

## Current status of reclaimed water in China: an overview

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### ABSTRACT

This paper presents the objectives of reclaimed water use in China and the current quantities used at the national and provincial levels. Using 2015 statistical data as an example, this paper studies the influences of water resources quantity, gross domestic product and policy promotion hierarchy on reclaimed water use in all provincial administrative regions in China. Reclaimed water use in Beijing and Jiangsu are presented as two representative examples. China's reclaimed water experience can provide some guidance for other countries facing similar water resource situations.

**Key words** | China, current status, overlook, reclaimed water

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### INTRODUCTION

China, as the second largest economic entity in the world, is a well-known country that faces serious water scarcity and water pollution (Ma *et al.* 2014). Its per capita water resource quantity was 2039.2 m<sup>3</sup> in 2015, approximately a quarter of the world's average level, and therefore it has been recognized as one of the 13 lowest water-availability countries throughout the world (Bai *et al.* 2007). Furthermore, the distribution of precipitation in China is uneven, with the northern and western regions having less precipitation and the eastern and southern regions having abundant rainfall (Bulletin of Water Resources in China 2016). As a result, floods and droughts frequently occur in China (Bulletin of Water Resources in China 2016). To tackle the serious disparity between water resource supply and demand, China has taken many measures to efficiently utilize surface and ground water (Yi *et al.* 2011; Lyu *et al.* 2016). These include implementing a very stringent water management system that specifies water efficiency targets (Wang *et al.* 2015), adjusting the inner structures of primary, second and tertiary industries for water-saving objectives (Chao *et al.* 2006), and implementing the trans-basin South-to-North Water Diversion Project across the country (Zhao *et al.* 2017).

In addition to regular water resources, China strives to develop alternative water resources to combat water conflict, including reclaimed water, seawater desalination and household-level rainwater harvesting (Yi *et al.* 2011; Lyu *et al.* 2016). The desalination of seawater, although its water source is stable and plentiful, requires advanced technology, incurs high cost (including capital, operation and maintenance costs) and large energy consumption and can only be utilized in coastal regions of China (Zheng *et al.* 2014). Household-level rainwater collection can provide only limited additional water resources because of the climate characteristics in China (Gu *et al.* 2015). With the advancement of water treatment technology, more and more attention has been paid to reclaimed water in providing alternative water resources to meet the increasing water demand in China (Chang & Ma 2012).

Although there have been some studies to introduce the development of China's reclaimed water (Zhang *et al.* 2007; Yi *et al.* 2011; Chang & Ma 2012; Lyu *et al.* 2016), it is still unclear what the current status of reclaimed water in China is. There seem to be some ambiguities in the statistical scope of reclaimed water in different studies or reports published by different departments or institutions (Yi *et al.* 2011). With the help of the Water Resources Management Center, Ministry of Water Resources, China, we collected some information on reclaimed water use in all of the provincial administrative

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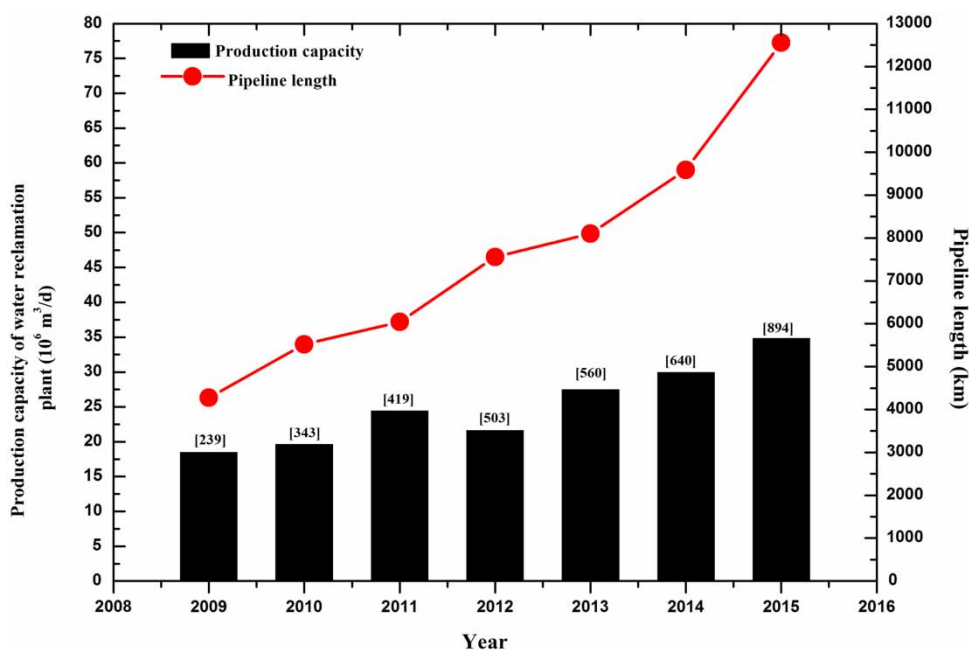
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regions (PARs) throughout China during 2009–2015, including utilization amount and objective of reclaimed water (as well as wastewater treatment amount), amount and treatment capacity of water reclamation plants and pipeline length. The statistical method was to first count reclaimed water data at a country level, then gather them in a city level, and finally add up all of the data in a PAR level by virtue of political administration. In this statistic, reclaimed water is specified to refer to: (i) the water through wastewater treatment plants whose water quality satisfies ‘Water Quality Standard for Reclaimed Water’ (SL368-2006) at the source of the domestic wastewater ([Standards for reclaimed water quality 2006](#)); (ii) the water through secondary treatment in wastewater treatment plants and further treatment of water reclamation plants (different treatment technologies depending on different use objectives), whose water quality satisfies ‘Water Quality Standard for Reclaimed Water’ (SL368-2006) ([Standards for reclaimed water quality 2006](#)); and (iii) the water which is diverted into water-using enterprises from wastewater treatment plants through special water supply pipelines, and further treated by those water-using enterprises. Part of this paper is a simple presentation of these statistical data as is shown in the ‘Utilization quantity and objective of reclaimed water’ section. Some laws, policies and technological standards

governing reclaimed water use are listed in the ‘Laws, policies and technological standards governing reclaimed water use’ section of this study. Taking recent statistical data in 2015 as a typical example, the ‘Factors influencing reclaimed water use’ section investigates the possible influences of water resources amount, gross domestic product (GDP) and policy support hierarchy on reclaimed water use for all PARs throughout China. The ‘Existing problems and suggestions regarding reclaimed water’ section summarizes existing problems and provides some suggestions regarding current development of reclaimed water use. Two representative examples, reclaimed water use in Beijing and Jiangsu, are presented in the ‘Case studies’ section as case studies. Finally, some simple concluding remarks are put forward in the ‘Concluding remarks’ section.

## UTILIZATION QUANTITY AND OBJECTIVE OF RECLAIMED WATER

As is shown in [Figure 1](#), the number and production capacity of water reclamation plants and the pipeline length of reclaimed water are increasing rapidly in China. With these developments, reclaimed water is playing an



**Figure 1** | Number and production capacity of water reclamation plants (the value in the bracket at the top of the column bar denotes the number) and pipeline length of reclaimed water during 2009–2015 in China.

increasing role in water resources supply, as is shown in Figure 2. Reclaimed water experienced a rapid increase during 2009–2013 and then a slowly increasing trend during 2013–2015, but it accounted for less than 1% of the total water use in China. The current distribution of the utilization quantity of reclaimed water in all of the PARs throughout China was uneven in 2015, as is shown in Figure 3; of the total reclaimed water quantity, Guangdong, Beijing and Jiangsu have used the most.

As Figure 4 clearly indicates, China has used the majority of its reclaimed water to satisfy landscape environmental and industrial requirements that have little contact with the human body and low environmental risks. Many cities in China have utilized reclaimed water to create man-made lakes, streams and rivers and to sustain environmental water for wetlands, etc. (Qian 2006; Bai *et al.* 2007; Ji *et al.* 2007; Xiang *et al.* 2015). Industrial water use refers to reclaimed water used as cooling water and washing water, as well as boiler feeding water, technological and product water (Zuo *et al.* 2009). China is cautious regarding using reclaimed water for agricultural, forestal and pasturable objectives because of environmental risk concerns (Wang *et al.* 2009; Zeng *et al.* 2015). With regard to the use of reclaimed water for urban non-potable purposes that are closely associated with human health, people become much more cautious (Zhang *et al.* 2012; Gu *et al.* 2015). There is a

small amount of reclaimed water used for groundwater replenishment in China (Wei *et al.* 2006; Li *et al.* 2017).

The ratio of different utilization objectives of reclaimed water in all PARs across China in 2015 can also be found in Figure 3. (1) Industrial reuse: Shanghai, Guangxi and Xinjiang provinces put all of their reclaimed water into industrial needs. Most reclaimed water has been used for industrial purposes in Ningxia, Tianjin, Liaoning, Zhejiang and Gansu provinces (the ratio of the industrial reclaimed water reuse volume to the total volume exceeded 60%). Beijing city and the provinces of Sichuan and Guangdong and Chongqing city distributed less reclaimed water to industry (the ratio was smaller than 10%). (2) Landscape reuse: Hunan and Guangdong provinces attempted to use all of their reclaimed water for landscape development. Plenty of reclaimed water was adopted for landscape purposes in Sichuan, Beijing, Jiangsu, Anhui and Shaanxi provinces (the ratio surpassed 65%). Landscape reclaimed water use smaller than 20% was found in the provinces of Shanxi, Ningxia and Gansu and Tianjin city. (3) Non-potable water reuse: except for Hainan province, where all of the wastewater was reclaimed for non-potable water reuse, the volume proportion of non-potable reclaimed water reuse was less than 37% over all PARs of China. Especially, less than 3% of the reclaimed water was applied into the non-potable water projects in the provinces of Liaoning, Hebei, Sichuan, Shanxi, Inner

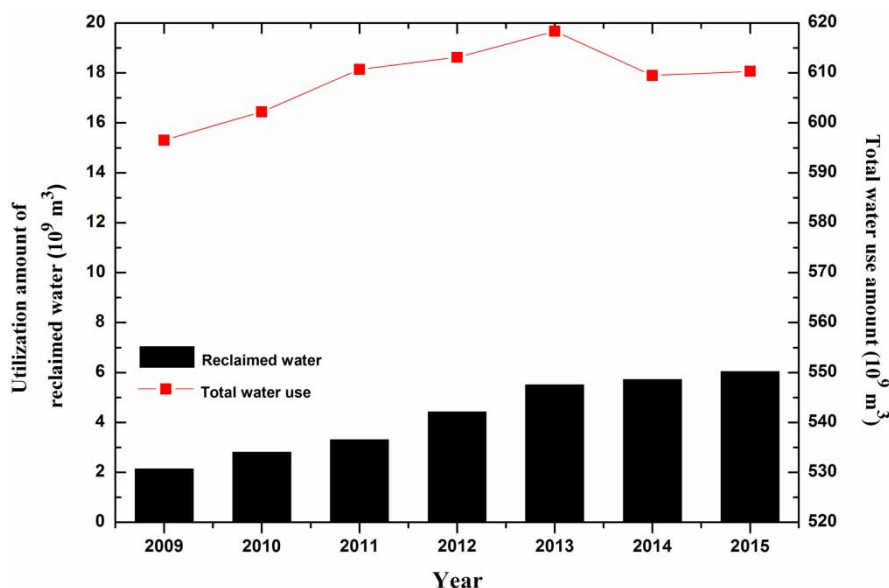
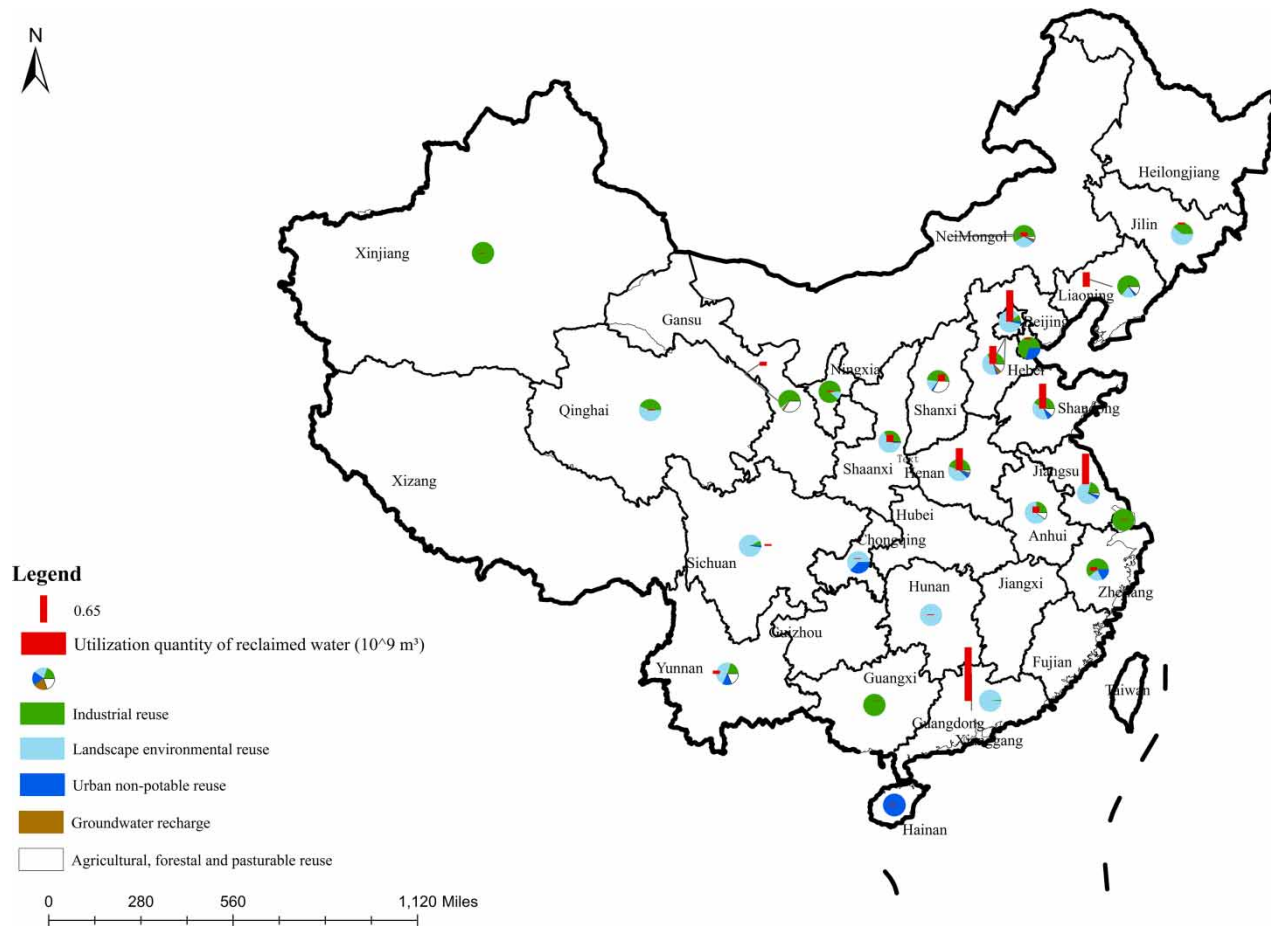


Figure 2 | Utilization quantity of reclaimed water and total water use quantity during 2009–2015 in China.

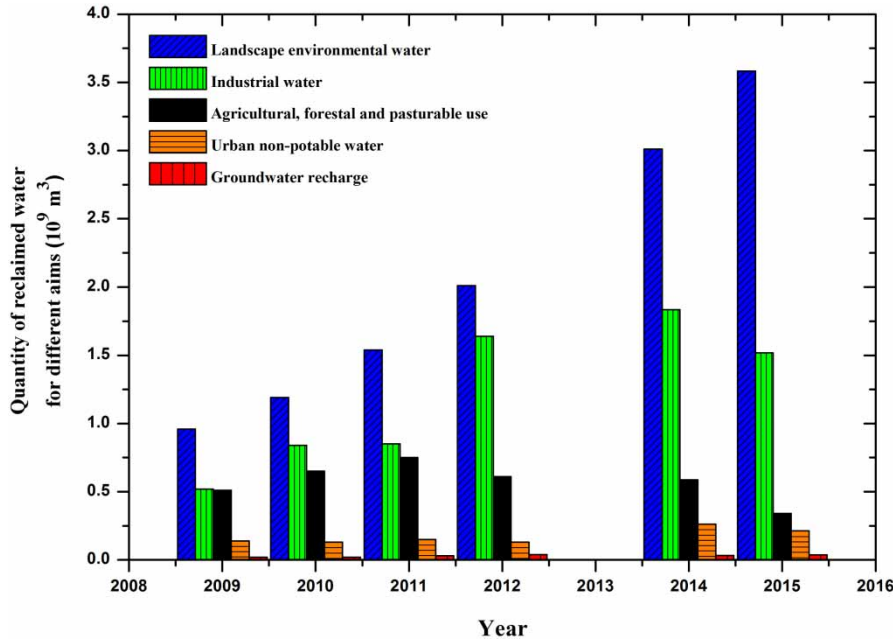


**Figure 3** | Utilization quantity and different utilization objectives of reclaimed water in some PARs across China in 2015.

Mongolia, Shaanxi and Anhui. (4) Groundwater recharge: in China, the reclaimed water was used for groundwater recharge only in the five provinces of Hebei, Gansu, Inner Mongolia, Henan and Shandong, which might be a result of the difficult match between the water quality of reclaimed water and the requirements needed for groundwater recharge. Some administrative authorities could be afraid of environmental risks related to infiltration of reclaimed water into groundwater (Wei *et al.* 2006; Li *et al.* 2017). (5) Agricultural, forestal and pasturable reuse: 12 of the 31 PARs carried out reclaimed water utilization for agriculture, forestry and pasture. The volume proportion was highest in Gansu and Shanxi provinces, reaching approximately 33%. There were five PARs that used less than 5% of the reclaimed water for agricultural, forestal and pasturable objectives: Inner Mongolia, Henan, Jiangsu, Shaanxi, and Beijing. The low ratio of agricultural, forestal and pasturable reclaimed

water reuse could be attributed to complicated environmental impacts of reclaimed water on plant growth, soil quality and groundwater quality and other factors (Li *et al.* 2015; Zeng *et al.* 2015; Lyu *et al.* 2016).

In 2015, the State Council of China issued 'Water Pollution Control Action Plan', and an objective regarding reclaimed water has been set in this file (Water Pollution Control Action Plan 2015): by 2020, the utilization ratio of reclaimed water (which is equal to the ratio of the utilized quantity of reclaimed water to the total treated wastewater amount) will have reached above 20% in water-deficient cities, and especially above 30% in the Beijing-Tianjin-Hebei region. We attempt to use '20%' and '30%' indexes to evaluate the current status of the utilization ratio of reclaimed water in all the PARs in 2015, and this result can be found in Figure 5. In 2015, the utilization ratio of reclaimed water exceeded 30% only in Beijing, the capital of China. Shandong, Henan



**Figure 4** | Utilization quantity of reclaimed water for different objectives during 2009–2012 and 2014–2015 in China.

and Liaoning provinces completed the ‘20% index’, and except for them, for other PARs across China, there is a gap to strive to fill to achieve the objective by 2020.

## LAWS, POLICIES AND TECHNOLOGICAL STANDARDS GOVERNING RECLAIMED WATER USE

There have been laws and policies promulgated by the State Council of China and some relevant departments to promote the development of reclaimed water issues in China. In this study, we collected these files in chronological order as follows.

The ninth Standing Committee of the National People’s Congress of China issued ‘Water Law in China’ in 2002 and modified it in 2016. The modified law required municipal governments to strengthen an integrated treatment of urban wastewater, and encouraged them to use reclaimed water and improve the utilization ratio of reclaimed water.

In 2006, the Ministry of Construction and the Ministry of Science and Technology jointly printed and distributed the notification ‘Utilization technology and policy of urban wastewater reuse’. This file set the overall and specific objective of urban wastewater reuse and specific measures. These include requiring urban integrated planning to incorporate

development objectives and the layout of urban wastewater reuse, requiring urban water supply and drainage planning to incorporate reasonable utilization planning of urban wastewater reuse based on water source, geographic location distribution of potential water consumers, requirements for water amount and water quality, and delivery and allocation means for reclaimed water. Important attention to planning and construction of reclaimed water infrastructure is also addressed in this file, including scale, utilization means and layout of the reclaimed water infrastructure. Additionally, the file also puts forth a requirement for reasonable methods for utilization of reclaimed water.

The tenth Standing Committee of the National People’s Congress of China issued ‘Law of PRC on Prevention and Control of Water Pollution’ in 2008. This law stressed that urban wastewater should be treated concentratedly. Local government should raise capital through a financial budget and in other ways to plan and implement urban wastewater treatment facilities and complementary pipe networks, with the aim of improving collection efficiency and treatment efficiency of urban wastewater. Supervision management of the maintenance of urban wastewater treatment facilities is also stressed. The operational unit in charge of an urban wastewater treatment facility has the right to collect treatment

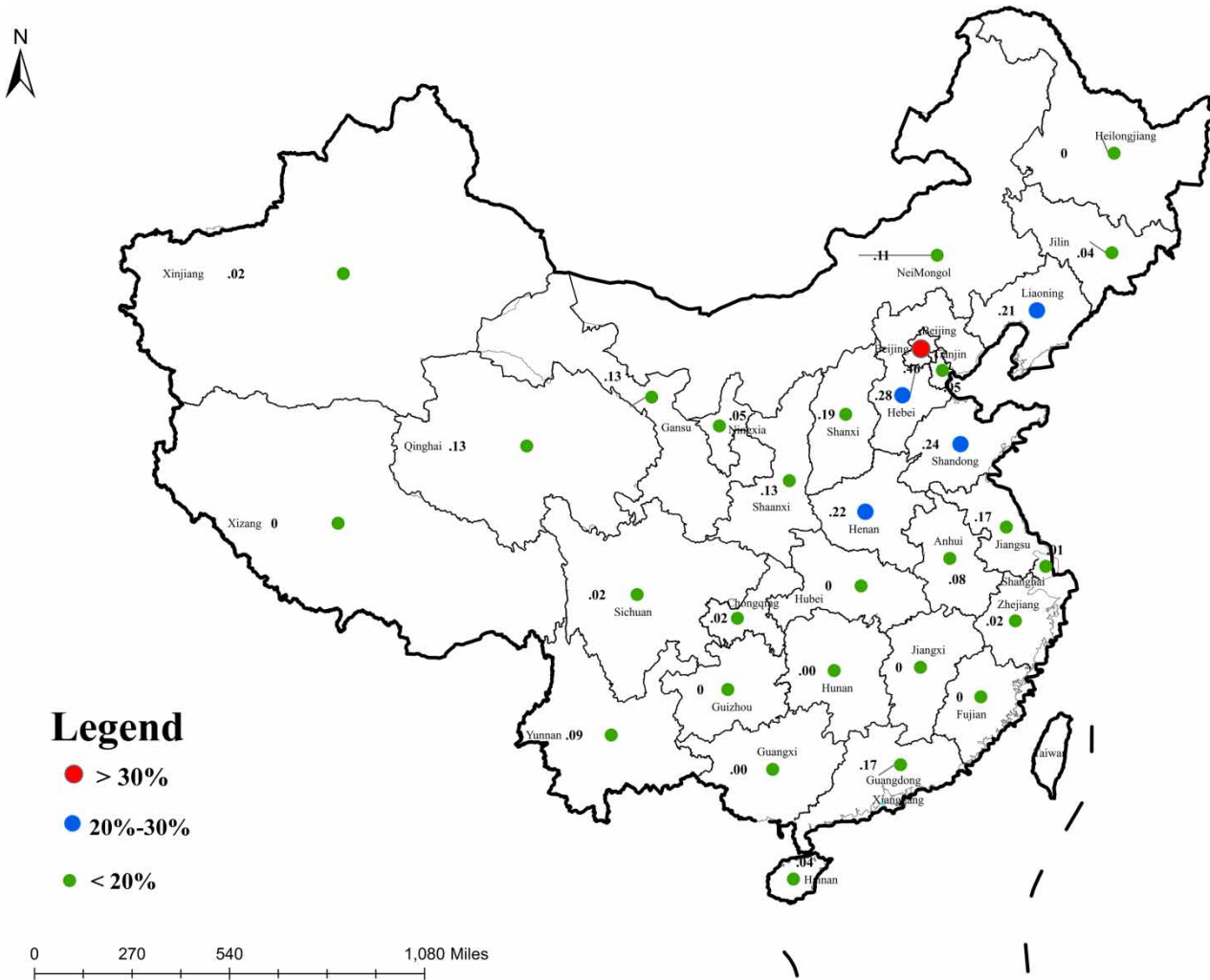


Figure 5 | Utilization ratio of reclaimed water for all PARs throughout China in 2015 (the value near the name of the PAR is the utilization ratio of reclaimed water).

fees from pollution emitters, and these fees should be used for the construction and maintenance of urban wastewater treatment facilities.

In 2009, the Ministry of Water Resources of China issued a notification ‘Strengthening urban wastewater reuse to promote water resources conservation and protection’. This file noted the significant importance and urgency of urban wastewater reuse. It is suggested that urban wastewater reuse be incorporated into the integrated allocation of regional water resources. This file required an increased utilization ratio of reclaimed water in application areas of groundwater recharge, industrial need, urban non-potable use, landscape environmental use, and agricultural, forestal and pasturable use. Urban and rural production and supply of reclaimed water

should be planned as a whole by comprehensively considering the drainage system, the reclaimed water facility, distribution of the pipeline network and distribution of reclaimed water to consumers to complete the recycling utilization of regional water resources. Multi-level water administrative departments should organize and compile urban wastewater reuse plans subject to a comprehensive water resources plan and overall city plan, which should be cohesive with the land plan, environmental protection plan, city water supply plan and city drainage and wastewater treatment plan.

Regarding the pricing relationship between reclaimed water and regular city water resources, the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development of China jointly put forward

a notification 'On completing management of city water supply price' in 2009. This document required relevant departments to study and draft the benefiting policy of production and utilization of reclaimed water and make efforts to decrease the utilization cost of reclaimed water. The price of reclaimed water should be determined to keep a price gap with tap water to encourage the utilization of reclaimed water.

It is noteworthy that the Ministry of Housing and Urban-Rural Development of China issued a file 'Guideline on technology of treatment and reuse of urban wastewater' in 2012. This guideline noted principal frames of urban wastewater reuse from the perspectives of planning, facility construction, operation, maintenance and management. This file reflected recent application experience and research results on urban wastewater reuse in China well.

In 2012, the State Council of China promulgated an official file 'Opinions on the implementation of the most stringent water resources management system'. The twelfth point of this file stated 'encourage and positively develop alternative water resources, including wastewater treatment and reuse, rainwater harvesting, brackish water development and seawater desalination; speed up the construction of pipelines of urban wastewater treatment and reuse and progressively improve the reuse ratio of urban wastewater; incorporate alternative water resources into an integrated water resources allocation system'.

The State Council of China issued a decree 'Urban drainage and wastewater treatment regulations' in 2013. This decree encouraged and supported local government in carrying out

scientific research regarding urban drainage and wastewater treatment technology, and spread and applied advanced technology, equipment and material to promoting wastewater reuse and improving the treatment capacity of urban drainage and wastewater. Reclaimed water should be given a priority to be used in areas of industrial production, afforestation of cities, road cleaning, car flushing, building operations and ecological landscaping. Local government should define a reasonable scale of reclaimed water use and draft some measures of safeguard for promoting the utilization of reclaimed water.

As is already mentioned, the State Council of China issued 'Water Pollution Control Action Plan', in 2015 and this document set an objective regarding reclaimed water use for all PARs across China by 2020.

Since 2002, 13 standards, specifications and guidelines regarding reclaimed water have been published to provide references for engineering design, construction and operation for reclaimed water. We have listed them in [Table 1](#).

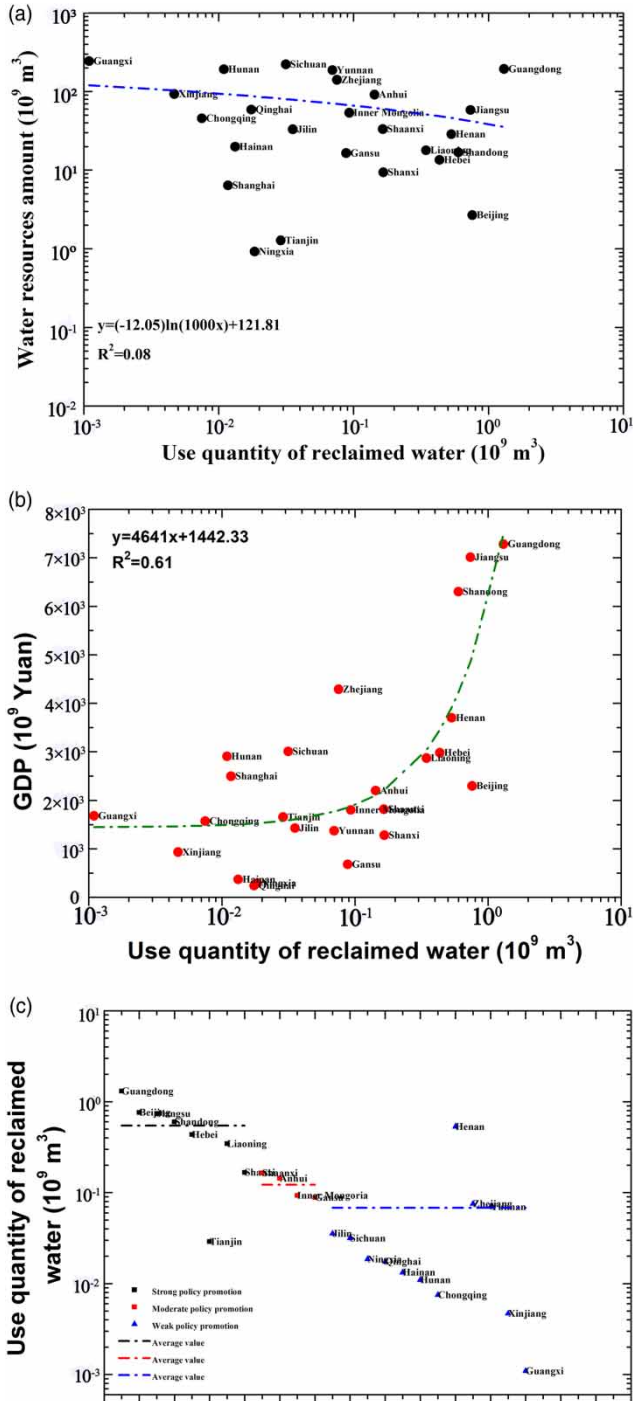
## FACTORS INFLUENCING RECLAIMED WATER USE

We attempt to investigate the possible influences of water resources amount, GDP, and policy support on the quantity of use of reclaimed water for all PARs throughout China in 2015, respectively, as is shown in [Figure 6\(a\)–6\(c\)](#).

There is an obvious data scatter in [Figure 6\(a\)](#), indicating that there seems to be no correlation between the amount of water resources of every PAR and the amount of reclaimed

**Table 1** | Standards, specifications and guidelines regarding reclaimed water in China

Category	Number	Nomenclature	
Standard	1	GB/T18918-2002	Discharge Standard of Pollutants of Urban Wastewater Treatment Plant
	2	GB/T18919-2002	Urban Wastewater Reuse Category
	3	GB/T18920-2002	Urban Wastewater Reuse Water Quality Standard for Urban Miscellaneous Water
	4	GB/T18921-2002	Urban Wastewater Reuse Water Quality Standard for Scenic Environment Water
	5	GB/T19923-2005	Urban Wastewater Reuse Water Quality Standard for Industrial Water
	6	GB/T19772-2005	Urban Wastewater Reuse Water Quality Standard for Groundwater Recharge
	7	SL368-2006	Wastewater Reuse Water Quality
	8	GB20922-2007	Urban Wastewater Reuse Water Quality Standard for Farmland Irrigation Water
	9	GB/T31962-2015	Water Quality Standard for Wastewater Discharge to Urban Sewer
Specification	1	GB50336-2002	Design Specification of Construction Wastewater
	2	GB/T22103-2008	Urban Wastewater Reuse Safety Specification for Farmland Irrigation Water
	3	GB50335-2016	Design Specification of Wastewater Reuse Engineering
Guideline	1	CJ[2012]No.197	Guideline for Urban Wastewater Reuse Technology



**Figure 6** | Relationships between water resource amount and reclaimed water use (a) between GDP and reclaimed water use (b) between reclaimed water use and policy support hierarchy and (c) for all PARs throughout China in 2015.

water used (a declining trend fitting relation is attempted to be drawn in the figure but the correlation coefficient  $R^2$  is only 0.08). This point seems counterintuitive at first, because

reclaimed water seemingly should develop quickly in water-deficient regions. However, this is not true because there may be some other options for those water-deficient regions to address their water resources shortage besides reclaimed water, for example, implementing water-saving projects (Sun & Kang 2000; Xu *et al.* 2007), reasonable use of water diversion and utilization of other alternative water resources (such as rainwater harvesting and desalinated seawater) (Chen *et al.* 2013; Zheng *et al.* 2014; Wang *et al.* 2015).

Figure 6(b) shows the relationship between the GDP of PARs and the amount of reclaimed water use across China. There is a better fitting relation between the GDP and reclaimed water use, with the correlation coefficient  $R^2$  reaching 0.61. This indicates that economically developed regions can invest more capital than economically underdeveloped regions to construct the infrastructure and management platform for reclaimed water and fill the funding gap of reclaimed water development, which facilitates the development of reclaimed water.

There are some laws, policies and regulations governing reclaimed water use, and they have played a significant role in the production and utilization of reclaimed water throughout China (Lyu *et al.* 2016). We collected all policies and regulations unveiled in all of the PARs, and simply further classified the PARs into three hierarchies considering the contents and numbers of these policies. The first hierarchy refers to ‘Strong policy promotion’ that supports and promotes the development of reclaimed water, including Beijing, Tianjin, Jiangsu, Shandong, Guangdong, Hebei, Shanxi, Liaoning. The second hierarchy refers to those regions with moderate policy supports (we simply term it ‘Moderate policy promotion’ here), mainly including Anhui, Shaanxi, Inner Mongolia and Gansu. The last hierarchy corresponds to those regions that have unveiled less important or fewer policies to promote the development of reclaimed water (we simply term it ‘Weak policy promotion’), including the following regions: Jilin, Zhejiang, Henan, Guangxi, Hainan, Chongqing, Sichuan, Yunnan, Qinghai, Ningxia, and Xinjiang. Figure 6(c) demonstrates quantities of reclaimed water use for all PARs based on the three different hierarchies. It can be observed that the regions with strong policy support for reclaimed water have utilized a larger amount of reclaimed water than those regions with moderate policy support, whereas only a small quantity of reclaimed water has been



utilized in the regions with weak policy support. This indicates that the introduction and implementation of policies and regulations play an important role in augmenting the utilization of reclaimed water in China. The outliers of these data are Tianjin, Henan, Zhejiang and Yunan. For the case of Tianjin, which eastwardly faces the Bohai, China, although the government has published a series of policies and regulations governing reclaimed water, the amount of reclaimed water is still limited because seawater desalination is playing a crucial role in supplying alternative water resources to meet all needs in Tianjin (Zheng *et al.* 2014). The reasons for the cases of Henan, Zhejiang and Yunan are not clear in this study and worthy of deep investigation in a future study.

## EXISTING PROBLEMS AND SUGGESTIONS REGARDING RECLAIMED WATER

### Existing problems

Currently, the definition and statistical scope of reclaimed water are not consistent in China's different departments. The term 'reclaimed water' has been used in documents issued by the Ministry of Housing and Urban-Rural Development of China, whereas the Ministry of Water Resources of China prefers to use the term 'wastewater reuse'. Even the definition of reclaimed water is not the same in some documents issued by the same department. Therefore, different departments have different statistical scopes of reclaimed water, leading to obvious deviations of the statistical data regarding reclaimed water published by these departments.

Although there are some policies and regulations to govern the development of reclaimed water, these policy and regulation systems are still incomplete. Currently, China has not put forward relevant and consistent laws and policies regarding reclaimed water from the specific perspectives of water source, production, market, utilization, supervision and control (Liu & Persson 2013).

Although some water quality standards have been published to guide the utilization of reclaimed water for different purposes in China, they are inconsistent in terms of indexes included in these standards and specified thresholds even for the same index (Lyu *et al.* 2016). Some water quality indexes of concern for water consumers are

not included in current standards, and some indexes, such as chloride and sulfate in industrial production, are also neglected in current water quality standards (Chang & Ma 2012).

There is an incomplete water pricing mechanism for reclaimed water. The price of reclaimed water could play an important role in determining the extent to which reclaimed water could be used in society (Chu *et al.* 2004). Currently, the price of reclaimed water only reflects the economic and operating costs of reclaimed water treatment facilities, but not the demand and supply of the reclaimed water market; thus, the market does not take a fundamental allocation effect on water resources into account very well (Xu *et al.* 2009). It is urgent to construct a complete water pricing system for reclaimed water and allocate tap water and reclaimed water using market mechanisms and economic leverage, with the aim of improving comprehensive utilization of water resources.

The current development of reclaimed water in China is unbalanced. Most reclaimed water has been used in water-deficient economically developed central and eastern regions, such as Beijing and Shandong province. In other regions, such as the northeast, the utilization amount of reclaimed water is relatively less, and reclaimed water facilities are also deficient.

The successful implementation of reclaimed water projects heavily depends on public perception and a positive public attitude towards reclaimed water (Hurlimann & Dolnicar 2010). At present, there is a low perception and receptivity towards reclaimed water in China (Zhang *et al.* 2012). The public lacks a general understanding of water resources, and their receptivity to some of the purposes (such as groundwater recharge) is relatively weak, especially with respect to domestic potable water, because of a concern for environmental and health risks (Zhang *et al.* 2012; Fielding *et al.* 2015; Hurlimann & Dolnicar 2016).

### Some suggested measures

Aiming at the above problems, we put forward the following suggested measures.

Unifying the definition of reclaimed water is beneficial to the advancement of the development of reclaimed water. In this study, we have used the definition of reclaimed water in 'Water Resources Terminology' (GB/T30943-2014)

(Terms for water resources 2014). This definition is explicit, and it can be employed by many departments to define a common and applicable statistical scope of reclaimed water. This will facilitate the comparison of statistical data on reclaimed water.

Currently, the development of reclaimed water in China is still at an early stage. The complete policies and regulations governing reclaimed water should be aimed at encouraging utilization of reclaimed water by formulating preferential policies from the perspectives of finance and taxes. It is important to gradually improve reclaimed water policies by incorporating relevant policies from the perspectives of water source, production, vendition, utilization and supervising management.

More attention should be paid to consistency among all of the published standards governing the utilization of reclaimed water in future standards research. Future standards can emphasize specifications regarding water sources of reclaimed water, construction of water reclamation plants, financing channels of reclaimed water projects, utilization methods, water quality, water delivery and marketing of reclaimed water (Lyu *et al.* 2016).

A price adjustment for reclaimed water is needed, and a rational, cost-justified price structure is necessary so that the demand for tap water and reclaimed water can be balanced. The current pricing structure of reclaimed water should compensate for the capital investments and operational costs of wastewater treatment and investments for production, operation and management of reclaimed water projects (Xu *et al.* 2009).

Local governments should develop reclaimed water according to local circumstances, such as regional water resources condition, population distribution characteristics, situation of economic development and support degree of relevant policies and regulations. Reclaimed water should be used in local regions by co-ordination of supply and demand corresponding to the different regions, different use objectives and different use methods, with the aim of maximizing the utilization efficiency of reclaimed water.

It is important to improve public awareness and receptivity towards reclaimed water (Zhang *et al.* 2012; Chen *et al.* 2015; Gu *et al.* 2015). Measures should be taken to encourage the public to engage in the comprehensive

management of water resources and play a positive role in the utilization of reclaimed water (Chen *et al.* 2015).

## CASE STUDIES

### Reclaimed water reuse in Beijing

Beijing is a typical northeast mega-city in China that faces serious water resources pressure (Wang *et al.* 2015). Its population reached 21.7 million, and per capita water resources quantity was 123 m<sup>3</sup> in 2015, accounting for only 6.08% and 1.52% of the annually averaged quantity in China and the global per capita water resources quantity, respectively (Beijing Water Resources Bulletin 2015). To tackle the serious disparity between water resource supply and demand, Beijing, on the one hand, has made efforts to use regular water resources (i.e., surface and ground water resources, and water from the South-to-North Water Diversion Project in China) efficiently; on the other hand, Beijing strives to reclaim urban wastewater and develop reclaimed water reuse to satisfy several kinds of needs (Wang *et al.* 2015). According to the Water Resources Bulletin of Beijing, of the total water supply amount ( $3.82 \times 10^9$  m<sup>3</sup>) in 2015, surface water resources and groundwater accounted for 8% and 47% respectively; reclaimed water accounted for 25%, and water diversion accounted for the remaining 20%.

Early in the 1950s, Beijing started to use wastewater for crop irrigation. In 1997, the wastewater quantity for agricultural irrigation amounted to  $0.22 \times 10^9$  m<sup>3</sup>, accounting for almost 25% of total urban wastewater quantity, and irrigation area reached  $29.6 \times 10^4$  hectares. In 1984, Beijing began to construct reclaimed water demonstration projects to supply reclaimed water for toilet flushing, green watering and car washing (Zhou *et al.* 2009). In 1987, the Beijing Government issued 'Management Code for Reclaimed Water Facilities in Beijing' to promote the development of building reclaimed water. By 2002, there were more than 100 building reclaimed water facilities constructed in Beijing.

With the construction of wastewater treatment plants, deep treatment and reuse of wastewater in wastewater treatment plants are developing rapidly. By 2015, 50 wastewater treatment plants with treatment capacity of  $43.8 \times 10^6$  m<sup>3</sup> per day had been constructed, and the yearly wastewater

treatment quantity reached  $1.45 \times 10^9 \text{ m}^3$  in 2015. Meanwhile, 34 water reclamation plants with production capacity of  $2.26 \times 10^6 \text{ m}^3$  per day were in operation in Beijing, mainly distributed in Chaoyang, Fengtai, Haidian, Mentougou, Fangshan, Tongzhou, Changping, Huairou and Daxing districts, and the pipeline length of reclaimed water approached 1,484 km. In 2015, the reclaimed water quantity in Beijing reached  $0.76 \times 10^9 \text{ m}^3$ , and Beijing was the second largest reclaimed water consumer among all PARs in China. Of the total reclaimed water amount, 87.12% has been applied for landscape environmental purposes, 9.66% has been used for industrial processing, and 3.17% for urban non-potable purposes. The remaining 0.05% has been adopted for agricultural, forestal and pasturable field objectives.

Reclaimed water has become an important part of the comprehensive water resources supply framework in Beijing. Rapid development of Beijing's reclaimed water is largely attributed to strong promotional policies and regulations from the Beijing Government and much capital investment in reclaimed water projects from relevant departments (Yang & Abbaspour 2007; Yi *et al.* 2011; Chen *et al.* 2015). However, there are still some factors inhibiting further development of Beijing's reclaimed water, listed as follows: (1) time required for high-quality reclaimed water projects is long and difficulties are great, and thus these projects do not effectively relieve the serious situation regarding urban water use; (2) the delivery, conservation and management system of reclaimed water is still incomplete; (3) the present water pricing mechanism of reclaimed water and tap water is still irrational; and (4) some rivers and lakes in Beijing lack ecological base flow during the dry season. Because the water quality standards of reclaimed water are still lower than the water quality standards of river and lake water bodies, using reclaimed water to supplement ecological environmental water requirements of rivers and lakes will lead to some pollution of rivers and lakes.

### Reclaimed water reuse in Jiangsu province

As opposed to Beijing, Jiangsu province is a typical province with a relatively abundant amount of water resources, however, the spatial distribution of its water resources is very uneven. The amount of water resources flowing through

the province is large, whereas the amount of local water resources is small; there is a large amount of polluted water resources and a small amount of high-quality water resources; water resources in the southern part of the province are much greater than in the northern part; the amount of water resources during flood periods is much larger than during non-flood periods. The amount of water resources in Jiangsu province reached  $39.93 \times 10^9 \text{ m}^3$  in 2014, whereas the total water use amount approached  $48.07 \times 10^9 \text{ m}^3$  (Water Resources Bulletin in Jiangsu Province 2014). To tackle an increasing water resources crisis, Jiangsu province has expended great efforts in reclaiming municipal wastewater and promoting the utilization of reclaimed water to relieve the stress on available water resources.

In the southern region of Jiangsu province, there is a sufficient amount of water resources but the water quality is insufficient. Local administrations have paid attention to dealing with water environmental problems and decreasing the discharge of pollutants into water bodies (Wei *et al.* 2015). Most of the reclaimed water has been used as an ecological environmental water source to alter the water environment, with the aim of reducing pollution load and improving the water quality of urban water bodies. Local administrations have also emphasized concentrated treatment and reuse of wastewater in industrial parks.

On the other hand, in the northern region of Jiangsu province there are insufficient local water resources. Together, increasingly serious water pollution, plus water resources shortages in amount and water quality coexist in the northern region. The main objective of reclaimed water utilization has been to increase the amount of water resources, greatly promote wastewater reuse and improve the recycling efficiency of wastewater (Wei *et al.* 2015). In these regions, local administrations have used reclaimed water to supplement the ecological environment of rivers and lakes and satisfy industrial needs.

In recent years, provincial governments, provincial development and reform commissions, and water resources departments in Jiangsu province have published 10 policies to promote the utilization and development of reclaimed water. By 2015, there were 352 wastewater treatment plants with total treatment capacity of  $14.3 \times 10^6 \text{ m}^3$  per day. Most of the wastewater treatment plants had performed

at the A/B water quality standard, and the drainage pipeline length had approached  $4.13 \times 10^4$  km. The treated wastewater amount in 2015 reached  $4.03 \times 10^9$  m<sup>3</sup>, and this provided Jiangsu province with an adequate amount of available fresh water resources. There were 170 wastewater reclamation plants in Jiangsu province with total production capacity of  $7.3 \times 10^6$  m<sup>3</sup> per day by 2015, and the pipeline length of reclaimed water reached 3,021 km.

In 2015, the utilized amount of reclaimed water was  $0.74 \times 10^9$  m<sup>3</sup>, of which 69.96% was used for landscape environmental purposes, 21.05% for industrial needs, 4.86% as an urban non-potable water source and the remaining 4.13% for agricultural, forestal and pasturable purposes. Suzhou and Wuxi cities have used an amount of reclaimed water of more than  $10^8$  m<sup>3</sup>, and those cities that have adopted reclaimed water of more than  $10^7$  m<sup>3</sup> are: Nanjing, Xuzhou, Changzhou, Nantong, Lianyungang, Huaian, Yangcheng, Zhenjiang and Suqian.

The following are some typical cases of reclaimed water utilization in Jiangsu province. (1) For industrial needs: the Urban Construction Bureau of Changzhou city has invested  $18 \times 10^9$  RMB to construct a pipeline to introduce the qualified tail water through the Qishuyan wastewater treatment plant as a supplementary water source for the industrial recycling cooling process in the Jiangsu Zhongtian Steel Factory. This project was initiated in 2011, and the daily water supply amounted to  $25 \sim 30 \times 10^3$  m<sup>3</sup>. A water reclamation plant in the economic developed zone of Xuzhou supplied reclaimed water to the Jiangsu Zhongneng Silicon Company and the Jinshanjiao Heat and Power Plant to satisfy industrial cooling needs from 2012. (2) For urban miscellaneous uses: a demonstrative project of reclaimed water of the Taihu Xincheng wastewater treatment plant was constructed in 2009. This project supplied reclaimed water at the scale of  $50 \times 10^3$  m<sup>3</sup> per day to satisfy urban miscellaneous uses, such as green watering and road flushing in the Taihu Xincheng central zone. Since 2012, the wastewater treatment plant in the Gaoxin district of Suzhou city has supplied an amount of reclaimed water of  $0.5 \sim 0.6 \times 10^3$  m<sup>3</sup> per day to the Xinyun garden village for firefighting, green watering and road washing in this village, and provided an amount of reclaimed water of  $0.5 \times 10^3$  m<sup>3</sup> per day to the Renheng Company for infrastructure and construction water use. The Water Source Heat Pump in the Xincheng district of Nantong began to

operate in 2008, and it mainly used reclaimed water from the first wastewater treatment plant of the economic zone of Nantong to gain heat energy. (3) For ecological environmental water: Changzhou Drainage Company constructed Baijiabang and Yejiabang ecological supplementary water projects in 2010, namely, supplying high-quality reclaimed water at  $7 \times 10^3$  m<sup>3</sup> per day and  $8 \times 10^3$  m<sup>3</sup> per day through the Qingtan wastewater treatment plant to the black and malodorous Baijiabang and Yejiabang rivers. In 2011, this company also invested more than  $3 \times 10^9$  RMB to perform Chaizhibang ecological supplementary water projects, namely, supplying high-quality reclaimed water at  $15 \times 10^3$  m<sup>3</sup> per day through the Chengbei wastewater treatment plant to the black and malodorous Chaizhibang river. In 2012, the Kunshan Government in Suzhou city invested  $19 \times 10^9$  RMB to construct wastewater reuse projects for green watering and landscape environment in Changjiang road; this project delivered an amount of reclaimed water of  $5 \times 10^3$  m<sup>3</sup> per day through wastewater treatment plants to wetland gullies around Changjiang road for green watering and landscape environmental needs. (4) For supplementary water of ecological wetlands there were two well-known cases: the ecological wetland purification project of wastewater through the Wunan wastewater treatment plant in Changzhou city, and the ecological wetland project of wastewater from Qingjian wastewater treatment plant in Hongze country of Huaian city.

Fast development of reclaimed water in Jiangsu province could benefit from the following four successful experiences (Wang *et al.* 2014):

1. Strong policy support. As is mentioned, many policies and regulations have been issued to promote the utilization and development of reclaimed water by provincial governments, provincial development and reform commissions, and water resources departments. Some of them were formulated from the perspective of water pricing and tax policy for reclaimed water, and others from the perspective of the infrastructure of reclaimed water projects. These policies played an important and positive role in the development of reclaimed water in Jiangsu province.
2. An administrative mechanism regarding reclaimed water was preliminarily established in Jiangsu province. Jiangsu province has preliminarily constructed an integrated

administrative system of water resources covering three administrative hierarchies of province, city and country. This system can plan allocation, conservation, protection and utilization of water resources within the province. Local governments regroup original water resources management departments to form new water resources bureaus responsible for supply and conservation of urban water, wastewater treatment and development of alternative water resources. Water resource bureaus in local regions can comprehensively draft the planning of reclaimed water, postulate the policies regarding reclaimed water, and implement effective management regarding reclaimed water.

3. Some demonstrative water-saving projects were constructed in Jiangsu province. Recently, Jiangsu province paid a great deal of attention to performing a water-saving society pilot construction as an important measure for sustainable development of economy and society. A number of wastewater treatment plants and water reclamation plants, and some demonstrative projects, have been carried out in the province, to good effect.
4. Public awareness and participation were greatly encouraged in Jiangsu province. The public shows an increasing consciousness of saving and protecting water resources in Jiangsu province.

## CONCLUDING REMARKS

China is facing serious water scarcity and water pollution, which restricts its further development. To tackle the serious disparity between water resource supply and demand, besides regular water resources, China has made many efforts to develop alternative water resources to combat water conflict, among which reclaimed water plays an important role. This paper reviewed and studied the current status of reclaimed water use in China, including the following:

- Utilization quantity and objectives of reclaimed water: reclaimed water experienced a rapid increase during 2009–2013 and then a slowly increasing trend during 2013–2015; China has used the majority of reclaimed water to satisfy landscape environmental and industrial

requirements that have less contact with the human body and low environmental risks.

- Laws, policies and technological standards governing reclaimed water use were listed in chronological order.
- Taking statistical data in 2015 as an example, the influences of water resources amount, GDP and policy promotion hierarchy on reclaimed water use for all PARs throughout China were investigated: there seemed to be no correlation between water resources amount and use amount of reclaimed water, whereas GDP and policy promotion hierarchy are driving forces for reclaimed water use.
- Existing problems and some suggestions regarding the present status of reclaimed water were also summarized.
- Two representative examples, reclaimed water use in Beijing (a typical northern water-deficient city) and Jiangsu (a typical southern province having a sufficient amount of water resources but still facing a water crisis), were presented.

On August 14th, 2017, the Ministry of Water Resources of China first published an official file ‘Guide on putting alternative water resources under an integrated water resource allocation in China’ that specifies allocation area, allocation means, allocation ratio, and motivation policy using alternative water resources for all PARs, to speed up the development and utilization of alternative water resources. The allocation amount of alternative water resources (not including the directly used seawater) was planned to exceed  $10 \times 10^9 \text{ m}^3$  by 2020 in this file, and especially at least  $2 \times 10^9 \text{ m}^3$  of alternative water resources need to be allocated in the Beijing-Tianjin-Hebei regions. The file specifies allocation of reclaimed water for industrial needs, ecological environmental uses and urban miscellaneous uses: reclaimed water should be given a priority to be allocated in high water-consuming industrial sectors, and urban miscellaneous sectors (including urban greening, toilet flushing, road washing, car washing, building operation and firefighting) in those water-deficient regions, groundwater exploitation regions and the Beijing-Tianjin-Hebei regions. Reclaimed water allocation should be given top priority in riverine ecological water and landscape water use as well. Some strengthening measures have been taken to promote the allocation of reclaimed water in an

integrated water resources system in the file, including strengthening the plan guide, strengthening the management of planned water use, promoting the engineering construction of reclaimed water facilities and implementing the examination and motivation of reclaimed water. Some supervision management was also introduced, including making up a complete technological standards system, strengthening the monitoring management of reclaimed water information, and strengthening the safety supervision and the risk control of reclaimed water projects.

With the advancement of wastewater treatment technology, increasing capital investment and strong policy support, China's reclaimed water is developing fast, and reclaimed water is expected to play an important role in tackling the serious water resources crisis in China.

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