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How could wastewater reuse in China meet the national ambitious water management strategy?

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ABSTRACT

Wastewater reuse could be an important way to augment the urban water supply. China has ambitious plans to promote wastewater reuse and make reclaimed wastewater as a key element of nationwide water resource management scheme. In this study, the development history and spatial-temporal distribution of wastewater reuse in China was firstly summarized, and then the challenges and recommendations of expanding wastewater reuse were analyzed. The growing water stress both in terms of water scarcity and quality deterioration has promoted the development of wastewater reuse in the past 70 years. The development of wastewater reclamation technologies, policies and regulations issued by governments significantly enhanced the process. Although rapid urban development offers favorable opportunities for wastewater reuse, management strategies for wastewater reuse have lagged far behind technology in the past few decades. Therefore, to meet the national ambitious strategy for water resource management, a series of management strategies that can create more secure, resilient and sustainable water systems are required, including improvement of reclaimed wastewater quality standard, establishment of comprehensive and mandatory regulation framework, enhancement of coordination between different agencies, increase of economic and financial assistances, and enhancement of public acceptance. The results could also provide references for other countries solving the problems during the development of wastewater reuse.

Keywords: Wastewater reuse; Water resource; Water management strategy; Sustainable development

1. Introduction

China faces an increasingly severe water scarcity. Two-thirds of China's 669 cities have water shortages, more than 40% of its rivers are severely polluted, 80% of its lakes suffer from eutrophication, and approximately 300 million rural residents lack access to safe drinking water [1]. China's per capita availability of water resources is about a quarter of the world's average, but water consumption per unit of Gross Domestic Product (GDP) is three times the world's average because of a water-intensive industrial structure, outdated technologies, low reuse rate, and wastefulness [2]. Rapid industrialization and urbanization, as well as uneven natural water distribution, significantly aggravates China's water crisis [3].

In 2010, the world's most ambitious strategy for water resource management ("three red lines" policy) was promulgated by China's Communist Party Central Committee and State Council to establish clear and binding limits on the quantity of water usage, its efficiency, and

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its quality [4]. Those limits were set at 700 billion cubic meters (BCM) per year for total national water consumption, 95% of treated wastewater must meet national water quality guidelines. Those guidelines have recently been expanded and updated to cover a wide range of organic and microbial pollutants as well as concentrations of heavy metals [5]. To accomplish the national water management strategy, China issued the Twelfth Five-Year Plan of Energy Conservation and Emission Reduction (2011–2015), which addresses the importance of wastewater treatment and reclamation [6]. The plan sets a goal for municipal wastewater treatment rates and wastewater reclamation rates so that they reach 85 and 15% by 2015, respectively [6].

Municipal wastewater reuse in China is in its infancy. The reclamation rate is much lower than that in developed countries (i.e., 70–80%) [7,8]. However, according to the Twelfth Five-Year Plan of Water Supply Facilities Renovation and 2020 Plan, reclaimed wastewater would account for 26.56% and 41.11% of the national urban water supply in 2015 and 2020, respectively [9]. If the rate of wastewater reuse were increased to 80%, the available urban water supply would increase by 49.18% in 2010. Without a doubt, reclaimed wastewater is a promising source of stable and reliable water. Moreover, the environmental benefit of wastewater reuse is enormous. It has been reported that the reduction in optimal biochemical oxygen demand on the fifth day (BOD_5) could be up to 1.76 million tons from wastewater reuse in China [10]. Therefore, wastewater reuse is playing an increasingly important role in meeting the world's most stringent strategy for water resource management and could be the most important way to alleviate urban water scarcity in China.

However, current wastewater reuse is mostly an afterthought in the development plan for national water resources. The infrastructure needs, use potentials, and development costs are neither accounted for nor planned for in the initial development plan for water [11]. Wastewater reclamation is still not broadly considered in the national pollution control plan. According to our previous study, the current scale of wastewater reuse only accounts for 21.59% of the control strategy, and the allocation is unreasonable [10]. China still has a long way to go to improve wastewater reuse to meet its strategy for national water management. The aims of this study are therefore to summarize the history and spatial-temporal distribution of wastewater reuse in China, identify the major issues associated with wastewater reuse, and offer recommendations for improvement.

2. History of wastewater reuse in China

China began using municipal wastewater to irrigate farmlands as early as the 1940s [12]. Along with urban development, wastewater treatment and reuse have increased gradually. The development of wastewater reuse in China can be roughly divided into three periods: the emerging stage before 1985, the demonstration stage from 1986 to 2000, and the developing stage since 2000 [13]. The history of wastewater reuse in China is summarized in Table 1.

2.1. The emerging stage

Wastewater irrigation was first included in the national scientific research plan in 1957 [14]. In the following 15 years, projects for wastewater irrigation were carried out nationwide. With the awareness on the negative effects of long-term wastewater irrigation, a national conference on wastewater irrigation was held to establish a "positive and cautious" approach as well as a tentative water quality standard for wastewater irrigation [15]. It was the first reclaimed wastewater quality standard in China and indicated that wastewater reclamation in China was on the agenda. Two pilot projects on wastewater reclamation were successfully carried out in Qingdao and Dalian in the Sixth Five-Year Plan period (1981–1985). These were the first attempt to improve the quality of reclaimed water in China. Based on the outcomes of trials, the government declared that, after proper treatment, wastewater could be reused as a promising water resource [11].

2.2. The demonstration stage

Since 1986, wastewater reuse has been sequentially included in the national key technologies research and development programs, namely "Technology of Water Pollution Control and Urban Wastewater Resourcization," "Technology of Wastewater Purification and Resourcization," and "Key Technology of Wastewater Treatment and Water Industry" [13].

Technology development and project demonstration were emphasized in the development of wastewater reuse for fifteen years. Wastewater reclamation technologies for different users were studied systematically in the Seventh Five-Year Plan period (1986–1990) [16]. Wastewater reuse projects were successfully demonstrated for landscape irrigation and environmental water replenishing in Dalian, Taiyuan, Tianjin, Taian, and Beijing in the Eighth Five-Year Plan period (1991–1995) [17]. Integrated technology for wastewater reclamation was derived from standalone technology and demonstration projects in the subsequent Ninth Five-Year Plan period (1996–2000) [18]. Moreover, wastewater reuse for groundwater recharge was carried out for the first time in China. Researchers from Tsinghua University undertook a study entitled Groundwater Recharge of Municipal Wastewater, which laid the foundations for China to develop a project for groundwater recharge demonstration [19].

During the demonstration stage, great efforts were made by the government for the management of wastewater reuse facilities, in which detailed use of reclaimed wastewater, the classification of buildings requiring reclaimed wastewater facilities, as well as incentives and disincentives were stipulated. Beijing promulgated the first local regulation on wastewater reuse and priced reclaimed wastewater for the first time in China at 1 RMB Yuan per cubic meter [10], indicating that wastewater was included in the market economy framework. Reclaimed wastewater was successfully used in industry with the guidance of the Water Industry Manual during this period. In 1997, wastewater reuse was first encouraged as part of the regulations for water resource management for regions suffering from quality-related water scarcity [20].

Table 1
History of wastewater reclamation and reuse in China

Stage	Time period	Achievements		
		Main projects	Policies, laws and regulations	Standards and specifications
Emerging	Before 1985	• Small scale plot of wastewater reuse in Dalian was identified as the first achievement of wastewater reuse in China in 1983. • Wastewater reuse was firstly included in the national science and technology programs by the Ministry of Construction (dissolved). • Pilot plant test of wastewater reuse in Qingdao was successfully completed in 1984.	• Wastewater irrigation was included into the national scientific research plan by Ministries of Construction (dissolved), Agriculture, and Health in 1957. • A "positive and cautious" approach and a tentative water quality standard were established for wastewater irrigation in 1972.	
Demonstration	The Seventh Five-Year Plan period (1985–1990)	• National key technologies research and development programs "Technology of Water Pollution Control and Urban Wastewater Resourcization" was carried out. • Secondary effluent from Jizhuangzi wastewater treatment plant in Tianjin was firstly used for landscape environment.	• Tianjin developed Water Quality Standards of Scenic River in Tianjin. • Beijing promulgated trial implementation of reclaimed water facilities construction and management in Beijing in 1987 (i.e. the first local regulation on wastewater reuse in China).	
	The Eighth Five-Year Plan period (1991–1995)	• National key technologies research and development programs "Technology of Wastewater Purification and Resourcization" was carried out. • A series of projects were successfully demonstrated using reclaimed wastewater for landscape irrigation and environmental water replenishing in Dalian, Taiyuan, Tianjin, Tai'an, and Beijing.	• Interim Measures of Urban Reclaimed Water Facilities Management was promulgated by the Ministry of Construction (dissolved) in 1995 (i.e. the first national regulation on wastewater reuse in China). • Reclaimed water facilities management in Dalian was promulgated.	• Design Specifications for Architectural Reclaimed Water was established by Ministry of Construction (dissolved) in 1991. • The price of reclaimed wastewater was set as 1 Yuan per cubic meter by Beijing for the first time in China.
	The Ninth Five-Year Plan period (1996–2000)	• National key technologies research and development programs "Key Technology of Wastewater Treatment and Water Industry" was carried out. • Two factories in Tianjin were set up especially to produce reclaimed water from municipal wastewater for surrounding industries. • The project of wastewater reuse for groundwater recharge was carried out in Beijing for the first time in China.	• Enhanced wastewater reuse was included in Regulations of Urban Water Conservation in 1998 and implementation details of Water Pollution Prevention and Control Law of the People's Republic of China in 2000. • Encouragement of wastewater reuse was included in Jiangsu Province Water Resources Management Regulations in 1997.	

(*Continued*)

Table 1 (*Continued*)

Stage	Time period	Achievements		
		Main projects	Policies, laws and regulations	Standards and specifications
Developing	The Tenth Five-Year Plan period (2001–2005)	• National key technologies research and development programs "Technology and Demonstration of Wastewater Resourcization" was carried out. • A series of demonstration projects were developed in Beijing, Dalian, Tianjin, and Qingdao.	• Wastewater reuse was included in the revised Water Law of the People's Republic of China and the Outline of the Tenth Five-Year Plan for National Economic and Social Development. • Regulations on wastewater reuse were promulgated by Tianjin, Shenzhen, Dalian, and Shandong.	• Urban Wastewater Reuse Category and correspondingly national standards were established.[a] • Municipal Wastewater Treatment Plant Construction Quality Acceptance, Code for Design of Wastewater Reclamation and Reuse, and Architecture Design for Reclaimed Water System were established by the Ministry of Construction (dissolved) and National Standardization Administration in 2002.
	The Eleventh Five-Year Plan period (2006–2010)	• National key technologies research and development programs "Key Technology of urban wastewater reuse for landscape environment" was carried out. • Wastewater reuse was included in the urban planning in many megacities	• The Eleventh Five-Year Plan of Construction of Water-Saving Society was jointly promulgated by Ministry of Water Resources, Ministry of Construction (dissolved), and National Development and Reform Commission, in which unconventional water resources development and utilization was encouraged. • Managements of wastewater reuse were promulgated by the government of Haerbin, Jiangsu, Kunming, and other cities. • The "three red lines" policy was promulgated by China's Communist Party Central Committee and State Council in 2010.	• National Urban Sewage Treatment and Recycling Facilities Plan was jointly developed by National Development and Reform Commission, Ministry of Construction and Environmental Protection Agency in 2006. • Urban Wastewater Reuse Water Quality Standard for Farmland Irrigation Water was established.[a]

[a]The government decree, Urban Wastewater Reuse Category (GB/T 189198-2002), divided wastewater reuse into five use categories, and correspondingly five recommended national standards, namely: (1) Urban Wastewater Reuse Water Quality Standard for Urban Miscellaneous Water (GB/T 18920-2002) that specified the standard for urban miscellaneous water quality, sampling, and analysis methods; (2) Urban Wastewater Reuse Water Quality Standard for Scenic Environment Water (GB/T 18921-2002) that provided water quality and use patterns of reclaimed water for landscape environment; (3) Urban Wastewater Reuse Water Quality Standard for Industrial Water (GB/T 19923-2005) that set water quality and use patterns of reclaimed water for industrial water; (4) Urban Wastewater Reuse Water Quality Standard for Groundwater Recharge (GB/T 19772-2005) that formulated control projects, limits, sampling and monitoring of reclaimed water for groundwater recharge; and (5) Urban Wastewater Reuse Water Quality Standard for Farmland Irrigation Water (GB 20922-2007) that stipulated water quality control programs, requirements and analysis methods of reclaimed water for farmland irrigation.

2.3. The developing stage

Since 2000, many cities have begun to develop their own municipal wastewater reclamation systems, using system outputs to meet the increasing water demand. Sustainable use of water resources and wastewater reuse were clearly written in the Outline of the Tenth Five-Year Plan for National Economic and Social Development and the national Water Law [21]. These actions indicate that wastewater was being considered as the second urban water resource in China.

During the Tenth Five-Year Plan period (2001–2005), safe and efficient utilization of reclaimed wastewater was emphasized [22]. In the subsequent Eleventh Five-Year Plan period (2006–2010), wastewater reuse was included again in the National Hi-Tech Research and Development Program of China [23]. These projects resulted in technical support and policy guarantees for reclaimed water use in China. In January 2011, the Chinese government's annual No. 1 Document, which reflects its top priority, clearly noted that wastewater reuse should be strengthened [4]. In May 2012, the Twelfth Five-Year Plan of National Urban Sewage Treatment and Recycling Facilities (2011–2015) was promulgated by China's State Council, in which 30.4 billion RMB Yuan was set aside to invest in the construction of reclaimed wastewater use facilities. By the end of 2015, the scale of reclaimed wastewater production is expected to be at 38.85 million cubic meters per day [24].

To ensure the safety of reclaimed wastewater, the national government established quality requirements for reclaimed wastewater specifying standards for five use categories: urban miscellaneous, scenic environment, industrial water, groundwater recharge, and farmland irrigation. Moreover, three design specifications on wastewater reuse were established for normalizing the technical data for developing effective reclaimed water systems nationwide and improving the reliability and performance of municipal wastewater treatment processes. The standards play an important role for the expansion of wastewater reuse in China.

The successful development of wastewater reuse has a close relationship with the quality of treated wastewater which depends upon the development of wastewater reclamation technology. By the end of 2010, 343 reclaimed water facilities had been constructed in China, and 54 of them were included in wastewater treatment plants [10]. Detailed technologies applied in these wastewater reuse facilities include biological treatments such as biofilter, maturation ponds and constructed wetlands, physical separations such as medium filtration and membrane filtration, disinfections such as sodium hypochlorite, ultra-violet radiation and ozone, and others such as electrochemical treatments [10]. With advances in technologies, wastewater can be treated to meet these reclaimed wastewater quality standards.

3. Spatial-temporal distribution of wastewater reuse in China

The water crisis in China is primarily driven by the interplay between demographics and the socio-economy. China suffers from a problem faced by many countries: the distribution of the country's population and its economy does not coincide with that of its water resources. The North China Plain has 33% of China's population and generates the same national percentage of GDP and industrial output, yet it contains only 7.7% of the nation's water resources. Conversely, 21.3% of the nation's water resources are in the southwest, but that region accounts for only 0.7% of the national GDP and industrial output [2,25]. Moreover, water pollution exacerbates the water shortage in northern, eastern, and even southern China because rapid development of housing and land consumes much water, generates wastewater, and expands impermeable surfaces that increase runoff [26]. Therefore, wastewater reuse, which is closely related to water resources, environment, as well as the socio-economy, is spatial-temporally distributed. The spatial-temporal distribution of wastewater reuse in China is summarized in Fig. 1. The contributions of different time periods on the increases of wastewater reuse scales and ratios in China from 2002 to 2015 were calculated by Eqs. (1), (2):

$$a = V_{RWl} - V_{RWp} \quad (1)$$

$$b = r_{RWl} - r_{RWp} = \frac{V_{RWl}}{V_{Wl}} - \frac{V_{RWp}}{V_{Wp}} \quad (2)$$

where V_{RWp} and V_{RWl} indicate the volumes of reused wastewater in the previous and later time periods, respectively. r_{RWp} and r_{RWl} are the ratios of wastewater reuse in the previous and later time periods, respectively. V_{Wp} and V_{Wl} are the volumes of treated wastewater in the previous and later time periods, respectively.

The volume of wastewater reuse was first included in China Urban Construction Statistics Yearbook in 2002, at a rate of 15.72% [27]. After that, the volume of wastewater reuse decreased more or less with as the standards of wastewater reuse improved because some of the reclaimed wastewater without value-in-use was not included in the Statistics Year-

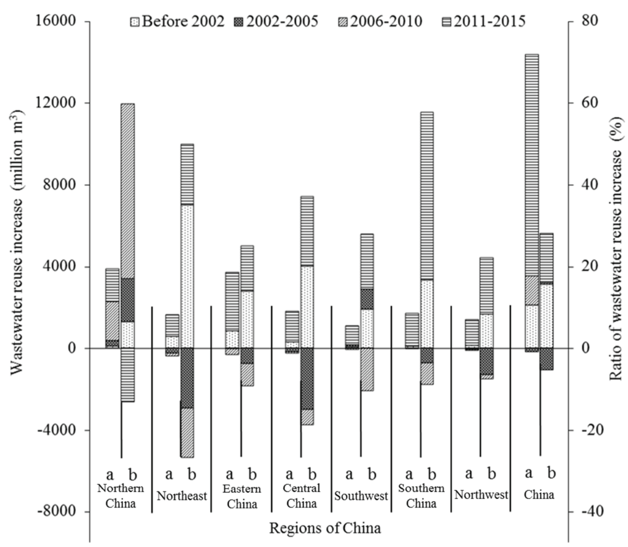

Fig. 1. Contributions of different time periods on the increases of wastewater reuse scales and ratios in China, 2002–2015. a: wastewater reuse scale, b: wastewater reuse ratio.

book. Therefore, contributions from different time periods on the increase for the scale of wastewater reuse registered as negative. Moreover, the rate of wastewater collection and treatment developments in China in the past 10 years has been much higher than wastewater reuse alone, resulting in significant negative growths for the rate of wastewater reuse. For example, the rate of wastewater reuse in 2002 (15.72%) is higher than it was in 2005 (10.47%), 2010 (10.83%) and is even higher than the goal established in the national Twelfth Five-Year Plan (15%) [27]. The quantity and rate of wastewater treatment have increased from 13.49 BCM and 39.97% to 31.17 BCM and 82.31% from 2002 to 2010, respectively. Moreover, it is interesting to note that the scale of wastewater reuse in 2002 (21.22 BCM) is larger than the scale in 2005 (19.55 BCM). This is due to the establishment and improvement of national quality requirements for using reclaimed wastewater in 2002 and 2005. Great efforts were made to improve the quality of reclaimed wastewater to meet the national standards during this time, in accordance with the goals set by national key technologies research and development programs in the Tenth and Eleventh Five-Year Plans.

China is geographically divided into seven regions: northern, northeast, eastern, central, southwest, southern, and northwest. Northern China is the most water-stressed region, with only 647.51 m^3 of water resources per capita per year (MWR 2004). Reclaimed wastewater as the region's secondary water resource expanded from 2002 and 2010 because of sufficient infrastructures and regulations on wastewater reuse. Beijing and Tianjin play important roles in the increase in wastewater reuse in this region. Although the rate of wastewater reuse will slightly decrease in the next five years (i.e., from 59.74% to 46.76%), it is still much higher than the goal set in the Twelfth Five-Year Plan. Agricultural irrigation and scenic environment are the main patterns of wastewater reuse in northeast, eastern, central, and southern China. With the rapid development of wastewater treatment and the improved quality standards for national reclaimed wastewater, the ratio of wastewater reuse has been steadily decreasing from 2002 to 2010. Southwest China is the most water-rich region in the country, with more than 3000 m^3 of water resources per capita per year [25]. However, regional wastewater reuse rates (4.07%) are higher than those in central China (1.41%) and southern China (0.91%) [28] [7]. This is because the regional governments there have promulgated sufficient policies and regulations on wastewater reuse. For example, since 2004, seven regulations have been sequentially promulgated by the government of Kunming, which detailed the classifications of buildings requiring reclaimed water facilities, the prices of reclaimed wastewater, as well as incentives and disincentives. Although the change in the scale of wastewater reuse in the northwest is small (within 10 million cubic meters from 2002 to 2010), great efforts have been made by the regional governments to improve reclaimed wastewater quality standards [28].

4. Issues on the refining of wastewater reuse and recommendations

China is a developing country experiencing rapid urban development. With the rapid development of wastewater treatment, large volumes of wastewater are collected and treated, offering favorable opportunities for wastewater reuse. Unfortunately, wastewater reuse in China started later and developed slower than in developed countries. At present, the development of management on wastewater reuse falls seriously behind China's technological capabilities. In the past few decades, great but insufficient efforts have been made by the government and society for the redefinition of wastewater reuse to meet the current strategy for national water management. Based on the summary of wastewater reuse in China, the major management issues impeding the redefinition of wastewater reuse are identified and corresponding recommendations for improvements are offered as follows.

4.1. Incomplete standards for high quality reclaimed wastewater

Wastewater has been successfully reclaimed for groundwater recharge in many countries, e.g., the United States, Singapore, and Israel [8]. However, the quantity of wastewater reuse for groundwater recharge was only 28.99 million cubic meters in 2011 in China, accounting for only 0.87% of the total amount [29].

The composition of urban wastewater is complex in China due to incomplete regulations for the management of hazardous materials and low pretreatment levels for industrial wastewater [30]. Although great efforts have been made, gaps in urban wastewater treatment between China and developed countries persist [31]. Reusable wastewater should be free of any toxic pollutants that escape from conventional wastewater treatment. Unfortunately, in China, the only standards for determining organic pollution in reclaimed wastewater are the chemical oxygen demand (COD) and BOD_5 [32]. Although the treated wastewater could meet the standards for wastewater reuse, it still contains some micropollutants, such as emerging contaminants, which would potentially threaten reclaimed wastewater utility customers, especially for high-quality water users [33,34]. Therefore, not only conventional pollutants but also emerging contaminants should be considered during the improvement of standards for reclaimed wastewater for high-quality water users.

4.2. Incomplete policies and regulations on wastewater reuse

Legal safeguards and management strategies are necessary for the expansion of wastewater reuse. However, national policies and regulations on wastewater reuse are insufficient. The current policies and regulations on the management of wastewater reuse in China lack coerciveness and are not fully integrated. Wastewater reuse legislation should be pushed forward as soon as possible.

The function of wastewater reuse should be defined clearly in national development plans. Detailed and mandatory requirements on water quality standards for reclaimed wastewater sources, treatment and production performances, reclaimed wastewater transmission and distribution, as well as field operation manuals for supervision and management of reclaimed wastewater applications should be established by the central government. Local wastewater reuse policies and regulations should be promulgated and implemented based on national provisions and regional water resources and water environment status. A systematic framework with a multi-objective optimization model has been developed for sustainable implementation of wastewater reuse in China [10]. According to the modeling results, the control strategy of the scale of wastewater reuse should be set at 15.39 BCM, with agricultural irrigation at 773.14 million m^3 (MCM), industrial reuse at 859.22 MCM, municipal reuse at 1099.81 MCM and recreational reuse at 1657.03 MCM [10]. Moreover, it has also been suggested that policies and regulations on wastewater reuse should focus on promoting municipal, domestic, and recreational uses in regions suffering from quantity-related water scarcity, while detailed requirements on industrial reuses are imperative in regions suffering from quality-related water scarcity [10].

4.3. Lack of coordination during wastewater reclamation and reuse

Many agencies are involved in the governance of wastewater reuse, but they lack coordination. At the central government level, the MWR is supposed to lead design and implementation of the new water plan. The Ministry of Housing and Urban-Rural Development (MHUD) should focus on construction and maintenance of wastewater reclamation facilities. The Ministry of Environmental Protection (MEP) oversees the quality of reclaimed wastewater. In the past few years, responsibility assignments have been unclear, and even the definition and scope of reclaimed wastewater were controversial. For example, quantities and patterns of wastewater reuse and the lengths of pipelines in statistical reports of MWR and MHUD are different from each other every year [7,27,30,35]. To implement effectively the promulgated laws, policies and regulations on wastewater reuse, relevant sectors and agencies must coordinate, and a special agency may even need to be created to take charge of national wastewater reuse.

With severe water shortages and rigorous management of water resources in China, potential consumers of reclaimed wastewater are increasing rapidly. However, conveyance and distribution networks are not ready for the widespread use of reclaimed wastewater. Wastewater reuse is often an afterthought in urban planning and development. Current urban constructions seldom take the distribution of reclaimed water into account, leaving little room in the utility corridor to accommodate the necessary pipeline networks for reclaimed water distribution. Retrofitting is costly, impractical and inconvenient. Therefore, the improvement of conveyance and distribution networks is a priority for management of wastewater reuse in the near future.

4.4. Non-competitive operating mechanism in the market economy framework

A proper pricing structure for reclaimed water is imperative to the success of wastewater reuse in the market economy framework [36]. The proper price should balance the demand for fresh and reclaimed water in a community. However, the current fresh water pricing structures in many cities are not reasonable. The pricing of fresh water is based only on cost recovery and does not consider water as a resource; therefore, it cannot reflect the market dynamics of supply and demand in the market economy framework. To enter the water resources market, the price of reclaimed wastewater has to be reduced to the greatest extent, resulting in a loss for reclaimed wastewater companies. For example, Beijing Jingcheng Reclaimed Water Co., Ltd, which is responsible for the reclaimed wastewater supply in Beijing's central region, sold approximately 500 million m^3 of reclaimed wastewater but lost more than 30 million RMB Yuan in 2007 [10].

Rational pricing for fresh water and reclaimed wastewater plays an important role in establishing a sound water–market economy system. Reclaimed wastewater should be priced on the basis of three factors: a water resources fee, which is not calculated based on the current policy; a processing fee for capital as well as operating and management costs; and an adjustment fee that is unique for reclaimed wastewater, which is used to guide users to select the target objective, that is, the use of reclaimed wastewater [37,38]. Compared with other public utility services, reclaimed water reuse projects have low or little profits in China because of large investment outlays and a lack of potential users. Therefore, central and local governments need to support funding and policies to promote competition in wastewater reuse in the market economy framework. Water companies that produce reclaimed wastewater for public welfare (e.g., agricultural irrigation, ecological water compensation, and recreation) should be given fiscal subsidies. It should be mandatory to use reclaimed wastewater in businesses with high water-consumption (e.g., road sweeping, landscaping, and car washing) and in industries that require water without high quality (e.g., circulating cooling water and ash-rinsing water in thermal power plants).

4.5. Lack of public awareness and acceptance

Whether wastewater reuse could be redefined would greatly depend on the awareness and acceptance of potential users in China [32]. Although the scale gap between reclaimed wastewater production and wastewater reuse has been narrowed from 1.95 BCM to 0.58 BCM from 2007 to 2010, the public currently has little knowledge on the benefit and safety of reclaimed wastewater due to a lack of public education by the government [7,27,30].

Compared with drinking water, reclaimed wastewater contains salts, nitrogen, phosphorus, and a variety of trace toxic substances and pathogens [39]. Reclaimed water from a pollution source has certain negative effects, which would be the dominant obstacle for expanding public acceptance of reclaimed wastewater. Therefore, security of reclaimed wastewater should be emphasized in public education. Moreover, it is suggested that the sensory index of reclaimed wastewater for toilet flushing and miscellaneous municipal uses should be more rigorous than current national standards. According to our survey, the most difficult obstacle to overcome in promoting wastewater reuse for domestic toilet flushing and car washing is the significant color difference between reclaimed wastewater and current water sources.

5. Conclusions

Wastewater reuse has been recognized as an integral part of the water and wastewater management scheme in China. The government has launched efforts nationwide to optimize the benefits of utilizing reclaimed wastewater over the past 70 years. With the widespread construction of wastewater treatment systems, large volumes of reclaimed wastewater have come online. Despite this progress, the development of management for wastewater reuse falls far behind the technology, and the redefinition of wastewater reuse is not sufficient to meet the current strategy for national water management.

To meet the national ambitious strategy for water resource management, a series of management strategies that can create more secure, resilient, and sustainable water systems are required: (1) Not only conventional pollutants but also emerging contaminants should be considered as standards are improved to reclaim wastewater for high-quality water users. (2) A comprehensive and mandatory regulation framework should be pushed forward as soon as possible to encourage efficient use of reclaimed wastewater. (3) The sectors and agencies related to wastewater reuse must coordinate to achieve and implement effectively the promulgated laws, policies and regulations. (4) Supportive funding and policies by the central and local governments are necessary for promoting competition in wastewater reuse in the market economy framework. (5) Raising the public's awareness of the security of reclaimed wastewater is crucial for the rapid expansion of wastewater reuse in China.

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