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Centralized water reuse system with multiple applications in urban areas: Lessons from China's experience

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ABSTRACT

In the context of rapid urbanization and water shortage, many cities of the world, especially megacities in rapidly developing zones, have urgent needs in improving their sustainable water management without compromising the local socioeconomic development. Water reuse has been increasingly recognized as a sustainable water management strategy. The results of this paper have shown that the development of water reuse in China is found to have positive correlations to local water resource availability and GDP levels, and the water reuse rate in some megacities has already reached 35–60%. Centralized water reuse systems have widely gained favor. Thus, a centralized water reuse framework with three utilization patterns is proposed. Particularly, a multiple-utilization model that applies a hierarchical use structure is found to be viable for meeting multiple water quality requirements. Other patterns address environmental and cascading ways in maximizing the value of reclaimed water use. A case study in a Chinese megacity, Tianjin, is demonstrated where a large-scale centralized water reuse project with a multiple barrier treatment approach and a hierarchical distribution and use structure has contributed to water reuse development in a safe, reliable and economical manner. This paper can be beneficial to water authorities and practitioners for long-term urban water management in other rapidly developing cities and regions that have encountered similar water-related problems.

1. Introduction

Population growth, climate change, industrialization, social and economic growth, along with elevated living standards, have generated ever-increasing demands for water resources around the globe (Jiménez-Cisneros, 2014; UNWWAP, 2015). In 2014, 3.9 billion people, or 54% of the global population, lived in cities. With a continuing social and economic development trend, two-thirds of the global population will be urban dwellers by 2050 when global water demand is projected to increase by 55% (WRG, 2009; UNWWAP, 2015). Notably, the number of megacities has nearly tripled since 1990 and about one in eight urban dwellers live in megacities. By 2030, 41 urban agglomerations are projected to exist, serving at least 10 million inhabitants each (UNDESA, 2015). Hence, water-related challenges including water scarcity and water quality deterioration issues will be increasingly concentrated in urban areas, particularly in the lower-middle income countries (e.g. Asia and Africa) where the pace of urbanization is fastest and the local governments have limited capacity to deal with the rising water supply and sanitation challenges (Cobbinah and Erdiaw-Kwasie, 2015; UNDESA, 2015; Li et al., 2016). As a major emerging economy and a developing country with the largest population base of the world, China also faces a myriad of urban water challenges (UNESCO, 2015; Hsu et al., 2014). Most of urban cities in the country are densely populated and 7 out of 34 megacities[1] in the world are located in mainland China (NBSC, 2016). Highly agglomerated urban population requires reliable, efficient and cost-effective urban water management systems (WWF, 2008; UNESCO, 2015). Water reuse has been increasingly considered as a promising alternative water resource for sustainable water supply and management practices (Garcia and Pargament, 2015). It has proven

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[1] Urban areas with a population of more than 10 million

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useful in increasing the reliability of long-term water supplies in many water-scarce areas of China (Hu et al., 2015). Thus, the construction and upgradation of wastewater treatment and reuse facilities have come into a high-speed development period across the country (Chang and Ma, 2012; Zheng et al., 2015).

In China, there is a population trend of gathering in megacities, very large cities and big cities.[2] In 2014, China's total population reached to 1.4 billion and 56% of the people are urban dwellers (NBSC, 2016). According to the National New Urbanization Plan (2014–2020), China's urbanization level in 2020 will reach to 60%, and a population of about 100 million rural residents will be new urban residents (Gu et al., 2015). The continuing urbanization and industrialization requires significant product, material and natural resources input and can lead to considerable waste streams and emissions. Meanwhile, China's Gross Domestic Product (GDP) has increased steadily, with an average growth rate of 6.9% and a figure of 68,000 billion Yuan[3] ($10,200 billion US dollars) in 2015 (Lyu et al., 2015; NBSC, 2016). Migration from rural to urban areas has resulted in high incomes and thus a substantial increase in household consumption and more resource intensive living standards (Feng et al., 2014). Hence, there has been increasing awareness on China's environmental capacity, water and food security, and resource shift and management in urban areas (Gu et al.,2013; Chen et al., 2015; Sun et al., 2016). Noticeably, water-related issues are considered as one of the most serious threats to the sustainable development of society (UNESCO, 2015). Approximately two thirds of China's 661 cities encountered water shortage problems and among which, over 100 cities faced acute shortages and megacities, though pioneers of urban development, have various water stress and eco-environmental problems (Lieberthal, 2011). In the long-term, water supply and demand pressure is a serious concern for China's urban population (Brubaker, 2015).

The fast-growing urban societies increased the quantity of water consumption and wastewater discharge while accelerating the development of wastewater treatment and reuse in both cities and counties of China (Hu et al., 2016). Consequently, the amount of total wastewater discharge had experienced steady growth over the years with an annual increase rate of 4%, which reached 7.2×10^{10} m^3 in 2014. The increase was largely accounted for by domestic effluent discharge (MOEP, 2014). At the same time, with a great deal of investment by the government, wastewater treatment facilities were extended dramatically in both cities and counties of China, where the overall treatment rate achieved a high level of over 82% by the end of 2014 (Table 1).

Nevertheless, at a national level, China's wastewater treatment development is uneven. Cities have experienced much greater development rates than counties, not to mention small-scale townships and villages (Liu and Persson, 2013; MOEP, 2014). At a global level, an indicator of wastewater treatment was introduced by the 2014 Environmental Performance Index (EPI) for comparison which measures the amount of collected wastewater that a country treats before releasing it back into the environment. As a result, China ranked 67th for its wastewater treatment, which lies behind other emerging economics, such as Mexico (49th), South Africa (56th) and Russia (62nd). Besides, the 2014 EPI indicates a low wastewater network connection rate of 47% in China, causing low utilization rates in some newly built wastewater treatment plants (WWTPs) (Hsu et al., 2014). Consequently, approaches to sustainable water management with an emphasis on advanced wastewater treatment, water reuse and resource recovery have received increasing attention.

As for wastewater management, there is always a wide discussion about optimized system models and their implications for innovative management (Padowski and Jawitz, 2013; McDonald et al., 2014). The provision of centralized water and wastewater services for urban areas has been common practice for over 100 years (Sapkota et al., 2015). The centralized wastewater systems involve the collection and transport of wastewater using an extensive network of pumps and piping, to a central location for subsequent treatment, discharge and/or reuse (Asano et al., 2007). However, some studies argue that centralized systems are expensive solutions that are normally associated with long-distance transport, large-scale distribution network, design complexity, high investment cost, high operational and maintenance requirements, lack of flexibility, and potential for catastrophic failure (Afferden et al., 2015; Chanan et al., 2009; Wang et al., 2008). Therefore, decentralized water treatment and reuse systems have been receiving much attention (Piratla and Goverdhanam, 2015; Sitzenfrei et al., 2013). The decentralized models address the collection, treatment, disposal and/or reclamation of wastewater at or near its point of generation (MOH, 2010). The decentralized systems have advantages in terms of flexibility, application in small, suburban and/or rural communities, viability in challenging topographical conditions, economies of scale, etc. Since decentralized systems can be managed as stand-alone facilities, clusters or semi-centralized or be integrated with centralized treatment systems, they complement rather than compete with centralized approaches (Wilderer and Schreff, 2000; Afferden et al., 2015).

In China, centralized wastewater treatment and reuse systems have been the preferred models serving most cities and counties (Chu et al., 2004; MOHURC, 2015). The centralized systems have distinct advantages for densely settled population in terms of safety, reliability, stability, and economic feasibility (ISO, 2016). Particularly, for water reuse applications with high exposure risks (potential or direct contact with reclaimed water), safety and reliability of reclaimed water quality are paramount for public health protection (Hu et al., 2011). Therefore, centralized models are now regarded as an effective component of urban water resources management in China (Cheng et al., 2009; MOHURC, 2015). The aim of this study is to provide an overview of water reuse and its development potentials in China, with an emphasis on centralized water reuse systems in urban areas. To facilitate the optimal design and management of centralized water reuse systems, a systematic framework with different reclaimed water usage patterns was proposed. A case study in Tianjin city was conducted afterwards to demonstrate the effectiveness of centralized water reuse systems for multiple applications with a hierarchical structure (each level of hierarchy is associated with specified water quality requirements of the application). The paper concludes with a highlight of the water reuse significance and a summary of sustainable water reuse via centralized management approaches.

2. Analysis of current status and development potentials of water reuse in China

Water reuse is among the fastest growing utility sectors in China and reclaimed water is being widely applied to satisfy a significant proportion of water demands (Chang et al., 2013). In 2013, there were 571 water reclamation plants (WRP) nationwide equipped to further treat secondary effluents for planned reuse

[2] According to the State Council of China (2014 No. 51), the administrative divisions in China are generally classified into cities, counties, townships, towns and villages. Cities are further grouped by size, including megacities (10 million), very large cities (5–10 million), big cities I (3–5 million), big cities II (1–3 million), medium-sized cities (0.5–1 million), and small cities and towns (0.5 million or less) (Gu et al., 2015). Individuals, who live in cities, counties or areas with over 50% of residents are non-agricultural population, are generally considered as urban residents. By the end of 2014, China has 653 designated cities (including 361 county-level cities), 1596 counties, and 20401 townships (MOHURC, 2015).

[3] 1 Yuan (RMB) roughly equals to 0.15 US dollar or 0.13 Euro.