

## Feasibility of on-site grey-water reuse for toilet flushing in China

Jie Zhu, Martin Wagner, Peter Cornel, Hongbin Chen and Xiaohu Dai

### ABSTRACT

Although the total reuse rate of municipal wastewater was 8.8% in China in 2012, water crisis is forcing China to increasingly develop water reuse. Urban reuse is comparatively poor and has significant potential to be promoted in China. It is a sensitive matter whether to include kitchen wastewater in grey-water reuse in water-deficient areas when kitchen wastewater accounts for a large proportion of total domestic water consumption. Concentrations of chemical oxygen demand, BOD<sub>5</sub> (biochemical oxygen demand), and total organic carbon in kitchen wastewater are comparatively lower in China than in other countries, but a high concentration of nitrogen from washing tableware and rice makes it difficult to meet nitrogen requirements in Chinese guidelines. Whether kitchen wastewater should be included in grey-water reuse in China needs further study. Aerobic biological processes combined with physical filtration and/or disinfection is preferred in grey-water treatment, and how to balance the investment and treatment costs with reuse criteria still needs to be researched further. The promotion of reclaimed water for toilet flushing faces resistance in China. The necessity and effectiveness of existing restrictions in water reuse guidelines for toilet flushing in China are in doubt and need further discussion.

**Key words** | grey-water, guidelines, kitchen wastewater, on-site reuse, toilet flushing

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### INTRODUCTION

Drought and water shortage are the key factors for water scarcity in arid and semi-arid areas in the world. Nowadays, overexploited underground water reservoirs and seriously polluted surface water have intensified the water crisis; moreover, population growth coupled with ever-increasing urbanization has resulted in continuous growth of urban water demand. As a result, there is a growing need to manage water resources in a sustainable manner, and reclaimed water has become an increasingly important source of water.

Recently, centralized wastewater treatment and reuse systems have been confronted with many problems, such as high susceptibility towards overloading during storm events, unnecessary or insufficient treatment for different reuse applications and long-distance conveying systems

(Hu *et al.* 2011). Meanwhile, flexible on-site water treatment and reuse systems are considered a promising solution for Jordan (Al-Jayyousi 2003), Israel (Friedler 2004), and the USA (Seattle Public Utilities 2008; Pacific Institute & NRDC 2014). Since 2000, China has made good progress in water reuse with governmental policy support, but is still confronting difficulties in water reuse (Yi *et al.* 2011). Whether on-site water reuse systems are appropriate for China needs further discussion.

Due to low-level contamination and continuous availability, grey-water reuse has become a special focus for on-site reuse. Grey-water is defined as wastewater without any input from toilets, and it includes wastewater from bathtubs, showers, washing basins, laundry and kitchen sinks (Eriksson *et al.* 2002). Sometimes, kitchen wastewater is not classified as grey-water because of its high content of oil and food residuals (Christova-Boal *et al.* 1996; Little 2002; Al-Jayyousi 2003; Wilderer 2004). However, the characterization of grey-water has not

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been studied intensively in China. Based on the limited literature data available, quantity and quality of domestic wastewater in China are assessed here. In addition, this paper discusses whether kitchen wastewater should be classified as grey-water.

As for water reuse, current technology manages to treat wastewater into any desired quality (U.S. Environmental Protection Agency 2012). Compared to household composite domestic wastewater, grey-water is more lightly polluted, thus the treatment process should be optimized; the key problem is how to balance the investment and treatment costs with reuse criteria. Hence, this paper summarizes the current grey-water treatment systems and proposes advice on application.

Recently, the most commonly described and promising application for grey-water reuse has been toilet/urinal flushing, which can reduce water demand within a dwelling by up to 10–30% (Friedler et al. 2005; Gisi et al. 2015). However, water reuse for toilet flushing has been the subject of many complaints because of the undesired odor and color (Narasimhan et al. 2005), corrosion of pipelines (Li et al. 2011a, 2011b; Wang et al. 2012), and potential health risks (Jjemba et al. 2010), most of which result from microbial regrowth. As a result, the reliability of water reuse guideline has been questioned. This paper compares guidelines for toilet flushing in China and other countries, and tries to calculate the key parameters leading to microbial regrowth in reclaimed water.

The purpose of this paper is: (1) to analyze the current state and potential of wastewater reuse in China and to propose possible solutions for improving water reuse rates; (2) to study the current situation regarding quantity and quality of grey-water in China and to analyze the feasibility of grey-water reuse in China; (3) to summarize grey-water treatment technologies and propose advice on proper application; and (4) to compare the guidelines of water reuse in China and other countries, and propose suggestions for maintaining biological stability of reclaimed water in toilet flushing.

## FEASIBILITY AND NECESSITY OF ON-SITE WATER REUSE IN CHINA

### Assessment of the national water reuse potential

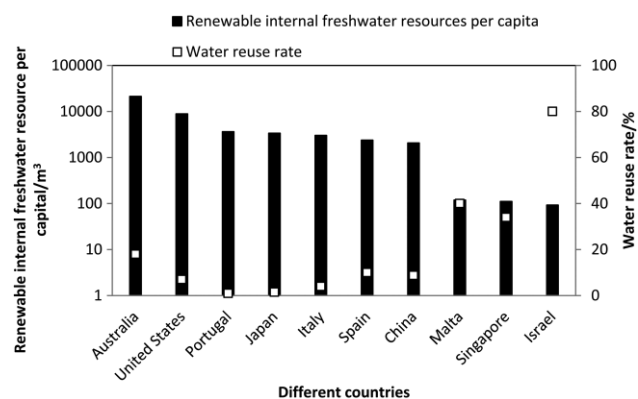
Water recycling projects for non-potable end use are a common practice with more than 3,300 projects registered

worldwide (European Commission 2013). Figure 1 shows freshwater resource quantities and water reuse rates in different countries.

Arid and freshwater-starved regions in the world are candidates for water reclamation. Israel, Malta, and Singapore are the top three countries in water reuse and reuse 80%, 40%, and 33% of total wastewater, respectively (World Bank 2013). In Israel, nearly all households have a double plumbing supply system (drinking water and reclaimed water). In Singapore, wastewater is being treated to such a quality level that it has been sold, inter alia, for use as potable water under the brand name NEWater since 2003 (Lee 2005). In the USA, direct potable reuse of reclaimed water was first proposed in California in 2012 (NWRI 2010) and was first put into practice in Texas in 2013 (TWDB 2015).

With 2,072 m<sup>3</sup> renewable internal freshwater per capita in China (one-third of the world average), 3.21 × 10<sup>9</sup> m<sup>3</sup> reclaimed water was used in 2012, amounting to 8.8% of the total treated municipal wastewater in China (MOHURD 2012a). Data on water reuse in China are shown in Figure 2.

In China, the majority of available water is concentrated in the south, leaving the north and west to experience perpetual droughts and the need to develop water reuse. Beijing reused 0.75 × 10<sup>9</sup> m<sup>3</sup> wastewater in 2012, and the reuse rate reached 59.3%. However, the reused rate varies throughout China and in 65% of the provinces or municipalities the reuse rate is lower than 8.8%, while in water-scarce Tianjin it is only 2.9%. Population growth coupled with



**Figure 1** | Fresh water resource quantity and reuse rates of the top ten countries in water reuse. Available from: World Bank (2013) and BlueTech Insight Report (2014).

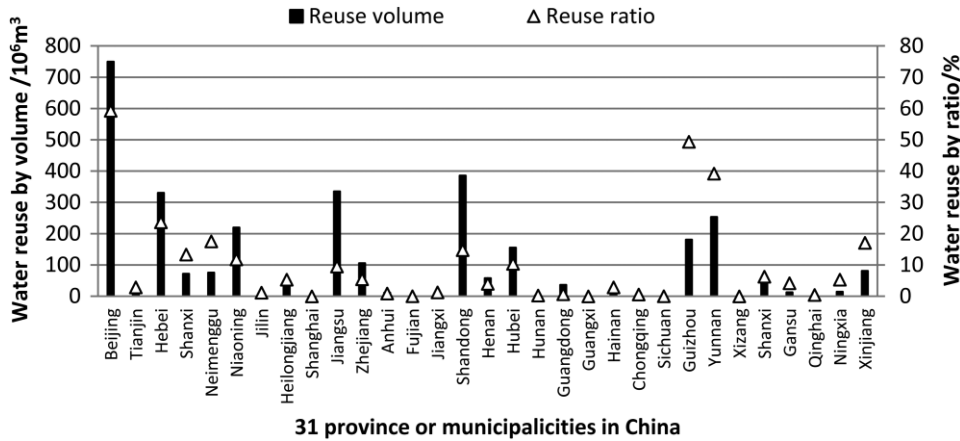


Figure 2 | Reuse volume and reuse rate in China in 2012 (MOHURD 2012a).

water pollution has left Shanghai only 1% of surface water available as a drinking water resource making wastewater reuse imperative (Ma *et al.* 2015).

Also, a recently established government policy advocates more water reuse. According to Action Plan for Water Pollution Prevention (GOSC 2015), the utilization rate of recycled water should be more than 20% in water-deficient cities and 30% in Beijing, Tianjin, and Hebei by 2020. The Beijing government planned to increase the water reuse rate to 75% in 2015 (BWA 2015a). According to assessment standards for water-saving cities, the water reuse rate should exceed 20% or the annual growth rate should be more than 5% (MOHURD 2012b). As a result, more water reuse schemes have to be developed to meet the ever-increasing water recycling requirements throughout China.

**Necessity of on-site treatment and urban reuse in China**

With an annual precipitation of 585 mm in Beijing (BWA 2015b) and 563 mm in California (NOAA 2010), drought undoubtedly motivates water reuse in these semi-arid areas (annual precipitation <700 mm) (Nkonya *et al.* 2016). High annual precipitation, a growing population, and increasing urbanization are the main incentives for water reuse in Japan and southern China. Considering these similarities, experiences from successful water reuse projects in Beijing, California, and Japan may be utilized by other Chinese regions. Details of water reuse applications in California, Japan, and Beijing are shown in Figure 3.

According to the Guidelines for Series of Standards on Water Reuse in China (AQSIQ 2002), water reuse is classified into urban, environmental, industrial, agricultural reuse, and groundwater recharge. In semi-arid regions, agriculture consumes one-third of the total reclaimed water (Figure 3). Environmental reuse (replenishing water courses) consumes the largest proportion of reclaimed water in Beijing, due to seriously polluted surface water. Industrial reuse accounted for 10–15% in three regions. In California, groundwater recharge, as indirect potable reuse (IPR), has been being practiced since 1962 (EPA 2012). In Beijing (BWA 2015a) and Japan (Yamagata *et al.* 2009), IPR is so far not being carried out.

In Japan, due to not facing immediate needs in agriculture, nearly 50% of the reclaimed water is directed towards urban miscellaneous reuse, using 27% in landscape irrigation, 18% in snow melting, and 3.5% in toilet flushing. Furthermore, urban reuse includes golf course irrigation, car

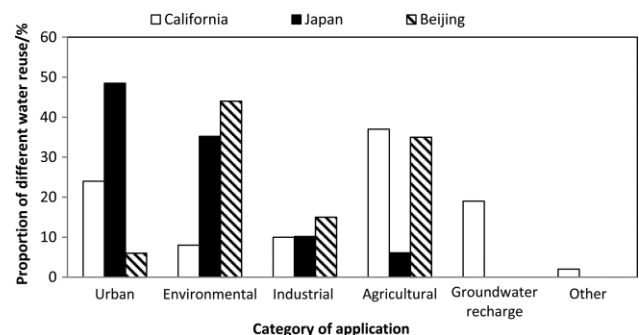


Figure 3 | Comparison of water reuse in California, Japan, and Beijing.

washing, housing construction, and heat exchange systems (UNEP & GEP 2004). By comparison, the proportion of urban reuse is low in Beijing, and until now, urban water reuse has not been used much in the south and the east of China. As a result, there is still significant potential to improve wastewater reuse rates by introducing more urban reuse throughout China.

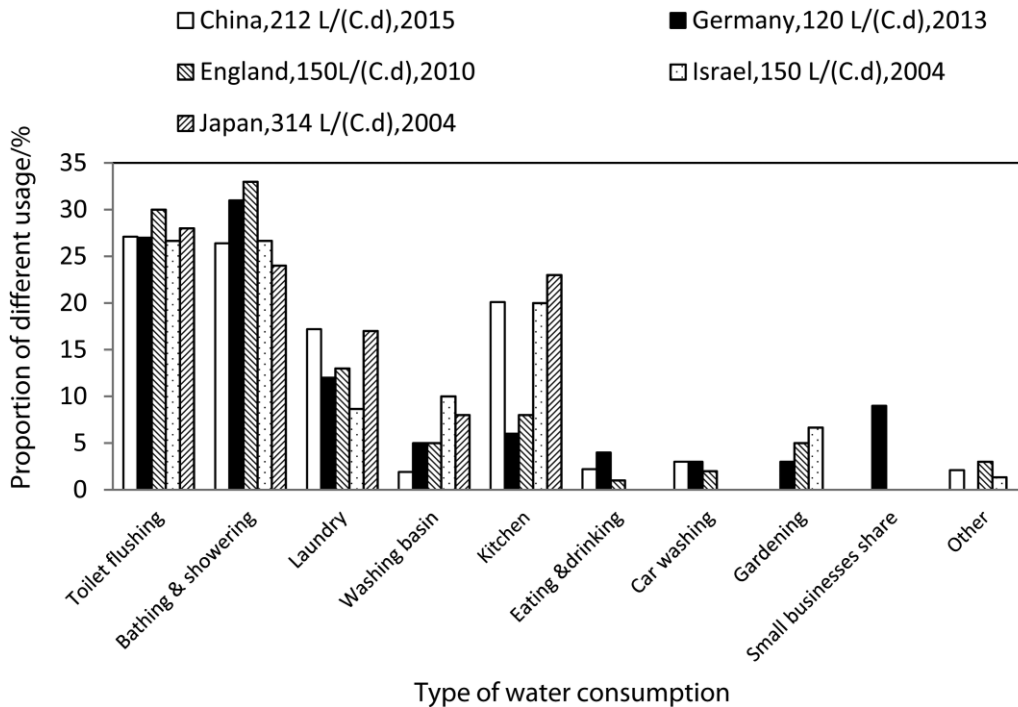
Thus far, a lack of conveying and distribution systems has impeded the promotion of urban water reuse in China, that is to say, urban reuse has no access to reclaimed water (Yi et al. 2011; Hu et al. 2011). In Japan, one-third of the total reclaimed water ( $2.0 \times 10^8 \text{ m}^3/\text{year}$ ) originates from 1,475 on-site individual buildings and block-wide water reclamation and reuse systems (Ogoshi et al. 2000). Without long-distance conveyance, on-site water treatment and reuse has been considered especially appropriate for high-density residential projects, such as multi-building complexes and commercial buildings in urban areas (Friedler & Galil 2003; Friedler 2004; Seattle Public Utilities 2008). With an ever-increasing population and urbanization, on-site water treatment and reuse is a good choice for improving the urban water reuse rate in China.

## CHARACTERIZATION OF GREY-WATER IN CHINA

### Quantity of grey-water in China

Compared with rainfall and mixed domestic wastewater, grey-water was preferred for on-site treatment due to being a stable resource and low polluter (Friedler 2004). The quantity of grey-water depends on lifestyle, population structure (age and gender), water installation and the degree of water abundance (Morel & Diener 2006). Figure 4 shows the domestic water consumption in China and other countries.

As can be seen in Figure 4, the percentages of wastewater consumption for toilet flushing, baths/showers, and laundry are between 27–30%, 24–33% and 9–17%, respectively, in different countries. Generally, bathing wastewater alone is not sufficient for toilet flushing. However, in Germany, many people shower every day and bathing wastewater is being successfully reused in multi-building complexes. Normally, bathing and laundry wastewater are collected and reused together to ensure sufficient grey-water quantity.



**Figure 4** | Domestic water consumption in China and other countries. Available from: MRW 2015 (China); BDEW 2014 (Germany); Waterwise 2012 (UK); Friedler 2004 (Israel); MLIT 2011 (Japan).

Due to different dietary habits in Asia and Europe, kitchen water consumption accounts for more than 20% in Asia and no more than 8% in Europe. This is because in Asia, in most households, warm food is served three times a day, while in Europe, most people only have one hot meal a day and often eat out. Regarding the produced wastewater quantity, the relevance of including kitchen wastewater in water reuse is limited in Europe, while in Asian countries, especially for the arid regions, kitchen wastewater could be a stable grey-water resource. If kitchen wastewater were included in grey-water in China, 63.7% of domestic water could be reused.

### Quality of grey-water in China

In China, there is an urgent need for more information regarding the characteristics of different types of grey-water, especially kitchen wastewater, in order to evaluate the reuse potential. The characteristics of different types of grey-water in China and in other countries is shown in Table 1.

As can be seen from Table 1, bathing wastewater is the least polluted and is therefore preferred in grey-water reuse. Laundry and kitchen wastewater were identified as major pollutant sources. The higher total suspended solid (TSS) and settleable solids (SS) concentrations in bathing wastewater in China may be due to lower bathing frequency. Phosphate concentrations are comparably low in grey-water in China due to the restricted use of phosphate detergents. Kitchen wastewater in China mainly comes from washing rice, uncooked food, and tableware. The pollutant composition of kitchen wastewater in China is shown in Figure 5.

Wastewater from washing tableware demonstrates the highest concentrations of total nitrogen (TN), total phosphate (TP), oil, and fat. Wastewater from washing rice has a high concentration of chemical oxygen demand (COD) and TN. The highly polluted wastewater from washing tableware and rice accounts for 31.6% of total kitchen wastewater and due to that, 68.4% of kitchen wastewater (coming from washing uncooked food) is lightly polluted. The concentrations of COD, BOD<sub>5</sub>, and total organic carbon (TOC) are comparatively lower in China than in other countries (Table 1).

Kitchen wastewater is excluded from grey-water reuse because of high oil and fat content. However, floating oil

and fat can be removed by a grease interceptor prior to the treatment system. Some authors (Gnirss *et al.* 2006; Knerr *et al.* 2008) have stated that mixed grey-water (including kitchen wastewater) has a balanced C:N:P ratio of 100:20:1, as suggested by Tchobanoglous *et al.* (1991), and benefits from biological treatment. However, kitchen wastewater in China contains higher nitrogen concentrations than in other regions. When kitchen wastewater is included in grey-water, nitrogen concentrations usually fail to meet the requirements of Chinese guidelines (Tolksdorf *et al.* 2016). As a result, significant attention should be focused on the characterization and reuse of grey-water, with or without kitchen wastewater, in China in the future.

### GREY-WATER TREATMENT TECHNOLOGIES

A wide spectrum of technologies, including physical (coarse sand, soil filtration, and membrane filtration), chemical (coagulation, photo-catalytic oxidation, ion exchange), and biological systems (rotary biological contactors (RBC), membrane bioreactors (MBR), constructed wetlands (CW), and sequencing batch reactors (SBR)) (Li 2009), can be utilized for grey-water treatment and reuse. Following the 'fit for purpose' principle, different treatment technologies can be combined, but biological treatment is the core technology (nearly all types of grey-water show good biodegradability (Gisi *et al.* 2015)), sedimentation and filtration are pre-treatment or post-treatment. Aside from the MBR process, most of the biological processes are followed by a filtration step and a disinfection step (UV or chlorination) to meet the non-potable reuse standards. Types of reuse appropriate for increasing levels of treatment are shown in Table 2.

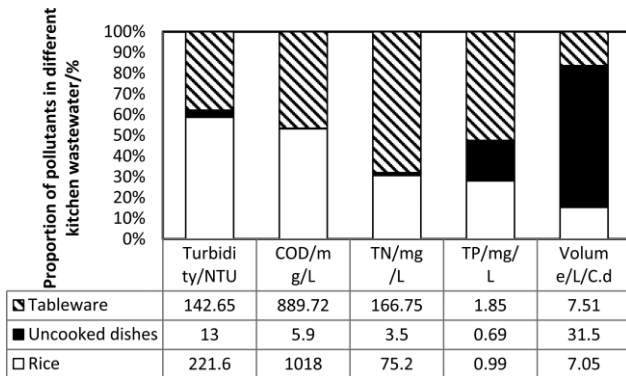
Although biogas production is an advantage, poor removal efficiencies of both organic substances and surfactants make anaerobic processes unsuitable for grey water recycling, and the mainstream biological treatment remains aerobic biological processes (Li 2009).

Hernandez *et al.* (2008) indicated that the low sludge yield of the aerobic SBR (0.12 g VSS/g COD) operated at  $32 \pm 3$  °C and a hydraulic retention time (HRT) of 12 hours makes it an attractive process for the treatment of grey-water. SBR technology was also considered to be promising when it was used in a sports center for grey-water reuse

**Table 1** | Characteristics of different types of grey-water in China and in other countries

	Bathroom		Laundry		Kitchen		Mixed	
	China <sup>a</sup>	Other countries <sup>e</sup>	China <sup>b</sup>	Other countries <sup>e</sup>	China <sup>c</sup>	Other countries <sup>e</sup>	China <sup>d</sup>	Other countries <sup>e</sup>
pH	6.8–7.7	6.4–8.1	7.0–10.5	7.5–10	4.6–8.3	4.6–8.3	5.7–7.6	5.0–8.7
COD cr/mg/L	73–463	95–645	276–1,342	12.8–1,815	183–1,776	183–1,776	202–1,014	13–700
BOD <sub>5</sub> /mg/L	15–69	33–424	94–512	48–470	88–858	88–858	88–535	41–194
TOC/mg/L	5.3–99	30–120	26.8–991	100–280	32.6–300.6	32.6–300.6	11.2–141.6	60–92
TN/mg/L	4.9–12.3	5–17	3.7–48.6	6–21	7.4–196.9	7.4–196.9	0.31–74	0.54–18.1
NH <sub>4</sub> -N/mg/L	2.3–6.1	<0.1–15	3.5–29	<0.1–11.3	0.7–62.1	0.7–62.1	0.002–23	<0.05–25.4
TP/mg/L	0.2–0.7	0.11–2	0.14–1.7	0.062–57	1.0–10.1	1.0–10.1	0.5–4.6	0.16–27.3
LAS/mg/L	6.0–15.2		0.7–15		0.3–16.9		1.1–40.5	
TSS/mg/L	570–779	54–205	193–826	65–280	325–2,258	325–2,258	335–2,656	
SS/mg/L	32–359	40–120	79.2–543.5	2.7–250	29–2,130	29–2,130	53–400	
Total bacteria/CFU/L	$2.0 \times 10^7$ – $2.5 \times 10^9$				$1.1 \times 10^9$ – $9.5 \times 10^9$		$1.4 \times 10^8$ – $7.9 \times 10^9$	
Total coliform/CFU/L	$4.3 \times 10^4$ – $3.5 \times 10^7$	$5$ – $2.4 \times 10^7$		$56$ – $8.9 \times 10^5$	$1.7 \times 10^7$ – $2.4 \times 10^8$		$4.9 \times 10^7$ – $9.4 \times 10^8$	$10^{7.2} \times 10^{8.8}$

<sup>a</sup>Jiang & Gao (2003), Chen et al. (2010).  
<sup>b</sup>Gu (2004), Xiao & Zhang (2009), Nie et al. (2013).  
<sup>c</sup>Chen et al. (2010), Ge & Ge (2010), Zhan (2015).  
<sup>d</sup>Tang et al. (2009), Chen et al. (2010).  
<sup>e</sup>Erksson et al. (2002); Friedler (2004), Lu (2011).



**Figure 5** | Pollutant composition of kitchen wastewater in China. Available from: Ge & Ge 2010.

in irrigation (Gaborro *et al.* 2013). Grey-water can be properly treated by a RBC system (Nolde 1999; Eriksson *et al.* 2009), which has several advantages over other grey water technologies in terms of operational cost, operational ease, and low technical personnel requirements (Abdel-Kader 2013). Constructed wetland is the most environmentally friendly and cost-effective technology for grey water treatment, but it requires a large space and is not suitable for application in urban areas (Comino *et al.* 2013).

MBR is the only technology able to meet non-potable reuse standards without a post-filtration and disinfection

step, but its realization costs are comparatively high (Bani-Melhem *et al.* 2015). The on-site MBR treatment for grey-water is considered to be economically realistic and feasible only when the building size exceeds 37 storeys (148 flats) (Friedler & Hadari 2006).

Since on-site grey-water recycling is a relatively new practice, only a few off-the-shelf systems are commercially available, and even less have been tested at full scale for long time periods. Up to 2005, about 300–400 grey water recycling systems were operating in Germany; however, some have been withdrawn as unsatisfactory following installation, whereas others have maintained more than ten years of successful operation (Nolde 1996, 2005).

Since 2001, the Beijing government announced that reclaimed water facilities must be built in newly built and centralized communities where the area covered is more than 50,000 m<sup>2</sup> or recycled water volume is more than 150 m<sup>3</sup>/d. However, in the 100 examined communities installed with semi-centralized system and dual pipeline system (drinking water pipeline and grey-water pipeline) in China, no more than 20% of the communal reclaimed system was used successfully because of uncompetitive reclaimed water price, poor water quality, and poor supervision system (Ma 2010; Zhang *et al.* 2016).

**Table 2** | Types of reuse appropriate for increasing levels of treatment (EPA 2012)

Treatment level	Increasing levels of treatment →			
	Primary	Secondary	Filtration and disinfection	Advanced
Process	Sedimentation	Biological oxidation and disinfection	Chemical coagulation, biological or chemical nutrient removal, filtration, and disinfection	Activated carbon, reverse osmosis, advanced oxidation process, soil aquifer treatment, etc.
End use	No uses recommended	Surface irrigation of orchard and vineyard Non-food crop irrigation Restricted landscape impoundments Groundwater recharge of non-potable aquifer Wetlands, wildlife habitat, stream augmentation Industrial cooling process	Landscape and golf course irrigation Toilet flushing Vehicle washing Food crop irrigation Unrestricted recreational impoundment Industrial system	IPR including groundwater reservoir augmentation and potable
Human exposure	Increasing acceptable levels of human exposure →			
Cost	Increasing levels of cost →			

As a result, the choice of a treatment system should be based on a careful evaluation of the local conditions (considering the beneficiaries of the system), the legislation as well as the socio-economic environment. It is suggested that an integrated design of the building (considering water and energy nexus) could make grey-water reuse system more economically sustainable (Gisi et al. 2015), and more full-scale grey-water reuse projects should be put into practice and studied over long time periods.

### COMPARISON OF WATER REUSE GUIDELINE FOR TOILET FLUSHING

As current technology manages to treat wastewater into any desired quality, establishing a proper reuse guideline becomes especially important. Only a few regulations and standards for grey-water reuse are available, especially for toilet flushing (Mourad et al. 2011). In this paper, the water reuse guidelines for toilet flushing in China, Japan, Great Britain, and the USA are compared, in order to establish the problems in the Chinese guidelines (Table 3).

Generally, water reuse guidelines include chemical and bacteria restrictions. Most countries and regions include pH-value (corrosion in pipes and other equipment), turbidity and odor (acceptance), and residual chlorine (restrict bacterial growth) as chemical restrictions. China has included eight more restrictions for chemical compounds, some of which refer to discharge standards of pollutants for municipal wastewater treatment plants (GB/T 18918-2002) (MEP & QSIQ 2002). Some of the compounds are considered potentially hazardous (e.g., ammonia nitrogen promotes the growth of nitrobacteria in pipelines and can reduce the inactivation rate of chlorine; dissolved solids may cause scaling (Zhao et al. 2008)). However, whether these parameters are necessary for the assessment of reclaimed water for toilet flushing has not been studied.

Total coliforms have generally been used as an indicator of fecal contamination. In China, based on Standards for Drinking Water, total coliforms and *Escherichia coli* should not be detectable in 100 mL water (GB 5749-2006) (He et al. 2006; MH & SAC 2006). In reclaimed water for toilet flushing, total coliforms are set to be lower than

0.3 CFU/100 mL (GB/T 18920-2002); however, this limit value is considered to be too stringent and not necessary in practice (He et al. 2006; Gong et al. 2011). In British guidelines, total coliforms are restricted to be lower than 1,000 CFU/100 mL, together with restrictions for *E. coli* ( $\leq 250$  CFU/100 mL), intestinal enterococci ( $\leq 100$  CFU/100 mL), and *Legionella pneumophila* (N.D./100 mL). In Germany, parameters are defined as: total coliform bacteria  $< 10^4$ /100 mL, *E. coli*  $< 10^3$ /100 mL, and *Pseudomonas aeruginosa*  $< 100$ /100 mL.

When total coliforms were recognized to not only include bacteria from feces but also from soil, fecal coliforms and *E. coli* became the preferred parameters. In Japan, the total coliform index ( $\leq 1,000$  CFU/100 mL) was replaced by *E. coli* (N.D./100 mL) in 2005 (Tajima et al. 2007). While in 1992 fecal coliforms were required to be lower than 200 CFU/100 mL in reclaimed water for toilet flushing in the USA (EPA 1992), they should not be detectable in 100 mL today (EPA 2012).

Besides the control of pathogens, another function of guidelines is to set criteria for maintaining the biological stability of reclaimed water in distribution systems where microbial growth has occurred when the total and free residual chlorine is lower than 0.36 and 0.09 mg/L, respectively (Thayanukul et al. 2013). All the guidelines for residual chlorine mentioned here met this requirement.

Many recent research projects have focused on identifying the key parameters leading to microbial regrowth. Assimilable organic carbon (AOC), which is used to assess the biological stability of drinking water, is starting to be applied in reclaimed water projects as well (Ryu et al. 2005; Weinrich et al. 2010; Thayanukul et al. 2013; Zhao et al. 2014). Drinking water is defined as biologically stable if AOC is below 10–20  $\mu\text{g/L}$  without disinfection or less than 50–100  $\mu\text{g/L}$  if it has been disinfected (LeChevallier et al. 1992, 1993). However, AOC levels in reclaimed water is up to ten times higher than that in drinking water (Thayanukul et al. 2013), which suggests more difficult management of reclaimed water with regard to biological stability. Other studies state that microbially available phosphorus (MAP) is the key index for microbial growth (Miettinen et al. 1997; Sathasivan et al. 1997; Lehtola et al. 2001). The relationship between microbial regrowth and AOC or MAP in reclaimed water still needs further research. When the key substance



**Table 3** | Water reuse guidelines for toilet flushing in different countries

	China <sup>a</sup>	Japan <sup>b</sup>	Britain <sup>c</sup>	USA <sup>d</sup>	Germany <sup>e</sup>
pH	6.0–9.0	5.8–8.6	5–9.5	6.0–9.0	
Odor	Not unpleasant	Not unpleasant			
Turbidity (NTU)	≤5	≤2	<10	≤2	
Residual chlorine (mg/L)	≥1.0 after 30 min, ≥0.2 at point of use	≥ free: 0.1, or ≥ combined: 0.4	<2.0	≥1.0	
Residual bromine (mg/L)			Not detectable		
Chromaticity	≤30				
DS (mg/L)	≤1,500				
BOD <sub>5</sub> (mg/L)	≤10			≤10	
NH <sub>4</sub> -N (mg/L)	≤10				<5
LAS (mg/L)	≤1.0				
Fe (mg/L)	≤0.3				
Mn (mg/L)	≤0.1				
DO (mg/L)	≥1.0				
Total coliform (number/100 mL)	≤0.3		1,000		<10 <sup>4</sup>
<i>E. coli</i> (number/100 mL)		Not detectable	250		
Intestinal enterococci (number/100 mL)			100		
<i>Legionella pneumophila</i> (number/100 mL)			Not detectable		
Fecal coliform (number/100 mL)				Not detectable	<10 <sup>3</sup>
<i>Pseudomonas aeruginosa</i> (number/100 mL)					<100

<sup>a</sup>Urban Wastewater Reuse Water Quality Standard for Urban Miscellaneous Water (GB/T 18920-2002) (AQSIQ 2002).

<sup>b</sup>New criteria for the reuse of treated wastewater in Japan (Tajima et al. 2007).

<sup>c</sup>British Standard 8525-1:2010 (BSI 2010).

<sup>d</sup>Water Reuse Guidelines 2012 (EPA 2012).

<sup>e</sup>Berlin Senate (1995).

supporting microbial regrowth is confirmed, it can be restricted in the guideline. As a result, more attention should be paid to the improvement of water reuse guidelines in China in further studies.

## CONCLUSIONS

The following conclusions were drawn:

(1) Although the total reuse rate of municipal wastewater was 8.8% in China in 2012, water crisis is forcing China to increasingly develop water reuse. Urban reuse is

comparatively poor and has significant potential to be promoted in China. On-site reuse system seems a good way to promote urban water reuse throughout China.

(2) The quantity of kitchen wastewater varied greatly due to dietary habits. It is sensible to include kitchen wastewater in the case where it accounts for a large proportion of domestic water consumption in water-deficient areas. Owing to a large amount of low polluted water from washing uncooked food, the concentrations of COD, BOD<sub>5</sub>, and TOC in kitchen wastewater are comparatively lower in China than in other countries. High concentrations of nitrogen from washing tableware and rice makes it difficult to meet the

Chinese guideline. Whether kitchen wastewater should be included in grey-water reuse in China needs further discussion.

- (3) The combination of aerobic biological processes with physical filtration and/or disinfection is considered to be the most economical and feasible solution for grey-water recycling. Medium to high strength grey-water is suggested to be treated by RBC, SBR, CW, and MBR technology, but how to balance the investment and treatment costs with reuse criteria still needs further study.
- (4) The Chinese guidelines for toilet flushing were compared with those of Japan, Great Britain, and the USA. Chemical restrictions in Chinese guidelines for toilet flushing are manifold and arduous; total coliforms alone are not suitable for indicating fecal contamination, and other bacteria should be taken into account. Also, the key restriction factors leading to microbial regrowth (e.g., AOC or MAP) should be identified and restricted in guidelines in future.

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