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An overview of reclaimed water reuse in China

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Abstract

China is facing severe water problems including scarcity and pollution which are now becoming key factors restricting developments. Creating an alternative water resource and reducing effluent discharges, water reuse has been recognized as an integral part of water and wastewater management scheme in China. The government has launched nationwide efforts to optimize the benefits of utilizing reclaimed water. This article reviewed the water reuse activities in China, including: (1) application history and current status; (2) potentials of reclaimed water reuse; (3) laws, policies and regulations governing reclaimed water reuse; (4) risks associated with reclaimed water reuse; (5) issues in reclaimed water reuse. Reclaimed water in Beijing and Tianjin were given as examples. Suggestions for improving the efficiencies of reusing urban wastewater were advanced. Being the largest user of reclaimed wastewater in the world, China's experience can benefit the development of water reuse in other regions.

Key words: water management; water crisis; recycling

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Introduction

China is facing increasing pressure on fresh water supplies. It is among the 13 lowest water availability countries in the world and the per capita water availability of China is about a quarter of the world average (Bai et al., 2007). Majority of the available water is concentrated in the south, leaving the northern and western China to experience perpetual droughts. Rivers, lakes and underground aquifers are literally drying up due to over drafts. Most of the remaining surface waters are so polluted that they are no longer suitable for human contacts (Weng and Zhao, 2002). With population growth, accelerated industrialization and urbanization, and global climate change, China's water crisis is exacerbating. Water shortage has become a major obstacle restricting China's economic development (Zhang et al., 2009).

China has taken great efforts in conserving and augmenting the limited water resources to meet the growing demands. Water reclamation, recycling and reuse are key components of the national water strategy (Fu et al., 2007). Many regions, especially urban centers in northern China, have made a great deal of efforts to maximize benefits of utilizing reclaimed water. With advances in wastewater treatment technologies, the reuse potentials of reclaimed water are expanding. Unlike long distant water transfer and exploitation that are uncertain and costly to develop, reclaimed water can be applied in many ways and be considered as a local, reliable, and considerably less costly water resource (Li et al., 2007).

There has been a significant increase in the use of reclaimed water in China. As a result, numbers of issues arose due to the complexity of implementing water reuse programs (Chen and Guan, 2008; Wang et al., 2004). There is still a long way to go in terms of expanding beneficial utilization of reclaimed water while minimizing the public health and environmental risks. In the following, we appraised the application history and current status of reclaimed water, evaluated the rules and regulations governing water reuses, and identified potential risks and bottlenecks that are hindering the further developments along with two case studies. Potentials of water reuse in China and suggestions of improvements were also delineated.

1 Application history and current status

China started using municipal wastewater to irrigate farmlands in the 1940s (Wei et al., 2006). The water quality

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was poor at that time, mostly untreated sewage or effluents of primary treatments. Along with the urban development, the comprehensive wastewater collection and treatment systems and recycling of reclaimed wastewater have increased gradually since the 1980s. The development of using reclaimed water in China may be roughly divided into three periods, namely, the emerging stage before 1985, the demonstration stage from 1985 to 2000, and the developing stage since 2000 (Pan et al., 2006).

The Ministry of Construction initiated pilot projects on reclaimed water in Qingdao and Dalian during the Sixth Five-Year Plan period (1981–1985). It was the first attempt involving the improved quality of reclaimed water in China. Based on the outcomes of trials in Qingdao and Dalian, the government declared that after proper treatment, wastewater could be reused and was a promising water resource (Ma, 2007).

Subsequently, a series of projects were launched in northern China such as Tianjin, Tai'an, Xi'an, and Taiyuan under the auspice of national water pollution control starting in 1985. They became the pioneers of wastewater reclamation in China. Under the National Key Technologies R&D Program, three projects involved reclaimed wastewater reuse were developed, namely "Technology of Water Pollution Control and Urban Water Resourcization" (1985–1990), "Technology of Wastewater purification and Resourcization" (1991–1995), and "Key Technology of Wastewater Treatment and Water Industry" (1996–2000). The technological knowhow gained from these projects greatly enhanced the development of wastewater reclamation technology in China. However, the public acceptance was low, and the government was willing to choose long-distance inter-basin water transfer and did not take waste water as a resource. In addition, there were the constraints from management platform and funding gap. As a result, the national climate of water reuse had not formed yet, reuse projects were few, and practical results were not pronounced. In the national and local water resource management plan, the reclaimed wastewater reuse was seldom taken into account.

Since 2000, numbers of cities in China started to develop their own municipal wastewater reclamation systems and used the outputs to meet the increasing water demand. Policies were promulgated to promote water reuses and financial supports for municipalities to develop wastewater reclamation projects, and preferential policies were enforced to promote the use of reclaimed water. Meanwhile, a great deal of resources has been invested on researches that in turn boosted for the uses of reclaimed water. Wastewater reuse has become a long term and important strategy in water resource management in China.

According to Ministry of Construction, 1.66×10^9 m^3 reclaimed wastewater was used in 2008, amounting to 8% of the total treated municipal wastewater. The reclaimed wastewater was used mainly for agricultural irrigation (0.48×10^9 m^3), recreational/environmental enhancement (0.56×10^9 m^3), urban miscellaneous use (0.2×10^9 m^3), industrial use (0.39×10^9 m^3) and groundwater recharge (0.03×10^9 m^3). Undoubtedly, there are great deals of potentials for using more reclaimed wastewater if obstacles hindering its progress are identified and removed.

China had a long history of using wastewater to irrigate farmland. The systematic investigations on the pros and cons of wastewater irrigation did not begin until 1957 (The writing group of guidelines for Series of Standard on Water Reuse, 2008). At that time, the Ministries of Construction, Agriculture, and Health jointly included wastewater irrigation into the national scientific research plan and started to establish wastewater irrigation projects. The wastewater irrigated area increased rapidly from 11,500 hm^2 in 1957 to 93,000 hm^2 in 1972 (Wei et al., 2006). In 1972, a national conference was held in Shijiazhuang to address the ever increasing water pollution incidents associated with wastewater irrigation. A "positive and cautious" approach emerged in further developments and a tentative water quality standard for wastewater irrigation was put forth (Huang and Wang, 2009). The Ministry of Water Resources reported the agriculture used 2.311×10^{12} m^3 of water in 2004, accounting for 77% of the total usage (Shi et al., 2008). Therefore, there are great potentials for saving water with application of reclaimed water for irrigation.

Faced with water shortage and pollution, many cities began to utilize reclaimed wastewater to replenish ornamental ponds and lakes in public parks, sustain or augment stream flows, create man-made wetlands, etc. During the Seventh Five-Year Plan period (1985–1990), Tianjin developed Water Quality Standards of Scenic River in Tianjin, and began to introduce the secondary effluent of Jizhuangzi wastewater treatment plant into the landscape channel (Ji, 2007). A series of projects demonstrate using reclaimed wastewater in landscape irrigation and replenish environmental water commenced in Tai'an, Beijing, Tianjin, Qingdao and other cities in succession, which laid the foundation in promoting water reuses for landscape irrigation.

Industrial uses of reclaimed water come in many different ways such as cooling-water, processing, and boiler feed water. The industrial water uses account for 50% to 80% of the total urban water consumption in China (Wei et al., 2006). Thus, there are great potentials in saving water if the demands may be partially or fully replaced by reclaimed water. The government has undertaken a series of measures to encourage industries to use reclaimed wastewater instead. For instance, two factories in Tianjin were set up especially to produce reclaimed water from municipal wastewater for surrounding industries.

While groundwater recharge is common around the world, recharging underground aquifers using reclaimed wastewater is relatively new development in China. The experimental studies mainly test the potential of treating and dissipating wastewater instead of optimizing reuse potentials. During the Ninth Five-Year Plan period (1995–2000), researchers of Tsinghua University undertook a study entitled Groundwater Recharge of Municipal Wastewater, which laid the foundations for China to develop groundwater recharge demonstration project (Wei et al., 2006).

2 Potentials of reclaimed water reuse

The application history of reclaimed water in China and around the world has demonstrated that it is feasible to apply reclaimed water in large scale and there is great market potentials for reclaimed water. The wastewater discharge in China was growing year by year (Table 1). From 2000 to 2008, the annual industrial wastewater volume increased around 24%, from 1.942×10^{10} m^3 to 2.417×10^{10} m^3. The annual domestic wastewater discharge increased around 50%, from 2.209×10^{10} m^3 to 3.30×10^{10} m^3 with the rapid urbanization. Meanwhile, the wastewater treatment rate increased rapidly from 2001 to 2008 (Fig. 1). In 2001, less than 20% of the wastewater was treated. By 2008, about 60% of the wastewater in China was treated.

Approximately, 80% of the water consumed in the urban area ends up in the wastewater stream and 70% of which may be reclaimed if the wastewater is collected and treated. If the reclaimed water is fully utilized, the available water supply would increase by 56%. Without a doubt, it is a promising source of stable and reliable water supply. It could resolve 50% plus of the urban water shortages if on the average 20% of reclaimed water is used nationwide (Zhou, 2006).

Table 1 Wastewater discharge from 2000 to 2008 in China*

Year	Total wastewater discharge ($\times 10^{10}$ tons)	Industrial discharge ($\times 10^{10}$ tons)	Household and dervice discharge ($\times 10^{10}$ tons)
2000	4.152	1.942	2.210
2001	4.280	2.010	2.280
2002	4.395	2.072	2.323
2003	4.600	2.124	2.476
2004	4.824	2.211	2.613
2005	5.245	2.431	2.814
2006	5.368	2.402	2.966
2007	5.568	2.466	3.102
2008	5.717	2.417	3.300

* Data are based on Environmental Statistics Bulletin 2001–2008, http://www.mep.gov.cn/zwgk/hjtj/.

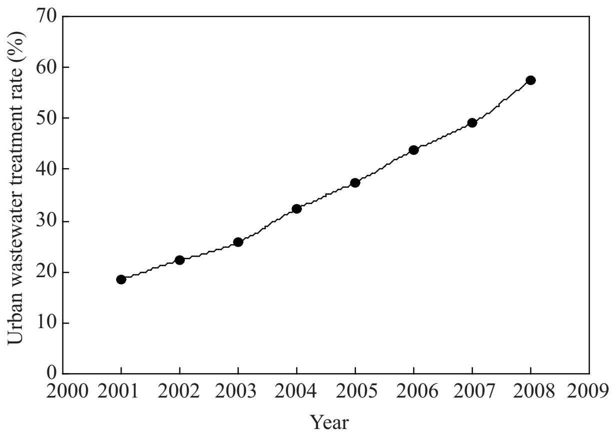

Fig. 1 Wastewater treatment rate from 2001 to 2008 in China. Data are based on Environmental Statistics Bulletin 2001–2008, http://www.mep.gov.cn/zwgk/hjtj/.

3 Laws, policies and regulations governing reclaimed water reuse

The government has played a significant role to promote the production and utilization of reclaimed water in China. As early as 1958, urban wastewater reuse was an issue on the national scientific and technological priority list and has been included in the national key scientific and technological project of the Seventh, Eighth, and Ninth Five-Year Plans since 1986. In the early days, the nation lacked the infrastructures in collecting and treating the urban wastewater, the wastewater reuses amounted to farms irrigated with untreated wastewater. Widespread adaptation of land applying wastewater reduced the pressures of finding disposal outlets and provided water and plant nutrients for growers at the urban-rural fringe. During the Tenth Five-Year Plan period (2001–2005), safe and efficient utilization of reclaimed water was emphasized, and irrigation with reclaimed water was studied thoroughly and systematically. When more and more cities installed the wastewater treatment systems, the quality of reclaimed wastewater continued to improve and the outputs might be suitable for uses other than the land applications. Reclaimed water was included again in the National Hi-Tech Research and Development Program (863) of China during the Eleventh Five-Year Plan period (2006–2010). The results from these research projects provided technical support and policy guarantee for reclaimed water utilization in China.

The government has established quality requirements for utilizing reclaimed water to regulate and ensure the safety of reclaimed water uses. 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 (Guidelines for Series of Standard on Water Reuse, 2008).

To implement the national urban wastewater reuse plan, the Ministry of Construction and National Standardization Administration established standards on wastewater reuses, which included Municipal Wastewater Treatment Plant Construction Quality Acceptance (GB 50334-2002), Code for Design of Wastewater Reclamation and Reuse (GB 50335-2002), and Architecture Design for Reclaimed Water System (GB 50336-2002) (Zhang, 2007). The provisions normalized the technical data for developing effective reclaimed water systems nationwide and improved the reliability and performance of municipal wastewater treatment processes.

In 2006, the National Development and Reform Commission, the Ministry of Construction and the Environmental Protection Agency jointly developed the National urban sewage treatment and recycling facilities plan, directing the local entities to expand the uses of reclaimed wastewater.

4 Risks associated with reclaimed water reuse

Compared with drinking water, reclaimed water contains high salts, nitrogen, phosphorus, and a variety of trace toxic substances (toxic ions, organic pollutants, etc.) and pathogens. Reclaimed water with the property of pollution source has certain negative effects that is, ecological risk. Nearly 30 years, with the increase in reclaimed water use, its safety and impact on the environment has attracted wide attention.

Long-term irrigation of reclaimed water may conceivably lead to soil salt levels intolerable to most landscape plants or crops, especially in heavy soil (Hogg et al., 1997; Qiao et al., 2005). Salts may migrate through groundwater in the long-term irrigation (Yan, 2009). China has researched short-term salt accumulation, but its systematic research of long-term cumulative effects is lack (Wang et al., 2009). Wei et al. (2008) stated that the total dissolved solids of 0 to 15 cm soil layer increased, the contents of soil cation were not obviously changed in the short-term irrigation. Beijing began large-scale irrigation in the late 1960s; therewith chloride, sulfide, sodium and total hardness of shallow groundwater rose fast. Pollution of nitrate nitrogen was serious, the content of nitrite nitrogen and ammonia nitrogen also increased year by year (Zou et al., 2002).

Reclaimed water can be high in nutrients, mainly as N, P, K. Nutrients enrichment such as nitrogen and phosphorus in aquatic ecosystems can result in algal blooms (Wang et al., 2010). Oversupply with nitrogen may result in excessive vegetative growth and reduced fruit set for crops, or delays in maturation (Huang and Wang, 2009). Nitrate (NO_3^-) is the most mobile form of nitrogen in the soil. Being poorly bound to soil particles, it leaches freely and is the most commonly reported pollutant in drinking waters around the world (Wan et al., 2004).

Reclaimed water usually contains a wide variety of elements in low concentrations. Problems occur if certain elements accumulate in the soil to levels toxic to plants. The most common toxicities can occur due to accumulation of boron, chloride, sodium, and some heavy metals (Wang et al., 2005). There were 22 significant pollution points in China's 37 major wastewater irrigation areas with mostly excessive accumulation of heavy metals (Xia and Wang, 2001). Xu et al. (2009a) stated that no significant differences were observed between the control of fresh water irrigation and the treatments of reclaimed wastewater irrigation on the quality of vitamin c, protein and dissolved sugar in short-term irrigation. For microelements, there were not significant differences for Na, Mg, K, Ca and Zn contents in cabbage in short-term irrigation.

The use of untreated or poorly treated wastewater for irrigation may lead to pollution of organic pollutants in the soil, and may thereby affect crop growth and quality (Xu et al., 2010). Organic pollutants may migrate into the groundwater by unreasonable irrigation. Han (2006) stated part of the groundwater of Haihe River Basin was polluted by chloroform, carbon tetrachloride, trichloroethene and tetrachloroethene. Recently, the risk of some new pollutants has been paid more and more attention to, such as disinfection byproducts, pharmaceutical and personal care products, and endocrine disrupting compounds.

In recent years the major risk to human health is pathogenic microorganisms in the process of wastewater reuse (Qiu and Wang, 2008). Pathogens in wastewater irrigation may enter the human respiratory system via air, and may indirectly enhance the probability of being infected by the pathogen through food consumption. Risk assessments of applying reclaimed water in agriculture suggested that when using tertiary effluent, secondary effluent and sewage separately, sewage and secondary effluent belonged to unsafe irrigation-used water to human health (Zhang, 2006).

5 Issues in reclaimed water reuse

Despite a long history and widespread adoption of wastewater reclamation, technical and managerial gaps and inadequacies remain (Cao and Guo, 2009). There are many water treatment technologies available around the world. For reclaimed water reuse, the key issue is to select proper technologies to meet the water quality requirement for specific reuse category at low cost. So far, the main issues limiting the reclaimed water reuse in China are mainly regard to the management issues, summarized as follows.

5.1 Insufficient knowledge on water resources and incomplete regulations and supporting policies on reclaimed water reuse

The national policy of water reuses has not been uniformly implemented across the country. In many regions, especially those not experiencing water shortage, water conservation and water reclamation have not been a high priority in their water resources management plans. When experiencing water shortage, cities tend to follow the traditional approaches of developing new water resources, such as inter-basin water transfers and groundwater exploitations (Qiu and Lu, 2007). Water reclamation as a way of supplementing water resources has not been broadly recognized. As a result, only a small percentage of the reclaimed water is effectively used.

For the reuse of urban wastewater, legal safeguard and management strategies are necessary to achieve safe and reliable outcomes (Bixio et al., 2008). The current policies and regulations on wastewater management in China are lack of consistencies and are not fully integrated. It is imperative that the government puts forth detailed and mandatory requirements on water quality standards of reclaimed water source, treatment and production performances, water transmission and distribution, and field operation manuals for supervision and management of the reclaimed water applications. In this manner, operations across the country may be evaluated on the same bases.

In addition, it is unclear how should the water reuse operations be financed. At the moment, it is not clear whether the cost of wastewater reclamation may be recouped by selling the reclaimed water. Users of reclaimed water often failed to pay for the water they used when the businesses became insolvent and companies reclaiming the wastewater were unable to operate and fulfill their obligations in turn. The contractual agreements on checks and penalties must be tightened. An efficient supporting network for promoting reclaimed water reuse is needed.

5.2 Pricing structure for marketing reclaimed water

Water supply is a public service. The current pricing of water is based on cost recovery and does not consider water as a resource. Water prices nationwide therefore do not reflect market dynamics of supply and demand, costs of wastewater treatment, and requirements of water reuse (Yang, 2010). Incentive mechanism of water reclamation has not been formed. Thus, the current formation of water price is not able to serve as an adjustment for the supply and demand of water resource. The current price structure for wastewater treatment is not adequate to compensate the capital investments and operation costs of wastewater treatments, not to mention additional investments necessary for production and operation of a water reuse program (Xu et al., 2009b).

Like developing new water supplies, the cost of reclaim and reuse water must be bear by the users. A proper pricing structure for reclaimed water is imperative to the success of water reclamation (Chu et al., 2004). It is necessary to set rational prices-such that the demands for fresh and reclaimed water in a community are balanced. However, the current water pricing structures in many cities are not reasonable. Even though reclaimed water cost is less than tap water, water companies lack the necessary motivation to supply reclaimed water.

5.3 Lack of public awareness and acceptance

So far, the reclaimed water has become available and been used in urban environment without a great deal of promotion and fanfare as the water reuse activities were largely due to the governmental decrees. The actual utilization has been rather limited. Whether or not the use of reclaimed water can be widely expanded would depend on greater acceptance by potential users that have not yet on line, whether or not they are able to trust the quality and reliability of reclaimed water supply and whether or not the government can recognize the benefits of water reclamation (Hartley, 2006; Dolnicar et al., 2010). Lacking outreach and promotions, the public have little knowledge on the benefit and safety of reclaimed water, and therefore public acceptance level is low toward the reclaimed water. Public education and technical supports are needed to expand the acceptance of reclaimed water.

5.4 Insufficient financial support

Compared with other public utility services, reclaimed water reuse projects have low or little profits in China because of large investment outlays and lack of potential users. Thus, the financing is difficult to secure. Currently, the construction of reclaimed water reuse projects is mainly subsidized by the central government and local government (Yang and Abbaspour, 2007). Investment from private sectors is limited. It is also quite difficult to apply for bank loans. Effective financing is necessary for promoting the reclaimed water reuse in China.

5.5 Lacking in distribution network

Reclaimed wastewater is produced in a centralized location yet the potential users are scattered across the entire community. The conveying and distribution networks are by far the most difficult obstacles to overcome in promoting widespread use of reclaimed wastewater in urban settings. Water reuse is frequently an afterthought in urban planning and development. The necessary infrastructures are not planned and built. The existing infrastructures of the cities often become obstacles for the construction of reclaimed water pipeline systems (Xuan and Xu, 2009). 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.

With water shortages experienced in many cities, potential clients of reclaimed water are increasing rapidly. However, reclaimed water pipe lines are not in position and clients are unable to tap into the reclaimed water. The purveyors of reclaimed water are unable to operate profitably due largely to difficulties of recruiting adequate numbers of users. For example, early facilities such as Fang Zhuang Wastewater Reclamation Plant and Jiu Xian Qiao Water Reclamation Plant in Beijing and Ji Zhuang Zi Water Reclamation Plant of Tianjin had demands only for approximately 50% of their respective production capacities. Again, Xian Yang Lu, Dong Jiao, Bei Chen water reclamation plants in Tianjin though on line did not officially provide reclaimed water for reuses because of a lack of clients and networks.

5.6 Lacking in provisions to ensure reliability of treatment facility

Reclaimed water derives from the treated water effluents whose volumes vary diurnally and seasonally. Its usages that are also vary diurnally and seasonally however demand that the supplies and delivery be reliable and adequate (Cirelli et al., 2008). Unless there are flow equalization provisions and water conveying capacities, it would be technically impossible to match the supplies with the demands and vice versa. Because the water source quality of reclaimed water fluctuates, the stability and reliability of reclaimed water quality are difficult to be ensured. The uncertainties of supplies and quality often adversely influence the reclaimed water services causing potential users reluctant to make the commitment and existing clients to drop the services. Currently, management provisions to ensure treatment reliability are lacked in many providers of reclaimed water supplies. It is imperative the reliability of the treatment processes be improved and the clients be forewarned in case of emergencies (Wu et al., 2009).

5.7 Lacking in systemic risk management

With proper provisions, the reclaimed water could be safely used and there have been a great deal of success experiences around the world (Furumai, 2008). To minimize the public health and environmental pollution risks, a systemic risk management platform that covers all aspects of the reclaimed water production process such as wastewater collection and conveyance, treatment and production, distribution, and utilizations of reclaimed water is necessary. For example, piping, valves, and hydrants should be marked or color-coded to differentiate reclaimed water from potable water to prevent accidental misuses. Reclaimed water delivery and utilization facilities in China often are lack of distinctive identification signs warning innocent bystanders and the general public about potential hazards. Reclaimed water coming out from irrigation sprinkler heads may be tapped by un-suspect peoples in parks or other public places to be confused as safe for general consumptions. Cross-connections between reclaimed water and drinking water delivery systems should not exist, and all possible measures must be exercised to prevent its happening (Wu et al., 2009). So far, no regulation exists requiring backflow prevention devices be installed when reclaimed water is utilized in the proximities.

6 Case studies

6.1 Reclaimed water reuse in Beijing

Beijing is an 18 million plus people mega city located in the water deficient region of China. There is not a major river in the basin and the underground water has been severely over drafted. The water availability per capita in Beijing was less than 150 m^3 in 2007, which equaled 8% and 2% of the annual China and global mean per capita water supplies, respectively (Beijing Municipal Bureau of Statistics and Beijing Survey Organization of the National Bureau, 2005–2010). Recent years, Beijing has taken great efforts in reclaiming municipal wastewater and promoting water reuse to remit the chronicle shortage of water.

Early in the 1940s, Beijing began to use the wastewater for crop irrigations. In 1987, the government proclaimed the Management Measures for Recycled Water Facility Construction in Beijing (Trial), that formulated various standards for recycling runoffs from residential areas. Since 1990, numbers of municipal wastewater treatment plants were constructed and brought online, thus promoting large-scale uses of reclaimed water (Zhou et al., 2009). As the wastewater treatment capacity grew, more and more industrial and domestic water in the city were being treated and recycled (Table 2).

Table 2 Annual wastewater discharge and treatment in Beijing*

Year	Total wastewater volume ($\times 10^9$ tons)	Discharged (% of total volume)	Reclaimed and reused (10000 tons)
2009	1.37	80.3	64999
2008	1.32	78.9	60000
2007	1.30	76.2	49501
2006	1.05	73.8	36087.6
2005	1.01	62.4	25980.7

* Data based on Beijing Statistics Yearbook 2006–2010.

Beijing produced 2.54×10^6 m^3 per day as reported in 2007 and was serviced by 9 wastewater treatment plants (Cong and Zhao, 2009). Treatment capacity of the systems amounted to 3.56×10^6 m^3 per day and the length of wastewater collection network reached 9344 km in 2009 (Beijing Municipal Bureau of Statistic, 2009). Reclaimed water is an importance resource in Beijing (Liu, 2007). With the improvement of urban wastewater treatment technology, the utilization amount of recycled water will continue to increase. In 2010, 47% of the reclaimed water was used for agricultural irrigation, about 30% and 20% of it was used for environmental reuse and industrial reuse, respectively, and 3% of it was used for urban miscellaneous reuses (Ma et al., 2010). The Management Measures on Water Drainage and Reclaimed Water Reuse in Beijing went into effect January 1st, 2010. With the improved rules, the reclaimed water is expected to be more effectively used.

In summary, utilization of wastewater has improved significantly in Beijing in recent years and reclaimed water reuse has become an integral part of its water resource management. The success use of reclaimed water in Beijing may be attributed to its promoting polices and supports from the local government. But there are still many questions, such as, water recycling plant and pipe network construction is not synchronous, recycled water management system is incomplete, and water price mechanism is irrational.

6.2 Reclaimed water reuse in Tianjin

The water supply situations in Tianjin are similar to that in Beijing. Being the next largest cities in northern China, it is also severely deficient in water resources. The per capita water availability, less than 160 m^3, is far below the world recognized margin for water shortage, 1000 m^3 per capita (Cheng et al., 2007). With continuing population growth and economic development, the city turned to groundwater to satisfy the ever increasing demand for water. Perennial droughts over the past several years have made the already serious shortage of water supply even worse. The record volumes of water consumption brought about increasing wastewater discharges. In 2007, there were five water purification facilities in Tianjin, with a water production capacity of 2.03 × 10^6 m^3 per day and a water-supplying pipeline network of 3249 km (Zheng, 2007). It is predicted that volume of municipal wastewater will reach 1.99 × 10^6 tons per day in 2015 (Ji et al., 2007). The reclaimed water reuses not only would complement scarce water supply, but also reduce wastewater discharge and downstream water pollution.

Tianjin has the first large-scale modern urban wastewater treatment plant in China. The Jizhuangzi wastewater treatment plant began services in 1984 with a design capacity treating 26,000 m^3 per day of wastewater (Zheng, 2007). The capacities have subsequently been expanded. Currently, two separate treatment processes are involved. One traditional treatment process has design capacity to reclaim 30,000 m^3 per day of wastewater for industrial cooling and production. The second process with design capacity of 30,000 m^3 per day produces higher quality reclaimed water, whose effluent water will be transferred to many residential areas such as Meijiang, Meijiangnan, Weinanwa, and be used for toilet washing, greenbelt watering, landscape and so on.

In addition, a well-known water reuse project is the Technologic-Economic Development Area (TEDA). The TEDA wastewater treatment plant was put into service in December 1992 and its planned capacity was 100,000 m^3 per day. Nowadays, the TEDA reclaims about 30,000 m^3 per day of wastewater of which about 10,000 m^3 per day is treated for uses in industrial production and domestic uses and about 20,000 m^3 per day is treated by continuous micro-filtration (CMF) for uses in landscape and greenbelt irrigation in the city.

In comparison with Beijing, the water reuse in Tianjin is considerably lower (Table 3) and mainly for miscellaneous uses in urban areas such as street cleaning, and dust control. The reclaimed water has a great deal of potentials in Tianjin and the usages are expected to increase rapidly in the coming years.

Beijing and Tianjin are among the leaders of reclaimed water reuse in China. Their cases show that utilization of reclaimed water can be an important measure to alleviate water shortage and water pollution in urban region. Finding a proper way for reclaimed water reuse is essential to achieve the sustainable development of the city and water resources. To successfully reuse reclaimed water, it is imperative for the local government to make an integrated reclaimed water reuse plan and a comprehensive and efficient regulatory framework, to find ways for financing, and to raise public awareness and participation.

Table 3 Utilization of reclaimed water in Beijing and Tianjin in 2007*

Category	Beijing	Tianjin
Amount reused (10000 m^3)	26900	328.69
Portion of reclaimed (%)	33.6	1.0
Industrial reuse (% of total reused)	45	20
Miscellaneous urban reuse (% of total reused)	7	65
Ecological reuse (% of total reused)	48	15

*Data are cited from Chen and Wu (2010).

7 Conclusion remarks

China has a long history of using municipal wastewater for irrigation. In the early, most uses, however, were limited to the untreated sewages because of a lack of infrastructures to collect and treat the wastewater. The nation is experiencing rapid urban developments. With the wide spread construction of wastewater treatment systems, large volumes of reclaimed water has come online. The water reuses, despite of wide spread water shortages, has been stagnant. Progresses are dependent on leaderships and improved management strategies at the national level: (1) Integrated reclaimed water reuse plan: Water reuses should be an integral part of the national water resources development plan. At present, water reuse has been mostly an afterthought. As a result, the infrastructure needs, use potentials, and development costs are not accounted and planned in the initial water development plan. Dependent on the needs, the wastewater may be treated accordingly. An integrated plan is imperative to use the reclaimed water economically and efficiently. (2) A comprehensive and efficient regulatory framework: The existing standards for reclaimed water need to be updated to protect the public health and environment and encourage the water reuses. The guidelines and standards should be simple, flexible, and easy to operate, making sure the water can achieve the desired performance objectives. A comprehensive regulatory framework is needed, including clear mandates and responsibilities in implementing and managing reclaimed water reuses, market-oriented incentives to increase interests in wastewater reuses and to encourage efficient use of reclaimed water, protocols on the production, and rules about distribution and uses of reclaimed water. (3) Systematic pollutant source control framework to insure product water quality: It is imperative that the wastewater treatment systems are properly operated to assure reliability of their performances. Some of the pollutants like metals, pharmaceutically-active chemicals, phenols, pesticides, and chlorinated hydrocarbons, however, are not effectively removed in conventional wastewater treatment processes. Preventive measures should be adopted to minimize the difficult-to-treat pollutants from entering the municipal sewer system through various point and non-point sources. Meanwhile, it is imperative for the wastewater treatment plan to implement necessary provisions to assure the reliability of the wastewater treatment process. (4) Raising public awareness and participation: So far, the general public is not aware that the extent reclaimed water is being used in the urban area and are not knowledgeable on pros and cons of reuse programs. Public awareness and cooperation could play vital rules in expanding the urban water reuse programs. If the reclaimed water is to be used in landscape irrigation, the general public should be well informed of the safety and potential public health issues. If dual water distribution and supply systems are to be introduced for domestic uses in the residential communities, the residents' participation and cooperation are essential to insure success. Raising the public's awareness of the water shortages and the rule of reclaimed water in future water supply picture is crucial in water reuses. (5) Expanding financing: The infrastructures for implementing the water reuse are costly to build and maintain. Unless the infrastructures are in place, there would not be reclaimed water so to speak. Even if the wastewater has been reclaimed, it would not be a resource and a marketable commodity unless there are infrastructures to deliver the product. The initial capital outlays are enormous. How does one finance the urban water reuse projects? It has been a dilemma. When the government is unable to bear the entire financial burden, new and creative consideration is needed to engage the private sector. New governmental policies are needed to make water reuses an attractive business adventure for financial services and investors.

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