization.](image)

The pipeline length is obviously positively correlated with the construction of municipal public facilities, the fixed assets investment of the whole society, financial revenue and GDP ($r>0.94$, $p<0.01$). The construction of municipal public facilities has an obvious positive correlation with the fixed asset investment, financial revenue and GDP ($r>0.94$, $p<0.01$). The fixed assets investment of the whole society has an obvious positive correlation with financial revenue and GDP ($r>0.99$, $p<0.01$), and there is an significant positive correlation between financial revenue and GDP ($r=0.997$, $p<0.01$). Among them, the annual reclaimed water utilization is less relevant to investment in reclaimed water utilization and investment in sewage treatment, mainly due to the lack of investment incentive policies for the sewage recycling industry, which results in the lack of investment sources. The construction of reclaimed water reuse projects requires a lot of funds. According to data, the cost of laying the trunk lines of the reclaimed water pipeline network alone is as high as 3 million yuan/km [4].

Due to lagging pipeline network construction and imperfect supporting facilities, the reclaimed water cannot be sent out, and the actual utilization is far less than the designed production capacity, and the long-term low-load operation affects the benefits. At present, the construction of supporting facilities for reclaimed water projects in many regions is still dominated by government investment, and the investment and financing system for reclaimed water projects has not been established [6].
There is a lack of diversified investment and financing channels, private capital and foreign investment have not been fully attracted. In addition to the above factors, the price of tap water has little impact on the development and utilization of reclaimed water, mainly because the price of traditional water resources in China has always been at a relatively low level, and water price system cannot stimulate consumers to actively adopt reclaimed water. Besides the water resource fees, consumers have basically not paid other fees for self-provided water sources (including surface water and groundwater), and their direct water costs are lower than the price of reclaimed water, causing some companies to refuse to use reclaimed water. Moreover, the charging mechanism of reclaimed water has not been established in China. There is no clear and reasonable standard to follow for the pricing of reclaimed water. The pricing process shows greater arbitrariness and subjectivity. This unreasonable price restricts the development of reclaimed water utilization [7]. There is no clear and reasonable standard to follow in the pricing of reclaimed water, and the pricing process is more arbitrary and subjective, which limits the development of reclaimed water utilization [8].

4. Problems existed in the utilization of reclaimed water
In recent years, although the reuse of reclaimed water has been paid more attention and developed rapidly in China, compared with developed countries, there is still a big gap and deficiency in the reuse of urban sewage. Mainly manifested in the following areas.

4.1. Policies and regulations on the utilization of reclaimed water
At the national level, apart from the exemption of value-added tax for the reclaimed water enterprises included in the comprehensive utilization of resources, there is no institutionalized financial subsidy and price incentive policies, and there is no comprehensive reclaimed water law that can regulate the interests of all parties [9]. From a local perspective, according to incomplete statistics, a total of 98 local regulations, government regulations and normative documents related to reclaimed water have been promulgated in China, including 8 provincial regulations, 6 provincial government regulations, 52 provincial normative documents, 11 municipal regulations, 11 municipal government regulations, and 10 municipal normative documents [10]. Formally, about 70% of the policies and regulations related to recycled water are scattered among laws, regulations, and normative documents such as sewage treatment, environmental protection, and resource utilization. Only 12 cities have issued specific regulations and norms for recycled water. Most of the documented countries are based on macroscopic "encourage" and "vigorous development" terms, and lack specific and clear incentive policies, supporting measures, and reward and punishment systems [10]. For example, the government can give priority to certain environmental protection project loans or reduce related taxes for enterprises that self-finance to build reclaimed water facilities. The promulgation of favorable policies will greatly increase the enthusiasm of enterprises in the development and utilization of reclaimed water, and promote the development of reclaimed water utilization.

4.2. Water price system of reclaimed water
The price of reclaimed water is the core element of the market. Under the condition that the quality and quantity of reclaimed water can satisfy the security and stability, the reasonable price mechanism can generate economic incentives for the demand for reclaimed water [11]. Only when the prices of reclaimed water, surface water, and groundwater have a certain degree of price comparison, so that the public feels that the use of reclaimed water is “profitable”, can reasonable water consumption be guided and promotion of reclaimed water be promoted. The current water price structure in most areas of China is unreasonable, and a complete water price system has not been formed [12]. The price of tap water is obviously low, and in some areas, the cost of water production and water supply cannot even be compensated. The low price of tap water makes it difficult for reclaimed water to reflect the price advantage [13]. In addition to water resources fees, the users basically pay no other fees. And their direct water cost is lower than the price of reclaimed water, resulting in some enterprises refused to use reclaimed water.
4.3. Water quality of reclaimed water
Water quality is a key indicator of reclaimed water utilization. The quality of reclaimed water is greatly affected by the treatment capacity of upstream sewage treatment plant. If the quality of the upstream water is unstable, the treatment capacity of the reclaimed water plant may be exceeded [14]. By comparing the water quality standards for different purposes such as reclaimed water for agricultural irrigation, industrial production, landscape water, and municipal miscellaneous use, it can be found that except for the water quality standards for reclaimed water for agricultural irrigation, which basically meets Class IV standards, all other indicators only meet Class V standards [15]. Some users need to perform secondary treatment on the reclaimed water again to reach the utilization standards. Different industries have different requirements for the quality of reclaimed water, which makes the transportation and large-scale use of reclaimed water more difficult [16].

4.4. Public perception
At present, reclaimed water utilization projects in some areas are small in scale, limited in scope of reuse, and the government’s insufficient publicity has made the public’s understanding of reclaimed water limited. Affected by traditional concepts, the public has concerns about the quality of reclaimed water, and the acceptance level is still relatively low [17]. In addition, the lack of public information on water scarcity, principles and procedures for setting water prices makes it difficult to participate in and supervise the management of water resources, which affects the promotion of wastewater recycling to some extent.

5. Suggestion on the utilization of reclaimed water
Solidly advance the work of “incorporating unconventional water sources such as recycled water, rainwater, and brackish water into the unified allocation of water resources” in the “Ten-point Water Plan”. Accelerate the introduction of national or industry guidelines for the promotion of the use of recycled water, and guide local governments to incorporate water resources and water environment management into the integration of water services. It is recommended to strengthen the long-term planning of reclaimed water utilization in cities with water shortages, and conduct detailed analysis and research on the feasibility and overall planning of reclaimed water utilization. On this basis, the scientific and rational medium-and long-term planning and implementation program of reclaimed water utilization are formulated. The planning should be forward-looking, to avoid the development of the city to a certain stage, and the reclaimed water pipeline network becomes a restrictive factor of reclaimed water utilization. The relevant national ministries and commissions should issue “Urban Reclaimed Water Utilization Regulations” and other industry-leading policies as soon as possible to guide water-deficient cities to promote the utilization of reclaimed water in accordance with local conditions. Clear legal guarantee should be provided from the aspects of industrial policies, departmental responsibilities and legal applicability to solve the problems existing in the supervision and management, planning, construction investment, operating expenses, layout of reclaimed water plants and price of reclaimed water.

6. Conclusion
With the acceleration of urbanization, the form of water shortage has become increasingly prominent. Promoting advanced sewage treatment and reclaimed water utilization has become the primary way to alleviate the contradiction between water supply and demand, improve the efficiency of comprehensive utilization of water resources, and reduce water pollution. Meanwhile, it is also an inevitable choice for building a resource-saving and environment-friendly society. To formulate laws and regulations on the use of reclaimed water, establish and improve legal guarantees, improve technologies for the use of reclaimed water, and increase awareness of the use of reclaimed water will be important approaches to solve water shortages. Therefore, the use of reclaimed water will play a very important role and far-reaching significance in solving the problem of water shortage in China and even the world.
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References
[1] He P, Phan L, Gu G, Hervouet G 2001 Reclaimed municipal wastewater--a potential water resource in China Water Science & Technology A Journal of the International Association on Water Pollution Research 43(10): 51-8
[2] Rajashree Hajare, Pawan 2021 Labhasetwar, Pranav Nagarnaik. A critical review of applications of QMRA for healthy and safe reclaimed water management Environmental Modeling & Assessment
[3] Bao C, He D M 2019 Scenario modeling of urbanization development and water scarcity based on system dynamics: A case study of Beijing–Tianjin–Hebei urban agglomeration, China International Journal of Environmental Research and Public Health 16(20)
[4] Ministry of Water Resources of the People's Republic of China 2020 2009-2019 China Water Resources Bulletin Beijing: China Water Resources and Hydropower Press
[5] Ministry of Housing and Urban-Rural Development of the People's Republic of China 2021 2019 Urban and Rural Construction Statistical Yearbook Beijing: China Planning Press
[6] Zhai X L, Zang Y Q 2019 Application of reclaimed water to the field of social life. Shandong Water Resources (11):20-21
[7] Li N 2021 Research on optimization of urban wastewater reclamation and reuse Modern Industrial Economy and Informationization 11(03):65-66
[8] Fan Y P 2014 Research on comprehensive benefit evaluation and policy impact of reclaimed water utilization University of Chinese Academy of Sciences
[9] Li C, Sun Y Y, Shen H Y, Xue Xiao 2010 Foreign reclaimed water reuse policy and its enlightenment to China Environmental Science & Technology 33(S2): 626-627
[10] Li M, Jin Y C 2005 Developing mechanism of reuse water price Journal of Hebei University of Engineering (Natural Science Edition) (02): 90-92
[11] Jing Guo 2020 The study on the effect of government subsidy considering ecological environmental benefits of recycled water reuse water Xi’an University of Architecture and Technology
[12] Duan T, Liu X J 2007 Study on demand for urban reused water Ecological Economy (04): 151-153
[13] Ma Z, Zhou F 2012 The current situation of my country's water price policy and its countermeasures Environmental Protection (19): 54-57
[14] Yuan Y 2019 Investigation of reclaimed water quality in wastewater treatment plant and study on its reuse in thermal power plants Xi’an University of Architecture and Technology
[15] Zhang C M, Liang J, Liu W Y 2021 Comparative study on the bacterial diversity and antibiotic resistance genes of urban landscape waters replenished by reclaimed water and surface water in Xi’an, China Environmental science and pollution research international
[16] Wei F,Yang X P, Wang Y, Huo M X 2020 Loopholes in the current reclaimed water quality standards for clogging control during aquifer storage and recovery in China Water Cycle 1
[17] Li L, Liu X J, Zhang X Y 2021 Public attention and sentiment of recycled water: Evidence from social media text mining in China Journal of Cleaner Production 303